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Aquatic Plants of Bangladesh Agricultural University Botanical Garden: Species Diversity and Potential Uses

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Abstract: Bangladesh Agricultural University Botanical Garden is home to 70 aquatic plant species belonging to 48 genera and 34 families of which Nymphaeaceae has nine species followed by Alismataceae (six); Pontederiaceae and Salviniaceae (four). Convolvulaceae, Cyperaceae, Hydrocharitaceae, Lythraceae, Menyanthaceae, and Onagraceae each are represented by three species. The rest five genera were represented by two and nineteen genera by one species, only. Recorded species are grouped into different ecological habitat categories. A total of seven categories of existing uses were found in the garden. According to the IUCN categories, most of the species 47 (67.14%) are in the least concern category, while only four species were found in the threatened category (one near threatened, two conservation dependent, and one vulnerable) in the natural wetlands. Interestingly, seven rare species (10%) were found in the water garden of BAUBG. Five new aquatic species were documented namely *Nymphoides peltata*, *Sagittaria latifolia*, *Sagittaria montevirdensis*, *Thalia dealbata*, and *Thalia geniculata*. A good number of aquatic species including 7 rare and 5 new species is an indication of richness in the gene pool of aquatic plants at BAUBG.

Keywords: Aquatic plants, Diversity, Ethnobotany, Medicinal plants, Water garden

Aquatic plants that grow naturally or grown artificially in water often form distinct communities depending on their habitats. They are an essential component of aquatic ecosystems and play a significant role in maintaining the ecological balance of freshwater and marine environments and serve as primary producers of oxygen through photosynthesis (Ravi et al 2020, Paul 2022). Some aquatic plants are emergent and rooted on the bottom, while others are submerged. Still, others are free-floating, and some are rooted in the banks of the impoundments, adapting to semi-aquatic habitats. Generally, aquatic macrophytes are herbaceous and very occasionally shrubby in nature. Most of these aquatic plants can grow very fast and directly or indirectly interfere with human activities. There are more than 100 families of vascular aquatic plants on the planet, with around 7.5% of them being dicotyledonous and 11% being monocotyledonous. These plants provide diverse nesting environments for aquatic organisms. They provide a substrate for epiphytic algae and shelter for numerous invertebrates, assist in the cycling of nutrients into sediments, and stabilize river and stream banks (Paul 2022). Aquatic plants or wetland flora has been threatened by several major impacts, such as overexploitation of wetland resources, water pollution from the use of agrochemicals, siltation from flood, wastes from modern agricultural practices, exotic plantations, flow modification including water abstraction, destruction, or degradation of habitat, and invasion by alien species, whose combined and interactive influences are responsible for the decline of water plant populations (Schuyt 2005, Dudgeon et al 2006, Sonal et al 2010). In terms of economic, cultural, artistic, scientific, and educational value, inland waters and freshwater biodiversity is an important natural resource. Their conservation and management are crucial to all human, national, and international interests. But, this priceless heritage is in jeopardy (Dudgeon et al 2006).

In Bangladesh, the most common types of freshwater environments are haor, baor, beel, lake, pond, rivers, and floodplains (Marwat et al 2013). Over 130 angiosperms, six pteridophytes, three bryophytes, and several hundred species of algae have been identified as water plants in Bangladesh. Many authors have well-documented studies on Bangladesh's aquatic and marshland plants (Rahman et al 2007, Mukhopadhyay et al 2017, Uddin and Paul 2020). About 123 aquatic species were meticulously documented and illustrated in previous studies. Many regions of the country have conducted extensive research on aquatic plant distribution. The Bangladesh Agricultural University Botanical Garden (BAUBG) is the second largest and one of the oldest botanical gardens in Bangladesh considering the number of plant species. It is enriched with the live collection and conservation of diverse plant species of terrestrial and aquatic habitats for educational and research purposes of BAU. Many aquatic plants are rich sources of natural compounds with medicinal properties, including anti-inflammatory, anti-cancer, anti-diabetic, and anti-microbial agents. However, despite their vast potential, most aquatic plants remain underexplored, and their full medicinal potential is yet to be realized. The present study targeted to document the diversity of aquatic plant species that are being conserved at the water garden of BAUBG including their habits, food and medicinal values, and conservation status.

MATERIAL AND METHODS

A survey on the aquatic and marshland angiosperms that are being grown and conserved in the water garden of BAUBG, Mymensingh, Bangladesh, had been carried out through frequent visits and observation from January 2022 to December 2022. The water garden consists of several concrete water tanks of different sizes (2.5 to 25 m^3) where a water depth of 0.5 to 2 ft is constantly maintained with tap water. It also has Chari, shallow water stagnant ponds, plastic drums, sewerage canals, and marshy places where tap water is supplied as and when required. The aquatic habitats contain many plant species of diverse habits *viz.* free-floating, rooted emergent, rooted submerged, rooted floating, submerged suspended, surface creeper, and near the water edge. The species names of aquatic plant species were used to identify and record them in the field. Specimens of unknown plant species were gathered for herbarium preparation. Herbarium was prepared from the fertile parts of plant specimens and put on a standard-sized sheet of paper (11.5" x 16.5"). Each sheet was labelled with the common name, scientific name, date of collection, habit, habitat, family, and collector's name and stored in Prof. Dr. Arshad Ali Herbarium at Bangladesh Agricultural University (AAHBAU). Taxonomists from the Bangladesh National Herbarium assisted in identifying the unidentified samples. A review of published journals and reference works, such as the Encyclopedia of Flora and Fauna of Bangladesh (Siddiqui et al 2007a, 2007b, Ahmed et al 2009a, 2009b), etc. was also conducted to identify the plant specimens. The dried specimens were put on the herbarium sheet. Identified plants were collected and classified according to their behaviour and environment. The relative fraction of species in various habitats, conservation status (i.e., NT, VU, CD, LC), taxonomic families, etc. were then estimated. All obtained data and information (qualitative and quantitative) were meticulously organized in a Microsoft Excel spreadsheet. Subsequently, we reorganized all the data methodically to obtain the intended research outcomes. We then examined the compiled data using spreadsheets (Microsoft Excel, version: 2019) and presented the results in the form of graphs and tables. The botanical names, common names, family, habitat, availability, the total number of species in each genus, prospective uses, and % distribution of families for various plant species are provided. Moreover, photographs of a few plants were taken and incorporated into the report (Fig. 5-6).

RESULTS AND DISCUSSION

The Bangladesh Agricultural University Botanical Garden is home to an abundance of aquatic species, making it a useful resource for examining the diversity and significance of these water plants. For each species, the scientific name, common name, family, habitat, status, and uses are included (Table 2). During the course of the study, 70 species, 48 genera, and 34 families were recorded in the research region (Table 1, Fig. 1). Nymphaeaceae was the largest contributor with nine species (12.85%), followed by Alismataceae with six species (8.57%), Pontederiaceae and Salviniaceae with four species (5.71% each), Convolvulaceae, Cyperaceae, Hydrocharitaceae, Lythraceae, Menyanthaceae, and Onagraceae with three species (4.28% each); five families with two species (2.85% each); and nineteen families with one species (1.42% each) (Fig. 1).

Recorded species are grouped into different ecological habitat categories. Among them, 12 free-floating (17.14%), 16 rooted floating (22.85%), 14 rooted emergent (20%), 13 species prefer to grow near water edge (18.57%), 7 rooted submerged (10%), 2 rootless submerged (2.85%), 5 species are water surface creeper (7.14%) and only one species as submerged and floating category in the aquatic habitat (Table 1, Fig. 2).

Potential uses: Aquatic plants are traditionally used as human medicine, human food as fruits and vegetables, fish food, and duck food. Some potential species are playing a good role as phytoremediators for pollutant removal from polluted water (Table 2). Out of the 70-plant species identified in the water garden, 56 species have been used for different purposes, such as human medicine 29 species (28%) followed by, fodder (7%), food as fruit & vegetables (14%), green manure & mulch (12%), fish food (7%), duck food (6%), phytoremediator (10%) and 6% as ornamental. There were still 10 species (10%) of aquatic macrophytes untapped for any uses including medicines in our country, though used in other countries of South Asia.

Twenty-five species (33%) are very much popular among rural peoples as medicine for different ailments. Fifteen percent of aquatic plants make important contributions to the

Table 1. List of aquatic plant spices with common names, scientific names, families, habitats, and conservation status

Common name	Scientific name	Family	Habitat	CS
Boch	*Acorus calamus* L.	Acoraceae	RE	VU
Kasuru	*Actinoscirpus grossus* (L.f.) Goetgh. & D.A.Simpson	Cyperaceae	RE	LC
Indian Joint Vetch	*Aeschynomene indica* L.	Leguminosae	NWE	LC
Malancha	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	NWE	LC
Gechu	*Apanogeton natans* (L.) Engl. & Krause	Aponogetonaceae	RS	NT
Mosquito Fern	*Azolla filiculiodes* Lam.	Salviniaceae	FF	LC
Azolla	*Azolla pinnata* R.Br.	Salviniaceae	FF	LC
Thankuni	*Centella asiatica* (L.) Urban	Apiaceae	NWE	LC
Jhanjhi	*Ceratophyllum demersum* L.	Ceratophyllaceae	rs	LC
Umbrella Plant	*Cyperus alternifolius* R.Br.	Cyperaceae	RE	NE
Mexican Sword Lily	*Echinodorus palifolius* (Nees & Mart.) J.F.Macbr	Alismataceae	RE	Rare
Kachuripana	*Eichhornia crassipes* (mart.) solms	Pontederiaceae	FF	LC
Ground Chestnut	*Eleocharis dulcis* (Burm.f.) Trin. ex Hensch.	Cyperaceae	RE	LC
Helencha	*Enhydra fluctuans* Lour	Compositae	WSC	LC
Water Rush Bamboo	*Equisetum hyemale* L.	Equisetaceae	RE	New
Makhna	*Euryale ferox* Salisb.	Nymphaeaceae	RF	Rare
Duck's Footprint Grass	*Floscopa scandens* Lour.	Commelinaceae	NWE	LC
Hydrilla	*Hydrilla verticillata* (L.f.) Royle	Hydrocharitaceae	RS	LC
Water Poppy	*Hydrocleys nymphoides* (Humb. & Bonpl. ex Willd.) Buch.	Alismataceae	RF	Rare
Kulekhara	*Hygrophila auriculata* Schumach.	Acanthaceae	NWE	Rare
Sutki	*Hygroryza aristata* (Retz.) Nees ex Wight & Arn.	Poaceae	FF	LC
Pani Kolmi	*Ipomoea aquatica* Forssk.	Convolvulaceae	WSC	LC
Dol Kolmi	*Ipomoea carnea* Jacq.	Convolvulaceae	NWE	LC
Sagor Kolmi	*Ipomoea pes-caprae* (L.) R. Br.	Convolvulaceae	NWE	LC
Khudipana	*Lemna minor* L.	Araceae	FF	LC
Lettuce Pana	*Limnocharis flava* L.	Limnocharitaceae	RF	LC
Marshweed	*Limnophila heterophylla*	Plantaginaceae	RS	LC
Ambulia	*Limnophila sessiliflora* (Vahl) Blume	Plantaginaceae	RS	LC
Motmotey	*Lippia alba* (Mill.) N.E.Br. ex Britton & P.Wilson	Verbenaceae	NWE	LC
Keshordam	*Ludwigia adscendens* (L.) H.Hara	Onagraceae	WSC	LC
Mexican Primrose-Willow	*Ludwigia octavalvis*	Onagraceae	NWE	LC
Water Mosaic Plant	*Ludwigia sedioides* (Humb. & Bonpl.) H.Hara	Onagraceae	WSC	New
Baranukha	*Monochoria hastata* (L.) Solms	Pontederiaceae	RE	LC
Chuto Nukha	*Monochoria vaginalis* (Burm. f.) Presl	Pontederiaceae	RE	LC
Paddo, Komol	*Nelumbo nucifera* Gaertn.	Nelumbonaceae	RF	LC
Water Mimosa	*Neptunia oleracea* Lour.	Leguminosae	WSC	NE
Sarnokomol	*Nuphar lutea* (L.) Sm.	Nymphaeaceae	RF	NE
Shapla (White)	*Nymphaea alba* L.	Nymphaeaceae	RF	NE
Shapla (Yellow)	*Nymphaea amazonum* Mart. & Zucc.	Nymphaeaceae	RF	CD
Shapla (Cape-Blue)	*Nymphaea capensis* Thunb.	Nymphaeaceae	RF	CD
Shapla (Nil)	*Nymphaea nouchali* Burm. f.	Nymphaeaceae	RF	LC
Shapla, Shaluk	*Nymphaea pubescens* Roxb. Ex Andr.	Nymphaeaceae	RF	LC
Shapla Red	*Nymphaea rubra* Willd.	Nymphaeaceae	RF	LC

Cont...

Table 1. List of aquatic plant spices with common names, scientific names, families, habitats, and conservation status

Common name	Scientific name	Family	Habitat	CS
White Snowflake	*Nymphoides hydrophylla* (Lour.) Kuntze	Menyanthaceae	RF	DD
Panchuli	*Nymphoides indica* (L.) Kuntze	Menyanthaceae	RF	LC
Holud Panchuli	*Nymphoides peltata* (S.G. Gmel.) Kuntze	Menyanthaceae	RF	New
Panikola	*Ottelia alismoides* (L.) Pers.	Hydrocharitaceae	RS	LC
Amrul	*Oxalis corniculata* Linn.	Oxalidaceae	NWE	LC
Bishkatali	*Persicaria hydropiper* (L.) Spach	Polygonaceae	NWE	LC
Chinese Money Plant	*Pilea peperomioides* Diels	Urticaceae	NWE	LC
Topapana	*Pistia stratiotes* L.	Araceae	FF	LC
Pickerel Weed	*Pontederia cordata* L.	Pontederiaceae		
Curly Pondweed	*Potamogeton crispus* L.	Potamogetonaceae	RS	LC
Floating Pondweed	*Potamogeton natans* L	Potamogetonaceae	SF	Rare
Swamp Potato	*Sagittaria guayanensis* Kunth	Alismataceae	RF	LC
Broadleaf Arrowhead	*Sagittaria latifolia* Willd.	Alismataceae	RE	Rare
Giant Arrowhead	*Sagittaria montevidensis* Cham. & Schltdl.	Alismataceae	RE	New
Muyamuya	*Sagittaria sagittifolia* L.	Alismataceae	RE	LC
Indurkani	*Salvania cucullata* Rexlo	Salviniaceae	FF	LC
Giant Salvania	*Salvania molesta* D.Mitch.	Salviniaceae	FF	LC
Hardy Water Canna	*Thalia dealbata* Fraser ex Roscoe	Marantaceae	RE	New
Red Stemmed Thalia	*Thalia geniculata* f. rheumoides	Marantaceae	RE	New
Kantasingra	*Trapa incisa* Siebold& Zucc.	Lythraceae	FF	LC
Water Chestnut	*Trapa natans* L.	Lythraceae	FF	Rare
Paniphal/Singra	*Trapa natans* var. *bispinosa* (Roxb.) Makino	Lythraceae	FF	LC
Hogla	*Typha domingensis* Pers.	Typhaceae	NWE	LC
Pata Zajhi	*Utricularia flexuosa* Vahl.	Lentibulariaceae	rs	LC
Patseola	*Vallisneria spiralis* L.	Hydrocharitaceae	RS	LC
Amazon Lily	*Victoria amazonica* (Poeppig) Sowerby	Nymphaeaceae	RF	NE
Shujipana	*Wolffia arrhiza* (L.) Horkel ex Wimmer	Lemnaceae	FF	LC

Habitat: RE- Rooted Emergent; RF- Rooted Floating; FF- Free-Floating; NWE- Near The Water Edge; RS- Rooted Submerged; Rs- Rootless Submerged; WSC- Water Surface Creeper; SF- Submerged And Floating. Conservation Status (CS): CD= Conservation Dependent, DD= Data Deficient, LC= Least Concerned, NE= Not Evaluated, NT= Near Threatened, VU= Vulnerable

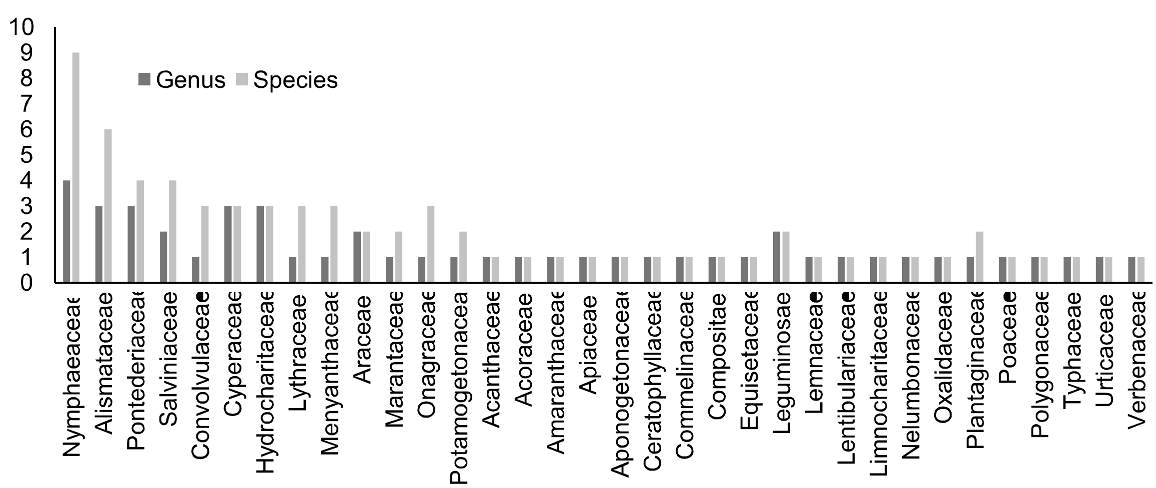

Fig. 1. Genus and species wise distribution of aquatic plant families

food of human beings e.g. Panifol, Panikola, Bet, Makna, and Poddo. Some of them are used as fruit either raw or after some processing. Azolla, shujipana, and kutipana are used for duckweed and fish food. Kachuripana, Topapana, Indurkani, and Giant salvania are very much useful as green manure and as mulch to conserve soil moisture and control weeds in crop fields (Tyagi and Agardwal 2014). Nonetheless, some of these plants pose a threat to aquatic ecosystems, as their rapid multiplication frequently clogs waterways, creates barriers for navigation, and kills fish by deoxygenating the water (e.g., Water Hyacinth, Duckweed, etc). Others transmit Cholera, Shigellosis, and other infections from one location to another. Pani Kolmi, Helencha, Maloncha, Keshordam, Water mimosa, and Lettuce pana are used both as vegetables and medicines for diabetes, stomach pain, and dysentery (Uddin et al 2014, Shethi and Uddin 2018). There is still a good number of aquatic plants untapped for any category of known uses.

Conservation status: The conservation status of the 70 aquatic plants in the water garden of BAUBG was assessed (Table 1 and Fig. 4). The most notable points arising from this study are a large number of species 47 (67.14%) assessed as least concern (LC) and 5.71% (1 Near Threatened, 2 Conservation dependent, and 1 Vulnerable) taxa assigned to a threatened category. Six (8.57%) species such as Equisetum hyemale, *Thalia dealbata* and *T. geniculata* (water canna), *Sagitaria montevidensis* (Giant arrowhead), *Ludwigia sedioides* and *Nymphoides peltata* (Halde Panchulimala) were found as new for the aquatic angiosperms of Bangladesh. Probably these are exotic species though they are very much naturalized to our aquatic environment. They are very much attractive for the water garden. Seven species (10%) were categorized as rare species as they are not frequently found in the natural wetlands. Conservation measures should be taken to save from the more threatened category. Five species (7.14%) were assessed as not evaluated category. White Snowflake has been assessed as Data Deficient because of this lack of information on threats or distribution. There is not enough information to assess whether they are threatened or not, and they are considered Data Deficient.

In BAUBG, some species can withstand waterlogged conditions but are not included in the list of aquatic plants. *Barringtonia acutangula* (Hizol), *Barringtonia asiatica* (L.) Kurz (Fish poison tree), *Calamus guruva* (Jalibet), *Crataeva nurvala* (Barun), *Cynometra ramiflora* L. (Singra), *Heritiera fomes* Buch.-Ham.(Sundori) *Nypa fruticans* Wurmb (Golpata), *Pongamia pinnata* (Karoj), *Trewia nudiflora* (Pidali), *Salix tetrasperma* Roxb.(Panijama), *Sonneratia caseolaris* (L.) Engl (Choila), and *Syzygium fruticossum* (Bhutijam) are the best example of such species. These species are thriving in proximity to and within water bodies.

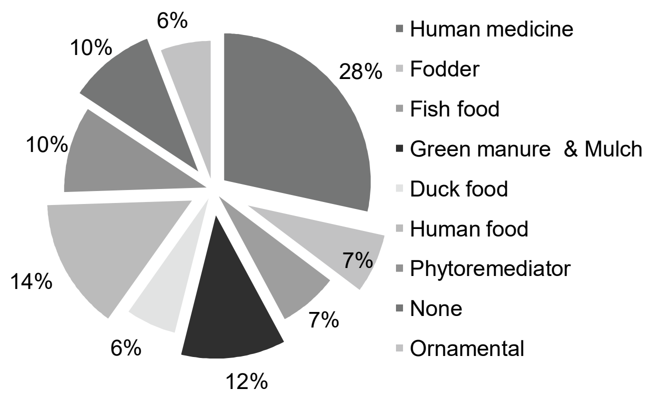

Fig. 3. Potential use wise distribution of aquatic plant species

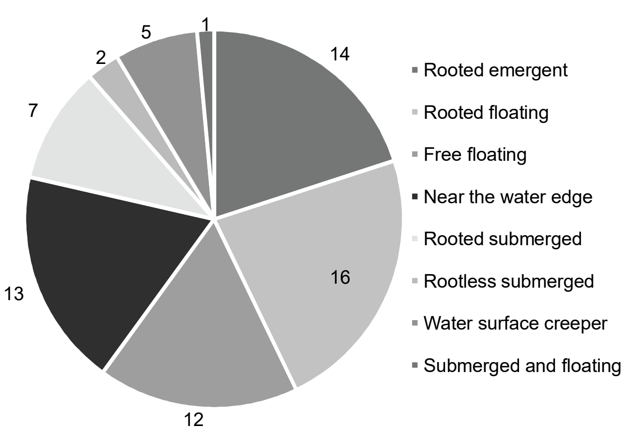

Fig. 2. Habitat-wise distribution of aquatic plant species

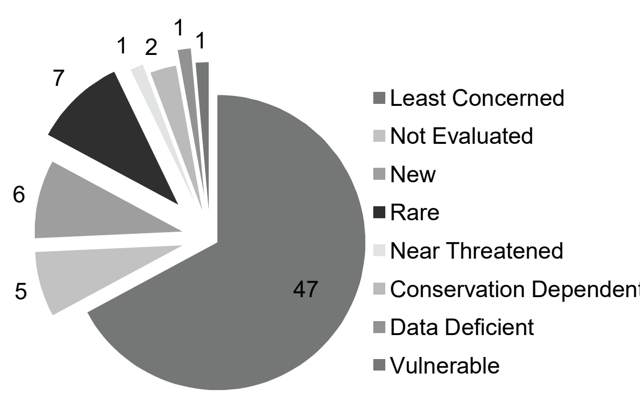

Fig. 4. Conservation status of aquatic plant species

Fig. 5. A. *Hydrocleys nymphoides* B. *Hygrophila auriculata* C. *Ipomoea pes-caprae* D. *Limnocharis flava* E. *Ludwigia adscendens* F. *Ludwigia sedioides* G. *Monochoria hastata* H. *Monochoria vaginalis* I. *Neptunia oleracea* J. *Nuphar lutea* K. *Nymphaea amazonum* L. *Nymphaea capensis*

Fig. 6. A. *Nymphoides indica* B. *Nymphoides peltata* C. *Ottelia alismoides* D. *Pontederia cordata* E. *Sagittaria guayanensis* F. *Sagittaria montevidensis* G. *Sagittaria sagittifolia* H. *Salvania cucullata* I. *Salvania molesta* J. *Thalia geniculata* K. *Trapa incisa* L. *Trapa natans*

Table 2. List of plants along with their scientific name, potential use(s), references(s)

Scientific name	Potential uses
Acorus calamus	Neurological, gastrointestinal, respiratory, metabolic, kidney, and liver disorders (Ranjan et al 2016; Sharma et al 2020).
Actinoscirpus grossus	Fodder (Uddin and Paul 2020), anti-diarrheal, anti-emetic, and liver tonic (Ganapathi et al 2017)
Aeschynomene indica	Hepatitis, enteritis, dysentery, nyctalopia, conjunctivitis, urticaria, and furuncle (Lei et al 2019)
Alternanthera philoxeroides	Vegetables; measles, influenza, and hemorrhagic fever (Nahar et al 2022)
Apanogeton natans	None
Azolla filiculiodes	Fish food, duck food, green manure (Dhawan et al 2010)
Azolla pinnata	Green manure in the rice fields (Jone et al 2022); fodder and duck food (Niroula and Singh 2011)
Centella asiatica	Human medicine, food, veterinary medicine (Dongol 2002), Fodder (Shrestha 1996)
Ceratophyllum demersum	Human medicine (Sarmah et al 2013); fish food (Joshi and Joshi 2007); duck food, green manure (Misra et al 2012)
Cyperus alternifolius	Forage, ornamental, human medicine
Echinodorus palifolius	None
Eichhornia crassipes	Manure and fodder, remediation of water pollution (De Laet et al 2019)
Eleocharis dulcis	None
Enhydra fluctuans	Inflammation, skin diseases, laxatives, bronchitis, nervous affection, leucoderma, biliousness, and smallpox. (Ali et al 2013)
Equisetum hyemale	Kidney pain, Urination
Euryale ferox	Raw or roasted seeds are both edible. The seed flour is nutritious and simple to digest
Floscopa scandens	Leaf paste is used for the treatment of bone fracture, and poisonous stings (Biswas et al 2010)
Hydrilla verticillata	Fish food, duck food; fodder; green manure
Hydrocleys nymphoides	None
Hygrophila auriculata	Human medicine (Niroula and Singh 2011); food (Misra et al 2012)
Hygroryza aristata	Fodder (Misra et al 2012)
Ipomoea aquatica	Human medicine (Niroula and Singh 2011); food (Sarmah et al 2013), fish food; duck food
Ipomoea carnea	Wound healing, anti-inflammatory, anti-fungal, hepatoprotective, anti-diabetic, antimicrobial, cardiovascular, anti-oxidant, immunomodulatory, and anti-cancer properties (Fatima et al 2014, Bhalerao and Teli 2016).
Ipomoea pes-caprae	Inflammation, gastrointestinal disorders, pain, and hypertension (Bragadeeswaran et al 2010, Akinniyi et al 2022).
Lemna minor	Fish food; duck food; green manure. Traditional uses included antipruritic, antiscorbutic, astringent, depurative, diuretic, febrifuge, and soporific. It was also used to treat colds, measles, oedema, and urinary incontinence (Al-Snafi 2019).
Limnocharis flava	Vegetables; feed for swine, cattle, and fish; green manure (Man 2022).
Limnophila heterophylla	None
Limnophila sessiliflora	None
Lippia alba	Antimalarial, spasmolytic, sedative, hypotensive, and anti-inflammatory; used to treat stomachic, nervine, gastrointestinal, and respiratory ailments, as well as a seasoning (Pascuala et al 2001)
Ludwigia adscendens	Vegetables; treat dysentery (Uddin and Paul 2020)
Ludwigia octavalvis	Oedema, nephritis, hypotension, and diabetes (Lin et al 2017)
Ludwigia sedioides	Ornamental, Edible
Monochoria hastata	Human medicine (Niroula and Singh 2011)
Monochoria vaginalis	Human medicine (Niroula and Singh 2011)
Nelumbo nucifera	Human medicine (Sarmah et al 2013); food (Misra et al 2012)
Neptunia oleracea	Food, human medicine, and green manure (Sagolshemcha and Singh 2017)
Nuphar lutea	Dysentery, gonorrhoea, and leucorrhoea. The leaves and roots have been applied to boils and inflamed skin as a poultice, while an infusion has been used as a gargle for oral and pharyngeal ulcers. (Kaur and Mukhtar 2016)
Nymphaea alba	Food
Nymphaea amazonum	Ornamental

Cont...

Table 2. List of plants along with their scientific name, potential use(s), references(s)

Scientific name	Potential uses
Nymphaea capensis	Food, Ornamental
Nymphaea nouchali	Food, Ornamental
Nymphaea pubescens	Food (Misra et al 2012)
Nymphaea rubra	Ornamental
Nymphoides hydrophylla	Leaves treat fever, jaundice, and snake/insect bite, powered seed is used for worm infestation,
Nymphoides indica	Human medicine (Sarmah et al 2013); food (Misra et al 2012, Niroula and Singh 2011), fodder
Nymphoides peltata	None
Ottelia alismoides	Fruit, Vegetable
Oxalis corniculata	Alternative vegetables; anti-cancer, anti-ulcer, anti-inflammatory, anti-fungal, anti-amoebic, and anti-microbial (Mukherjee 2019).
Persicaria hydropiper	Leaf juice for menstruation pain, leaf paste to halt bleeding, and leaf paste with black pepper for headaches; the entire plant as a pesticide for stored grains (Rahmatullah et al 2009).
Pilea peperomioides	Ornamental
Pistia stratiotes	Mulch, Human medicine (Sarmah et al 2013); duck food, green manure (Niroula and Singh 2011)
Potamogeton crispus	None
Potamogeton natans	None
Pontederia cordata	Ornamental
Sagittaria guayanensis	A good oxygenator of water (Rahman et al 2007)
Sagittaria latifolia	A good oxygenator of water (Rahman et al 2007)
Sagittaria montevidensis	A good oxygenator of water (Rahman et al 2007)
Sagittaria sagittifolia	A good oxygenator of water (Rahman et al 2007)
Salvania cucullata	Efficient phytoremediators in the treatment of industrial wastewater (Alam and Hoque 2017), Mulch
Salvania molesta	Mulch, considered for the bioremediation of polluted and contaminated water
Thalia dealbata	Ornamental. Insecticide or insect repellant. Absorbs excess nutrients of nitrogen and phosphorous.
Thalia geniculata	Ornamental. Insecticide or insect repellant. Absorbs excess nutrients of nitrogen and phosphorous.
Trapa incisa	Human medicine (Mohammad et al 2011), food
Trapa natans	Human medicine (Mohammad et al 2011), food
T. natans var. bispinosa	Human medicine (Mohammad et al 2011), food
Typha domingensis	To make mat, fence, and roof thatch, and to cover the pile of fish in a box that keeps them fresh. Root holds soil.
Utricularia flexuosa	None
Vallisneria spiralis	Fish food, a good oxygenator of water (Sambamurty 2005).
Victoria amazonica	Ornamental
Wolffia arrhiza	Fish Food

CONCLUSION

The study led to the conclusion that the water garden of BAUBG is enriched with diverse aquatic plant species while most of them are severely threatened in their original/native wetland habitats. In addition to the native species, some new species are being conserved in the garden. Rare, endangered, vulnerable, and new species should be multiplied and reintroduced to the wetlands of the country because of their importance in food, medicine, and livelihood development of rural peoples. Therefore, there is a need for continued research and development to identify and characterize novel bioactive compounds from aquatic plants and explore their potential applications in the pharmaceutical industry. In collaboration with government and/or non-government organizations, educating and motivating the common people about the significance of aquatic plants and their habitats (wetlands) is an effective method for conserving natural wetland habitats and enhancing native aquatic species for the sustainability of wetland ecosystems.

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Structure, Composition and Distribution Pattern of Agroforestry Flora along Altitudinal Gradient in Kirtinagar Block of District Tehri Garhwal, Uttarakhand, India

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***Abstract*:** In this study, we investigated phytosociological attributes of traditional agroforestry systems in Kirtinagar Block of Tehri Garhwal, Uttarakhand, India. The objective of this study was to explore and compare phytosociological attributes along the altitudinal gradient of traditional agroforestry components species. Three different indigenous agroforestry systems *i.e.* agri-silviculture, silvi-pasture and homegarden were selected for documentation of agrobiodiversity through quadrat method. Further, density, frequency, IVI, and abundance-frequency ratio was calculated for each component of agroforestry system. The study reported that *Grewia optiva, celtis australis, Mallotus phillipensis, Citrus sinensis* and *Morus alba* were the most dominant tree species in the area.

Keywords: Agrobiodiversity, Altitudinal gradient, Traditional agroforestry systems, Himalaya

In India, agroforestry has been recognised as a traditional method of land usage and distributed over 11.54 m ha (3.39 %) of the total geographic area of country (FSI 2019). Numerous unsustainable farming, illicit tree felling, conversion of lands, encroachment are the principal factors have led to overexploitation of natural resources. In Indian mountainous regions, the loss of agricultural land attributed to alterations in rainfall patterns, landslides, runoff, nutrient leaching, the drying up of natural springs, and a lack of irrigation facilities has made farming unprofitable and unsubstantial. To address this, agroforestry is considered as an alternative approach to restore the environmental and livelihood security of the region. In such scenarios, integration of trees on farm boundaries, croplands, fallow lands, and village settlement *etc*. provides enhanced tree cover, biodiversity maintenance, improved soil health, delivery of multiple products and carbon sequestration benefits (FAO 2005). There are numerous traditional agroforestry systems in Garhwal Himalaya, Uttarakhand which is in the northern region of India. Under these systems, farmers have been cultivating a wide variety of annual, biennial, and seasonal crops. The fragile environment created by the terraced slopes and scattered agricultural land, which makes it difficult to conduct agricultural activities and even prohibits the annual demand of food grains by households (Kanwal et al 2022). Agroforestry systems are crucial for maintaining farm productivity and production, creating a resilient farming system, and improving livelihoods and employment prospects. Additionally, agroforestry might be a useful technology in regions with subsistence farming and delicate ecosystems. Agroforestry produced a considerable sum of money that is used by the farmers to provide subsistence income for their families. This has a major impact on improving the rural areas' economies (Sangeetha et al 2016).

Traditional agroforestry systems are practiced from many decades, which combines agriculture crops along with the trees species. A significant portion of Garhwal Himalaya constitutes diversified traditional agroforestry systems. The hilly regions of Uttarakhand are primarily consisting of agri-silviculture, agrihorticulture, and agri-silvi-horticulture systems. Each of these agroforestry systems has the potential to store significant amounts of carbon while also producing fuel, fruits, fodder, fibres, and organic fertilisers (Thakur et al 2007, Bijalwan et al 2015). Due to variable terrain and climatic conditions, vegetation is complex in nature, and its structure and composition changes from place to place (Raturi 2012). Vikrant et al (2016) documented traditional agroforestry systems from Tehri Garhwal i.e., Agrisilviculture, Agri-horticulture and Agri-hortisilvicultural system and it consists of total 22 forest tree species, 11 fruit tree species, and 15 crops species in studied area. The identification of available tree species, their compositions, structure, and functions are need of the hour to design the site-specific agroforestry models to address poverty, land degradation and climate change. Therefore, a study was planned with objective to document the traditional agroforestry systems Kirtinagar Block of Tehri Garhwal.

MATERIAL AND METHODS

The study was conducted in Kirtinagar Block of district Tehri Garhwal (Uttarakhand). The studied Community Development Block covers total of 153 villages and covers an area of about 264.83 km^2, Latitude ranges from 30°12'38” to 30°23'17” North and Longitude ranges from 78° 55'19” to 78°37'15” East. The elevation ranges from 492 m to 2712 m throughout the block from mean sea level (Fig. 1). Three different indigenous agroforestry systems *i.e.* agri-silviculture, silvi-pasture and home garden were selected from 300-1200 m amsl (Lower Altitude) and 1200-2000 m amsl (Upper Altitude) for documentation of agrobiodiversity. Quadrat method was adopted to access the agrobiodiversity, in which 10×10 m, 5×5 m, 1×1 m quadrates were laid out for trees, shrubs, crops and herbs, respectively. Further, density, frequency, Important Value Index (IVI), and abundance-frequency ratio was calculated for each component of agroforestry system. The quantitative analyses for frequency, density, and abundance was done by following methodology developed by Curtis and MacIntosh (1950). Other parameters such as relative frequency, relative density, relative dominance was calculated by following Phillips (1959). The importance value index (IVI) at species level was calculated from the sum of relative frequency, relative density, and relative dominance (Curtis, 1959). The ratio of abundance to frequency is generally used to interpret the distribution pattern of species (Whitford 1949). The ratio of abundance to frequency indicates regular distribution if below 0.025, random distribution between 0.025-0.05 and contagious if it is >0.05 (Curtis and Cottam 1956).

RESULTS AND DISCUSSION

Agri-silviculture: Agri-silviculture system usually comprises of fuelwood and fodder trees, which are grown along the bunds of the farmlands. Total 14 tree, 6 agricultural crops and 6 species of different herbs were found in upper altitudinal zone (1200-2000 m amsl) of study area. Whereas, 13 tree, 8 agricultural crops and 7 species of herbs were found in lower altitudinal (below 1200 m amsl) zone of the study area (Table 1). In upper altitude total tree density was 514 trees/ha, in which *Grewia optiva* had maximum tree density (186 trees/ha) and frequency (85.71), whereas minimum tree density (7 trees/ha) and frequency (7.14) was of *Ficus palmata*. Maximum IVI (94.32) recorded for *Celtis australis* and minimum IVI (3.91) was of *Nyctanthes arbortristis*. *Melia azedarach* had highest abundance frequency ratio of 0.28 and *Ficus roxburghii* had lowest (0.02). In the lower altitudinal zone, the total tree density was 494 trees/ha, out of which *G. optiva* had maximum density (219 trees/ha) and frequency (100). Minimum tree density (6) and frequency (6.25) was of *Ficus hispida*. IVI of *G. optiva* was highest (110.39) and *Ficus cunia* had lowest IVI (3.66) among all trees. The highest and lowest abundance factor was observed for *Morus alba* (0.32) and *Grewia optiva* (0.02), respectively. The similar results were also reported by Manzoor and Jazib (2020). Vikrant et al (2018) found that the major agroforestry systems in same district were dominated by *Grewia oppositifolia*, *Celtis australis* and *Quercus leucotrichophora*.

Among agricultural crops total density was found 1000037/ha in upper altitude, in which *Eleusine coracana* had maximum density (523167), frequency (57.14) and IVI (111.31), while *Cajanus cajan* had minimum density (37038), frequency (7.14) and IVI (19.46). *Oryza sativa* had maximum abundance and frequency ratio (3.64) and *Amaranthus viridis* had minimum A/F (0.10). On the other hand, in lower elevation, crop density/ha was found 125625, in which *Eleusine coracana* had maximum density (46875), frequency (43.75) and IVI (82.13) and *Cajanus cajan* had minimum density (1875), Frequency (6.25) and IVI (10.48). Sesamum indicum had maximum abundance and frequency ratio (1.28) and *Amaranthus viridis* had minimum A/F (0.09). Mahato et al (2016) also found these species prominent in their study.

The total herb density was 80000 individuals/ha in upper altitude in which *Bidens Pilosa* had maximum density (31429), frequency (64.29), and IVI (96.14) and *Euphorbia*

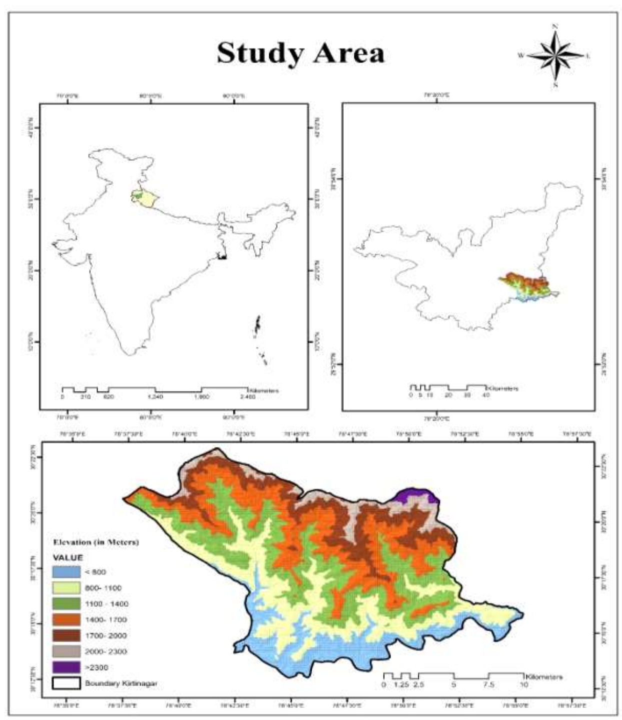

Fig. 1. Digital elevation map of study area

Table 1. Phytosociological attributes of different species in Agrisilviculture system

Trees in Agrisilviculture system		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Khair	*Acacia catechu*	0	0.00	0.00	0.00	13	12.50	7.67	0.08
Kachnar	*Bauhinia variegata*	21	14.29	11.03	0.11	0	0.00	0.00	0.00
Kharik	*Celtis australis*	136	71.43	94.32	0.03	113	56.25	68.27	0.04
Khinna	*Falconeria insignis*	7	7.14	4.01	0.14	0	0.00	0.00	0.00
Khaina	*Ficus cunia*	0	0.00	0.00	0.00	6	6.25	3.66	0.16
Cluster Fig	*Ficus hispida*	0	0.00	0.00	0.00	6	6.25	9.15	0.16
Dudhila	*Ficus neriifolia*	7	7.14	5.12	0.14	0	0.00	0.00	0.00
Bedu	*Ficus palmata*	7	7.14	3.98	0.14	0	0.00	0.00	0.00
Timla	*Ficus roxburghii*	43	42.86	32.58	0.02	19	18.75	15.23	0.05
Chanchri	*Ficus subincisa*	29	28.57	19.94	0.04	6	6.25	9.16	0.16
Bhimal	*Grewia optiva*	186	85.71	87.83	0.03	219	100.00	110.4	0.02
Subabool	*Leucaena leucocephala*	0	0.00	0.00	0.00	25	18.75	16.35	0.07
Ruina	*Mallotus phillipensis*	0	0.00	0.00	0.00	19	18.75	11.74	0.05
Dainkan	*Melia azedarach*	14	7.14	7.25	0.28	31	25.00	20.08	0.05
Sehtoot	*Morus alba*	21	14.29	9.99	0.11	13	6.25	5.53	0.32
Parijat	*Nyctanthes arbortristis*	7	7.14	3.91	0.14	0	0.00	0.00	0.00
Sandan	*Ougeinia oojeinense*	14	7.14	5.75	0.28	0	0.00	0.00	0.00
Panya	*Prunus cerasoides*	14	14.29	10.10	0.07	0	0.00	0.00	0.00
Asan	*Terminalia elliptica*	0	0.00	0.00	0.00	6	6.25	4.17	0.16
Toon	*Toona ciliate*	7	7.14	4.19	0.14	19	18.75	18.60	0.05
Crop in Agrisilviculture system		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Marcha	*Amaranthus viridis*	83336	35.71	38.17	0.10	13125	37.50	38.84	0.09
Toor Dal	*Cajanus cajan*	37038	7.14	19.46	1.12	1875	6.25	10.49	0.48
Jhangora	*Echinochloa esculenta*	157413	14.29	48.59	1.19	30000	18.75	63.21	0.85
Koda	*Eleusine coracana*	523168	57.14	111.31	0.25	46875	43.75	82.13	0.24
Geheth	*Macrotyloma uniflorum*	0	0.00	0.00	0.00	6250	12.50	21.20	0.40
Dhan	*Oryza sativa*	120375	7.14	51.99	3.64	0	0.00	0.00	0.00
Till	*Sesamum indicum*	0	0.00	0.00	0.00	5000	6.25	21.79	1.28
Urad	*Vigna mungo*	0	0.00	0.00	0.00	6875	12.50	22.58	0.44
Ranyas	*Vigna umbellata*	78707	21.43	30.49	0.26	15625	31.25	39.77	0.16
Herbs in Agrisilviculture system		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Billygoat herb	*Ageratum conyzoides*	24286	50.00	78.40	0.10	31875	21.57	66.67	0.21
Kumarr	*Bidens pilosa*	31429	64.29	96.14	0.08	13125	28.57	42.41	0.12
Kana	*Commelina benghalensis*	2857	7.14	22.42	0.56	5000	37.50	33.53	0.07
Ashthma plant	*Euphorbia hirta*	2143	7.14	17.90	0.42	8750	35.71	37.86	0.08
Oxalis	*Oxalis spp.*	7857	14.29	38.46	0.39	16875	11.11	58.03	0.81
Gaajar ghaas	*Parthenium hysterophorus*	0	0.00	0.00	0.00	2500	25.00	29.07	0.16
Yellow Foxtail	*Setaria pumila*	11429	21.43	46.67	0.25	0	0.00	0.00	0.00

hirta had minimum density (2143) frequency (7.14) and IVI (17.90). *Commelina benghalensis* had maximum abundance and frequency ratio (0.56) and *B. Pilosa* minimum A/F (0.08). In lower altitude total density of herbs was 79375 individuals/ha, in which *Ageratum conyzoides* had maximum density (31875) and *Setaria pumila* had minimum density of 1250 individuals/ha. *Setaria pumila* had maximum (50) and *Oxalis species* had minimum (11.11) frequency. *Ageratum conyzoides* had highest (66.66) and *Parthenium hysterophorus* had lowest (29.06) IVI. *Oxalis spp*. had maximum abundance and frequency ratio (0.81) and *Setaria pumila* had minimum A/F (0.04).

Silvi-pasture: In silvi-pastoral system, trees, grasses, shrubs, and herbs were found spread on the uncultivated land. This agroforestry system is being practiced for fuel, fodder and timber. Total 16 tree, 11 grass, 9 shrub and 8 herb species were encountered in upper altitudinal zone of study. On the other hand, 24 tree, 9 grass, 15 shrub and 13 species of herb were found in lower altitudinal zone of the study area (Table 2).

In upper altitudinal zone, total tree density was found 550 individuals/ha in which *Celtis australis* had highest density (143 trees/ha) and frequency (85.71). Whereas, *Melia azedarach* had minimum density (7 trees/ha) and frequency (7.14). Maximum IVI in *C. australis* (82.15) and minimum was of *Morus alba* (3.64). Maximum abundance and frequency ratio was of *Bauhinia retusa* (0.56) and minimum A/F was for *Celtis australis* (0.01). In lower altitudinal zone, total tree density was 569 individuals/ha in which the highest density (81 trees/ha) and frequency (43.75) was of *Mallotus phillipensis* and lowest density (6 trees/ha) and frequency (6.25) was recorded for *Madhuca indica*. IVI, was maximum (34.07) for *M. phillipensis* and minimum (2.95) of *Leucaena leucocephala*. Abundance and frequency ratio was found maximum (0.48) for *Adina cordifolia* and minimum (0.03) was of *Celtis australis*. The phytosociological attributes of *C. australis, G. optiva, Lantana camara* and associated species were recorded are similar to findings of Thakur et al (2004).

Total density of grasses in upper altitude was 106428 individuals/ha in which highest density (37857 individuals/ha), frequency (78.57) and IVI (79.31) was of *Apluda mutica* and lowest density (1428 individuals/ha), frequency (7.14) and IVI (8.69) was for *Brachypodium sylvaticum*. Abundance and frequency ratio was found maximum (0.98) for *Heteropogon contortus* and minimum (0.06) was of *Apluda mutica*. In lower altitudinal zone, the total density of grasses was 104375 individuals/ha in which highest density (33750 individuals/ha), frequency (56.25) and IVI (74.92) was of *Crysopogon montanus,* whereas lowest density (1857 individuals/ha), frequency (6.25) and IVI (12.48) was recorded for *Heteropogon contortus*. A/F was maximum for *Bothriochloa ischarmum* (0.48) and minimum was of *Crysopogon montanus* (0.10). In the Garhwal Himalayan region, there are many types of grasses that grow abundantly during the rainy season. Bagwari and Todaria (2011) observed same trend about range grasses under silvi-pasture systems.

Density of shrubs was 2542 individuals/ha in upper altitudinal zone of study area in which maximum density (743 individuals/ha), frequency (50) and IVI (68.24) was of *Eupatorium adenophorum* and minimum density (57 individuals/ha), frequency (7.14) and IVI (13) was of *Carissa spinarum*. Abundance and frequency ratio was maximum (0.42) for *Senna occidentalis* and minimum (0.07) was of *Eupatorium adenophorum*. In lower altitude, total density of shrubs was 2825 individuals/ha in which highest density (500 individuals/ha), frequency (43.75) and IVI (40.71) was recorded for *Rhus parviflora* and lowest density (50 individuals/ha), frequency (6.25) and IVI (9.39) was of *Carissa spinarum*. Maximum abundance and frequency ratio was found in *Colebrookea oppositifolia* (0.48) and minimum A/F found in *Lantana camara* (0.04).

In upper altitudinal zone, total density of herbs was 47857 individuals/ha in which maximum density (22142 individuals/ha), frequency (57.14) and IVI (102.28) was of *Bidens pilosa* and minimum density (2143 individuals/ha), frequency (7.14) and IVI (20.50) was noted for *Cynoglossum lanceolatum*. Abundance and frequency ratio was found maximum (0.70) in *Geranium lucidum* and minimum (0.06) in *B. Pilosa*. In lower altitude the total density of herbs was 48125 individuals/ha in which maximum density (13125 individuals/ha), frequency (43.75) and IVI (63.50) was observed for *B. Pilosa* and minimum density (625 individuals/ha), frequency (6.25) and IVI (7.81) was of *Thalictrum foliolosum.* Maximum abundance and frequency ratio was of *Synedrella nodiflora* (0.96) and minimum A/F found was recorded for *B. Pilosa* (0.06). Bijalwan (2013), also mentioned same species in his study carried out in district Tehri Garhwal of Uttarakhand, India.

Homegarden: In homegardens, tree and fruit crops were the main woody components whereas crops and vegetable were main understory components. Total 17 tree, 14 crops and 5 herb species were reported in upper altitudinal zone. On the other hand, 24 tree, 11 crop and 6 species of herbs were found in lower altitudinal zone of the study area (Table 3).

In upper altitude total tree density of 564 individuals/ha was recorded, in which *Citrus sinensis* had maximum density (107 individuals/ha), frequency (57.14) and IVI (48.20) and *Phyllanthus emblica* had minimum density (7 individuals/ha), frequency (7.14) and IVI (3.73). *Ficus roxburghii* had minimum abundance and frequency ratio (0.28) and

Table 2. Phytosociological attributes of different species in silvipasture system

Trees in Silvipasture system		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Khair	*Acacia catechu*	0	0.00	0.00	0.00	19	18.75	11.54	0.05
Haldu	*Adina cordifolia*	0	0.00	0.00	0.00	19	6.25	8.97	0.48
Dhaura	*Anogeissus latifolia*	0	0.00	0.00	0.00	13	6.25	8.04	0.32
Kandi	*Bauhinia retusa*	29	7.14	9.69	0.56	13	6.25	7.79	0.32
Kachnar	*Bauhinia variegata*	7	7.14	3.93	0.14	56	31.25	22.22	0.06
Amaltas	*Cassia fistula*	0	0.00	0.00	0.00	6	6.25	7.33	0.16
Kharik	*Celtis australis*	143	85.71	82.16	0.02	44	37.50	28.50	0.03
Shisham	*Dalbergia sissoo*	0	0.00	0.00	0.00	6	6.25	3.23	0.16
Khinna	*Falconeria insignis*	21	21.43	14.18	0.05	13	12.50	7.11	0.08
Khaina	*Ficus cunia*	0	0.00	0.00	0.00	19	12.50	13.94	0.12
Cluster Fig	*Ficus hispida*	0	0.00	0.00	0.00	6	6.25	3.52	0.16
Dudhila	*Ficus neriifolia*	21	7.14	12.73	0.42	0	0.00	0.00	0.00
Timla	*Ficus roxburghii*	50	42.86	31.43	0.03	38	25.00	16.91	0.06
Chanchri	*Ficus subincisa*	14	14.29	6.87	0.07	0	0.00	0.00	0.00
Bhimal	*Grewia optiva*	64	35.71	32.26	0.05	44	31.25	21.47	0.04
Jamun	*Syzygium cumini*	0	0.00	0.00	0.00	19	18.75	14.17	0.05
Bahera	*Terminalia bellirica*	0	0.00	0.00	0.00	13	12.50	10.13	0.08
Harad	*Terminalia chebula*	0	0.00	0.00	0.00	31	12.50	13.21	0.20
Toon	*Toona ciliata*	21	14.29	17.72	0.11	25	18.75	20.30	0.07
Indrjau	*Wrightia tinctoria*	0	0.00	0.00	0.00	6	6.25	3.78	0.16
Grasses in Silvipasture system		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Tachlu	*Apluda mutica*	37857	78.57	79.32	0.06	21250	37.50	53.01	0.15
Dhaddu	*Arundinella nepalensis*	17143	35.71	41.63	0.13	19375	37.50	49.94	0.14
Yellow bluestem	*Bothriochloa ischarmum*	5714	14.29	20.07	0.28	1875	6.25	12.49	0.48
False brome	*Brachypodium sylvaticum*	1429	7.14	8.69	0.28	10000	18.75	32.29	0.28
Salmu	*Bromus inermis*	2143	7.14	11.53	0.42	0	0.00	0.00	0.00
Gurla	*Crysopogon montanus*	7857	14.29	25.33	0.39	33750	56.25	74.93	0.11
Dub	*Cynodon dactylon*	0	0.00	0.00	0.00	3125	12.50	15.44	0.20
Nut Grass	*Cyprus rotundus*	1429	7.14	8.69	0.28	0	0.00	0.00	0.00
Finger grass	*Digitaria spp.*	2857	7.14	14.36	0.56	7500	18.75	26.49	0.21
Black speargrass	*Heteropogon contortus*	5000	7.14	22.85	0.98	1875	6.25	12.49	0.48
Daba	*Juncus inflexus*	1429	7.14	8.69	0.28	0	0.00	0.00	0.00
Birachu	*Pennisetum species*	22143	42.86	50.15	0.12	5625	12.50	22.94	0.36
Naru		1429	7.14	8.69	0.28	0	0.00	0.00	0.00
Shrubs in Silvipasture system		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Kingod	*Berberis aristata*	0	0.00	0.00	0.00	150	18.75	17.29	0.11
Khakshu	*Boehmeria macrophylla*	371	21.43	41.00	0.20	300	31.25	28.04	0.08

Cont...

Table 2. Phytosociological attributes of different species in silvipasture system

Trees in Silvipasture system		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Kharanu	*Carissa spinarum*	57	7.14	13.01	0.28	50	6.25	9.40	0.32
Bhindu	*Colebrookea oppositifolia*	0	0.00	0.00	0.00	75	6.25	13.01	0.48
Kala bansa	*Eupatorium adenophorum*	743	50.00	68.24	0.07	225	18.75	22.67	0.16
Sakina	*Indigofera tinctoria*	200	14.29	27.62	0.25	100	12.50	13.34	0.16
Lantana	*Lantana camara*	286	21.43	34.11	0.16	375	43.75	34.34	0.05
Chui Mui	*Mimosa pudica*	0	0.00	0.00	0.00	50	6.25	9.40	0.32
Kari Patta	*Murraya koenigii*	0	0.00	0.00	0.00	425	43.75	36.89	0.06
Tungla	*Rhus parviflora*	400	35.71	44.13	0.08	500	43.75	40.71	0.07
Hisalu	*Rubus ellipticus*	229	21.43	29.51	0.12	150	12.50	17.84	0.24
Ameda	*Rumex hastatus*	171	14.29	24.73	0.21	125	12.50	15.59	0.20
Chakunda	*Senna occidentalis*	86	7.14	17.66	0.42	0	0.00	0.00	0.00
Bala	*Sida cordifolia*	0	0.00	0.00	0.00	75	6.25	13.01	0.48
Bariyara	*Urena lobata*	0	0.00	0.00	0.00	50	6.25	9.40	0.32
Dhaud	*Woodfordia fruticosa*	0	0.00	0.00	0.00	175	18.75	19.08	0.12
Herbs in Silvipasture system		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Billygoat herb	*Ageratum conyzoides*	0	0.00	0.00	0.00	1250	6.25	11.47	0.32
Bukifool	*Anaphalis busua*	0	0.00	0.00	0.00	1875	6.25	15.12	0.48
Kunja	*Artemisia vulgaris*	5000	14.29	33.53	0.25	5000	12.50	28.14	0.32
Kumarr	*Bidens pilosa*	22143	57.14	102.28	0.07	13125	43.75	63.50	0.07
Kana	*Commelina benghalensis*	2143	7.14	20.50	0.42	0	0.00	0.00	0.00
Lechkumar	*Cynoglossum lanceolatum*	2143	7.14	20.50	0.42	0	0.00	0.00	0.00
Horseherb	*Erigeron canadensis*	0	0.00	0.00	0.00	2500	12.50	18.23	0.16
Kaliko plant	*Euphorbia heterophylla*	0	0.00	0.00	0.00	2500	6.25	18.77	0.64
Ashthma plant	*Euphorbia hirta*	2857	7.14	25.58	0.56	1875	6.25	15.12	0.48
Shining cranesbill	*Geranium lucidum*	3571	7.14	30.66	0.70	2500	6.25	18.77	0.64
Kharenti	*Malvastrum coromandelianum*	0	0.00	0.00	0.00	1875	6.25	15.12	0.48
Gaajar ghaas	*Parthenium hysterophorus*	0	0.00	0.00	0.00	8750	25.00	43.09	0.14
Yellow Foxtail	*Setaria pumila*	6429	21.43	39.99	0.14	0	0.00	0.00	0.00
Synedrella grass	*Synedrella nodiflora*	0	0.00	0.00	0.00	3750	6.25	26.08	0.96
Mamira	*Thalictrum foliolosum*	3571	14.29	26.96	0.18	625	6.25	7.82	0.16
Tridex daisy	*Tridex procumbens*	0	0.00	0.00	0.00	2500	6.25	18.77	0.64

Table 3. Phytosociological attributes of different species in Homegarden

Trees in Homegarden		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Dhaura	*Anogeissus latifolia*	0	0.00	0.00	0.00	6	6.25	3.91	0.16
Kathal	*Artocarpus heterophyllus*	0	0.00	0.00	0.00	6	6.25	6.70	0.16
Kachnar	*Bauhinia variegata*	21	21.43	13.18	0.05	0	0.00	0.00	0.00
Papeeta	*Carica papaya*	0	0.00	0.00	0.00	56	43.75	23.40	0.03
Yellow Kaner	*Cascabela thevetia*	0	0.00	0.00	0.00	6	6.25	2.60	0.16
Kharik	*Celtis australis*	43	35.71	36.78	0.03	13	12.50	6.35	0.08
Orange	*Citru aurantium*	14	7.14	5.09	0.28	6	6.25	3.00	0.16
Malta	*Citru sinensis*	107	57.14	48.20	0.03	38	25.00	14.04	0.06
Nimbu	*Citrus aurantiifolia*	0	0.00	0.00	0.00	25	25.00	10.64	0.04
Galgal	*Citrus limon*	14	14.29	7.80	0.07	6	6.25	2.63	0.16
Chabutra	*Citrus paradisi*	0	0.00	0.00	0.00	25	18.75	11.20	0.07
Bedu	*Ficus palmata*	14	7.14	5.62	0.28	0	0.00	0.00	0.00
Timla	*Ficus roxburghii*	14	7.14	6.84	0.28	0	0.00	0.00	0.00
Chanchri	*Ficus subincisa*	0	0.00	0.00	0.00	6	6.25	2.82	0.16
Phalsa	*Grewia asiatica*	0	0.00	0.00	0.00	6	6.25	8.88	0.16
Bhimal	*Grewia optiva*	57	28.57	28.31	0.07	13	12.50	6.86	0.08
Akhrot	*Juglans regia*	7	7.14	7.78	0.14	6	6.25	9.69	0.16
Subabool	*Leucaena leucocephala*	0	0.00	0.00	0.00	6	6.25	3.34	0.16
Mango	*Mangifera indica*	43	28.57	25.33	0.05	69	43.75	37.65	0.04
Dainkan	*Melia azedarach*	14	14.29	11.12	0.07	44	31.25	25.89	0.04
Sehtoot	*Morus alba*	7	7.14	5.14	0.14	88	62.50	39.56	0.02
Banana	*Musa paradisiaca*	57	28.57	28.76	0.07	56	31.25	26.40	0.06
Aonla	*Phyllanthus emblica*	7	7.14	3.74	0.14	0	0.00	0.00	0.00
Chulu	*Prunus armeniaca*	0	0.00	0.00	0.00	6	6.25	3.11	0.16
Aadu	*Prunus persica*	43	35.71	23.60	0.03	13	12.50	6.04	0.08
Guava	*Psidium guajava*	50	28.57	24.02	0.06	63	56.25	29.77	0.02
Anar	*Punica granatum*	50	28.57	18.71	0.06	25	25.00	10.15	0.04
Jamun	*Syzygium cumini*	0	0.00	0.00	0.00	6	6.25	5.41	0.16
Crops in Homegarden		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Bhindi	*Abelmoschus esculentus*	4286	14.29	20.77	0.21	1875	6.25	15.34	0.48
Marcha	*Amaranthus viridis*	714	7.14	6.88	0.14	1875	6.25	15.34	0.48
Patta Gobhi	*Brassica oleracea var. capitata*	714	7.14	6.88	0.14	0	0.00	0.00	0.00
Mirch	*Capsicum annum*	30000	64.29	75.69	0.07	39375	87.50	99.93	0.05
Arbi	*Colocasia esculenta*	18571	64.29	55.43	0.04	16250	68.75	55.76	0.03
Kaddu	*Cucurbita pepo*	1429	14.29	10.26	0.07	0	0.00	0.00	0.00
Haldi	*Curcuma longa*	0	0.00	0.00	0.00	9375	43.75	36.50	0.05
Lauki	*Lagenaria siceraria*	714	7.14	6.88	0.14	625	6.25	6.74	0.16

Table 3. Phytosociological attributes of different species in Homegarden

Trees in Homegarden		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Common name	Botanical name	Density/ha	Frequency	IVI	A/F	Density/ha	Frequency	IVI	A/F
Karela	*Memordica charantia*	714	7.14	6.88	0.14	625	6.25	6.74	0.16
Mentha	*Mentha spicata*	0	0.00	0.00	0.00	2500	6.25	19.65	0.64
Beans	*Phaseolus vulgaris*	2857	14.29	15.51	0.14	0	0.00	0.00	0.00
Mooli	*Raphanus sativus*	714	7.14	6.88	0.14	0	0.00	0.00	0.00
Tomato	*Solanum lycopersicum*	1429	14.29	10.26	0.07	0	0.00	0.00	0.00
Baingan	*Solanum melongena*	5000	21.43	21.81	0.11	3125	12.50	17.62	0.20
Makka	*Zea mays*	5714	21.43	23.86	0.12	1250	6.25	11.04	0.32
Adrak	*Zingiber officinale*	8571	21.43	32.04	0.19	1875	6.25	15.34	0.48
Herbs		Upper Altitude 1200-2000 m				Lower altitude <1200 m			
Billygoat weed	*Ageratum conyzoides*	14286	35.71	82.62	0.11	21875	56.25	91.71	0.07
Kumarr	*Bidens pilosa*	13571	50.00	86.49	0.05	9375	37.50	51.57	0.07
Kana	*Commelina benghalensis*	4286	14.29	36.42	0.21	5000	18.75	32.61	0.14
Ashthma plant	*Euphorbia hirta*	0	0.00	0.00	0.00	3750	12.50	27.89	0.24
Gallant soldier	*Gallinsoga parviflora*	4286	14.29	36.42	0.21	0	0.00	0.00	0.00
Oxalis	*Oxalis* spp.	5714	7.14	58.06	1.12	13750	25.00	64.56	0.22
Trifolium	*Trifolium* spp.	0	0.00	0.00	0.00	3125	6.25	31.66	0.80

maximum A/F was in *C. sinensis* (0.03). *C. sinensis* in the northern aspect showed the highest IVI value (48.84). The concomitant results was also found in for fruit trees in that area (Bijalwan 2012). In lower altitude total tree density was 594 individuals/ha out of which *Morus alba* had highest density (87 individuals/ha), frequency (62.50) and IVI (39.56) and *Cascabela thevetia* showed lowest density (6 individuals/ha), frequency (6.25) and IVI (2.59). Abundance and frequency ratio was found maximum in *Juglans regia* (0.16) and minimum in *Psidium guajava* (0.01).

Among crops, total density was 81429 individuals/ha in upper altitude out of which *Capsicum annum* had maximum density (30000 individuals/ha), frequency (64.28) and IVI (75.68). *Lagenaria siceraria* showed minimum density (714 individuals/ha), frequency (7.14) and IVI (6.87). Maximum abundance and frequency ratio (0.21) was for *Abelmoschus esculentus* and minimum (0.04) of *Colocasia esculenta*. In lower altitude the total density of crops was 78750 individuals/ha, in which *C. annum* had maximum density (39375 individuals/ha), frequency (87.50) and IVI (99.93) and *Memordica charantia* had minimum density (625 individuals/ha), frequency (6.25) and IVI (6.74). Maximum abundance and frequency ratio (0.64) was of *Mentha spicata* and minimum (0.03) was for *Colocasia esculenta* (0.03). Findings of Vibhuti et al (2018) also depicted maximum frequency in *C. annum* (100) and minimum in *C. esculenta* (33.33).

Total density of herbs in upper altitudinal zone was 42143 individuals/ha in which *Ageratum conyzoides* had maximum (14285 individuals/ha) and *Gallinsoga parviflora* had minimum density (4285 individuals/ha). *Bidens Pilosa* had maximum (50) and *Oxalis species* had minimum (7.14) frequency. IVI was maximum (86.48) for *Bidens pilosa* and minimum (36.41) was of *Gallinsoga parviflora*. Abundance and frequency ratio was found maximum (1.12) for *Oxalis* species and minimum (0.05) was recorded for *B. Pilosa* (0.05). In lower altitudinal zone the total density of herbs was 56875 individuals/ha in which *Ageratum conyzoides* had maximum density (21875 individuals/ha) and frequency (56.25) and *Trifolium* species had minimum density (3125) and frequency (6.25). IVI was maximum (91.70) for *Ageratum conyzoides* and minimum for *Euphorbia hirta* (27.89). Abundance and frequency ratio was maximum (0.80) for *Trifolium* species and minimum (0.06) was of *Bidens pilosa*.

CONCLUSION

The present findings indicated that, there are relatively few trees in agricultural fields. It is perceived that homegardens provided a variety of ecological services since they are rich in tree species or tree diversity. Trees like *Grewia optiva, Celtis australis, Mallotus phillipensis, Citrus sinensis* and *Morus alba* are the most prominent tree species and suitable for restoration programme. Considering that traditional agroforestry systems provide a variety of economic and ecological benefits; it is crucial to preserve their sustainability.

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Impact of Climate Change and Human Activities on Groundwater Resources in the Alluvial Aquifer of Upper Cheliff, Algeria

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Abstract: In the agricultural plain of Upper Cheliff, the human activities increased water demand. The objective of this study is to identify the impact of the anthropogenic activities on groundwater resources of the alluvial aquifer in the Upper Cheliff (Algeria) due to intense agricultural activity. The groundwater recharge reduced by 30% in the 50 years from 1970 to 2020 in this alluvial aquifer due to the mean yearly growth rate of the population of 20 ‰ and associated with the water use rate increasing from 25 % to 50%. In addition to that, the water seepage in the network of drinking water coming from groundwater pumping is up to 10%. The use of water for irrigation agriculture is increased 30 % over the period of 50 years due to the development of agricultural programs, which have significant effects on the status of the water resources in the aquifer. As a result, groundwater levels dropped by 2-15 meters in most areas, except in some irrigation areas in this plain. We also observed a decrease in water discharge from wells by 30-60% of the alluvial aquifer, and an expansion of the area of polluted groundwater with high concentrations of certain chemical parameters.

Keywords: Anthropogenic activities, Alluvial aquifer, Upper Cheliff, Agricultural activity, Groundwater depletion

Groundwater resources in alluvial aquifers are crucial for human activities such as agriculture, industry, and domestic use. Alluvial aquifers are found in the permeable layers of sand, gravel, probes making them a significant source of fresh water, and can be recharged by infiltration of water from the surface, from rivers, or from effective precipitation, and they can be a reliable source of water in areas with limited surface water resources. However, groundwater resources in alluvial aquifers face a number of challenges, including overexploitation, contamination, and declining water levels. Human activities such as land use change, urbanization, and groundwater pumping can lead to depletion of groundwater resources (Wang et al 2022). Contamination from agricultural chemicals, industrial pollutants, and waste disposal can also negatively impact the quality of groundwater. Climate change, with its impacts on precipitation patterns and temperature, can further exacerbate these challenges (Swain et al 2022, El-Rawy et al 2023). To ensure the long-term sustainability of groundwater resources in these aquifers, it is necessary to implement better management practices and address the challenges they face (Bouderbala 2014, Mersha et al 2018). Compared to other countries with a humid climate, countries with semi-arid and arid climates have unstable water reserves and they are extremely vulnerable to the climatic conditions. The decrease in precipitation and the increase in temperature observed in the last four decades had directly affected surface water resources and made them limited, for this reason, the recourse for the use of groundwater is an inevitable solution to guarantee sustainable satisfaction in water needs. Indeed, groundwater is widely used for irrigation, domestic and industrial purposes in regions with a semi-arid and arid climate, which is the cases of the Sidi Bouzid aquifer in Tunisia, Tadla and Haouz aquifer in Morocco, Mitidja and Haut Chéliff aquifer in Algeria (Bouderbala et al 2021).

Population growth, industrial development, and the launch of the agricultural program in 2004 by the Algerian government, as well as the incentives for agricultural investors, are factors that have favoured the exploitation increase of groundwater in this alluvial aquifer through intensive pumping, while during the last years this region has experienced remarkable drought, resulting from low recharge rates of the aquifer (Chaudhari and Pathak 2022). The decrease in the flow rates of certain wells, the drying up of shallow boreholes (< 50m), and the deterioration of the quality of groundwater by the increase of some chemical concentrations, are harmful to humans and crops, and they are really felt by farmers and citizens in this region (Hennia et al 2022, Guenfoud et al 2021). In addition to that, this plain knew a decrease of rainfall between 10 and 20% and an increase of temperatures between 0.5 and 1.0°C, and it will augment from 2 to 4°C over the next 100 years based on some researchers, which has a direct consequence on the global weather by rising evaporation and an indirect impact on groundwater resources. Algeria has a semi-arid climate for the most part in the north of the country. It will suffer droughts, desertification, soil salinization and water supply under the pressure of population growth and continued needs (Bouderbala 2019, Bouderbala 2020). This survey highlights the impact of anthropogenic activities and climate change on groundwater resources in the alluvial aquifer of the Upper Cheliff. Using an analysis of the annual rainfall data recorded at a pluviometric station located in the plain, and the analysis of the temporal evolution of piezometric levels in some wells, as well as, the analysis of groundwater quality can identify the influence of the natural and human activities on the groundwater resources in this agricultural plain.

MATERIAL AND METHODS

Study area: The Upper Cheliff plain is located approximately 120 km south-west of the capital Algiers, between 36°10' and 36°20' north latitude and 02°00' and 02°25' east longitude and covers an area of 370 km². The plain lies between the massif of Zaccar in the North (1580m.s.l) and the Ouarsenis chain in the South (1985 m.s.l). The width is between 5 to 12 Km and length is approximately 55 Km. The Wadi Chéliff watercourse crosses the plain from east to west, and divides it into two large irrigated perimeters, one on the left bank and the other on the right bank. The most significant tributaries which discharge into the main watercourses are: Deurdeur, Harreza, Boutane, Erraihane, Telbanet, and Massine wadis. The plain that contains this aquifer is an agricultural area with wheat, tomatoes, potatoes, and fruits as the main crops, and it requires vast amounts of irrigation water. The irrigation is ensured by private drillings and by a pressure network supplied from three dams located near the plain. The study area is characterized by a Mediterranean semi-arid climate, with hot dry summer and cold rainy winter. The annual average temperature for the period of 1971-2021 is 17°C, and the rainfall average for the same period is about 430 mm, concentrated between December and April. The average annual evapotranspiration according to Thornthwaite method is about 350 mm/year, and an infiltration rate is of 9 % of rainfall.

Geologic and hydrogeology context: The plain of Upper Cheliff is a large depression with a syncline axis orientation from East to West, where Mio-Plio-Quaternary deposits have been accumulated (Fig. 1). The stratigraphy of the formations from bottom to top is as follows.

The primary formations are observed in Zaccar and Doui massifs, and are formed of black schist, clays and quartzite. The Triassic is characterized by massive gypsum, dolomitic limestone and dolomite formations. The Jurassic in Zaccar massif is mainly underlain by sedimentary rocks of fractured and karstified limestone, dolomite and other carbonate rocks, with a thickness can reach 1000 m. The Cretaceous outcrops are observed on the lateral borders of the plain, and they are represented by a highly thick series of Neocomian schists (about 1000 m), a grey schist alternating with benches quartzite of Albian-Aptian (near to 1000 m). The Miocene formation is about 300 m thick. The lower Miocene is essentially represented by blue marls. It is surmounted by Burdigalian (middle Miocene) with sandstone, conglomerates and marls. The outcrop of coarse sandstones interbedded with conglomerates and clays appear in the Gantas hills where completes the Miocene cycle (Upper Miocene) with thickness of about 100 m. The Mio-Pliocene consists of pebbles, conglomerates, detrital sandstones and clays, and travertine deposited at the Zaccar sources.

In terms of hydrogeological context, the analysis of lithostratigraphic layers in this plain highlighted the existence of two principal aquifers (Fig. 2). The unconfined Quaternary aquifer consists of alluvial and terrace deposits of silt, clay, sand, gravel and pebbles of Quaternary age. It has a heterogeneous layer's system, and the recharge to the alluvial and terrace deposits is mostly from precipitation, and from the Wadi Cheliff in certain sections of the wadi, and the excess of irrigation water can contribute also to the recharge of the Quaternary aquifer. This aquifer is the most exploited in this region, where the wells and boreholes of 40 to 150m are used commonly for drinking supply and irrigation of agricultural lands. The Quaternary aquifer is covered by silt and clay on the surface, from 5 to 20 m of thickness in the centre of the plain (Bouderbala and Gharbi 2017). The

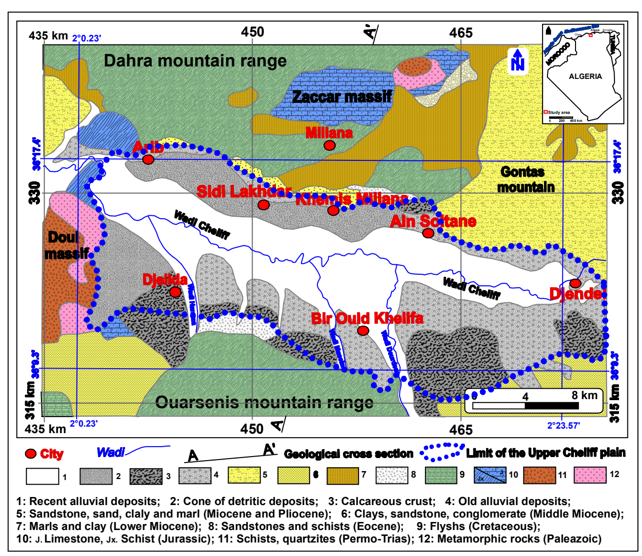

Fig. 1. Geological map of the Upper Cheliff plain

confined Mio-plioce aquifer is the deeper one, it is collected by deep well drilling exceeding 200m, and groundwater of this has a good quality. It is mainly formed by sands and sandstones with clayey and marly intercalations. The sandstone and sands of Miocene appear mainly in the north-east of the plain in Gontas Mountain, and in the southeast of the city Djendel (Bouderbala 2017). The system aquifer in this area can be considered as multi-layered aquifer systems. The hydraulic continuity between the alluvial aquifer and Mio-Pliocene aquifer exists only in the borders of the plain where there is a contact between the two aquifers without impermeable layer between them; however, in the centre of the plain there is thick clay layer between the two aquifers (Bouderbala and Gharbi 2017). We note here that we are only interested in the quaternary alluvial aquifer in this study.

The piezometric map dressed from data of groundwater in metres above sea levels are important to characterize the aquifer behaviour (spatial distribution of hydraulic loads and potentials of groundwater, the hydrodynamic boundary conditions of aquifer, the directions of groundwater flow path, the recharge areas, the outlet of the water table, relationship watercourse and groundwater.

The piezometric map established for the dry water period 2018 (Fig. 3) shows an alluvial aquifer flows toward the centre of the plain where the main drainage axis is located, which coincides with wadi Cheliff, with a main flow is from east to west. The aquifer's flows are conditioned by the geological structure of the basin, the hydrodynamic parameters, as well as, the supply and exploitation conditions of this aquifer. The depth of groundwater levels varies from 5 m in the west part of the plain (near to Djelida and Arib cities) to 40 m in the east of the plain (near to Djendel city), while in the central part of the plain the depth of the groundwater levels is about 25 m. This indicates that the eastern part of the aquifer is more vulnerable to anthropogenic pollution, and as results a probable degradation of groundwater quality, particularly when the unsaturated area is composed with a permeable soil.

The hydraulic gradient in the eastern part of the plain is

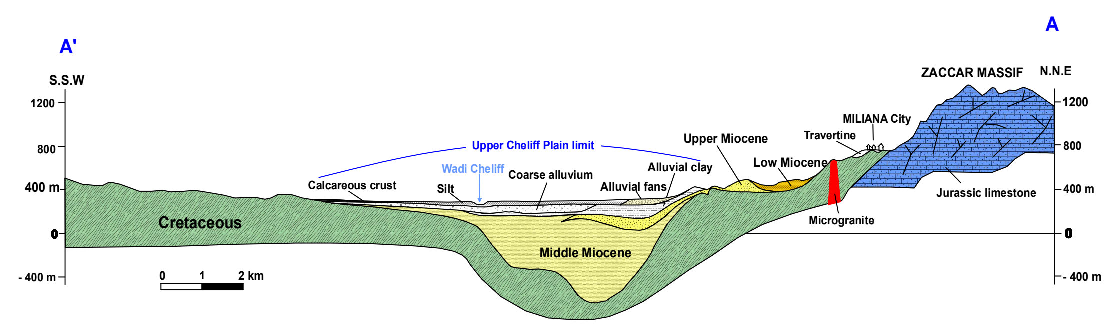

Fig. 2. Geological cross section A–A' in the Upper Cheliff plain

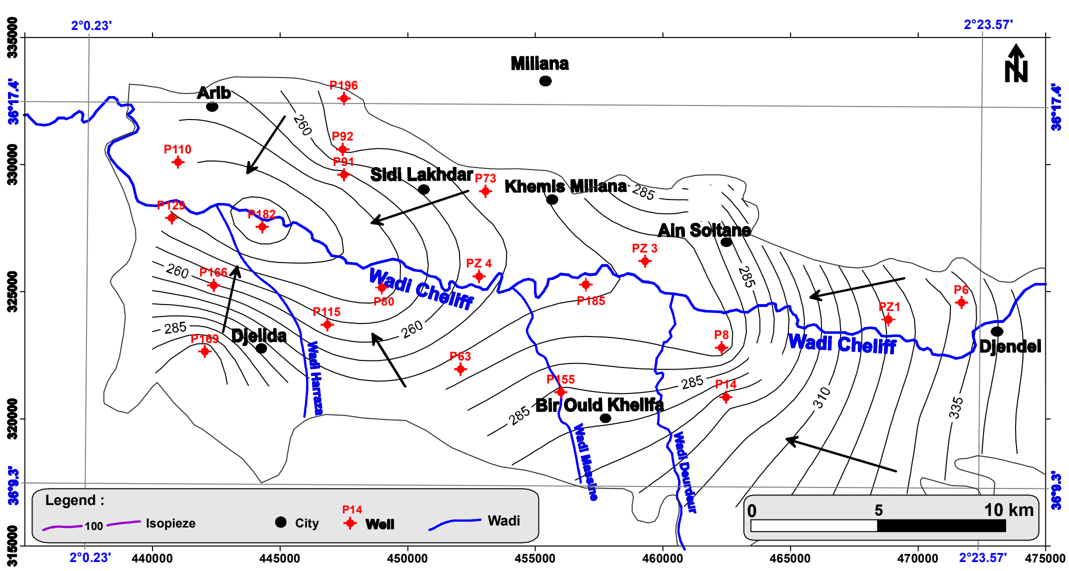

Fig. 3. Groundwater level contour map of the Upper Cheliff plain, dry period 2018

quite high, oscillates from 10^{-2} and 3. 10^{-2} and in the south-western zone near to Djelida city the hydraulic gradient oscillates from 10^{-2} to 2.5 10^{-2}. This is due to the rising of the aquifer substratum (sloping situation) and the low thickness of the aquifer. While, in the central part the plain, the hydraulic gradients are between 0.9 10^{-3} to 9 10^{-3}; which is explained by the high thickness of the aquifer; the high permeability and the low slope of the substratum. We also note that relationship between watercourse of Cheliff and aquifer is not very clear due to the low density of the monitoring wells network near this watercourse of Wadi Cheliff.

Caractérisation of the climate régime: Analyze the impact of climate change on ground water ressources in the alluvial aquifer, including changes in précipitation patterns, and temperature, base on the data acquisition and analysing. The data of precipitation used in this study belong to one long observation rainfall station located in the center of the alluvial plain. In this work, piezometric water levels recorded in years 1975, 1991 and 2014 were used to see the spatio-temporal evolution of groundwater in this alluvial aquifer, by using geographical information system (GIS). Data were collected from technical service in charge of water resources mobilisation (ANRH and DRE). The data were used to calculate the balance between water need and groundwater resource available.

The trends and breaks through the analysis of rainfall variability were examined, mainly by analysing the main trends of the annual rainfall during the time of the series (observation period), and the determination of the breaks of each rainfall station. This rupture of chronological series marks the modification of hydrological regime. The detection of one or more breaks provides information on the rainfall trend in a given region.

The Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought associated with climate change on a range of timescales. The SPI is closely related to soil moisture and can be related to groundwater and reservoir storage. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data (Karavitis et al 2011). The SPI is done by the formula:

SPI = (Pi – Pm)/σ Where:

Pi: rainfall for the year I (in mm); Pm: Average of rainfall (in mm); σ: standard deviation (in mm).

The SPI values for any area are classified into seven different precipitation regimes, from dry to wet (Table 2).

The Standardized Precipitation Index (SPI) is used to analyse the various aspects of drought based on time-scale. The SPI range is divided into near normal conditions (−1<SPI≤1), moderately dry (−1.5<SPI≤−1), severely dry (−2<SPI≤ −1.5) and extremely dry (SPI≤−2.0). A drought event starts when SPI value reaches −1.0 and ends when SPI becomes positive or close to positive again.

Quantitatif and qualitatif of groundwater resources reserves : The quantity of groundwater reserves is derived from natural recharge of the aquifer, which occurs when a portion of rainfall infiltrates into the soil and reaches the water table. Natural recharge is closely linked to the climate regime; during rainy periods, high recharge of the aquifer can be observed, and vice versa. Determining natural recharge is one of the most challenging hydrogeological parameters, and estimates obtained using different methods tend to approximate the true value. In this study, we use the simple and traditional WTF method, which is applied to unconfined aquifers. This method takes into account fluctuations in groundwater levels and is used when the groundwater storage is unknown (Maréchal et al 2006, Khatri and Tyagi 2015). The recharge is estimated by the following equation (Addisie 2022):

$$R = S_y . \frac{\Delta h}{\Delta t}$$

where Sy is the specific yield or drainable porosity of the unconfined aquifer, h is the water table height, and t is time. Δh is the difference between the peak of the rise and the low point of the extrapolated antecedent recession curve at the time of the peak.

RESULTS AND DISCUSSION

Trend of the interannual rainfall: The analysis of annual rainfall data of the ITGC station, located in Khemis Miliana city, recorded during the period from 1971 to 2021, highlighted that the Haut Cheliff plain is characterized by a great irregularity of rainfall regime, with an annual average of 430 mm, a maximum value of 720 mm recorded in 1972, and a minimum value of 147 mm recorded in 1994. Rainfall data also show a rainy season from November to April and a dry season with very low rainfall during months between June to August.

The trend analysis performed on annual rainfall values recorded over 50 years (period from 1971 to 2021) by using the three (3) years moving average filter highlight the rainy years and the less one. Three distinct periods are observed: a moderately rainy period extending from 1971 to 1982 (517 mm), a second period of decline rainfall ranging from 1983 to 2007 (380 mm), with values below the average of annual period and a third one is slightly rainy period extending from 2008 to 2021 (454 mm). The rainfall station from the 82 until 2007 show a deficit period in term of intensity and duration, which had a direct impact of groundwater resources in term of quantity and quality (Fig. 4).

In order to characterize the drought in the Upper Cheliff plain, the SPI index was calculated for a time scale of one year. The examination of the chronological variations of the SPI index shows that the 'extreme drought' character is not dominant in the plain, except for the year 1994 where an extreme drought was recorded, corresponding to the value of -2. We also note that the SPI values show dry conditions (negative values) for the period from 1982 to 2007 with an extended drought event. This indicates that the drought conditions in the Upper Cheliff plain have been persistent for a long period of time, which can have severe impacts on the water resources in the region (Fig. 5).

Drought can have a significant impact on the groundwater resources in the Upper Cheliff plain, as it reduces the recharge rate of the aquifer and increases the demand for water. This can lead to groundwater depletion and a decline in the water table. It can also affect the quality of groundwater, as it can lead to a higher concentration of dissolved ions and pollutants. Additionally, drought conditions can have a significant impact on the agricultural sector in the Upper Cheliff plain. Reduced water availability can lead to a decline in crop yields and a loss of productivity.

Trend of temperature: Algeria over the last fourteen years, the annual average temperatures have increased by 0.5°C, which has an effect on quantity and quality of groundwater reserve. The analysis of the variations in the annual average temperatures recorded at the Herreza climatic station located in the Upper Cheliff plain shows an average annual temperature of approximately 18.5°C, with a high value of 20.3°C recorded in 2010 and a low of 16.0°C recorded in 1993. The increase in temperatures over the past few decades, has a direct impact on the evaporation of water reserves in the soil and aquifer. The warmer temperatures lead to a higher rate of evaporation and transpiration of water from the soil and aquifer, which can cause a decline in the water table and water availability. This can have a significant impact on the groundwater resources in the Upper Cheliff plain, particularly for the irrigation and domestic water supply. As a result of the increased temperatures, the water demand in the agricultural sector increases, and it may lead to over-exploitation of the groundwater resources, which can cause groundwater depletion and reduction of the water table (Fig. 6).

Natural recharge of groundwater: Evaluation of natural

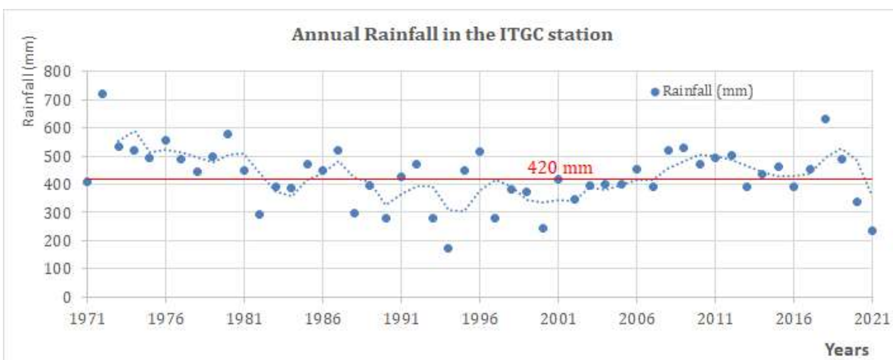

Fig. 4. Evolution of annual rainfall including the three years moving filter

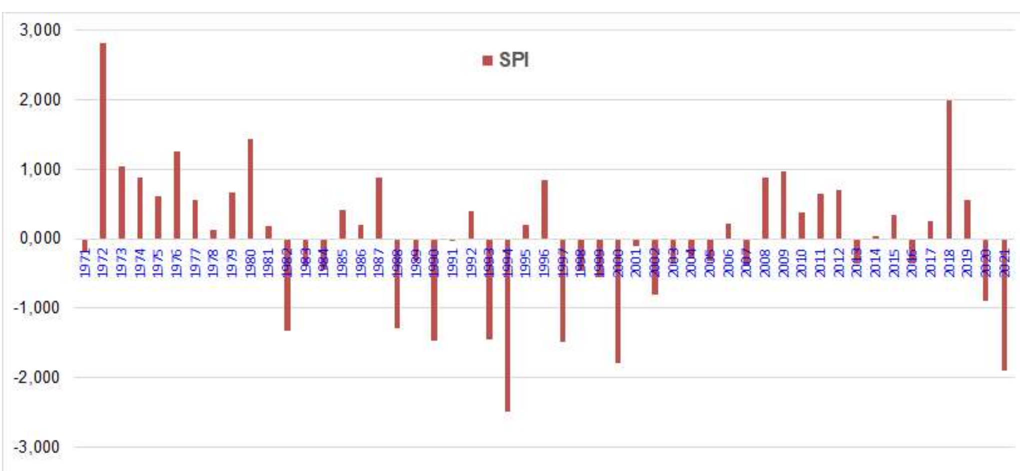

Fig. 5. Standardized Precipitation Index (SPI) for the rainfall data

recharge in an alluvial aquifer typically involves measuring the amount of water entering the aquifer and comparing it to the amount of water being withdrawn through pumping or other means. This can be done using groundwater level monitoring by measuring the water level in wells over the aquifer. The first sector represents the recharge area of the alluvial aquifer on the eastern part of the plain, where significant drawdown of the water table is observed, with fluctuations exceeding 15m, and where the hydraulic gradient is greater than 10^{-2}. The central zone of the plain is characterized by a hydraulic gradients between 10^{-2} and 10^{-3}, with drawdowns between 4 and 10 m. The downstream zone, where hydraulic gradient is less than 10^{-3}, which showed weak fluctuations between the two periods, less than 4m. The analysis of piezometric variations between high and low water periods for the periods 1971-1981, 1982-2007, and 2008-2021 showed average fluctuations of the piezometric levels of: 7m, 15m and 10m for the first zone across the three periods, respectively; 4 m, 9 m and 6.5 m for the second sector across the three periods respectively; and 0.8 m, 3.5 m and 1.2 m for the third sector across the three periods, respectively. The storage coefficient of an aquifer is equal to effective porosity can vary widely depending on the specific characteristics of the aquifer material and the conditions of the site. Generally, they range from 0.2 to 0.4 for coarse-grained aquifers on grain size range from fine-sand to coarse-gravel, and from 0.01 to 0.2 for fine-grained aquifers on grain size range from fine sand to Coarse-silt. The estimation of the approximative groundwater reserve in the alluvial aquifer of the Upper Cheliff showed a decrease when we compare volume of the decade 1971-1981 (195.8 H.m^3) with that of the next two decades 1982-2007 (102 H.m^3), which was contacted to rate of the natural recharge. In the last decade 2008-2021 we assist to a small increase of volume of groundwater in the alluvial aquifer to 135 H.m^3 (Table 1).

Evolution of groundwater levels: The analysis revealed a strong correlation between rainfall levels and groundwater levels during the wet period. However, during dry periods, our analysis also revealed that the pumping of water for various uses has a significant impact on the aquifer. This is confirmed by the observed decrease in water levels during these periods. The overexploitation of the aquifer to ensure different uses supplies, such as irrigation, industrial and domestic use, leads to an imbalance in the water resources management, which could have severe consequences on the long term.

Overall, our study provides important insights into the relationship between hydroclimatic conditions and the groundwater resources of the Upper Cheliff alluvial aquifer. It highlights the need for proper management of water resources, especially during dry periods, to ensure the sustainable use and preservation of this important resource. Regarding low water levels, the series of consecutive deficit years observed in the study region has resulted in a decrease of groundwater levels, particularly during the period of low precipitation from 1985 to the early 2000s. The evolution of the average piezometric levels in the Upper Cheliff alluvial aquifer from 1970 to 2020 during dry periods indicates a drop in the water table by about 8.0 meters over the entire period. Afterward, there is a gradual increase starting in the 2000s, with the aquifer level rising by over 6.0 meters (Fig. 7, 8 and 9).

Groundwater quality: The analysis of groundwater samples

Table 2. SPI classification scheme used by European Drought Observatory (EDO)

Anomaly	Range of SPI values	Precipitation regime
Positive	2.0 ≤ SPI ≤ Max.	Extremely wet
	1.5 ≤ SPI ≤ 2.0	Very wet
	1.0 ≤ SPI ≤ 1.5	Moderately wet
None	-1.0 ≤ SPI ≤ 1.0	Normal precipitation
Negative	-1.5 ≤ SPI ≤ -1.0	Moderately dry
	-2.0 ≤ SPI ≤ -1.5	Very dry
	Min. ≤ SPI ≤ -2.0	Extremely dry

Table 1. Average water table drawdown and groundwater volume reserve

Sector	Surface (Km²)	Aquifer materials	Sy	Q (l/s)	Water table drawdown 1971-1981 (m)	Water table drawdown 1982-2007 (m)	Water table drawdown 2008-2021 (m)
1	15	Fine-grained	0.05	4-8	7	4.5	6
	25	Medium-grained	0.15	10-15	6	4	5.5
	30	Coarse-grained	0.25	20-35	5	3.5	5
2	100	Coarse-grained	0.25	10-40	3	1.5	2
3	90	Coarse-grained	0.30	20-70	2	0.7	0.8
	30	Fine-grained	0.05	1-5	1	0.6	0.7
Volume (H.m^3)					195.8	102	135

for the dry season of 2021 in the Upper Cheliff plain showed slightly alkaline water with a pH range of 7.1 to 8.3. Electrical conductivity (EC) was used to assess the ionic content of the groundwater. The groundwater in this alluvial aquifer is moderately mineralized (EC range of 1300 to 5000 μS/cm; TDS range from 650 to 2950 mg/l, TH range from 35 to 150 °F) and is not suitable for drinking or irrigation in some parts of the agricultural plain. This is due to hydrogeological conditions and anthropogenic pollution, specifically from fertilizers such as ammonium sulphate $(NH_4)_2SO_4$ and superphosphate Ca $(H_2PO_4)_2$, as well as untreated wastewater (Fig. 10).

The untreated wastewater flowing in Wadi Cheliff, where it was analyzed at different points during the dry period of

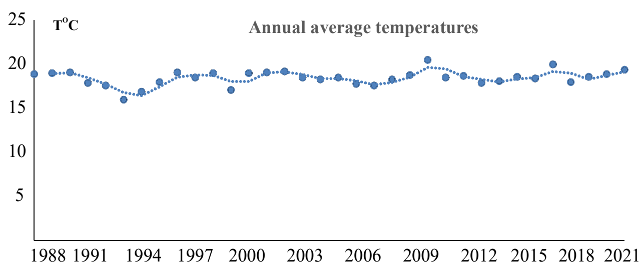

Fig. 6. Evolution of annual average temperature for the period 1988-2021

2021, showed very high values on average: (pH = 5, EC = 4500 μS/cm, Cl^- = 1000 mg/l, SO_4^{2-} = 75 mg/l, Na^+ = 600 mg/l, Ca^{2+} = 2400 mg/l, Total Nitrogen = 300 mg/l, Phosphorus = 10 mg/l, Ammonium = 400 mg/l). This confirms that one of the major sources of groundwater pollution is the untreated wastewater flowing in Wadi Cheliff. In terms of ion concentration, calcium and sodium were the most dominant cations, while chloride and bicarbonate were the most dominant anions, making up 75% and 15% of the anions and cations respectively. This resulted in the dominant chemical facies of the groundwater being calcium-chloride (> 50%) and sodium chloride (> 25%). Calcium was the dominant cation, followed by sodium and magnesium (Fig. 11). The high concentration of calcium ions is likely due to the dissolution of limestone crusts, while the high sodium levels may be due to the leaching of sodium fertilizers used in agricultural activities, as well as organic pollution from untreated wastewater discharge and cation exchange processes in the aquifer. The high levels of chloride in the groundwater may be due to the dissolution of NaCl salts, seepage of wastewater, and the flow direction and residence time of the groundwater in the aquifer. The high levels of sulfate may be due to the use of fertilizers in agriculture, evaporation, wastewater discharge, and the dissolution of gypsum minerals. The nitrate levels in the study area range from 2 to 160 mg/l, with more than 30% of wells exceeding the

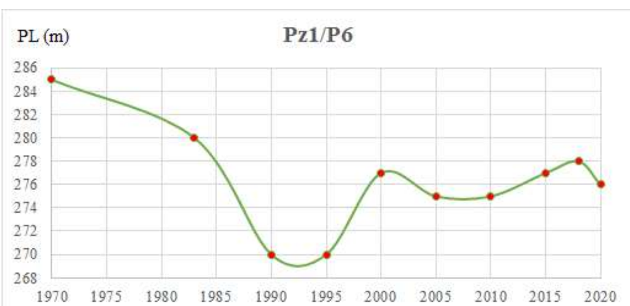

Fig. 7. Evolution of piezometric levels in the upstream of the Upper Cheliff Aquifer

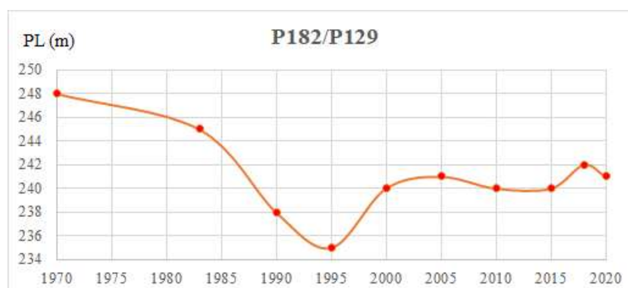

Fig. 9. Evolution of piezometric levels in the downstream of the Upper Cheliff Aquifer

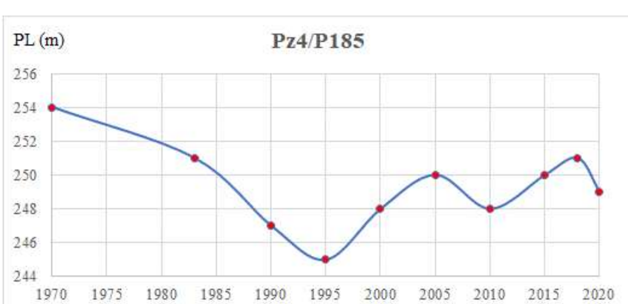

Fig. 8. Evolution of piezometric levels in centre of the Upper Cheliff Aquifer

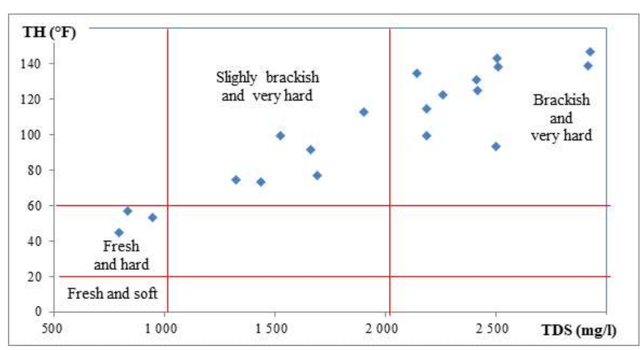

Fig. 10. TH (°F) Vs TDS (mg/l) for the dry period 2021 in the alluvial aquifer

limit of 50 mg/l set by the World Health Organization (WHO). This may be related to the use of nitrogen-based fertilizers in the agricultural area, which is characterized by high permeability in the old quaternary formations (conglomerate, pebble, calcareous crust and alluvial fans), and may also be related to waste discharge from animals, manure, and soils containing nitrogen compounds.

The groundwater in this alluvial aquifer is not suitable for drinking or irrigation in some parts of the agricultural plain due to the high levels of ions, specifically calcium and sodium, as well as the high levels of chloride and sulfate. These high ion levels are a result of both natural processes, such as the dissolution of limestone crusts, and anthropogenic pollution from fertilizers and untreated wastewater. It is important to note that these high ion levels can have negative effects on both the environment and human health. High levels of calcium and sodium can affect the taste and quality of the water, and can also lead to scaling and corrosion in pipes and other equipment. High levels of chloride and sulfate can be toxic to certain plants and animals, and can also affect the taste and quality of the water. Additionally, the high nitrate levels present in the study area can pose a risk to human health, particularly for infants and pregnant women. It is important for local authorities and water management agencies to take action to address the issues of groundwater pollution in this agricultural plain. This could include stricter regulations on the use of fertilizers and the disposal of wastewater, as well as implementing water treatment and conservation measures to ensure that the groundwater is safe for drinking and irrigation. Additionally, more frequent monitoring and testing of the groundwater should be carried out to keep track of any changes in water quality and to identify potential sources of pollution.

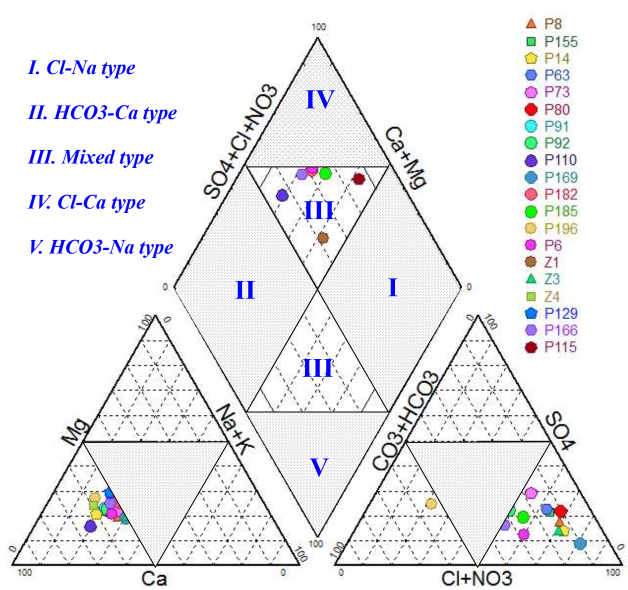

Fig. 11. Piper's diagram for dry period 2021 in the alluvial aquifer of Upper Cheliff

CONCLUSIONS

The study focuses on the Upper Cheliff alluvial aquifer in Algeria and its groundwater resources, and it reveals some concerning findings about the current state of the aquifer. The data collected over 50 years shows irregular rainfall, with a rainy season from November to April and a dry season from June to August. The decline in rainfall from 1983 to 2007 has affected the quantity and quality of groundwater resources in the area. Additionally, over the last 14 years, the annual average temperatures in Algeria have increased by 0.5°C, which has further impacted the groundwater reserves. The evaluation of natural recharge in the alluvial aquifer involves measuring the water entering and leaving the aquifer, which can be done through groundwater level monitoring. The analysis of piezometric maps for this aquifer reveals three sectors with different fluctuations in water levels. The eastern sector has the greatest drawdown and hydraulic gradient, the central sector has moderate drawdown and gradient, and the downstream sector has the least drawdown and gradient. The study finds that there is a correlation between rainfall and groundwater levels during wet periods. However, during dry periods, pumping has a significant impact on the aquifer, leading to an imbalance in water resources management. Overexploitation of the aquifer for various uses has further worsened the situation. The analysis of groundwater in the Upper Cheliff plain during the dry season of 2021 found slightly alkaline water with moderate mineralization. This water is not suitable for drinking or irrigation in some parts of the agricultural plain due to hydrogeological conditions and anthropogenic pollution, specifically from fertilizers and untreated wastewater. The untreated wastewater in Wadi Cheliff during the dry season of 2021 showed high levels of ions and pollutants, confirming it as a major source of pollution. The groundwater has high levels of calcium, sodium, chloride, and sulfate, which can affect taste, quality, and be harmful to plants and animals, and human health. The study highlights the need for proper management of water resources to ensure sustainable use and preservation of this important resource. Local authorities need to take action to address the issues of groundwater pollution in this agricultural plain through regulations, treatment, and monitoring.

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Comparative Assessment of Soil Chemical Properties in Upper and Lower Forest Zones of Zanübu Mountain Range of Phek District, Nagaland, India

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Abstract: The present study was conducted in Zanübu mountain range of Phek district, Nagaland, India, to estimate the variability of soil chemical properties at two forest zones i.e., 2000-2426m amsl (Zone-I, the undisturbed forest) and 1600-2000m amsl (Zone-II, which is disturbed by human activities such as hunting, logging, grazing, collection of wild edible resources, jhum cultivation, and cardamom plantation). Soil samples were collected at different depths and soil chemical properties such as organic carbon, available nitrogen, available phosphorus, exchangeable potassium and pH were analysed using standard procedures. The organic carbon, available nitrogen and available phosphorus were higher in Zone-I (undisturbed forest) as compared to Zone-II (disturbed forest). The factors responsible for the variability of the soil nutrients were altitude, different land use system and anthropogenic disturbances. Exchangeable potassium had significant positive correlation with organic carbon in Zone -I and negative with phosphorus in Zone-II. A negative correlation was observed between exchangeable potassium and pH in both the two zones. If the trend of anthropogenic activities continues in zone-II, it will affect restoration process of soil.

Keywords: Soil chemical properties, Zanübu mountain range, Phek district, Undisturbed forest, Disturbed forest

Formation of soil is influenced by various factors such as parent material, relief, climate, organisms and time. Since the wide meteorological variation results in different climatic zones, soils also differ according to these variations (Poji et al 2017). Altitude plays a significant role in changing the climatic characteristics, soil properties and land use patterns (Deb et al 2019). Knowledge about the vertical distribution of soil nutrients under various forest soils help to understand the biogeochemical cycles (Yang et al 2010). The knowledge of chemical and physical properties of soils has always helped foresters to assess capacity of sites to support productive forests (Schoenholtz et al 2000). Himalayan forests play an important role in moderating the severity of the climate, in cooling and purifying the atmosphere, in protecting and conserving the soil, in holding the hill slopes in position and in cushioning up huge reserves of soil nutrients (Sharma et al 2010). Eastern Himalaya, one of the biodiversity hotspot of the world is a fragile region due to frequent land-use transformation through deforestation, land degradation, and disruption of the hydrological cycle (Tiwari 2008) and these forests, in general, are under high anthropogenic pressure due to excessive extraction of biomass in the form of fuel wood and fodder (Malik et al 2014, Singh et al 2017, Haq et al 2019a, 2019b). Himalayas have high variation in the landscape and hence, the bioclimatic conditions change rapidly within a very short distance resulting in different soil properties and types (Baumler 2015). Soil degradation process is influenced by land management, as well as by topographic factors such as altitude (Mishra and Francaviglia 2021). Zanübu mountain range is a community conserved forest conserved by seven surrounding Chakhesang villages. In the recent past, rapid land use change has occurred especially in the lower altitude caused by deforestation of natural forests for shifting agriculture, plantations and logging which has led to increase of soil erosion. Therefore, the present study aims to compare the soil chemical characteristics between the upper zone which is undisturbed forest and the lower zone forest which is disturbed by different anthropogenic forces. This will help to formulate management strategies to restore soil fertility and to maintain biodiversity.

MATERIAL AND METHODS

Experimental area and sampling site: The present study was conducted in Zanübu mountain range forests in Phek district in southern Nagaland. Mount Zanübu is the highest point at 2426 m above mean sea level, and it is the highest mountain peak in Phek district. The present study was conducted at two forest zones and designated as: zone-I (undisturbed forest) 2000-2426m amsl, which lies between

N25º40393' to N25º39800' latitude and E94º21955' to E94º21753' longitude, and zone II (disturbed forest) 1600-2000m amsl, which lies between N25º39477' to N25º38530' latitude and E94º21530' and E94º21753' longitude. Zone- I is a protected forest, hence it is free from anthropogenic disturbances. Zone II is prone to anthropogenic activities like logging, hunting, shifting cultivation, grazing, collection of wild edible resources and commercial plantations.

Soil sampling and analysis: Soil samples were collected from August 2019 to March 2022 covering all the four seasons of spring, summer, autumn, and winter, by random sampling method. Soils were collected from three different depths i.e 0-10 cm, 10-20 cm and 20-30 cm, and each layer was mixed to form composite samples. pH was analysed following Jackson (1973), organic carbon, available nitrogen, phosphorus and exchangeable potassium were analysed by Walkley and Black's method (1934), Kjeldahl method (1883), Bray's No.1 extract method (1945), and photometric method as outlined by Jackson (1973) respectively. A single-tailed Pearson correlation coefficient was calculated between various chemical parameters of soil for both the forest zones using statistical software SPSS version 23.

RESULTS AND DISCUSSION

pH: The range of pH at Zone I is 4.86 (spring, 0-10cm) - 5.85 (spring, 10-20cm) and for Zone II is 5.12 (summer, 0-10cm) - 5.56(autumn, 20-30cm). The soils are acidic in both the two zones. Panda (1998) reported that about 84% soils of Nagaland are strongly acidic. Similar range of pH (4.17 to 5.74) had been reported by Poji et al (2017) in the forest soil of Phek district. The findings are also within the range of pH value (4.1 to 5.8) as reported by Singh and Munth (2013) in forest soils of Nagaland. The acidity of the soil is because of acidic nature of parent material and also because of a prolonged uptake of basic cations by tree roots (Tegenu et al 2008). The pH increase with soil depth. The lowest value of pH was found in 0-10 cm layer of undisturbed forest. This low pH can be attributed to high amount of humus in the forest soils and subsequent slow decomposition of organic matter, which releases acid. There is not so much variation in the pH values of different soil samples during different seasons from the two zones. The small variation in soil pH in the study area during different seasons shows pH stability (Zubair et al 2022).

Organic carbon: The percentage of soil organic carbon in zone-I forest was highest (2.97%) in summer at 20-30cm depth of soil and lowest (1.52%) in winter at 20-30 cm soil depth. While for zone-II, highest value of organic carbon was observed in autumn and winter (2.56%) both at soil depth of 0-10 cm, and the lowest percentage (1.30%) was observed in spring at soil depth of 10-20cm. Organic carbon was found to be high in both the forests. Similar range of organic carbon content (1.59 to 2.76%) was reported by Singh and Munth (2013) in the forest soils of Nagaland. Soil organic carbon tends to accumulate in forest ecosystem which may be due to addition of huge quantity of forest litter to the soils (Poji et al

Table 1. Seasonal variation in the soil chemical properties of zone-I (UF) and zone-II (DF)

Soil chemical properties	Soil depth	Seasons							
		Spring		Summer		Autumn		Winter	
		Zone I	Zone II	Zone I	Zone II	Zone I	Zone II	Zone I	Zone II
pH	0-10	4.86	5.38	5.26	5.12	5.27	5.35	5.59	5.39
	10-20	5.85	5.55	5.27	5.17	5.34	5.46	5.57	5.51
	20-30	5.10	5.40	5.26	5.40	5.50	5.56	5.50	5.47
Organic carbon (%)	0-10	2.72	2.30	2.38	1.99	2.44	2.56	1.94	2.56
	10-20	2.26	1.30	2.72	1.95	2.74	1.55	1.54	1.69
	20-30	1.92	1.74	2.97	1.69	2.74	1.56	1.52	1.47
Available nitrogen ($Kg\ ha^{-1}$)	0-10	868.26	915.42	827.64	551.76	1065.9	877.8	1191.3	1003.2
	10-20	902.88	689.7	777.48	438.9	1040.82	727.32	852.72	777.48
	20-30	865.26	529.38	790.02	426.36	890.34	714.78	539.22	627
Available phosphorus ($Kg\ ha^{-1}$)	0-10	30.52	24.08	29.4	29.904	36.288	34.608	34.94	34.72
	10-20	28.616	22.904	28.61	34.32	33.20	34.66	38.36	37.24
	20-30	22.848	28.84	34.44	33.54	34.27	33.432	39.76	37.24
Exchangeable potassium ($Kg\ ha^{-1}$)	0-10	280.44	435.512	267.568	432.88	258.552	195.328	113.736	147.784
	10-20	155.68	216.104	144.48	215.32	148.064	92.736	63.112	102.928
	20-30	117.208	210.224	131.936	141.008	102.704	105.56	43.024	72.296

2017). Organic carbon was higher in zone-I as compared to zone-II. The higher soil organic carbon stock in zone-I (undisturbed forest) could be because, at higher altitude, the lower mean temperature and increasing rainfall decreases soil organic matter decomposition (Du et al 2014). Similar result was obtained by Mishra and Francaviglia in Mon and Zunheboto districts of Nagaland (2021) where soil organic carbon showed an increasing trend with altitude. Andrew et al (2020) observed higher organic carbon content in undisturbed sites as compared to disturbed sites from Takamanda rainforest, Cameroon. Soil organic carbon decreased with soil depth in both the two zones with maximum content in topsoil, which is due to the availability of more organic matter from trees. The presence of trees continuously adds litter in the upper layer (Kimmins 2004) which further enhanced soil organic carbon due to positive priming (Wu et al 1993). The percentage of soil organic carbon in the disturbed forest was lower as compared to the undisturbed forest, which might be due to deforestation which has reduced the amount of organic matter on the forest floor.

Exchangeable potassium: The concentration of potassium in zone-I is highest (280.448 Kg ha^{-1}) in spring at 0-10 cm soil depth and lowest (43.024 Kg ha^{-1}) in winter at soil depth of 20-30 cm. in zone II, highest value (435.512 Kg ha^{-1}) was observed in spring at 0-10 cm soil depth and lowest value (72.296 Kg ha^{-1}) was observed in winter at 20-30 cm soil depth. Potassium content varied from high to low, but majority of the soil samples showed low to medium potassium content, which is in conformity with the results of Motsara (2002) in soils of Nagaland. Poji et al (2017) also reported medium class exchangeable potassium content in the soils of Phek district, Nagaland. Available potassium in both the zones generally decreases with increase in soil depths. Maximum value of potassium was recorded at zone-II i.e., lower elevation zone, which is in conformity with the results obtained by Mishra and Francaviglia (2021) in lower elevation of Zunheboto district in Nagaland. The lower elevation zone is subjected to disturbances like deforestation, forest fire and jhum cultivation which may be the reason for higher contents in available potassium, derived from the ash left on the field after burning.

Available phosphorus: Highest available phosphorus (39.76 Kg ha^{-1}) in zone -I was observed in winter and lowest (22.848 Kg ha^{-1}) in spring, both at 20-30 cm soil depth. In zone-II, highest value (37.46 Kg ha^{-1}) was observed in winter and lowest value (22.904 Kg ha^{-1}) in spring, both at 10-20 cm soil depth. Available phosphorus in both the zones varied from low to medium. Over 60% of the soils in Nagaland were reported to be deficient in available phosphorus (Sharma et al 2001). The low content of available phosphorus in these soils might be due to higher formation of phosphorus by Fe2+, Mn2+ and Al3+ (Medhi et al 2002). Available phosphorus was higher in zone-I as compared to zone-II. The lower concentration of available phosphorus in the disturbed site could be due to anthropogenic activities which might increase the rate of soil erosion and thereby influence leaching of these nutrients. In most cases, phosphorus content was found to be higher in lower depths than upper and middle ones (Table 1) which may be due to leaching process of nutrients. This result is in conformity with the findings of Zubair et al (2022) in the forest soils of Western Himalaya, India.

Available nitrogen: Highest available nitrogen (1191.3 Kg

Table 2. Correlation matrix between the soil chemical properties

Soil parameters	Nitrogen	Phosphorus	Potassium	OC	pH
Zone I (Undisturbed forest)					
Nitrogen	1				
Phosphorus	-0.190	1			
Potassium	0.335	-0.484	1		
OC	0.245	-0.458	0.633*	1	
pH	0.096	0.420	-0.587	-0.474	1
Zone II (Disturbed forest)					
Soil parameters	Nitrogen	Phosphorus	Potassium	OC	pH
Nitrogen	1				
Phosphorus	-0.036	1			
Potassium	0.028	-0.686*	1		
OC	0.547	0.053	0.399	1	
pH	0.329	0.007	-0.614*	-0.487	1

ha^{-1}) in zone-I and highest (1003.2 Kg ha^{-1}) in zone-II was observed both in winter at 0-10 cm, while lowest (539.22 Kg ha^{-1}) in zone-I was observed in winter at 20-30 cm and lowest (426.36 Kg ha^{-1}) in zone-II was observed in summer at 20-30 cm. Available nitrogen is found to be high in both the two zones. But it was higher in zone-I than in zone-II. This may be due to the fact that organic carbon is higher in the undisturbed forest which contributes to the available nitrogen content in the soil. The available nitrogen decreases with soil depth in both the two zones. This could be attributed to the presence of heavy litter and humus contents in the upper layers of the forests leading to the richness of nitrogen in the upper layers as compared to lower layers. Similar result was obtained by Semy et al (2021) in the coal-mining affected and non-affected forest soil at Changki, Nagaland.

CORRELATION

Available potassium had significant positive correlation with organic carbon under zone-I i.e., undisturbed forest zone. Similar correlations were reported by Gairola et al (2012), Kumar et al (2013) and Pandey et al (2018). This might be due to creation of favourable soil environment with presence of high organic carbon (Meena et al 2006). A negative correlation was observed between available potassium and pH of the soil in both the two forest zones. These correlations indicate that soil pH and organic carbon govern nutrient availability in these soils. These results are in agreement with those of Somasundaram et al (2009), Tsanglao et al (2014), and Poji et al (2017). A negative correlation was also observed between potassium and phosphorus in zone-II.

CONCLUSION

The results of the present study revealed that the soils of both the forest zones were acidic. Soil chemical parameters such as organic carbon, available phosphorus and available nitrogen were higher in the undisturbed forest. Soil organic carbon, available nitrogen and exchangeable potassium were generally higher at the surface soil (0-10 cm) than the deeper layers (10-20 cm and 20-30 cm). Organic matter from forest litter increase soil organic carbon thereby restoring soil fertility and ensures proper functioning of the forest ecosystem. Lower content of soil nutrients in the disturbed forest zone may be due to the complex interactions of forest disturbances, such as, slash and burn agriculture, landslides, selective logging, grazing and commercial plantations. If the trend of anthropogenic activities continues, it will lead to harmful environmental changes and affect restoration process of soil. The results from this study indicates that there is a need for proper land use planning and adoption of sustainable farming systems in order to prevent further deterioration of soils in the lower elevation forest zone of Zanübu mountain range.

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Assessment of Soil Erosion using Remote Sensing Techniques: A Global Review

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***Abstract*:** Soil is considered to be an important component of the terrestrial ecosystem. It possesses inherent capability of food and biomass production and maintaining soil biodiversity. Both natural and anthropogenic activities are leading to soil erosion, hence directly affecting the soil fertility as well as food security. Among the different factors, soil erosion is one of the major constraints resulting in low productivity of soils as the macro as well as the micronutrients along with the organic matter are washed away with the soils. Moreover, soil organic carbon also moves out of the carbon cycle which results in depletion of soil fertility. Thus, the prime need in this alarming situation is to shift from our traditional ways of assessment of soil erosion to its estimation through remote sensing. Remote sensing technology proves to be a valuable tool in developing suitable models through utilization of advanced features of data storage and management, interpretation and display of spatial data. Moreover, integrated erosion forecasting models not only estimates the soil loss but also provides spatial distribution of the eroded material. Overall, the aim of this paper is to review the role of remote sensing in determining the extent of soil erosion and to highlight the lacuna associated with these techniques and recommendations for future applications. These would help the researchers to apply these advanced techniques more energetically in a wide range of agro-climatic zones and regions with variations that exists among the data availability and modelling at finer spatial and temporal scales.

Keywords: Degradation, Remote sensing, Sequestration, Soil erosion, Sustainable management

Degradation of agricultural land has become a global issue in the recent few years (Eswaran et al 2001). Escalating population growth, deforestation activities, excessive cultivation and overgrazing has led to expedite erosion activities in the world mainly developing countries (Zemenu and Minale 2014,; Gelagay and Minale 2016). A nation's economic growth predominantly relies on industrialization and agriculture. These directly or indirectly depend on the soil conservation while direct correlation was observed between crop yield and soil loss (Prasad and Tiwari 2019). Soil detachment and transportation hamper the soil fertility, posing threat to agricultural sustainability, productivity and economy of the country (Pimentel et al 1995, Prasannakumar et al 2012). Soil erosion is the most serious form of land degradation which severely affects food production. Out of 30,60,500 km^2 land area, 13,00,000 km^2 area was seriously affected by soil erosion i.e., 42.5% (Prasad and Tiwari 2019). Out of the total 3,280,000 sq. km land area, nearly 53% area is highly prone to soil erosion (1,750,000 sq.km) [GIS, RUSLE and SEDD 2003]. Estimation of soil degradation by remote sensing is instrumental in analyzing the rate and spatial extent of this problem. To prevent the deterioration of agricultural lands, improved management practices should be adopted for managing as well as monitoring the soil resources. Remote sensing plays a crucial role in mapping the extent of degraded soils and monitoring the current scenario in erosion-threatened soils for initiating proper planning response measures and assessing their efficiency (Shoshany et al 2013). Wide applications of remote sensing in soil erosion mapping and modeling have gained considerable momentum in the last few decades where multispectral data (Landsat imagery) is prominently recommended for soil erosion modeling. Besides its few limitations viz. cost and time consuming, remote sensing techniques provide suitable quantitative information which is necessary for the assessment and monitoring of erosion level (Sepuru and Dube 2018). Both remote sensing and GIS techniques have become valuable tools for the digitization of input data and map generation (Agarwal et al 2016). The Universal Soil Loss Equation developed by Wischmeier and Smith (1965), is one of the most widely adopted empirical models for the estimation of soil loss. The Revised Universal Soil Loss Equation (RUSLE) model is a much more advanced version of USLE (Wischmeier and Smith 1978), for predicting the long-term average annual soil loss from slopy fields under specified cropping, and additionally from rangeland (Renard et al 1997). It is quite effective in estimating soil loss from different parts of the world (Rozos et al 2013, Ganasri and Ramesh 2015, Zhao et al 2017). It can even predict erosion potential on a cell-by-cell basis but not on the basis of sediment yield (Anees et al 2018). Other than USLE, substantial efforts have been made to develop various erosion models such as Water Erosion Prediction Project Soil Loss Equation (WEPP) (Gansari and Ramesh 2015), European Soil Erosion Model (EUROSEM) and Soil and Water Assessment Tool (SWAT) (Wishmeir and Smith 1978). Using Geographical Information System environment derived from SRTM DEM, systematic analysis of watershed characteristics was carried out concerning soil erosion under intense weather conditions (Ali et al 2018). Remote sensing technology proves to be a valuable tool in developing suitable models through the utilization of advanced features of data storage and management, interpretation, and display of spatial data. Integrating these models not only aids in quantifying soil loss but also provides sound knowledge about the spatial distribution of the eroded material. Thus, rendering a practically feasible solution for the assessment of soil degradation. Overall, the emphasis is to review the role of remote sensing in determining the extent of soil erosion and to highlight the lacuna associated with these techniques and recommendations for future applications so that these advanced techniques can be applied in a wide range of agro-climatic zones. Integrating GIS with empirical erosion models viz. RUSLE, not only estimates soil loss but also estimate the extent of the spatial distribution of erosion. GIS environment aids in generating erosion risk maps to facilitate areas with high erosion risks for prioritization (Kushwaha and Yousuf 2017). Using Remotely sensed data, the extent of erosion was enumerated to delineate the land cover changes and an algorithm was developed for long-term Universal Soil Loss Equation (USLE model) for parameter acquisition, calculation as well as validation based on remote sensing data (Ma et al 2003). Baban and Yusof (1999) assessed soil erosion using remotely sensed data (RUSLE model) and GIS and identified the spatial pattern and expanse of erosion and categorized different erosion risk areas in Ethiopia (Mekonnen and Melesse 2011). Prasad and Tiwari (2019) utilized USLE to measure soil disintegration in upper lake Bhopal, India. Soil loss was evaluated using RUSLE in the Southwestern part of India (Ganasri and Ramesh 2015). Ashiagbor et al (2013) depicted spatial circulation of soil disintegration using RUSLE and GIS gadgets and studied the relation between slope and Land use and Land Cover (LULC) in Ghana. Chang and Bayes (2013) used the RUSLE model to work out the most erodible territories in Ohio. GIS-based USLE approach was employed for spatial Conveyance of various erosion inclined regions in Bhopal (Prasad and Tiwari 2019). Waghmare and Suryawanshi (2017) mapped five soil erosion risk classes (very low, low, medium, medium-high, and high) based on RUSLE within the GIS environment. They explored relationships between soil erosion risk and LULC distribution. RUSLE model outstretches its application to different scenarios, including forest, rangeland, and disturbed areas (Renard et al 1997). New remote sensing technology estimates soil erosion and its spatial distribution from large areas (Waghmare and Suryawanshi 2017). Different approaches were used to assess soil erosion risk using different models (Bartsch et al 2002). A ranking method based on indicators viz. percentage of bare ground, organic carbon, aggregate stability, percent clay, and bulk density (Shakesby et al 2002), and qualitative erosion risk mapping based on the combination of five factors such as geology, soil, relief, climate, and vegetation (Vrieling et al 2002) play a crucial role in mapping soil erosion risk. Developed for the USA, RUSLE has proved to be crucial for delineating the extent of soil erosion in other regions of the world (Waghmare and Suryawanshi 2017). Morgan method, a much powerful method was used to solve the modeling problem of soil erosion. It is a quite easy and flexible method than the CREAMS method and fundamental than the USLE method. It was depicted that cover fraction (15%) by corn residues minimizes the soil runoff by 75% (Melesse and Jordan 2002). GIS software namely ILWIS and ERDAS Imagine were used to monitor the probable success of the Morgan method for soil erosion modeling (Ustun 2008). Integration of remote sensing with Geographic Information System (GIS), provides critical information on erosional dynamics and intensity over time and space, which is essential in providing major criteria for mapping soil erosion, control, and prediction (Sepuru and Dube 2018). Remote sensing acts as an indispensable tool in mapping land use/ land cover (LULC) and modelling soil erosion. Integrating GIS with the remotely sensed data, spatial distribution is the baseline step in assessing soil erosion vulnerable areas at basin and/ or regional scale (Krishna Bahadur 2009, Magliulo 2010, 2012, Chen et al 2011, Prasannakumar et al 2011, Mhangara et al 2012), is the most powerful and fundamental tool for land-use planning (Aydda et al 2014, Magliulo et al 2020), natural resources inventory for natural resources management (Lillesand and Kiefer 1994) and estimating soil erosion extent (Knight et al 2007, Sepuru and Dube 2018). With the furtherance of innovation and headway in the field of GIS and remote sensing, researchers have estimated extent of soil erosion throught the use of well-developed models (Prasad and Tiwari 2019).

Data source for soil erosion modelling: Highly advocated remotely sensed data for erosion modeling were multispectral sensors, viz. Landsat data imagery, while the use of high spectral resolution information was limited, predominantly due to the acquisition cost (Sepuru and Dube

2018). The data commonly utilized for RUSLE and preparation of erosion hazard map were obtained using various sources viz. topographic sheets (58 I/11, 12, 15, 16) and Landsat8 OLI/TIRS data using Earth Explorer and CARTO DEM (30m resolution) bhuvan website. The rainfall and soil data were obtained from IMSD data center, India and NBSS and land use planning centre, Tamilnadu, respectively. Processing of the data was done using maximum possibility classification algorithm and spatial analyst in ERDAS imagine and Arc GIS 10.1, respectively (Karthick et al 2017). To generate RUSLE factors, data was obtained from Landsat thematic mapper, digitized soil and topographic maps as well as the precipitation data (Millward and Mersey 1999). Landsar 8 imagery, Shuttle Radar Topography Mission (SRTM) imagery, Era-Interim integrated with soil database were utilized as a digital data source for preparing land use maps, digital elevation model (DEM), rainfall as well as soil data, respectively, to produce USLE (Universal Soil Loss Equation (USLE) variables (Ajibade et al 2020).

Soil loss: Now-a-days, much of the global attention is towards soil erosion due to various ecological and environmental problems viz. land degradation, soil fertility loss, drainage and river siltation (Anees et al 2018, Wang et al 2018) leading to reduction in reservoir capacity thus, negatively impacting aquatic habitats, hydrologic systems as well as quality of water downstream as the sediments are usually combined with nutrients, toxic chemicals and metals (Kouli et al 2009, Zhang et al 2009, Kim 2014, Lamyaa et al 2018). Soil degradation relies upon both natural and anthropogenic elements. These elements are classified as quasi-static factors (morphology, infiltration and erodibility) and temporally variable factors (rainfall intensity, vegetation cover, land use and agricultural practices) (Roose & Lelong 1976, Boukheir et al 2006, Bouhadeb et al 2018, Ajibade et al 2020). Soil erosion is perceived as one of the most problematic and visible form of soil degradation (Boardman and Poesen 2006, EEA and JRC, 2010, Grimm et al 2002, Panagos et al 2016, Stolte et al 2016, Žížala et al 2019). Soil losses occur when erosion rates exceeds the deposition rates, resulting in soil loss which is the outcome of increasing surface erodibility, as well as rise in water or wind-erosive energy (Cerdà et al 2012, Shoshany et al 2013). In case of watershed, water erosion was found to be a critical problem causing soil loss ranging from zero in gentle slope of forest lands to 442.92 t ha^{-1} $year^{-1}$ on very steep slope cultivated lands. Belayneh et al (2019) estimated the average soil erosion rate to be nearly 42.67 t ha^{-1} $year^{-1}$. A total of 9.68 mt of gross surface soil has been lost annually, of which 62.1% was generated from cultivated land area. According to the latest estimates, an area of about 120.72 Mha (million hectares) is affected by various forms of land degradation in India, out of which 82.57 Mha is solely as a result of water induced soil erosion (Maji et al 2010, Das and Poongathai 2018). The momentous effects of erosion includes degradation in soil productivity and water quality because of siltation, sedimentation and eutrophication of water bodies (Onyando et al 2005, Das et al 2020). Soil loss is enhanced by coalescence of various factors viz. climate change, slope length-steepness, land cover patterns and soil's intrinsic properties (Gelagay and Minale 2016). According to the report by the European Commission on 'Implementing Soil Thematic Strategy Protection' for Soil (European Commission 2012), soil erosion was observed to be an irreparable damage in Europe. When the soil loss is more than 1 t ha^{-1} $year^{-1}$, this causes an irretrievable damage to the soil (Verheijen et al 2009, Novotný et al 2016). Soil erosion exacerbates already existing land-related issues viz. landslides, drought, floods and other disasters (Munodawafa 2007, Rickson 2014, Zeng et al 2017).

Thus, remote sensing studies emphasize on exploring specific erosional processes concerned with overall soil losses. The fundamental methods involved in these studies includes a) direct methods, where indicators are explicitly linked to certain soil-erosion processes; b) indirect methods, where indicators can be linked implicitly to some specific processes of erosion and c) phenomenological methods describing the link between environmental parameters as well as actual soil loss (Shoshany et al 2013).

Remote Sensing Methods for Mapping Specific Soil Erosion Types

Direct method: These methods involves estimation through focus on studies related to properties like surface lowering (subsidence), change in soil roughness, etc. In surface lowering, changes in geomorphic surface are detected using temporal changes in interferometric coherence (Liu et al 1999, Smith et al 2002, Roering et al 2009, Zhao et al 2009) while radar backscattering and lidar mapping are used to evaluate changes in soil roughness (Fernández-Calviño et al 2010). For bare soil surfaces, radar backscatter is estimated by surface roughness and SM (Morgan 2005). Barber and Mahler (2010) reported High-resolution mapping of gullies, InSAR multi-temporal interferometric coherence change technique for analysing sheet, rill and gully erosion (Liu et al 1999, 2004). Roering et al (2009) further studied this approach by integrating air photographs and lidar data with InSAR for detecting erosional features. The methods aids in identification and delineation of individual erosion features (rills, gullies and sediment depositions) (Fadul et al 1999, Martínez-Casasnovas 2003), or eroded and accumulated areas (Alatorre and Beguería 2009, Žížala et al 2018)

Indirect method: Remote sensing plays a crucial role in erosion studies by acquiring input data for various erosion models or an indirect assessment of soil erosion through indirect method involves the analysis of vegetation cover. (Luleva 2013, Shoshany et al 2013, Vrieling 2007). These methods provide input data for erosion models. Reiche et al (2012) adopted vegetative cover typologies (satellite imagery and digital elevation model (DEM) data) for mapping the intensity of wind erosion in grazing areas of Inner Mongolia using Landsat Thematic Mapper (TM) and in Northern China (Yan et al 2005). Some of the indirect methods viz. NDVI time series method (Clark et al 2010), integration of NDVI in the Computational Environmental Management System (Smith and Leys 2009) in Australia and annual NDVI time series from MODIS correlated well with risk of wind-erosion in agricultural lands. Gully erosion can be detected using Landsat Enhanced Thematic Mapper (ETM) and Systéme Pour l'Observation de la Terre 5 (SPOT 5) in Sudan (Fadul et al 1999), Nigeria (Igbokwe et al 2008), the two-phase method combining classification (Landsat TM bands 3, 5, 7 and NDVI) in Spain (Martinez-Casasnovas and Zaragoza 1996), Landsat TM imagery (Barber and Mahler 2010), using simple supervised classification techniques (Torkashvand and Shadparvar 2011) and Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer images (Bouaziz et al 2009).

Satellite remote sensing of soil erosion: Both Remote sensing and GIS are considered to be the fundamental tools for estimating soil loss and even for detecting the places that are under peril or encountering an alarming rate of soil erosion. Some studies focussed on quantitative estimation of soil erosion through satellite imagery (Tanser and Palmer 1999, Wessels et al 2004, 2007, Bai and Dent 2007, Thompson et al 2009, Bennett et al 2012). The data obtained through remote sensing is particularly useful for policy and decision-makers to preserve the environment and indulge in soil conservation measures to reduce soil loss as and where needed (Ahmed et al 2018). Remote sensing and GIS are constantly been used to estimate land use and change in land cover (Anees et al 2014, 2017), morphometric analysis (Ahmed et al 2010, Dinesh et al 2012), estimating soil loss (Ochoa-Cueva et al 2015, Markose and Jayappa 2016), sediment yield (Rawat et al 2014, Zhao et al 2017), watershed prioritisation; Malekian and Azarnivand 2016) and for various other hydrological models to work out input data (Anees et al 2018). Aerial photographs and satellite imagery are highly capable of quantifying and monitoring erosion at local, national and regional scales (Le Roux et al 2007, Sepuru and Dube 2018). Some Satellite-based spectral indices such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Soil Index (NDSI), Tasselled Cap Transformation (TCT), along with Linear Spectral Unmixing Analysis (LSMA) are oftenly employed to assess soil erosion process (Singh et al 2004, Vrieling 2006), analyze soil exposure intensity (Xu 2014), estimate soil reflectance (Sayao et al 2018, Lobser and Cohen 2007), work out soil erosion status (Zhang et al 2014, Metternicht 1998) and evaluate different soil properties as well as bare soil fractions (Guerschman et al 2015). Unmanned Aerial Vehicle (UAV) imagery was used for small-scale monitoring of erosion thus providing very high spatial resolution imagery (Xu et al 2019). High resolution GeoEye-1 satellite data were obtained to extract information about soil, land cover and topography (Alexakis et al 2013). To work out land use/ cover data, high-resolution satellite imagery were used (Yuksel et al 2008). For estimating soil erosion, image obtained through Satellite (NDVI, SAVI and SARVI) was found to be the most simple, cheap and quick (Singh et al 2004, Gandhi et al 2015, Alhawiti and Mitsova 2016, Sonawane and Bhagat 2017, Sepuru and Dube 2018).

RUSLE–IDM (Information Diffusion Model) coupled model revealed soil erosion risk in different scenarios. It was observed that USLE algorithms do predict field erosion and are highly sensitive to slope gradients thus leading to overestimation of steep slopes (> 30%) (Liu et al 1994, Xu et al 2012). Figure 1 depicts methodology to depict various factors associated with soil erosion.

Mapping of soil eroded areas: Beguería (2006) adopted supervised classification procedure (multinomial logistic model) for mapping of soil eroded areas and hence used for developing a map of highly eroded areas in a mountain catchment. The ability of multi-temporal data (integration of

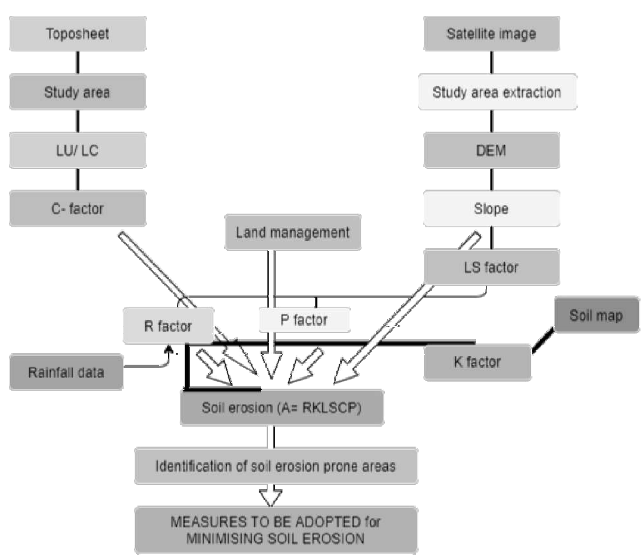

Fig. 1. Flow chart of methodology (Prasad and Tiwari 2019)

images from different seasons) was used for discriminating soil erosion features, and was compared to the use of single images (Beguería 2006, Dhakal et al 2002). Jensen (2005) further highlighted the use of Landsat TM (higher spectral resolution of seven bands) making it better suited for mapping the eroded landscapes. Dhakal et al (2002) used visible bands (Red, Green and Blue) in detecting eroded areas resulting from an extreme rainfall event. A remote-sensing based method was tested using a combination of time series of free access Sentinel-2 image data, airborne ortho images and ground truth data for detecting eroded areas. For identification of eroded areas, unsupervised classification ISODATA of the Sentinel-2A images has been performed (Žížala et al 2018) at the regional scale.

Available soil erosion modeling techniques: Several researchers (Lal 1994, Hudson 1995, Merritt et al 2003) applied different techniques viz. empirical, conceptual and physically based models. Empirical models, one of the simplest models depend upon field observation/ experiment, measurement reflecting observed facts and statistical techniques making prediction regarding future (Petter 1992). Conceptual models acts as an intermediate between empirical and physical models. These depict a true representation of reality by including general processes such as generation of sediment and runoff in the structure. These represent both qualitative as well as quantitative effects of land use without requirement of huge amount of spatial and temporal data (Merritt et al 2003). Some Physically based models include Soil and Water Assessment Tool (SWAT), Erosion Model for Mediterranean regions (SEMMED) (De Jong et al 1999) and the Water Erosion Prediction Project (WEPP) (Flanagan and Laflen 1997, Huang et al 1996, Laflen et al, 2004, Rosewell 2001, Brazier et al 2000, Sepuru and Dube 2018). In another classification models were categorized as Empirical and Deterministic models. Deterministic models illustrate the process of soil erosion with physical-mathematical relationships yielding accurate results (Hammond and McCullagh 1980). These models can be grouped into 'lumped' and 'distributed' models. 'Lumped' models (CREAMS) portrays average response of watershed because of spatial variation of erosion process (Beasley 1986) while the distributed model exacerbates the efficiency of stimulating simulation by using information of all the spatial variables. These models have the ability of depicting accurate information and presuming spatial distribution of the hydrological conditions (Beven 1985). Table 1 depicts various soil loss erosion equations and models (Kushwaha and Yousuf 2017).

Factors related to soil erosion estimation and delineation of soil conservation units: Factors such as fractional vegetation coverage, yellow leaf index, nitrogen reflectance index, bare soil index and slope are closely related to soil erosion. These can be derived through remote sensing imagery and rely upon related thematic indices or algorithms. Quantitatively, these represent vegetation density, soil exposure intensity, vegetation health status, and terrain steepness which are highly relevant to estimate soil erosion in forest (Xu et al 2019). Multi-criteria overlay analysis (using GIS) of different parameters such as soil erosion, soil depth, slope, land cover and surface texture was carried out for delineation of nine conservation units. Identification of conservation units was based on degree of erosion and site characteristics (slope, soil depth, and soil texture and land cover) (Srinivas et al 2002). Millward and

Table 1. Erosion and soil erosion models (Kushwaha and Yousuf 2017)

	Model	References
USLE	Universal soil loss equation	Wischmeier and Smith (1978)
MUSLE	Modified universal soil loss equation	Williams (1975)
RUSLE	Revised universal soil loss equation	Renard et al (1991)
DUSLE	Differentiated universal soil loss equation	Flacke et al (1990)
CREAMS	Chemical runoff and erosion from agriculture management systems	Knisel (1980)
ANSWERS	Areal nonpoint source watershed environment response system	Beasley and Huggins (1982)
WEPP	Water erosion prediction project	Lane and Nearing 1989
OPUS	Advanced simulation model for nonpoint source pollution transport	Ferreira and Smith 1992
EROSION2D	Erosion-2D	Schimdt (1991)
PEPP	Process-oriented erosion prognosis program	Schramm (1994)
KINEROS	Kinematic erosion simulation	Woolhiser et al (1990)
EUROSEM	European soil erosion model	Morgan et al (1992)
LISEM	Limburg soil erosion model	De roo et al (1994)

Mersey (1999) predicted the soil loss quantitatively and it was then categorized into five classes. Five classes were observed for estimating soil erosion risk under Indian condition and these were Low (>5), Moderate (5-10), High (10-20), Very high (20-40) and Severe (40-80) (Karthick et al 2017). Soil loss was estimated using USLE coupled with GIS to priortise tehsils for conservation and delineation of soil units. Remote Sensing integrated with GIS techniques have proved to be of immense importance for land cover mapping (Srinivas et al 2002).

Rusle model: RUSLE is a highly influential and well pronounced model for qualitative and quantitative estimation of soil erosion with reasonably high accuracy (Mekonnen and Melesse 2011). RUSLE coupled with GIS was used for modeling the erosion potential for soil conservation planning in Mexico. Several researchers (Martinez R 1997, Millward and Mersey 1999) used raster-based GIS program i.e. IDRISI software package in Mexico. A combination of RS, GIS and RUSLE acts as a practically effective tool to estimate soil loss on cell-by-cell basis (Saini et al 2015). Slope length-gradient (LS) factor was predominantly an influential RUSLE factor followed by soil erodibility (K) (Gelagay and Minale 2016).

RUSLE is a revised version of USLE which can be employed with the assistance of computer program (Morgan et al 1998). USLE, an acknowledged equation is employed for categorizing in watershed management for large areas (Jain and Kothyari 2000). It predicts erosion rates of ungauged watersheds using watershed characteristics and local hydro-climatic conditions. It presents the spatial heterogeneity with practical viability as well as better accuracy in larger areas (Wishcheimer and Smith 1978]. The RUSLE model follows the equation (Kothyari 1996):

$$A = R * K * LS * C * P$$

where,

- A is the computed average soil loss over a period selected for R, usually on yearly basis (t ha^{-1} yr^{-1});
- The *R*-factor (rainfall-runoff erosivity factor; MJ mm ha^{-1} h^{-1} yr^{-1}) can be determined by the product (*EI*) of total storm energy (*E*) with the maximum 30-min intensity (*I*30) for all the storms over a long period of time (Brown and Foster 1987). *EI* computes raindrop impact and reflects the amount and runoff rate associated with the rain (Wischmeier and Smith 1978).
- K-factor (soil erodibility factor; t ha h ha^{-1} MJ^{-1} mm^{-1}) portrays the change in the soil per unit of applied external force of energy. It depends on the combined effect of rainfall, infiltration and runoff, thus influencing the soil properties on sloppy areas. This factor is highly applicable to tropical soils (Kaolinite dominant), but is less observed with Vertisols dominant soils (Roose 1977).
- The *LS*-factor (slope length and slope gradient factor; dimensionless) depicts the integrated effect of slope length and gradient on soil erosion. RUSLE model dispense conversion tables for evaluating *LS* on uniform slopes (Renard et al 1997). With the increment in soil steepness, an increase in soil loss was observed (McCool et al 1987).
- *C*-factor (cropping management factor; dimensionless; ranging between 0 and 1) determines the impact of all interrelated cover and management variables (Renard et al 1991). C values vary from near zero (well-protected soils) to 1.5 (finely tilled, ridged surfaces that are highly vulnerable to rill erosion) (Renard et al 1997).
- *P*-factor (supporting conservation practice factor; dimensionless; ranging between 0 and 1) is evaluated as the ratio of soil loss with specific support practice to soil loss with up and downslope tillage. *P*-factor extends from 0.2 (reverse-slope bench terraces) to 1.0 (no erosion control practices) (Wischmeier and Smith 1978, Angima et al 2003).

Integrating USLE with GIS aids in predicting soil erosion hazard (Xu and Shao 2006, Zhang et al 2007), hazard mapping (Youssef et al 2009, Qin et al 2009) and model potential soil erosion change for soil conservation planning (Millward and Mersey 1999, Huang 2018). ArcGIS and ERDAS software were utilized to produce desired amount of output using RUSLE equation (RKLSCP) (Srinivasan et al 2019). Using ArcGIS 10.1, inputs were digitized and thematic maps of different factors were generated. Later on, these were used to compute LS factor (Gelagay and Minale 2016). Schwab et al (1981) recommended use of relationship between soil texture and soil organic matter amount to figure out soil erodibility (K) (Stone and Hillborn 2000). An affiliation of soil slope on topography was observed under different conditions by some scientists (Yildirim 2012, Ozsoy et al 2012). Srinivasan et al 2019 estimated soil loss per annum on pixel-by-pixel basis and its spatial extent using an integrated combination of RUSLE and GIS.

By integrating RUSLE with remote sensing and GIS, the distribution and yearly mean value of soil erosion was computed (Ahmed et al 2018, Srinivasan et al 2019). Also, this exacerbates the appraisal of soil erosion, yielding better results and topographical analysis (Durigon et al 2014, Falcão et al 2020). Anees et al (2018) worked out soil erosion probability zones using pixel-based soil erosion analysis through RUSLE and sediment yield model. Soil erosion probability zones were also divided into five categories in which 20.1% and 17.8% represented very high and high probability zones respectively. Das and Poongothai (2018) computed RUSLE factors and presented them by raster layer in a GIS environment, then multiplied together to predict rates of soil erosion rates and for generating maps. The outcome obtained was then reclassified into varied erosion classes on basis of erosion intensity. Angima et al 2003 predicted annual soil loss using RUSLE (Version 1.06) to conclude erosion hazard areas and target locations for conservation measures. Erosion rates of ungauged catchments was also assessed using the understanding of catchment characteristics as well as local hydro-climatic conditions (Garde and Kathyari 1990).

Polykretis et al 2020a analysed the temporal variations among the two RUSLE factors viz. rainfall erosivity (R) and cover management (C) using high temporal resolution. While the rest three factors namely soil erodibility (K), slope length and steepness (LS) and support practice (P) characterized by the data of soil, topography and land cover. Headway in the field of remote sensing have facilitated soil erosion modeling thus enabling quantitative estimation and spatial extent of soil erosion.

The average rainfall erosivity is then estimated according to:

$$R=\frac{1}{n}\sum_{i=1}^{n}\sum_{k=1}^{mj}(7.5R_{10}-150D_{10})k,j$$

where R_{10} is the total rainfall within a month (mm) and only for the days with rainfall ≥10 mm (otherwise, set to zero), D10 is the number of days with rainfall ≥10 mm, n is the number of days covered by the rainfall data, k is the individual erosive events of each month j, and mj is the total number of erosive events of this month. The R-factor was estimated at point (rainfall station) level. The estimated values were extrapolated to island level by applying ordinary kriging-based interpolation (Grillakis et al 2020) in the ArcGIS environment.

The approach developed by Williams and Renard (1983) was applied to estimate the K-factor. It is expressed as follows:

$$K= 0.2+ 0.3e^{(0.0256\times SAN\times(1-\frac{SIL}{100}))}\times\left(\frac{SIL}{CLA+SIL}\right)^{0.3}\times$$

$$\left(1-\frac{0.25\times C}{C+e^{(3.72-2.95\times C)}}\right)\times\left(1-\frac{0.7SN}{SN+e^{(-5.51+22.9\times SN)}}\right)$$

where SAN is the sand content (%), SIL is the silt content (%), CLA is the clay content (%), C is the organic carbon content (%), and SN = 1 - (SAN/100). The soil properties included in “WISE30sec” database were linked to the six different soil types of study area from the “ESDB v2.0” within the ArcGIS environment. The K values for the different soil types were then calculated by Equation (3) in order to obtain the spatial distribution of K-factor in the study area.

The LS-factor was created using a hydrology module provided by SAGA GIS (v2.3.2) software package. The module was selected to incorporate the SRTM DEM derivative of slope gradient as S and the approach proposed by Desmet and Govers (1996) for L estimation. This approach is defined as:

$$L=\frac{((A_{i.j.-in}+D^{2}))^{m+1}-A_{i,j-in}^{m+1}}{D^{m+2}\times x_{i,j}^{m}\times 22.13^{m}}$$

where $A_{i,j,-in}$ is the contributing area (m^2) at the inlet of grid pixel (i,j), D is the grid pixel size (m), xi,j is the summation of the sine and cosine of aspect direction (αi,j) of grid pixel (xi,j = sinαi,j + cosαi,j), and m is a ratio of the rill to interill erosion ranging from 0 to 1.

The C-factor was generated monthly for each time frame (2016 and 2019) by handling the respective Sentinel-2 imagery data. Afterwards, the Normalized Difference Vegetation Index (NDVI) was calculated in the ArcGIS environment by the following Equation (Polykretis et al 2020b):

$$NDVI=\frac{(\rho NIR-\rho RED)}{(\rho NIR+\rho RED)}$$

where ρNIR and αβρRED are the reflectance values at NIR and Red spectral bands, respectively. As an indicator of the energy reflected from the earth's surface, NDVI has been widely used to represent the various vegetation coverage conditions of several regions (Baiamonte et al 2019, Maury et al 2019). Its values range between -1 and 1 indicating a lack of vegetation or dense vegetation, respectively. The approach proposed by Van der Knijff et al 1999 was eventually followed to estimate the C-factor as follows:

$$C= \exp\left[-\alpha\left(\frac{NDVI}{\beta-NDVI}\right)\right]$$

where α and β are constants with value 2 and 1, respectively. All the negative C-factor values were set to 0, and the values higher than 1 were set to 1.

Its estimation in the ArcGIS environment had the form of the product of the (sub) P-factors of these practices (Panagos et al 2015):

$P= P_{cf}\times P_{sw}\times P_{gm}$

where P_{cf}, P_{sw}, and P_{gm} are the P-factor values for contour farming, stone walls, and grass margins, respectively.

Although RUSLE is considered as a leading model in soil erosion assessment, the data availability for generating some of its factors remains a major limitation for maximizing the model accuracy (Karamage et al 2017).

Evaluation of different morphometric characteristics, land use/ land cover and USLE was carried out using ArcGIS and

ArcSWAT. SWAT model proved to be an indispensable tool for pinpointing and characterizing erosion vulnerable areas (Ghafari et al 2017). To estimate the extent of erosion, Raja et al (2015) utilized Sediment Yield Index (SYI) as the method for prioritizing watershed (Shivhare et al 2017).

There's been a considerable shift from the empirical models viz. USLE and SLEMSA (Stocking 1981), towards highly analytical and deterministic models eg. CREAMS (Knisel 1980) and ANSWERS (Beasley and Huggins 1982, de Roo et al 1989). Several modifications were observed from empirical model (USLE) (Warren et al 1989, Flacke et al 1990), and to watershed models which acts as non-point source of pollution e.g., AGNPS or ANSWERS (de Roo et al 1989, Rewerts and Engel 1991, Srinivasan and Engel 1991, Mitasova et al 1996). Using WEPP, erosion rate as well as sediment yield were analysed on the basis of erosion factors for diverse time periods (Yuksel et al 2008)

Comparison between RUSLE and AHP method: RUSLE model estimates the soil loss potential without considering the interdependency of soil erosion factors while AHP (Analytical Hierarchy Process) permits interrelationship between the decision factors (Nekhay et al 2009). RUSLE analyzes rill erosion but not gully or stream-channel erosion (Karydas et al 2009). Point allocation and multi-attribute utility theory, flexibility, minimizes biasedness in making decisions by evaluating geometric mean of the individual pairwise comparisons (Zahir 1999), ability to check inconsistencies and appeal to decision makers prove supremacy of AHP method over RUSLE methodology (Ramanathan 2001). RUSLE estimates absolute value of soil loss potential whereas AHP assesses and constructs soil erosion risk map (Alexakis et al 2013).

Pan-European soil erosion risk assessment (pesera) model: This model runs over a stipulated time period of 20 years duration assessing both monthly and annual soil loss for nearly 12 land use/ land cover types with the input of 128 variables computed from climate, soil, land use/ land cover and topographic data. It focussed around one-dimension hydrological balance that segregates precipitation among evapotranspiration, subsurface flow, overland flow and groundwater recharge. Factors augmenting soil erosion were decline in soil organic carbon, meagre and scattered vegetation cover and varying climatic conditions. This model was developed for large scales concerning mainly rill and sheet erosion and index of soil erosion risk at the regional scale (Kirkby et al 2008). SVAT (Soil-Vegetation-Atmosphere Transfer) deviates from PESERA by considering water and sidestepping energy balance utilizing potential evapotranspiration as the major input variable.

The model integrates the impacts of soil, climate, vegetation, topography and soil erosion (E; t ha^{-1} yr^{-1}) in the PESERA model is determined by:

$$E=k\Delta\Omega$$

where k represents erodibility based on vegetation cover, soil parameters and land use, Δ represents the prospective topography based on a digital elevation model (DEM) and Ω represents the prospective vegetation/ climate and runoff soil erosion based on a plant growth model, vegetation cover and gridded climate data (Kirkby et al 2008).

According to PESERA model, forests, pastures and grasslands are at minimum risk while degraded natural vegetation and scrublands are highly susceptible to erosion (Berberoglu *et al.* 2020). PESERA acts as a diagnostic tool for estimating erosion rate of different soils and topographical characteristics (Kirkby et al 2008, Licciardello et al 2009, Karamesouti et al 2016).

Comparison between RUSLE and PESERA model: RUSLE is an empirical model (Renard et al 1991) whereas PESERA is run-off based mechanistic model for estimating soil erosion (Kirkby et al 2004). RUSLE model yields extremely high values i.e. prediction values with extreme peaks. The outcome was filtered to prevent fallacious results. Contrarily, PESERA portrayed smoother behaviour. RUSLE model was observed to be highly sensitive to C factor (Karaburun 2009), particularly when erosion was analysed after a fire events (Larsen and MacDonald 2007). Post-fire incident erosion rate varied from 1.7 to 113.2 t ha^{-1} yr^{-1} in Mexico (Miller et al 2003). PESERA offers its applications in wide scenarios as the output was obtained with reasonable spatial distribution (Esteves et al 2012). RUSLE anticipated remarkably higher erosion for areas with slope more than 60%. Its outcome is highly sensitive to rainfall erosivity and rainfall. PESERA depicted high vulnerability to vegetation coverage and characteristics of soil (Karamesouti et al 2016).

Answers model: It is a distributed parameter model for mapping soil erosion as well as surface runoff (Beasley and Huggins 1982). This model is constructed to simulate the watershed characteristics. Variables for each characteristic are slope, aspect, crop variables (interception capacity, coverage and USLE C/P factor), soil variables (porosity, field capacity, moisture content, erodibility factor, infiltration capacity), surface variables (surface retention and surface retention) and channel variables (roughness and width). The original version of the model permitted only 20 soils as well as land use/ land cover types for simulation with the hypothesis that they were spatially homogenous. With further advancements and modifications in the model, soil and land use types were limited by the square elements. This model cannot be utilized without integration with GIS at optimal spatial resolution. The supremacy of ANSWERS in comparison to USLE relies on the following heads viz. high accuracy for prognosticating runoff as well as erosion, physically-based mathematical relationships; integrating recently developed relationships, spatial variability. While ANSWERS model lag behind due to certain theoretical weaknesses (eg. subsurface flow, gully erosion, and infiltration), acquisition cost, highly sensitive to certain variables such as soil moisture, infiltration and soil roughness, quantity as well as quality of required input information.

Primarily, use of USLE model was limited to agricultural fields alone and its use for modeling erosion in the landscape was considered quite inappropriate (Foster and Wischmeier 1974, Moore and Wilson 1992). Complete integration of GIS with the topographic data alongwith three-dimensional visualization yields an efficacious environment for evaluation of different approaches to erosion risk analysis for applications to landscape.

A number of studies were conducted primarily focussed on field data, laboratory analysis and satellite remote sensing thus analyzing post-fire effect on different soil properties, processes and functions (Varela et al 2010, Shakesby 2011, Esteves et al 2012, de Vente et al 2013). In the current scenario, two commonly used models are RUSLE (Wischmeier and Smith 1978, van der Knijff et al 2000) and PESERA (Kirkby et al 2003). Initially, both these models were developed for analysing average annual sheet, rill and inter-rill water erosion in the agricultural fields (Kinnell 2010). Several studies (Miller et al 2003, Larsen and MacDonald 2007, Deog Park et al 2012, Esteves et al 2012, Karamesouti et al 2016) notably contributed to post-fire erosion estimation in forest using RUSLE and PESERA models.

Corine model: Coupling CORINE model with remote sensing and GIS plays an indispensable role in mapping erosion risk in Turkey. The digitized input data of various factors viz. topography, soil type and climate was generated by using ArcGIS v9.2 software and these were integrated to produce erosion risk maps (Yuksel et al 2008). Based on CooRdination of Information on the Environment (CORINE) model, soil erosion risk map were generated. Nearly, 2.47% of the study area was observed to be under high risk of soil erosion, while moderate soil risk was in 22.18% and low in 75.35% of the study area (Barakat et al 2015). Ustun (2008) adopted Morgan method for soil erosion modelling as this method. A diverse number of studies were carried out for soil erosion modeling by integrating remote sensing and GIS (Millward and Mersey 1999, Jong et al 1999, Yuksel et al 2008). This aids in soil loss as well as spatial extent of erosion (Okalp 2005), land degradation and mapping erosion (Sazbo et al 1998), erosion surveys and estimating risks (Yuksel et al 2008).

CORINE model, a renowned methodology for presuming soil erosion risk by coupling two parameters i.e. potential erosion risk (function of soil erosivity, erodibility and topography) and vegetation cover data (as the intensity of vegetation cover impacts rate of erosion (Lal 1994, Evrendilek et al 2007). In accordance with CORINE (1992) and Soil Survey Division Staff (1993), distinguishing parameters observed were soil erosivity, erodibility, slope and land use/ land cover. Soil erodibilty was estimated by contemplating soil depth, texture (slightly, moderately and highly erodible) and stoniness. Soil erodibility index was found to be dependent on soil depth, texture and stoniness (CORINE 1992, Yuksel et al 2008).

Soil Erodibility Index = Texture Class x Depth Class x Stoniness Class

Soil erodibility maps were prepared by using “Raster Calculator” tool using ArcGIS v9.2 (Editions of ESRI 2004). To estimate potential soil erosion risk, soil erosivity, erodibility and topography layers were imbricated by using “Raster Calculator” tool of ArcGIS v9.2 to estimate potential soil erosion risk (Yuksel et al 2008)

Potential Soil Erosion Risk Index = Soil Erodibility Index x Erosivity Index x Slope index

Figure 2 depicts flow diagram of CORINE method (Modified from CORINE 1992).

Spot and landsat tm imagery for soil erosion modelling: Multispectral Landsat series and SPOT data or high-resolution data, such as IKONOS and QuickBird are the most widely used satellite data in soil erosion research (Luleva et al 2012, Sepuru and Dube 2018, Vrieling 2006). Landsat-8 and Sentinel-2 are newly launched satellites with their improved spectral, radiometric as well as spatial characteristics provide freely available multi-temporal data suitable for soil erosion mapping (Žížala et al 2018). Even though Landsat data is taking over in soil erosion modelling, it is therefore encouraged to compare its effectiveness with other remote sensing data sets. Dwivedi et al 1997 also found that SPOT image improved the classification of eroded lands as compared to Landsat TM bands. Although SPOT image has proven better at mapping soil eroded areas, its low spectral sampling (4 bands) has shown to be a limitation in mapping gullies (Servenay and Prat 2003). Serveney and Prat (2003) reported that SPOT was unable to identify outcropping eroded areas even it possess unique spectral signatures. While there is an insufficient literature available about SPOT and Landsat TM comparison for mapping gullies, it is depicted that Landsat TM prove to be better at mapping gullies due to higher spectral, spatial resolution and on spectral sampling capabilities of the sensor (Luleva et al 2012). Soil erosion model was integrated with NDVI as well

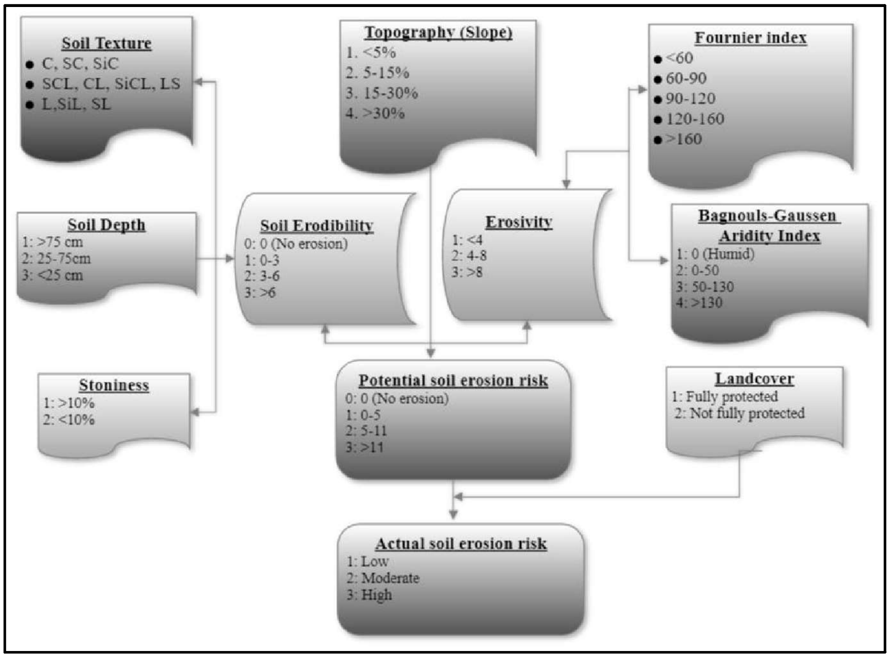

Fig. 2. Flow diagram of CORINE method (Modified from CORINE 1992)

as slope for analysing soil erosion rate per annum (Hazarika and Honda 2001). Landsat data imagery was predominantly used for soil erosion monitoring (Luleva et al 2012). Beguería (2006) distinguished soil erosion on bare soil using supervised classification procedure (multinomial logistic model) over three Landsat thematic mapper (TM). Fulajtar (2001) identified soil erosion patterns using high spatial resolution SPOT PAN Image and procured finest results in contrast with conventional field survey method (Sepuru and Dube 2018). Landsat and SPOT satellite images with very high spatial resolution thus aids in recognizing both medium and large sized landforms (Millington and Townshend 1984), for efficacious analysis of the extent of wide erosion prone areas (Vrieling 2006, Luleva et al 2012, Conforti et al 2013, Sepuru and Dube 2018, Magliulo et al 2020). SPOT-I dominated in mapping accuracy (94%) as compared to 92% in LANDSAT-D (average accuracy) and 89% in TM 2, 3, 5 combinations. Both satellite and airborne images were highly renowned for mapping soil erosion and routine erosion monitoring (Cihlar 1987). Gully erosion was mapped in Northern France by estimating NDVI, brightness index and masked out effect of vegetation using SPOT imagery (Mathieu et al 1997, Sepuru and Dube 2018).

Delineation of soil erosion types: Hochschild et al (2003) delineated various types of soil erosion which can be ranged from slight rill to deep gullies of which rill to inter-rill erosion and deep linear erosion (gully erosion) are predominant in the Mbuluzi catchment using Landsat satellite data. In Nsikazi, Mpumalanga Province of South Africa, Wentzel (2002) adopted Indian Remote Sensing satellite (IRS) data to derive bare soil index for soil erosion mapping. Delineated gully and sheet erosion areas were delineated using Landsat TM images in Olifants River catchment, South Africa to explore whether gullies could be mapped more accurately (Randall 1993). Correspondingly, Liggitt (1988) portrayed remotely sensed data to assess soil erosion in Mfolozi and comprehended orthophotos as well as aerial photographs at different times and scales to analyse the spatial extent of both gully and sheet erosion..

Mapping soil erosion using spectral signature: Alatorre and Begueria (2009) demonstrated use of classification algorithms for obtaining digital information dependent on spectral or structural patterns for recognizing and estimation of soil erosion Different approaches for classification includes supervised, unsupervised and hybrid (i.e. combination of supervised and unsupervised classification) methods (Vrieling 2006, Sepuru and Dube 2018). There lies a direct relationship between the soil and spectral reflectance that permits identification of disturbed soils (Price 1993). Each and every feature on this earth possesses a different spectral signature. Spectral reflectance differs with surface features viz. water body, vegetation cover, cultivated lands, etc (De Asis and Omasa 2007). Spectral signature of bare soil was mainly governed by the texture, moisture content, mineral composition as well as the organic matter of soil (Barnes and Baker 2000, Sujatha et al 2000). Predominantly used NDVI modifications in soil erosion study were Soil Adjusted Vegetation Index (SAVI, Huete 1988), and Soil and

Atmospherically Resistant Vegetation Index (SARVI; Huete and Liu 1994) (Kwanele and Njoya 2017). Remote sensing was profoundly used for assessing soil erosion which include Normalized Difference Water Index (NDWI) (Dasgupta et al 2007), Modified Temperature - Vegetation Dryness Index (MTVDI) (Kimura 2007), Land Surface Temperature (LST), Leaf Area Index (LAI), Normalized Soil Moisture Index (NSMI) (Haubrock et al 2008, Luleva et al 2012, Sepuru and Dube 2018). Spectral reflectance differs with different soil properties viz. organic matter, particle size, iron oxides, moisture content, type and amount of minerals (Magliulo et al 2020).

Mapping soil degradation using aerial data: Progression in space technology led to development of new possibilities in the field of soil science. Using airborne as well as spaceborne data for mapping bear greater accuracy, economy and efficiency as compared to conventional methods. The efficacy of soil mapping in case of computer techniques, interpretation of aerial photos and conventional method is in the ratio of 1:5:10. At both semi-detailed and reconnaissance levels, aerial photointerpretation techniques were adopted (Srinivasan 1972, Ahuja and Manchanda 1980). Govindarajan and Mouttapa (1967) reported for the first-time use of photo-interpretation techniques for mapping soil degradation. Kamphrost and Iyer (1972) carried out study on aerial photos and classified ravine areas based on width and depth of ravines into four major classes in the Northern part of India. While scrutinizing saline soils of Haryana and Punjab, three levels of soil salinity were observed and analysed through photo interpretation studies (Shanwal et al 1980, Bhargava and Sharma 1980). Some peculiar and advanced techniques such as band stretching, enhancement, ratioing, computer aided statistical functions and clustering techniques in decoding digital data proved highly useful in soil mapping. Image enhancement technique was effective in differentiating shallow red soils from the deeper ones that portrayed same spectral response (Karale et al 1983).

Limitations in use of satellite imagery: Although higher spatial resolution imagery such as SPOT 5, IKONOS, Quikbird, etc. offers high grade data for potential use in soil erosion mapping (Taruvinga 2009) but they are not utilized. The high-resolution data (IKONOS and QuickBird) are quite costly to be used for mapping erosion in wide area (Vrieling et al 2008) and not affordable for the developing countries. According to Sepuru et al (2018), high spectral resolution information remained limited mainly due to high acquisition cost. Another reason behind the limited use is knowledge gap which can limit the regular use of these advance methods for the quantification of eroded soils. Some other factors involved are indispensability of precise atmospheric corrections, masking of the clouds and their shadows, heterogeneity of environmental factors especially soil cover structure (occurrence of different soil types and parent material, historical human-induced disturbances (Zádorová et al 2018, Žížala et al 2018). The stumbling block in RUSLE model are extrapolation, spatial scale effects as well as the complexity of entire procedure of soil erosion (Xu et al 2012); restriction in understanding process involved mainly in spatial distribution of eroded areas (Croke and Mockler 2001), depending on small scale application (Nigel and Rughooputh 2010). In current generation satellite data, spatial resolution and stereoscopic coverage inhibit effective soil mapping at both the meium as well as large scale (Karale et al 1983).

Future prospects: Integrating remote sensing with GIS has given ways to a number of opportunities in the field of mapping soil erosion. Remote sensing has opened new ideas for characterization and monitoring of degraded lands (Tesfamichael 2004). Le Roux (2007) recommended that remote sensing approach for soil erosion modelling must be expanded to a regional scale. Future studies should involve use of 2D hydrological modelling for rainfall–runoff relationships and to determine the accuracy of RUSLE and sediment yield models with high resolution remote sensing data such as SPOT 5 (2.5 m resolution) and LIDAR based DEM (2.5 m resolution). Sediment yield models should also be correlated with in situ sediment yield data through hydrological modelling. (Anees et al 2018). Both Future generation satellite and Microwave sensing are valuble tools for developing an efficient and reliable system for soil studies. As the shorter wavelength radar system estimates vegetation parameters whereas the longer wavelength radar system analyse subsurface soil conditions also (Karale et al 1983). Inspite of the drawbacks involved Satellite remote sensing sensors are leading way forward to solve the environmental problems (Morgan, 2005, Le Roux et al 2008, Seutloali et al 2016, Sepuru and Dube 2018).

CONCLUSION

Soil erosion has constantly been a threatening problem for agricultural production today. Due to human intervention, its condition is worsening so proper remedial measures needs to be taken in action. Immediate intervention is needed for better conservation planning for identifying the soil priority classes and hotspot areas. Now a days, Geographic Information System (GIS) and remote Sensing are emerging as most effective tools for estimating spatial information in a vast area. The use of the USLE model integrated to GIS and RS are quite efficient for assessing the soil loss vulnerability in a basin's scale. This is useful for decision making to establish appropriate strategies for soil and water conservation.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTION

Garima Dahiya: Conceptualization; writing - original draft; writing-review & editing. Hardeep Singh Sheoran: Conceptualization; writing - original draft; supervision, writing-review & editing. Isha Ahlawat: Conceptualization; writing-review & editing. Roohi: Conceptualization; writing-review & editing.

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Uptake and Micronutrient Cations Transfer in Acid Alfisol as Influenced by Four Decadal Continuous Use of Amendments and Chemical Fertilizers in Maize-Wheat Cropping System

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Abstract: For a healthy human population and to improve maize quality, it is necessary to increase and maintain micronutrient content. A few studies have evaluated the long term impacts of nutrient management practices on micronutrient uptake and their translocation.The micronutrient uptake by maize, soil recovery (SRC) and transfer coefficients (TC) were determined in a 46-years-old long-term fertilizer experiment at Palampur (Himachal Pradesh) during *kharif* 2018. The study revealed improved micronutrients uptake by maize with balanced NPK application along with FYM or lime. Treatment 100% NPK+FYM and 100% NPK+lime witnessed higher level of micronutrients than other treatments. The SRC values of micronutrients followed the order: Zn>Cu>Fe>Mn. However, no significant difference in translocation coefficient was noted. Soil organic carbon was positively and significantly correlated with Cu , Fe , Mn and Zn uptake . Integrated use of inorganic fertilizers along with FYM or lime in acidic soils can regulate the micronutrient uptake in soil-plant systems, therefore eliminating the need to supply micronutrients from external sources and ultimately assisting in the production of crops with grater nutritional value.

Keywords: FYM, Lime, Micronutrients, Soil recovery coefficient, Transfer coefficient

Nearly 30% of India's cultivated land is covered with acid soils (Kumar et al 2014), suffering from low agricultural production because of hydrogen (H^+), iron (Fe), aluminum (Al) and manganese (Mn) toxicities and/or nitrogen (N), phosphorus (P), calcium (Ca), magnesium (Mg) and zinc (Zn) deficiencies (Andric et al 2012). Even the external addition of chemical fertilisers does not seem to help the situation because nutrient fixation results in low use efficiency. Numerous researchers have recommended various nutrient management practices to increase crop yields in acid soils, such as neutralization of soil acidity using limestone, dolomite or similar liming materials; application of organic manures alone or in combination with balanced chemical fertilisers etc. (Lelei et al 2006, Onwonga 2006, Gowda et al 2017, Dhiman et al 2019). Generally, acid soils have sufficient or even toxic levels of micronutrients (Kovačević and Rastija 2010, Castro and Crusciol 2015), but their plant availability and uptake are affected due to agricultural practices. Micronutrients play major structural and functional roles in a plant's physiological processes and are critical for increasing crop yields and nutritional quality, albeit required in a minimal amount (Ciampitti and Vyn 2013). Despite this, micronutrient deficiency is a worldwide problem leading to poor micronutrient uptake. As a result, the productivity of agriculture systems is declining, human and animal health is also affected due to low micronutrient contents in food grains (Saha et al 2019). Welch and Graham (2004) estimated that nearly 2 billion people in the world are deficient in Fe and Zn, most of which belong to developing and under-developed countries. The situation worsens due to the heavy use of macronutrient fertilisers, with little or no application of micronutrients. Being a costly strategy, soil and foliar application of micronutrients are not popular among farmers.

Dynamic processes of root uptake, transportation and translocation, and dry matter accumulation affect the micronutrient concentrations in a plant, besides their sufficient availability in the soil (Miner et al 2018). Integration of chemical NPK fertilisers with organic amendments such as FYM has been reported to correct the micronutrient deficiencies and regulate their supply to the plants (Shabnam and Sharma 2016, Khaliq et al 2017, Parmar et al 2022). Ma and Zheng (2018) ascribed this to the synergistic or antagonistic interactions between macro- and micronutrients that occur in soil and plants. Increased organic matter content increases the availability of micronutrients, facilitating the transfer of micronutrients from soil to plants (Moharana et al 2017). Therefore, it is essential to obtain an understanding of the interaction between nutrient management practice, soil properties and plant's micronutrient uptake in the long term. However, literature reports regarding the impact of continuous cropping, fertilizer and amendments on the uptake of micronutrients with respect to their soil availability and their translocation from vegetative to economic plant parts are very few. Therefore, present study was conducted to investigate the effect of continuous use of NPK fertilisers, FYM and lime for forty-six years on maize yield, micronutrients uptake, transfer and soil recovery and the relationship between soil organic carbon content and micronutrients uptake in an acid Alfisol. It is hypothesised that the application of fertilisers, FYM and liming would affect the uptake of micronutrients and transport.

MATERIAL AND METHODS

Location of the field experiment: The study was carried out in the ongoing long-term fertilizer experiment on maize-wheat cropping sequence, sited at the experimental farm of the Department of Soil Science, Chaudhary Sarwan Kumar Himachal Pradesh Agriculture University, in Palampur, India (31°6′ and 76°3′ E) (Fig. 1). The experiment was started in the year 1972, following a randomized block design on Typic Hapludalf of silt loam texture. The initial soil properties have been given in Table 1.

Treatment details: The study was carried out in maize-wheat system which included eleven treatments with three replications (Table 1) in plot size of 15 m^2. The 100% NPK represents the recommended doses of N (urea): 120, P_2O_5 (single super phosphate) - 60, and K_2O (muriate of potash) - 40 kg/ha. Since *kharif* 2011, 100% and 150% doses of P were reduced by 50% because of P build-up over the years, and farmyard manure (FYM) application was started in T_1 at the rate of 5 t/ha (dry weight). In T_9, S-free diammonium phosphate was used to supply P. Zinc sulfate (25 kg/ha) was applied every year in treatment T_5 until *rabi* 2010-11. Farmyard manure was applied in T_8 at the rate of 5 t/ha (dry weight) rate to the maize crop, corresponding to local practice. In T_{10}, lime at the rate of 900 kg/ha lime ($CaCO_3$) sifted through a 100-mesh sieve was applied.

Field experiment: A power tiller was used for field preparation, and the maize hybrid Kanchan Gold was sown after irrigation. Afterwards, the crop's water requirement was met through the monsoon rainfall received during the crop growth period (2605 mm). Active ingredients of atrazine (1.125 kg/ha) were applied before emergence for chemical weed control in all the treatments except in T_4, where weeds were removed manually and incorporated in the same plots. The standard package of practices was followed for raising the crop. The crop was harvested upon attaining physiological maturity, and grain and stover yield was recorded at harvesting.

Sample collection and processing: Grain and stover samples of maize were collected from each plot at harvesting time. The collected plant samples were washed under running tap water and then dried in a hot air oven at 60 ℃ for 48 hours till a constant weight was attained. The dried grain samples were ground to a fine powder using a stainless-steel grinder and stored in air-tight bags for further analysis. The dried stover samples were ground in a Wiley mill fitted with stainless-steel parts and stored in paper bags.

Analytical procedure: A finely ground plant sample (1 g) was taken in a 150 ml Erlenmeyer flask and digested in a di-acid mixture (HNO_3 and $HClO_4$ in a 9:4 ratio). The sample digest was diluted to 100 ml with double distilled water, followed by filtration of the aqueous extract through Whatman no. 42 filter paper. The filtrate's concentration of the micronutrient cations (Fe, Mn, Cu, and Zn) was directly measured in an atomic absorption spectrophotometer (Jackson 1973). Soil organic carbon content (SOC), DTPA-

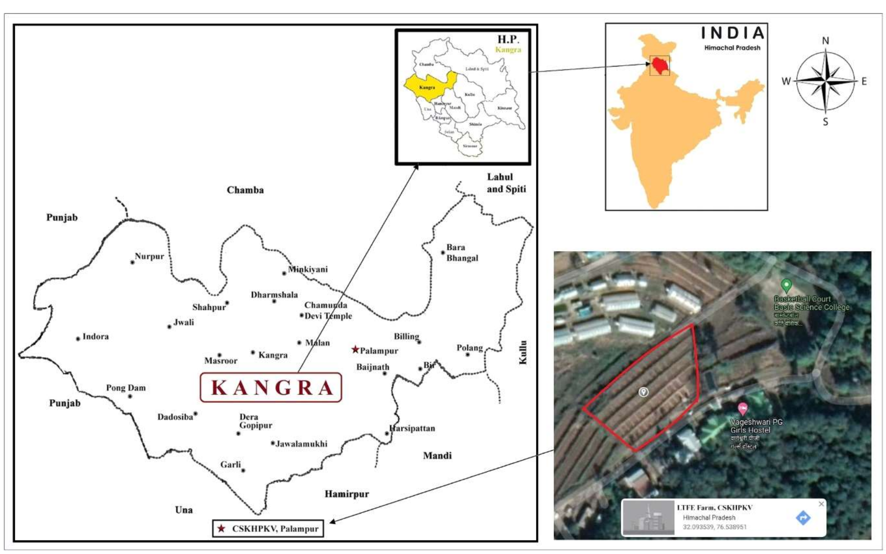

Fig. 1. Experimental location

extractable Fe, Mn, Cu, and Zn have been described by Thakur et al (2023).

Calculation of Nutrient Uptake, Transfer Coefficients, and Soil Recovery Coefficient

Nutrient uptake: The micronutrient uptake by maize was calculated following the formula below:

$$\text{Micronutrient uptake (g/ha)} = \frac{\text{Nutrient concentration (mg/kg)} \times \text{Dry matter yield (kg/ha)}}{100}$$

Soil recovery coefficient: The following formula calculated the soil recovery coefficient (SRC):

$$\text{Soil recovery coefficient} = \frac{\text{Nutrient uptake by plant (g/ha)}}{\text{Nutrient content in soil (g/ha)}}$$

Transfer coefficient: The transfer coefficient (TC) was of each micronutrient was worked out by using the following formula:

$$\text{Transfer coefficient} = \frac{\text{Concentration of the element in grain (mg/kg)}}{\text{Concentration of the element in stover (mg/kg)}}$$

Statistical analysis: Web Agri Stat Package 2.0 (WASP 2.0) was used for statistical analysis of the data and compared at a significance level of 0.05 using Duncan's multiple range test (DMRT). Graphs and tables were prepared using MS WORD 2019.

RESULTS AND DISCUSSION

Maize yield and micronutrient cations uptake: Maize yield in all the treatments, except 100% N, was significantly higher than the control (Fig. 2). In 100% N treatment, no grain and stover yield was recorded. Applying FYM or lime with a recommended dose of fertilisers significantly increased maize grain yield over sole application of fertilisers by almost 48 and 37 per cent, respectively. In T_4, maize grain yield recorded a nearly 16 per cent increase over T_2. In T_6 and T_9, a respective decline of almost 53 and 55 per cent was recorded in grain yield compared to T_2. With the application of Zn (T_5) or higher NPK doses (T_3), no significant improvement in grain yield over recommended NPK application (T_2) was recorded. Significant difference among treatments with respect to micronutrient uptake was observed due to the long-term application of fertilisers, FYM and lime (Table 2). Iron uptake by maize grain was recorded lowest in control (26.2 g/ha) and highest in 100% NPK + FYM (369.2 g/ha), followed by 100% NPK + lime (281.5 g/ha). The Fe uptake by maize stover recorded in FYM amended plots (T_8) was significantly higher than the rest of the treatments. The Mn uptake in 100% NPK + FYM by maize grain was nearly 65 per cent higher than in 100% NPK treatment, while the lowest Mn uptake by grain (18.0 g/ha) and stover (42.3 g/ha) was recorded in control, apart from zero uptakes in T_7. Zinc uptake by maize grain in 100% NPK + FYM (151.7 g/ha) was at par with 100% NPK + Zn (136.5 g/ha), followed by 124.4 g/ha in 100% NPK + lime. Similarly, Cu uptake by maize grain varied from 37.4-549.9 g/ha. In 100% NPK + FYM, Cu uptake by maize stover was highest and was statistically superior over the rest of the treatments.

The higher uptake of micronutrient cations (Fe, Mn, Zn, and Cu) in FYM treated plots was probably due to the release of micronutrients from FYM, reduced losses of micronutrients

Table 1. Soil properties (0-15 cm) before the sowing of maize (2018)

Treatment	pH*	Organic carbon (g/kg)	DTPA extractable micronutrients (mg/kg)			
			Fe	Mn	Zn	Cu
T_1 (50% NPK+FYM)	5.31	10.70	27.8	21.1	1.3	1.7
T_2 (100% NPK)	5.24	10.20	30.2	23.0	1.2	1.6
T_3 (150% NPK)	4.92	9.75	31.1	25.8	1.3	1.7
T_4 (100% NPK + hand weeding)	5.23	11.70	30.8	22.6	1.4	1.8
T_5 (100% NPK + Zn)	5.38	9.25	27.8	22.5	4.1	1.8
T_6 (100% NP)	5.14	9.70	28.4	23.2	1.3	1.6
T_7 (100% N)	4.40	8.10	32.5	22.9	1.4	1.5
T_8 (100% NPK + FYM)	5.54	13.40	37.3	37.7	2.4	2.3
T_9 (100% NPK (-S))	5.28	9.65	22.6	21.8	1.5	1.7
T_{10} (100% NPK + lime)	6.27	11.10	23.5	23.5	1.3	1.7
T_{11} (Control)	5.46	8.05	18.9	16.7	1.1	1.3
Initial (1973)	5.80	7.90	26.0	24.3	1.9	0.4

*(1:2.5, soil: water)

through chelation and proliferation of root growth, resulting in better nutrient uptake and higher crop yield. Li et al (2007) observed that incorporating organic manures significantly increased nutrient uptake by maize plants and facilitated the allocation and transfer of nutrient elements to the maize ears and grains. Furthermore, soil amendment with lime (T_{10}) improved soil health, increased nutrient uptake, and thereby higher productivity over NPK alone (T_2) (Lelei et al 2006). The omission of essential plant nutrients in T_6 and T_9 might have created nutrient imbalances in the soil, resulting in lesser micronutrient uptake and poor crop yield in these plots compared to the balanced fertilizer application (T_2). In the absence of the addition of nutrients from external sources and continuous removal of nutrients by crops, control recorded the least micronutrient cation uptake (Thangasamy et al 2017, Shambhavi et al 2018). In our study, zero yields recorded in T_7 indicated that continuous urea application had substantially declined the soil pH, which led to poor soil structure and reduced and imbalanced availability of essential plant nutrients (Ma and Zheng 2018). Application of Zn in T_5 improved the Zn uptake significantly over 100% NPK, as reported by Behera et al (2015).

Soil recovery coefficient: The soil recovery coefficient (SRC) is an indicator of micronutrient uptake by plants in relation to their availability in the soil. If the SRC value is less than one, the nutrient element is present in a sufficient amount in the soil to meet the nutritional needs of the plants. This study observed a significant effect of different fertilizer

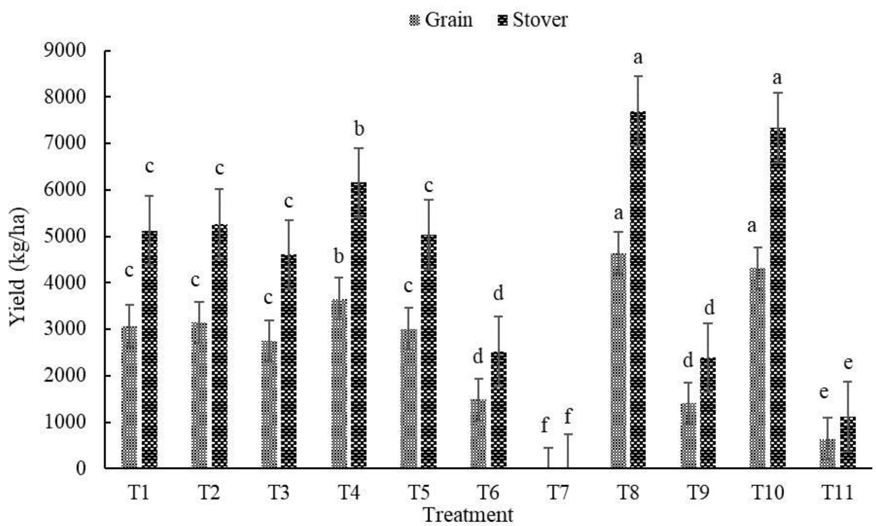

Fig. 2. Effect of continuous use of fertilizers and amendments on maize grain and stover yield. Values with the same letters are not significantly different at P ≤ 0.05. Bars represent standard error

Table 2. Effect of continuous use of fertilizers and amendments on Fe, Mn, Zn and Cu uptake by maize grain and stover

Treatment	Fe uptake (g ha^{-1})		Mn uptake (g ha^{-1})		Zn uptake (g ha^{-1})		Cu uptake (g ha^{-1})	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
T_1	193.3^{c}	717.8^{d}	136.7^{c}	338.2^{d}	74.9^{d}	196.0^{d}	67.6^{d}	170.1^{d}
T_2	210.2^{c}	758.1^{d}	144.6^{c}	355.5^{d}	85.6^{cd}	211.3^{d}	78.0^{d}	185.3^{d}
T_3	192.6^{c}	737.0^{d}	130.1^{c}	314.7^{d}	76.8^{d}	196.7^{d}	72.7^{d}	184.8^{d}
T_4	262.2^{b}	935.4^{c}	178.0^{b}	439.9^{c}	104.0^{c}	266.0^{c}	100.2^{c}	262.2^{c}
T_5	195.8^{c}	698.4^{d}	132.8^{c}	334.6^{d}	136.5^{ab}	339.7^{b}	71.9^{d}	161.1^{d}
T_6	79.8^{d}	317.8^{e}	57.4^{d}	147.1^{e}	31.0^{e}	82.7^{e}	32.7^{e}	73.4^{e}
T_7	0.0^{e}	0.0^{f}	0.0^{e}	0.0^{e}	0.0^{g}	0.0^{f}	0.0^{f}	0.0^{f}
T_8	369.2^{a}	1443.0^{a}	238.5^{a}	672.7^{a}	151.7^{a}	407.4^{a}	151.8^{a}	398.1^{a}
T_9	78.2^{d}	296.0^{e}	53.0^{d}	144.9^{e}	30.0^{ef}	87.3^{e}	29.6^{e}	66.9^{e}
T_{10}	281.5^{b}	1132.8^{b}	198.3^{b}	553.0^{b}	124.4^{b}	338.7^{b}	124.6^{b}	306.4^{b}
T_{11}	26.2^{e}	99.5^{f}	18.0^{e}	42.3^{e}	10.9^{fg}	26.4^{f}	9.3^{f}	28.0^{f}

Values with the same letters are not significantly different at P <0.05

treatments on SRC (Table 3). The SRC values were less than one in all the treatments but zero in T_7. Apart from zero in T_7, the lowest SRC value for all micronutrient cations was obtained in control. At the same time, significantly greater SRCs were recorded under balanced application of fertilisers alone (Fe-0.014, Mn-0.01, Cu-0.069, Zn-0.106) and in treatment integration with FYM (Fe-0.023, Mn-0.011, Cu-0.107, Zn-0.097) or lime (Fe-0.027, Mn-0.013, Cu-0.110, Zn-0.135). Hand-weeding treatment (T_4) also recorded significantly higher SRC values (Fe-0.017, Mn-0.012, Cu-0.090, Zn-0.121). The SRC values of micronutrients followed the order Zn (0.016-0.135) > Cu (0.110-0.013)> Fe (0.027-0.003) > Mn (0.013-0.002).

The SRC value of more than one indicates insufficiency of the element for plant nutritional needs (Rutkowska et al 2014). In study, the micronutrient amounts in the soil were sufficient to meet the nutritional needs of the plants, irrespective of the fertilisers and amendments applied as indicated by SRC values of less than one. The lowest SRC values under control could be due to exhausted nutrient reserves that declined the overall biomass production. In contrast, fertilisers and amendments markedly increased the phyto-availability of micronutrients, overall crop growth and biomass production. Previous studies have also reported similar improvements in soil micronutrient recovery due to fertilizer and organic manure in maize-wheat rotation (Li et al 2007), wheat-potato-lupines sequence (Rutkowska et al 2014) and rice-wheat system (Saha et al 2019). Weed biomass incorporation in T_4 improved the SOC content and created congenial conditions for nutrient recycling and crop growth.

Transfer coefficient: The TCs of micronutrients from maize stover to grain were computed and presented in Table 3. The TCs of Fe, Mn, Zn and Cu varied in the range of 0.42-0.47, 0.61-0.70, 0.58-0.71 and 0.58-0.77, respectively. Except T_7, all the treatments were statistically comparable, and no significant effect of fertilizer and amendment application was observed on the translocation of micronutrient cations from maize stover to grain. However, TCs of Fe were recorded lower as compared to TC values of Zn, Cu and Mn. TCs of micronutrient cations were not affected by the application of fertilisers and manures. Although the application of balanced fertilisers and amendments (T_2, T_4, T_8 and T_{10}) increased the micronutrient uptake as indicated by SRC values and it is speculated that starch dilution of micronutrients in grains as a result of increased dry matter production nullified the effects of increased uptake. The results differ from some studies that have reported an increase in the micronutrient TCs with fertilisers and organic manure application (Li et al 2007, Ma and Zheng 2018, Saha et al 2019), but our results corroborate with the findings of Behera et al (2015) and Miner et al (2018). We attributed the lower TC values of Fe, as compared to Zn, Cu and Mn, to their functional roles in the plants. Since Fe is involved in the lignin and suberin formation, its major portion remained in the vegetative parts. In contrast, comparatively higher amounts of Zn, Cu and Mn were transported to grains.

Relationship between nutrient uptake and soil organic carbon: Micronutrient cations' uptake by maize (grain and stover) was strongly associated with SOC content, and the correlation was significant at 1 and 5 per cent level of significance (Fig. 3). The Pearson's correlation coefficients between micronutrient uptake and SOC content followed the order of Cu > Fe > Mn > Zn (from high to low, r = 0.924-0.807). Iron, Mn, Zn and Cu play a critical role in numerous metabolic functions and structural build-up of plants. Their availability in

Table 3. Effect of continuous use of fertilizers and amendments on soil recovery coefficient and transfer coefficient

Treatment	Soil recovery coefficient				Transfer coefficient			
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
T_1	0.015^{cd}	0.010^{cd}	0.093^{c}	0.062^{c}	0.45^{a}	0.67^{a}	0.64^{a}	0.67^{a}
T_2	0.014^{cd}	0.010^{bc}	0.106^{c}	0.069^{c}	0.47^{a}	0.68^{a}	0.68^{a}	0.70^{a}
T_3	0.013^{d}	0.008^{d}	0.097^{c}	0.069^{c}	0.44^{a}	0.69^{a}	0.65^{a}	0.66^{a}
T_4	0.017^{c}	0.012^{ab}	0.121^{b}	0.090^{b}	0.47^{a}	0.68^{a}	0.66^{a}	0.64^{a}
T_5	0.015^{cd}	0.010^{cd}	0.055^{d}	0.063^{c}	0.47^{a}	0.66^{a}	0.67^{a}	0.74^{a}
T_6	0.006^{e}	0.004^{e}	0.040^{e}	0.030^{d}	0.43^{a}	0.66^{a}	0.63^{a}	0.76^{a}
T_7	0.000^{g}	0.000^{f}	0.000^{g}	0.000^{f}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
T_8	0.023^{b}	0.011^{bc}	0.097^{c}	0.107^{a}	0.42^{a}	0.61^{a}	0.62^{a}	0.63^{a}
T_9	0.007^{e}	0.004^{e}	0.044^{de}	0.026^{d}	0.45^{a}	0.62^{a}	0.58^{a}	0.77^{a}
T_{10}	0.027^{a}	0.013^{a}	0.135^{a}	0.110^{a}	0.42^{a}	0.61^{a}	0.63^{a}	0.69^{a}
T_{11}	0.003^{f}	0.002^{f}	0.016^{f}	0.013^{e}	0.46^{a}	0.70^{a}	0.71^{a}	0.58^{a}

Values with the same letters are not significantly different at $P < 0.05$

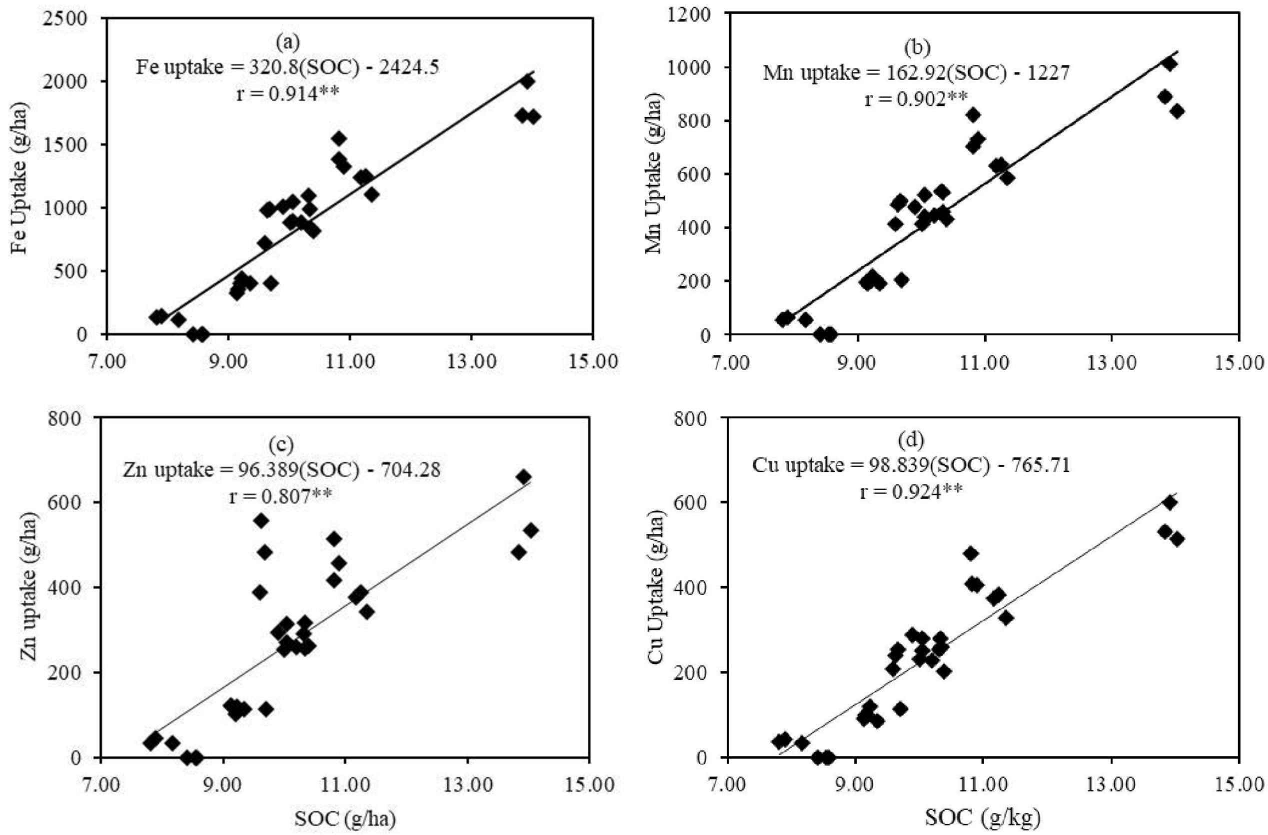

Fig. 3. Linear regression relationship of soil organic carbon (SOC) with a) Fe uptake, b) Mn uptake, c) Zn uptake and d) Cu uptake (n=33)as affected by continuous use of fertilizers and amendments. Note that the axes may not begin from zero

the soil predominantly affects their plant uptake (Li et al 2007). Therefore, factors affecting the availability of micronutrients in the soil can also affect their uptake by the crops. Soil organic matter is one of the most critical factors affecting the soil's micronutrient availability, directly impacts its uptake (Miner et al 2018).The study confirm that a strong correlation was observed between SOC content and uptake of Fe, Mn, Zn and Cu. This was ascribed to the formation of complexes between micronutrient cations and organic complexes that increased the availability of native micronutrients and eased their uptake by plants (Chaudhary and Narwal 2005).

CONCLUSIONS

The uptake of micronutrients and their soil recovery quantitatively varied depending on the fertilisers and amendments added to the soil during the last forty-six years. The results confirmed our hypothesis that integration of balanced fertilisation with FYM or liming led to a marked improvement in the uptake of micronutrients. The SRC values indicated a sufficient availability of micronutrients to the plants, but long-term integrated application of fertilisers with FYM or lime proved to be significantly superior in increasing the micronutrient uptake in relation to their availability in the soil. Regardless of the fertiliser or amendments applied, the translocation of micronutrients from stover to grain in the plants was not affected significantly. Hence maintaining or improving soil organic matter is necessary to increase the micronutrient uptake in the crops, which will ultimately result in crops of superior nutritional quality.

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Evaluation of PGPR Isolated from *Sesuvium portulacastrum* on Crop Growth under Salinity

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***Abstract*:** Salinity is one of the major factors that adversely affect plant growth causing considerable loss in agricultural production. The halo-tolerant bacteria associated with halophyte rhizosphere can be used as a cost effective and economical tool for salinity tolerance and growth promotion in plants. The total of 8 independent isolates from the rhizosphere of *Sesuvium portulacastrum* from coastal soils were isolated for their plant growth promotion potential. All the isolates had at least one plant growth promoting property. In order to ascertain the true salinity tolerance levels of the isolates, a growth curve experiment with 0, 3, 5 and 7% NaCl was carried out. Among all the isolates RB_5 and RB_6 had high tolerance for salinity. The highest ammonia production was in RB_5 at 1.46 mg/Land IAA (Indole Acetic Acid) production was in RB_6 at 21.75 µg/ml. The bioinoculation of *Neobacillus niacini* increased seed germination (23.2%), shoot length (35.1%), root length (34.2%), and total dry matter (43.5%) even under high salinity (7.78 dS/m). These saline tolerant beneficial bacteria could serve as inoculant for non-host plant cultivation or for phytoremediation of saline soils.

***Keywords*:** Halophilic bacteria, Salinity tolerance, Plant growth promotion, Germination study

Salinity is a major problem causing substantial loss in agricultural production around many parts of the world leading to degradation of land. Soil salinization is a worldwide problem that could affect 1-10 billion hectares with a potential increase of around 15% per year. It is also estimated that up to 50% of the irrigated lands could be affected by salinity or sodicity (Rodríguez-llorente et al 2019). Saline soil is characterized by the presence of neutral soluble salts on the soil surface and root zones at higher concentration. It has an electrical conductivity of >4 dS m^{-1} (~20 mM NaCl) at 25°C and exchangeable sodium <15%. Reclamation of saline soil requires good quality irrigation water for leaching, infrastructure for drainage and amendments like gypsum. These processes are continuous in nature and is laborious and cost-intensive. An alternative approach to remediate saline soils is use of plants with its associated endophytes and rhizosphere microorganisms (Nath et al 2020). *Sesuvium portulacastrum* being a succulent halophyte somehow manage to uptake water from the soil with high salinity. The unique metabolic activities such as production of phytohormones and siderophores by the microorganisms associated with halophytic plants are responsible for the plant-microbe interactions at saline sites (Majeed et al 2015). Siderophore, a low molecular weight iron chelator is released by some microbes when plant is under salt stress (Beneduzi et al 2012). Similarly, phytohormones (auxins, gibberellins, abscisic acid, indole acetic acid) are growth regulators synthesized in defined organs of the plant and play a major role in the mitigation of abiotic stresses (Ahemad 2014).

To use PGPR as a saline soil remediation tool, more research of halophyte-associated rhizobacteria and interactions with halophytes and glycophytes' is needed to understand the processes of their survival and protection from salt stress and to design plant protection measures (Ruppel et al 2013, Miransari 2014). All bacteria require different environmental conditions for expression of genes and beneficial characters for plant growth especially halophilic microbes require saline environment (Oren 2008). Plant tolerance to salt is more effective in rhizobacteria isolated from a salty habitat than by PGPR isolated from non-saline habitats (Katoka et al 2017, Palacio-Rodríguez et al 2017, Etesami and Beattie 2018, Numan et al 2018). Black gram (*Vigna mungo* L.) belongs to the family of Fabaceae and is one of the most significant economical pulse crops used as a food, green manure and fodder. Being salt sensitive crop, high salinity inhibits photosynthetic activity, growth rate along with denaturation of membrane and chlorophyll (Munns et al 2008, Chaves et al 2009, Mittal et al 2012). Hence, the potential of halotolerant bacteria to improve the growth of black gram under saline condition was evaluated.

MATERIAL AND METHODS

Collection of *Sesuvium portulacastrum*: The halophyte, *S. portulacastrum* (L.) was collected from coastal region (11º29'40'' N, 79º46'2'' E) of Parangipettai, Cuddalore, India. Identification and authentication using the inflorescence was carried out with the help of Botanical Survey of India (BSI), Madras zone, Coimbatore. Even though *S. portulacastrum* could be propagated through vegetative methods and was collected along with rhizospheric soil for isolation of PGPR bacteria.

Isolation of salt tolerant rhizospheric bacteria: For isolation of rhizospheric bacteria, soil from rhizosphere of halophyte plants (1 g) were mixed with 25 ml of sterile distilled water and were plated in nutrient agar (NA) (Anburaj et al 2012). After the appearance of colonies, individual colonies were picked up with sterilized loop, transferred to fresh NA slants and the pure cultures so obtained were stored in refrigerator at 4ºC (Haiyambo et al 2015). Subsequent sub-culturing was then made in NA media and Nutrient Broth for further biochemical and molecular analyses. All the cultures were tested for salt tolerance by culturing in Mannitol Salt Agar (MSA) containing 5% NaCl to confirm the salt tolerance ability (Shields and Tsang 2006). The development of halo zone indicates the salt tolerance ability. The halo zones were measured for each culture which is used to calculate the tolerance index (Equation 1).

$$\text{Salinity tolerance index} = \frac{(\text{Colony diameter} + \text{Halozone diameter})}{\text{Colony diameter}} \quad (1)$$

Production of plant growth promoting substances: The production of ammonia by rhizobacteria was tested in 10 ml of peptone water. After 48 h of incubation at 30ºC, the Nessler's reagent (0.5 ml) was added to each tube (Bhavani and Kumari 2019). Development of brown to yellow color was quantified using spectrophotometer. Bacterial isolates were also screened to produce siderophores on the Chrome azurol S (CAS) agar medium (Schwyn and Neilands 1987) and SPI (Siderophore Production Index) was calculated (Equation 2). The production of IAA like compounds was detected from the culture supernatants of the bacterial isolates (Thakuria et al 2004). Pure colonies from a 24 h culture was inoculated into nutrient broth with 2 mg of tryptophan/g and in the absence of tryptophan, and were incubated at 28ºC for 48 h. Five ml culture was taken from each tube and centrifuged at 10,000 rpm for 15 min. Two milliliter aliquots of the supernatant were transferred to a fresh tube and washed with ethyl acetate to extract free IAA-like substance. The extracts were then treated with 4 ml Salkowski reagent and incubated at room temperature for 25 min. The absorbance of the solution (pink colour developed) was read at 530 nm. For the control experiment, sterile nutrient broth was used. The concentration of IAA in the culture supernatants was determined using a calibration curve with pure IAA as a standard (Shahzad et al 2017).

$$\text{Siderophore production index} = \frac{\text{Colony diameter} + \text{Orange zone diameter}}{\text{Colony diameter}} \quad (2)$$

Assessing salinity tolerance of isolates: The ability to grow in different concentration of NaCl was assessed by growth curve experiment. A 1ml inoculum from 48 hours broth was transferred to 100 ml NA broth supplemented with 0, 3, 5 and 7% NaCl and incubated at 30ºC. The OD 600 nm value was observed every 4 hours after inoculation. The absorbance is recorded for 72 hours or until the curve attains stationary phase (Ramadoss et al 2013, Nagaraju and Mahadevaswamy 2020).

Genetic identification and phylogenetic tree construction: The DNA was isolated from microbial samples and PCR amplification was done by adding 5 µL of isolated DNA in 25 µL of PCR reaction solution (1.5 µL of Forward Primer and Reverse Primer, 5 µL of deionized water, and 12 µL of Taq Master Mix). The forward Primer, 27F (5' AGAGTTTGATCTGGCTCAG 3') with 20 base pairs and Reverse primer, 1492R (5' TACGGTACCTTGTTACGACTT 3') with 20 base pairs was used to perform PCR. Then the DNA sequencing was performed using an ABI PRISM® Big Dye TM Terminator Cycle Sequencing Kits with AmpliTaq® DNA polymerase (FS enzyme) (Applied Biosystems). The 16s rRNA sequence was blasted using NCBI blast similarity search tool. The phylogeny analysis with the closely related sequence of blast results was performed by multiple sequence alignment. The MUSCLE 3.7 was used for multiple alignments of sequences (Edgar 2004). Poorly aligned positions and divergent regions were cured using the program G blocks 0.91b (Talavera and Castresana 2007). Finally, the program Tree Dyn 198.3 was used for tree rendering (Dereeper et al 2008).

Germination study using selected isolates as bioinoculum: The two most salt tolerant isolates were selected to study their effect on germination and growth attributes of black gram (*Vigna mung L.*) under salinity. The black gram genotype, VBN-8 seeds were used for the study after surface sterilization in 0.1% sodium hypochlorite for 3 mins and repeated washing with distilled water. After which the 28-hour old inoculum of isolate, I_1-RB5 and I_2-RB6 was used for seed priming and distilled water as control. The seeds were soaked in optimized microbial inoculum with OD of 1 at 600 nm for 3 hours. In initial screening, black gram seeds failed to germinate at 2 % NaCl. The seeds were grown in germination sheets at 3 levels of salinity (T_1- 0, T_2 - 0.5 and

T_3 - 1 percent of NaCl). The EC of the 0, 0.5 and 1 percent of NaCl concentrations were 0, 4.28 and 7.78 dS/m, respectively. The germination percentage, root length, shoot length and total dry weight were calculated after 15 days.

RESULTS AND DISCUSSION

Microbial isolates and salt tolerance: The soil in coastal area was sandy in nature with low organic and nutrient content. The seasonal intrusion of sea water through backwaters results in high EC of 12 dS/min the soil. The total of 8 bacterial isolates (RB_1 to RB_8) were isolated from rhizosphere of *S. portulacastrum*, naturally established in the extreme saline conditions located in Parangipettai, India. These isolates were pure cultured and tested in mannitol agar with 5% NaCl (Kumar et al 2020). Among these, isolates RB_1, RB_4, RB_5, RB_6, RB_7 and RB_8 developed halo zone around the colonies proving their potential to tolerate salinity. Salinity tolerance index (STI) was in the order of $RB_5 > RB_6 > RB_1 > RB_8 > RB_7 > RB_4$ (Table 1). The isolate RB_5 had the highest STI of 3.69 followed by RB_6 (3.13). The isolates RB_2 and RB_3 failed to grow in the saline condition (5% NaCl) and lowest STI was in RB_4 at 2.56. The pure cultures were isolated from morphologically different colonies. The isolate RB_6 was very high in numbers during enumeration which could be due to high association with *S. portulacas*trum rhizosphere. Since plants release root exudates which plays a major role in the root microbiome.

Evaluation of direct plant growth promotion mechanisms: All the eight isolates had the potential to produce ammonia, IAA and Siderophore (Table 1). The ammonia production by the bacteria promotes high growth and yield in crops along with various benefits like remediation of polluted environment (Bledsoe and Boopathy 2016, Raklami et al 2021), carbon sequestration (John and Lakshmanan 2018) and various ecosystem services (Ebadi et al 2018, Razzaghi et al 2019). Highest ammonia production was reported in the isolate RB_8 (2.40 mg/L) and lowest was in RB_6 (0.16 mg \/L). Ammonia production is associated with the presence of *nif* gene in diazotrophs which is to be verified with further study. Among the isolates, RB_8, RB_5, RB_4 and RB_2 recorded the highest ammonia production of 2.40, 1.46, 1.36 and 1.25. mg/L¸ respectively. The ammonia and nitrogen producing bacteria isolated from rhizosphere ensures plants growth even in nitrogen deficit soils (Patrick et al 2018). The IAA production (µg/ml) was reported in all the isolates except RB_4 and ranged from 1.34 to 21.75 µg/ml (Table 1). Isolates RB_6, RB_5, RB_3 and RB_2 recorded highest IAA production of 21.75, 18.13, 11.26 and 10.81 µg/ml, respectively. This IAA production of microbes in the host plant rhizosphere increase the yield and stress tolerance in crops (Shahzad et al 2017). The PGPR bacteria application improved the crop stress tolerance and evaluated over recent years (Seema et al 2016, Bhavani and Kumari 2019, Goyal et al 2020). Upadhyay et al (2009) found that only 18% of strains isolated from wheat rhizosphere in soils of Varanasi, were tolerant to 8% of NaCl, while maintaining PGP activities. Siderophore production ensures the availability of nutrient through iron chelation hence it was qualitatively assessed through SPI (Siderophore production index) (Panda and Parida 2019). The siderophore production ranged from RB_6 (2.77) to RB_4 (1.92). The SPI was recorded in the order of $RB_6 > RB_1 > RB_8 > RB_7 > RB_5 > RB_4$. The isolates RB_1, RB_5, RB_6 and RB_8 had all the PGPR activity investigated in this study. These isolated strains were assessed for their salt tolerance and can be used as inoculum in the nutrient management practice after formulating the application strategies (Hameeda et al 2006, Rundan et al 2021).

Growth curve experiment to assess the salt tolerance: In the experiment to assess the growth potential of the isolated strains, strain RB_1 and RB_4 failed to grow in broth with 3 % NaCl. The growth curve showed that RB_5, RB_6, RB_7 and RB_8 reached stationary phase during different time (Fig. 1). In isolates RB_5, RB_6, RB_7 and RB_8 lag phase lasted upto 8, 8, 16 and 20 hours, respectively in control (0% NaCl). This is due to

Table 1. Salinity tolerance and PGPR (Ammonia, IAA and siderophore) production potentials of the microbial isolates

Isolates	Salinity tolerance index	Ammonia production (mg/L)	IAA production (µg/ml)	Siderophore production Index
RB_1	3.00	0.31	8.92	2.25
RB_2	0.00	1.25	10.81	0.00
RB_3	0.00	0.86	11.26	0.00
RB_4	2.56	1.36	0.00	1.92
RB_5	3.69	1.46	18.13	2.00
RB_6	3.13	0.16	21.75	2. 77
RB_7	2.76	0.00	5.71	2.07
RB_8	2.89	2.40	1.34	2.17

difference in the microbial growth kinetics among the isolates and phase at which the microbe prepares itself for the log phase (Rolfe et al 2012). The log phase lasted upto 32, 44, 64 and 48 hours in isolate RB_4, RB_5, RB_6 and RB_7, respectively after inoculation in control. The shorter log phase indicates the potential of microbe to grow at favourable environment. All the isolates showed growth in 3 % NaCl broth. However, the isolates RB_4 and RB_7 showed low growth in 3 % NaCl than their respective control treatments (0% NaCl). The growth curve indicated that both isolates (RB_4 and RB_7) didn't generously grow at 3 % NaCl and stationary phase was achieved much earlier (12 and 24 hours in RB_4 and RB_7, respectively) than their respective controls. The long stationary phase could be due to the synthesis of protective factors and adaptation of current environmental conditions at higher NaCl concentrations (Finkel and Kolter 1999). But, isolates, RB_5 and RB_6 had similar growth pattern to control in NA with 3% NaCl but lag and log phase delayed slightly in both isolates. This change could be the time required to adapt the high salt content. In RB_5, lag phase was upto 28 hours and 32 hours in RB_6. The reasons for long delay in RB_5 are unclear. Isolates RB_4 and RB_7, didn't record any growth in NA broth with 5 and 7% NaCl indicating their low potential for salinity tolerance. But RB_5 and RB_6 had fair growth in 5 and 7% NaCl concentration. Isolate RB_5 had similar growth pattern at 5 and 7% NaCl, but the curve lacked distinctive lag, log and stationary phase. The OD 600 nm at 7% of NaCl was lower than 5%. The isolate RB_6 had distinctive lag, log, and stationary phase in 5% NaCl indicating high tolerance than RB_5. But the growth was less pronounced at 7% NaCl with same hours of lag, log and stationary phase. The microbial growth curve of RB_5 and RB_6 at different salt concentration were similar to the extreme halophytes isolated from saline lakes (Ramadoss et al 2013).

Phylogenetic identification of 16S R DNA: The bacterial strains were identified by 16S rDNA sequencing and their sequences were submitted for comparison with the sequences in the NCBI database by BLAST search in order to find out the homologous sequences of related strains. The Blast results based on 16S rRNA, showed that the two isolates were 99 and 100% related to *Metabacillus indicus* and *Neobacillus niacini,* respectively (Fig. 2, 3). In Figure 2, the 0.01 shows the length of branch that represents an amount genetic change between the strains. The units of

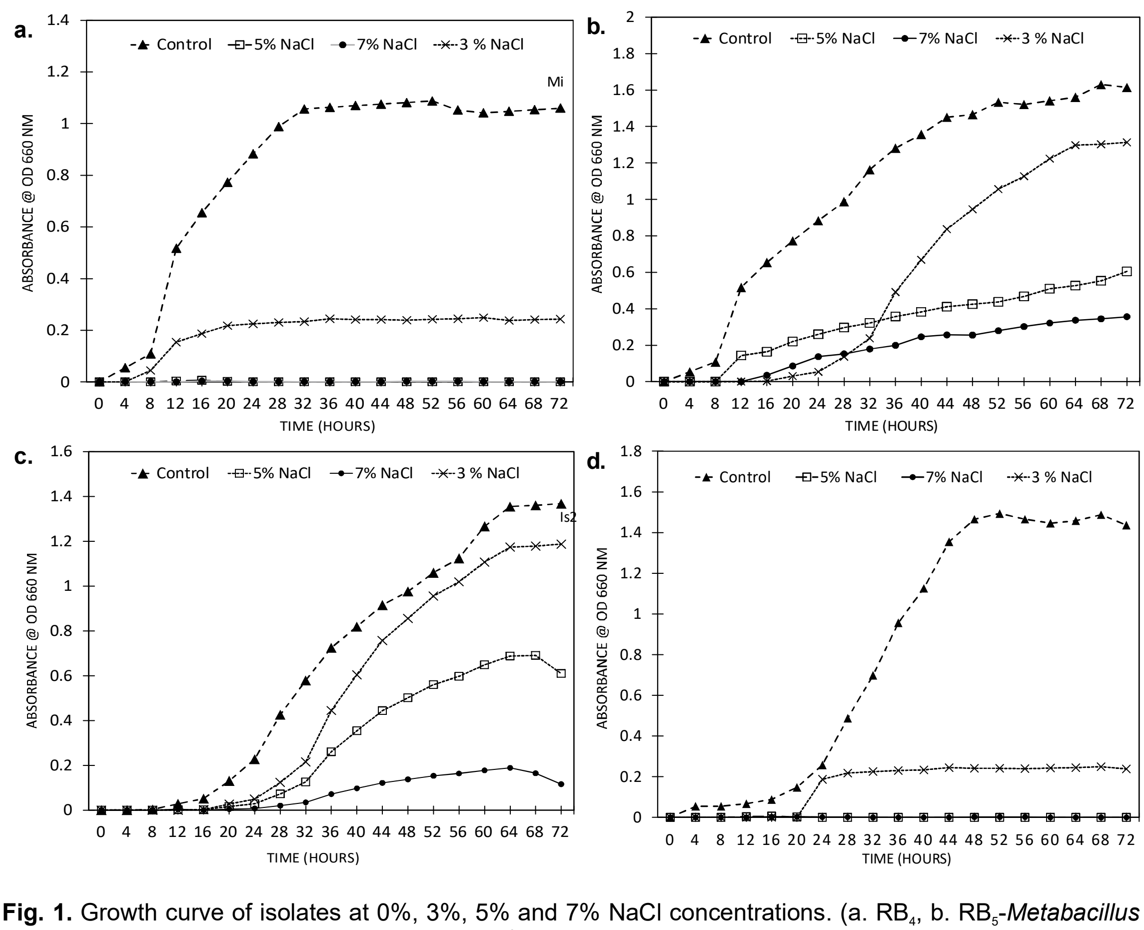

Fig. 1. Growth curve of isolates at 0%, 3%, 5% and 7% NaCl concentrations. (a. RB_4, b. RB_5-*Metabacillus indicus*, c. RB_6-*Neobacillus niacini*, d. RB_7)

branch length are usually nucleotide substitutions per site *i.e.,* the number of changes or 'substitutions' divided by the length of the sequence. Since the tree is developed by neighbour linking method the nearest resembling strain for RB_5 is *Metabacillus indicus*. The isolate comes under the genera of *Metabacillus* which is generally in the coastal saline environments. The strain *Paenibacillus endophyticus* is ascertained as the outward link to the isolate. In Figure 3, the 0.002 shows the length of branch that represents an amount genetic change between the strains and the nearest resembling strain for RB_6 is *Neobacillus niacini*. The isolate comes under the genera of *Neobacillus* which is a new sub-genus in the genera *Bacillus*. The strain *Neobacillus pocheonensis* is ascertained as the outward link to the phylogenetic tree. The organism before the node of the isolated is earlier in the evolution in this case the *Neobacillus pocheonensis* and *Neobacillus ginsengisoli.*

Effect of bio inoculum on black gram growth under salinity germination potential of seeds: The germination percentage decreased with the increase in salinity. However, the inoculation of isolates increased the germination potential of black gram (Table 2). The highest germination potential was recorded in T_1I_2 followed by T_1I_1. The germination percentage was 27% lower in T_3C than T_1C (non-inoculated). In comparison with T_1C, the germination percentage was only 24 and 13% lower in T_3I_1 than T_3I_2. In treatment T_2 (4.28 dS/m) the inoculation of I_2 recorded germination percentage same as T_1C, denoting the potential of the isolate to promote germination under salinity. The inoculation of *M. indicus* (I_1) and *N. niacini* (I_2) improved the germination percentage of the seeds even under high salinity (7.78 dS/m).

Growth attributes of seedlings: The highest shoot length was recorded in T_1I_1 (14.6 cm) followed by T_1I_2 (14.1 cm) (Table 2). In treatment T_2 (4.25 dS/m), I_1 and I_2 recorded 12.5 and 18.8 % high shoot length than C (control). Similarly, in T_3 (7.78 dS/m) I_1 and I_2 recorded 31 and 35.1 % high shoot length than C (control). The root length was also high in all

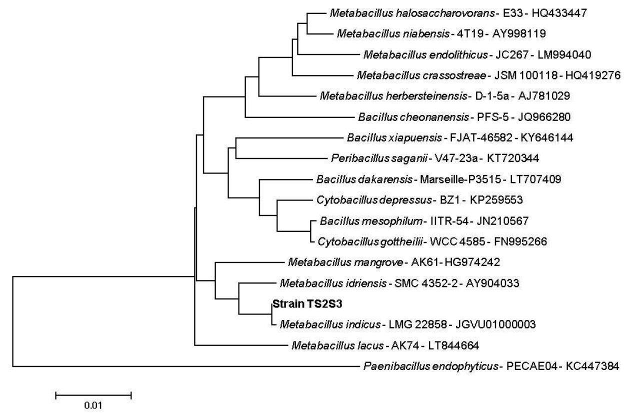

Fig. 2. Phylogenetic tree by neighbour joining method of salt tolerant rhizospheric bacteria RB_5 with unit branch length of 0.01

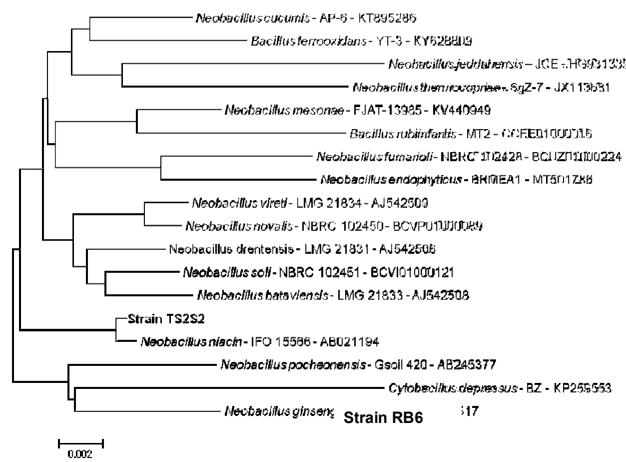

Fig. 3. Phylogenetic tree by neighbour joining method of salt tolerant rhizospheric bacteria RB_6 with unit branch length of 0.002

Table 2. Growth attributes of black gram (*Vigna mungo* L.) under different salinity levels

NaCl concentration (%)	Treatment	GP (%)	SL (cm)	RL (cm)	TDM (mg/plant)
T_1	C	93 (±3.8)	13.8 (±0.6)	5.9 (±0.2)	75.2 (±3.1)
	I_1	95 (±3.7)	14.6 (±0.8)	6.8 (±0.4)	110.4 (±6.3)
	I_2	96 (±1.5)	14.1 (±0.3)	7.4 (±0.2)	119.8 (±2.9)
T_2	C	90 (±6.4)	11.2 (±1.2)	5.3 (±0.6)	64.8 (±7.2)
	I_1	92 (±4.9)	12.6 (±0.7)	4.9 (±0.3)	75.2 (±4.0)
	I_2	96 (±3.8)	13.3 (±0.5)	6.8 (±0.3)	89.2 (±3.6)
T_3	C	75 (±2.8)	8.2 (±0.3	3.8 (±0.2)	54.0 (±2.2)
	I_1	79 (±4.2)	10.7 (±0.6)	4.3 (±0.2)	65.8 (±3.8)
	I_2	84 (±3.5)	11.1 (±0.5)	5.1(±0.2)	77.5 (±3.2)

Note: C – control, I_1 – Bioinoculum of *Metabacillus indicus*, I_2 - Bioinoculum of *Neobacillus niacini;* T_1 – 0 % NaCl, T_2 – 0.5 % NaCl, T_3 - 1 % NaCl; GP – Germination percentage, SL – Shoot Length, RL - Root Length, TDM – Total Dry Matter.
The values represent the mean of three replications, and the figures in parenthesis are the standard deviation

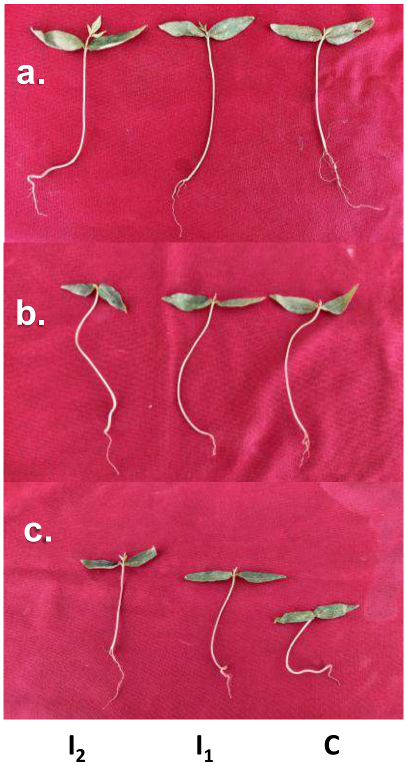

Fig. 4. Effect of bioinoculants on black gram (*Vigna mungo* L.) under salinity levels (a. 0 %, b. 0.5 %, c. 1 % of NaCl concentration and I_1 - inoculation of RB_5, I_2 - inoculation of RB_6, C- uninoculated)

treatments with bioinoculant I_2(Fig. 4). Apart from root length the number root nodes were high in treatments with both I_1 and I_2. The increase in total dry matter (TDM) was significant with application of bioinoculants (Hassan et al 2020). The application of bioinoculant I_1 and I_2 increased the TDM by 46.9 and 59.4 %, respectively in T_1. The inoculation of these saline tolerant isolates as bioinoculants improved the seed germination and growth attributes significantly even under high EC (7.78 dS/m). These results were in line with the earlier studies (Etesami and Maheshwari 2018, Hassan et al 2018, Priyadharshini et al 2019).

CONCLUSION

The potential of rhizobacteria to stimulate plant growth in poor quality soil is an important component that is required to be addressed for sustainable future. Hence, the isolation and characterization of rhizospheric soil bacteria from saline environments was carried out. In summary, isolated plant growth promoting bacterial species associated with rhizosphere of *Sesuvium portulacastrum* growing in highly saline coastal soil and evaluated salinity tolerance of two promising isolates (*Metabacillus indicus* and *Neobacillus niacini*). Subsequently, their potential to promote black gram growth was assessed by germination study. These isolates have high potential to survive under saline conditions (EC > 4 dS/m) and even promote plant growth. High siderophore production index , ammonia and IAA production were also reported in the two isolates. The seed primming of black gram with *Metabacillus indicus* and *Neobacillus niacin*) resulted in significant improvement in crop growth attributes under high saline conditions (7.78 ds/m). The promising results from this study warrant further, in-depth analysis of plant growth promotion by these and other halophilic bacterial species isolated from non-target halophilic crops. This research will have a significant impact on efforts to identify bacteria that stimulate growth of crop under high saline conditions.

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Characterization of Lowland Acid Soils for Secondary Nutrients in Central Parts of Western Ghats

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Abstract: The present investigation was made to study the "Characterization of lowland acid soils for secondary nutrients in hilly zone of Karnataka." Soil samples were collected from the Kodagu and Chikkamagaluru districts of the hilly zone of Karnataka to know the status of secondary nutrients, along with different forms of soil acidity were also analyzed. Soils of the Kodagu and Chikkamagaluru districts are moderately acidic to neutral in soil reaction, ranging from 5.16 to 6.97. EC values of all the soil samples grouped under the non-saline (< 2.0 dSm^{-1}) class. Organic carbon content low to high ranged from 4.12 to 22.90 g kg^{-1}, and the Cation exchange capacity of soils ranged from 10.60 to 26.90 cmol (p^+) kg^{-1}, respectively. Potential acidity appears to be a dominant fraction in the soil which includes both exchangeable and pH-dependent acidity. However, their distribution in soil was found to be in the following order, viz., Potential acidity > Exchangeable acidity > Active acidity. Available calcium in soil was high, ranged 4.30 to 16.00 cmol (p^+) kg^{-1}. Available magnesium in soil ranged from 2.00 to 9.80 cmol (p^+) kg^{-1}. Available sulphur in soil was medium to high, ranging from 9.40 to 22.90 mg kg^{-1}. High rainfall in Karnataka causes the hilly region's soils to become acidic, which makes growing crops difficult. Farmers are using liming material in uplands to combat this. Due to heavy rains and the leaching of highly mobile secondary nutrients from upland areas, paddy fields on lower slopes get accumulated.

Keywords: Lowland paddy fields, Secondary nutrients, Potential acidity, Exchangeable acidity, Active acidity

Enhancement and sustained crop production play an essential role in improving soil fertility. Using fertilizers in India has never kept pace with the crop's need for nutrients. Due to intensive farming, there is a shortage of secondary and primary nutrients. The vital plant nutrients calcium (Ca), magnesium (Mg), and sulphur (S) are crucial for the growth and development of plants and plants need these nutrients lesser than nitrogen, phosphorus, and potassium. Calcium, the fifth most abundant element, constitutes about 3.64 % of the calcium in the Earth's crust. It is distributed in feldspar, amphiboles, apatite, and limestone minerals. Like calcium, magnesium makes up 1.93 % of the Earth's crust. The breakdown of rocks containing the principal minerals biotite, dolomite, hornblende, olivine, and serpentine results in the release of magnesium into the soil (Bindhu et al 2021). Sulphur is one of the seventeen necessary elements and is the fourth to most crucial nutrient for crop productivity after nitrogen, phosphorus, and potassium. About 0.03 to 0.1 % sulphur occurs in the Earth's crust.

The productivity of acid soil is low because of issues associated with soil acidities, such as leaching loss of bases, a high concentration of exchangeable aluminium and a low CEC. Soils with low pH contain relatively high amounts of exchangeable H^+ and Al^{+3}, considered acid soil. Acid soils occur in those areas where rainfall is higher, *i.e*., precipitation > evapotranspiration. Karnataka agro-climatic zone 9, i.e., Hilly zone, covers Kodagu, Hassan, Chikkamagaluru, Shivamogga, Haveri, Uttara Kannada, Dharwad and Belgaum districts. The primary cropping system in these areas is coffee-based agroforestry in sloppy regions, followed by lowland paddy. The other crops cultivated in these areas include pepper, rubber, tea, cashew, areca nut, cocoa, and spices. Liming is a fundamental management strategy to deal with acid soil problems and boost productivity, and it is always suggested for the acidic soils found in the hilly zone. There hasn't been much research done in the hilly region of Karnataka on calcium, magnesium, or sulphur. Because less research has been done in the low-lying areas of hilly regions, their nutritional status will be different from that of upland places. There is no systematic information available regarding soil acidity and Ca, Mg, and Sulphur dynamics in lowland acid soils of Karnataka's hilly zone.

MATERIAL AND METHODS

The study area covered in Madikeri, Virajpet and Somvarpet taluks of Kodagu district and Chikkamagaluru, Koppa, Mudigere, Narasimharajapur and Sringeri taluks of Chikkamagaluru district in Karnataka. Kodagu and Chikkamagaluru districts are situated in the South-West part of the state; Kodagu district lies between the latitudes 11˚56'00" to 12˚50'00" N and longitudes 75˚22'00" to 76˚11'00" E and Chikkamagaluru districts lies in between latitudes 12˚54'42" to 13˚53'53" N and longitudes 75˚04'46" to 76˚21'15" E. The temperature of Kodagu district begins to increase from March till April, which is the hottest month, with the mean daily maximum temperature at 28.6˚C. The average annual rainfall of the Kodagu district is about 2729 mm. The climate of the Chikkamagaluru district is very pleasant and cool. April is generally the hottest month, with the mean daily maximum temperature at 30.7˚C. The average annual rainfall of the taluks coming under the hilly zone in the Chikkamagaluru district is 2807 mm.

The study area was undertaken to know the status of secondary nutrients under lowland paddy areas of two districts, *i.e.,* the Kodagu and Chikkamagaluru districts. Lowland paddy field. The 200 representative soil samples were collected randomly from 0 to 20 cm depth at different locations under lowland paddy areas. Collected soil samples were processed and used for further physical and chemical analysis.

Particle size distribution: The relative proportion of clay present in soil samples was determined by international pipette method by using sodium hexametaphosphate as dispersing agent (Piper 1966), then soil texture was identified based on relative proportion of sand, silt and clay present in these soils using the textural diagram given by IUSS and USDA (Ghildhayal and Tripathi 1987).

RESULTS AND DISCUSSION

The pH of low land paddy cover in the Kodagu and Chikkamagaluru districts was in the range of 5.16 to 6.97 (Table 2). It shows that soils were moderately acidic to neutral in soil reaction. About 62.00 % of samples were moderately acidic this might be due to the predominance of igneous and metamorphic rock parent material and heavy rainfall which may leach out basic cations from the soil solum and the similar results have been reported by Asha (2016). About 38.00 % of samples of were neutral in soil reaction this might be due to an increase in pH of the soil upon submergence to a stable value (Meetei et al 2020). Electrical conductivity (EC) were normal in soil ranged from 0.02 to 0.59 (dS/m). Which shows that soil were non saline in nature. The normal electrical conductivity might be attributed to leaching of salts due to high rainfall. Devi et al (2015).

Organic carbon was in the range of 4.12 to 22.90 (g /kg) indicating that soil were low too high in organic carbon status. Only 1.00 % of samples were having low organic carbon status, about 10.00 % of samples were having medium organic carbon status and remaining 89.00 % of samples were having high organic carbon status. The low biotic activity in these soils caused by the acidic pH which increases the accumulation of organic matter in soil may be responsible for their medium to high organic carbon status, which led to the buildup of organic matter in these soils. Same results were reported by Ragini (2018), Seema (2019). Cation exchange capacity of soil was obtained in the range of 10.60 to 26.90 (cmol (p^+) /kg) which shows that cation exchange capacity soil was medium to high. After the few days submergence the pH of soil get increases and soluble exchangeable cations will increases in the soil leads to increase in soil CEC of soil. Fine texture of soil has greater CEC compare to the coarse texture soil Mulugeta et al (2019).

As per textural diagram given by USDA (Black 1965), texture of study area was sandy clay loam to clay this might be attributed to soils derived from acidic granite and gneiss parent rock and due to heavy rainfall transportation and deposition of finer particles from upland to low land through runoff, leaching process and illuviation in subsurface horizons. (Amara and Momoh 2014, Pulakeshi et al 2014). Distribution of acidity types in the Kodagu and Chikkamagaluru district soils under low land paddy cover of hilly zone. In Kodagu district only 34.00 % of samples were neutral in pH but about 66.00 % of samples exhibit moderate soil acidity and in Chikkamagaluru district 42.00 % of

Table 1. Method of analysis

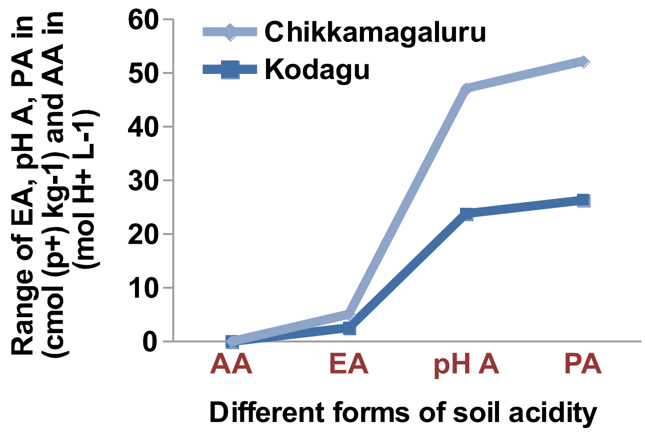
Parameters	Methods	Reference
Soil pH (1: 2.5)	Potentiometric method	Jackson (1973)
EC (dS m^{-1}) (1:2) at 25^{0}C	Conductivity bridge	Jackson (1973)
Organic carbon (g/Kg)	Walkley and Black Wet oxidation method	Walkley and Black (1934)
Cation exchange capacity (Cmol (p^+) /kg)	Neutral 1N ammonium acetate method	Page et al (1982)
Available calcium and magnesium (Cmol (p^+) /kg)	Neutral 1N Ammonium acetate extraction	Jackson (1973)
Available sulphur (ppm)	Turbidimetric method	Black (1965)
Exchangeable acidity (Cmol (p^+) /kg)	Ten grams of soil was leached with 1N KCl solution	Baruah and Barthakur (1999)
Potential acidity (Cmol (p^+) /kg)	0.5 N $BaCl_2$ + triethanolamine	Baruah and Barthakur (1999)

samples were neutral in pH and about 58.00 % of samples were moderately acidic in nature. It showed that Potential acidity > Exchangeable acidity > Active acidity. Potential acidity appears to be a dominant fraction in the soil which includes both exchangeable and pH dependent acidity. The predominance of Fe and Al oxides, and medium to high levels of organic matter status (Table 2) in soils may be responsible for their high potential acidity. The aforementioned materials were being saturated with both exchangeable and non-exchangeable forms of $H^+$and Al^{3+} ions. Same results were reported by Dolui and Sarkar 2001 and Arunima et al 2012.

The available calcium was in the range of 4.30 to 16.00 (cmol (p^+) /kg) indicating that soil were rich with calcium content. Calcium showed a variation in soil this is due to in coffee based agroforestry in hilly zones to neutralize the soil acidity farmers were applying liming materials, the free calcium carbonate which is present in the liming material will get deposited in the low land paddy fields. Hence instead of leaching accumulation of calcium carbonate takes in low lying paddy fields. The available magnesium was in the range of 2.00 to 9.80 (cmol (p^+) /kg). Magnesium content in soil comparatively lower than calcium this might be attributed to higher mobility of magnesium compared to calcium. Farhat et al (2021). The Available sulphur in low land paddy soil of hilly zone of Karnataka covering Kodagu and Chikkamagaluru districts (Table 2) obtained in the range of 9.40 to 22.90 (mg kg^{-1}). It shows the soils were medium to high in the sulphur content. The presence of high amount of sulphur might be due to contribution of organic matter to the available sulphur

Table 2. Chemical properties and secondary nutrient status of soils under low land paddy cover in hilly zone of Karnataka

Parameters	Range	Mean
pH	5.16 to 6.97	5.90
EC (dS/m)	0.02 to 0.59	0.28
OC (g /kg)	4.12 to 22.90	10.20
CEC (cmol (p^+) /kg)	10.60 to 26.90	20.15
Sand (%)	69.25 to 22.65	45.35
Silt (%)	62.72 to 3.84	28.78
Clay (%)	46.90 to 7.20	25.83
Active acidity (mol H^+/L)	1.07×10^{-7} to 6.91×10^{-6}	1.80×10^{-6}
Ex. acidity (cmol (p^+) /kg)	0.28 to 5.83	2.53
pH dependent acidity (cmol (p^+) /kg)	9.12 to 46.64	23.54
Potential acidity (cmol (p^+) /kg)	11.8 to 49.6	26.32
Available Ca (cmol (p^+) /kg)	4.30 to 16.00	10.08
Available Mg (cmol (p^+) /kg)	2.00 to 9.80	6.025
Available S (mg /kg)	9.40 to 22.90	16.20



NOTE: **AA**= Active acidity (Mole H^+ /L)
EA= Exchangeable acidity (C mol (p^+) /kg)
PA= Potential acidity (C mol (p^+) /kg)

Fig. 3. Distribution of different form of soil acidity in Kodagu and Chikkamagaluru districts

pool of the soil was very high in those soils. Similar results were reported by Sen et al (2017), Gourav et al (2018).

CONCLUSION

Soils coming under low land paddy cover of hilly zone of Kodagu and Chikkamagaluru districts moderately acidic to neutral in soil reaction with normal electrical conductivity shows that soils were non saline. Organic carbon status was medium to high. Cation exchange capacity was also medium to high in soil. Texture of soil in the study area was sandy clay loam to loam. Among different forms of soil acidity potential acidity was dominant which includes both exchangeable acidity and pH dependent acidity. This suggests that appropriate management practices are very much essential for sustainable crop production.

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Effect of Mustard Based Intercropping Systems on Yield and Profitability under Organic Management in Bundelkhand Region

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***Abstract*:** A field experiment was conducted at the Institute of Agricultural Sciences Bundelkhand University Jhansi to study the effect of mustard-based intercropping systems using skip-row method under organic management during *Rabi* 2021 - 2022. Nine treatments comprising of mustard, *kabuli* chickpea, field pea, fenugreek and desi chickpea as sole crops, mustard + *kabuli* chickpea, mustard + field pea, mustard + fenugreek and mustard + desi chickpea (1:2 ratio) in intercropping system skipping one row of mustard were evaluated. The mustard intercropping with other crops considerably affected the yield parameters compared to their comparable sole crops, but all intercropping methods provided greater equivalent yields and land equivalent ratio. The cost and return analysis showed that the highest net return (Rs. 110552 ha^{-1}) and benefit-cost ratio (3.8) was obtained when mustard intercropped with desi chickpea compared to sole crop of mustard while it was minimum (2.7) in mustard alone. Significantly highest profitability (Rs 888 ha^{-1} day^{-1}) was observed when mustard intercropped with desi chickpea compared to sole crop of mustard but it was statistically at par with rest of the treatments.

***Keywords*:** Biological yield, LER, Intercropping with mustard, Profitability

Successful intercropping systems provide more diversified crops and yield higher monetary returns per unit area than producing a single crop with greater resource use efficiency (Bhuiyan et al 2013). Intercropping is an essential multiple cropping technique that has been employed extensively in underdeveloped and developing countries. Inter-cropping is preferable to monoculture since it enhances productivity by effectively utilizing resources like water, nutrients and solar energy. Out of the seven edible oilseeds grown in India, rapeseed and mustard produce 28.6% of the total amount of oilseeds. The most important pulse crops / legumes grown in India during *Rabi* season are Desi chickpea, Kabuli or White Gram, Field Pea as pulse crop while Fenugreek (Methi) is mostly grown for seeds as spice and condiments, green and dry leaves to enhance the flavour and nutritional content of dishes. In fact, Bundelkhand is considered a bowl of pulses in the U.P. Mustard is also very important crop for improving the farmer's income. The information on intercropping of mustard with pulses in organic management is not available. Therefore, present attempt was made to identify the most suitable mustard-based intercropping system for obtaining higher yield, profitability, and resource-saving in the Bundelkhand region.

MATERIAL AND METHODS

A field experiment was conducted during the *Rabi* season of 2021-22 at the Institute of Agricultural Sciences, Bundelkhand University, Jhansi, Uttar Pradesh involving nine treatments comprising of five crops and four intercropping systems in a Randomised block design with three replications as detailed in Table 2. The experiment was carried out on a silt loam soil having pH of 8.2, low in organic carbon, medium nitrogen, phosphorus and potash availability. Field pea (Prakash), Kabuli chickpea (L-552), Fenugreek (Pusa Early Bold) and Desi chickpea (RVG202) were intercropped according to row proportion with the primary crop mustard variety NRCHB 101. In all intercropping plots, Indian mustard was sown in replacement series skipping one row of mustard. The experiment was planted on October 29, 2021 and harvested on March 24, 2022. Data were analysed using OPSTAT. The intercropping systems were assessed in terms of land equivalent ratio (LER), harvest index, seed yield, biological yield, mustard equivalent yield (MEY),gross return, net return, benefit cost ratio and profitability considering based on prevailing market rates.

Grain yield (q ha^{-1}): After threshing and winnowing the produce of individual plot, the seed yield/ plot was finally converted in to q/ha.

Biological yield (qha^{-1}): Each net plot's crop was harvested, left to dry in the field and then weighed separately. It had both straw and grain. In the end, the biological yield per plot was converted to q/ha.

Harvest index (%): The harvest index was calculated in percentage by the following formula.

$$HI\ (\%) = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Mustard equivalent yield: Based on the prices of mustard and Desi chickpea, Kabuli chickpea, fenugreek and Field pea, the grain yields as obtained under various treatments were converted into mustard yield equivalent as per Katyal and Gangwar (2014).

$$MEY = \frac{\text{Yield of intercrop (q/ha)} \times \text{Price of intercrop (Rs/q)}}{\text{Price of mustard crop (Rs/q)}}$$

Land equivalent ratio (LER): It denotes relative land area under sole crop required to give the same yield as obtained under a mixed or an intercropping system at the same level of management which was calculated (Willey 1979).

$$LER = La + Lb = Ya/Sa + Yb/Sb$$

Where:

La =LER of crop a, Lb = LER of crop b, Ya & Yb =Yield of individual crop a & b, respectively in mixture, Sa & Sb =Yield of individual crop a & b, respectively in pure stand

Economics of treatments: The gross returns were calculated by multiplying quantity of product with market price at the time of harvest. The net returns were computed by subtracting cost of cultivation from gross returns. The benefit-cost ratio was determined by dividing the value of net returns by the value of cost of cultivation. The profitability of various treatment combinations was determined by dividing the net return per hectare by the total number of days the field remained occupied.

RESULTS AND DISCUSSION

Yield and Yield Attributes

Number of siliqua plant^{-1}: The number of siliqua plant^{-1} was highest (184) when mustard was grown alone but decreased in intercropping treatments up to 144, 149,163 and 135 when grown with *kabuli* chickpea, field pea, fenugreek, and desi chickpea respectively (Table 2). It may be due to better use of nutrients and space which results in a greater number of branches and increase in number of siliqua/ plants. Similar findings were also reported by Gokhale et al (2008)and Abraham et al (2010).

Number of seed siliqua^{-1}: The number of seed siliqua^{-1}of mustard was recorded higher when mustard was grown with *desi* chickpea (18),fenugreek (17), *Kabuli* chickpea (15) (Table 2) in intercropping system compared to sole crop of mustard (14). It may be due to better utilization of nutrients and space. Similar findings were also reported by Kumar and Singh et al (2006).

Seed yield (qha^{-1}): The yield of mustard decreased by 19.7, 15.3, 8.7, and 1.4% when intercropped with kabuli chickpea, fenugreek, field pea and *desi* chickpea respectively whereas the highest grain yield of 13.7 q ha^{-1} (Table 2) was obtained when grown alone. The intercropping of mustard with *Kabuli* chickpea and fenugreek demonstrates that there was resource competition. However, when desi chickpea was intercropped with mustard, the yield rose by 8.7%, indicating a favourable interaction between the two crops. The result of this investigation also supported by Kumar et al (2006).

Straw Yield (q ha^{-1}): The mustard intercropped with desi chickpea produced the maximum straw yield of 44.9 q ha^{-1} (Table 2), but the yield decreased up to 47.6, 20.0, and 10.9% when intercropped with fenugreek, field pea, and *Kabuli* chickpea, respectively. It shows that there was competition for resources when mustard was intercropped with fenugreek, field pea, and kabuli chickpea. But, when mustard and desi chickpea were grown together, yield increased by 16.5%. The higher straw yield was mainly due to higher dry matter accumulation and also more translocation of photosynthates towards sink. Similar findings were also reported by Chand et al (2004).

Mustard equivalent yield (q ha^{-1}): In comparison to mustard cultivated as a single crop with field pea and desi chickpea, the intercropped mustard yield (26.7q ha-^{1}) was significantly higher, but statistically comparable to other treatments (Table-2). These results are supported by Islam et al (2011) and Yadav et al (2018).

Biological yield (q ha^{-1}): The biological yield of mustard crop was

Table 1. Meteorological data during cropping period 2021-22

Month	SW	Temperature (^{o}C)		Humidity (%)		Wind velocity (km/hr)	Rainfall (mm)	Rainy days	Evaporation (mm)
		Maximum	Minimum	Morning	Evening				
October	43	31.6	16.7	80	53	3.2	0	0	4.8
	44	30.5	12.6	82	52	3.4	0	0	4.8
November	45	30.8	9.9	81	46	3.1	0	0	4.6
	46	27.9	10.6	84	50	3.1	0	0	4.0
	47	28.1	12.0	85	49	3.2	0	0	3.6
	48	27.5	9.3	85	57	2.8	0	0	3.3
December	49	24.7	11.2	88	56	3.2	0	0	2.8
	50	23.4	7.8	89	60	3.0	0	0	2.5
	51	22.9	4.4	88	61	2.8	0	0	2.4
	52	22.3	8.4	90	65	3.2	12	1	2.3
January	1	20.9	7.7	91	71	3.1	18.0	2	2.0
	2	19.2	10.4	91	71	2.9	23.8	1	1.7
	3	18.3	5.8	91	72	2.8	0.0	0	1.6
	4	19.9	7.6	91	71	2.6	3.6	1	1.6
February	5	26.4	7.3	89	59	2.9	0.0	0	3.0
	6	24.0	7.5	88	47	3.6	0.0	0	3.2
	7	25.8	8.0	87	46	4.4	0.0	0	3.7
	8	28.0	11.3	84	46	3.7	0.0	0	4.1
March	9	28.5	11.3	84	45	4.8	0.0	0	4.6
	10	30.0	12.6	81	44	5.1	0.4	0	4.7

highest (57.4q ha^{-1}) when mustard was grown with desi chickpea in inter-cropping system while reduced when mustard was grown with *kabuli* chickpea, field pea and fenugreek in inter-cropping system compared to sole crop of mustard (Table 2). Similar findings were reported by Abraham and Lal (2002).

Harvest index (%): The harvest index of mustard crop was higher when mustard was grown with fenugreek (36.5%), field pea (28.8%) while reduced with *kabuli* chickpea (24.3%) and desi chickpea (21.9%) in intercropping system compared to sole crop of mustard (26.2) (Fig 1). There was the beneficial relationship of desi chickpea with mustard in intercropping system while all other associated crops showed reduced harvest index in intercropping treatments compared to their respective sole crops.

Land equivalent ratio (LER): Highest land equivalent ratio of 1.7 (Fig. 1) was obtained when mustard was intercropped with desi chickpea compared to sole crop of mustard. It shows that Mustard + Desi chickpea intercropping system is beneficial.

Economics

Cost of cultivation: Significantly highest cost of cultivation (46300Rs ha^{-1}) (Table 3) was incurred when mustard was intercropped with fenugreek due to high cost of seed compared to sole crop of mustard and other treatments. Statistically, similar findings were also reported by Prasad et al (2006).

Gross returns: Significantly highest gross return of Rs.151,772 ha^{-1} (Table 3) was recorded when mustard was intercropped with fenugreek compared to sole crop of mustard, field pea, desi chickpea, fenugreek and *kabuli* chickpea. But it was statistically at par with intercropping treatments. The gross revenue has been universally reported markedly higher under intercropping systems under good management conditions as compared to sole cropping and chick pea + mustard oilseeds have proved to generate high revenues by Tichy et al (2001).

Table 2. Effect of mustard-based intercropping systems on yield and yield contributing parameters

Treatments	No. of siliqua or pod $plant^{-1}$		No. of seed $siliqua^{-1}$		Seed yield (q ha^{-1})		Straw yield (q ha^{-1})		Biological yield (q ha^{-1})	Mustard equivalent yield (q ha^{-1})
	Main crops	Associate crops	Main crops	Associate crops	Main crops	Associate crops	Main crops	Associate crops		
T_0 Mustard	184	-	14	-	13.7	-	38.5	-	52.2	13.7
T_1 Kabuli Chickpea alone	29	-	1	-	14.6	-	18.1	-	32.7	18.2
T_2 Pea alone	10	-	5	-	14.5	-	4.5	-	19.5	13.5
T_3 Fenugreek alone	44	-	14	-	10.6	-	13.6	-	24.2	15.6
T_4 Desi chickpea alone	52	-	2	-	12.6	-	21.3	-	33.9	13.5
T_5 Mustard + Kabuli chickpea	144	23	15	1	11.0 (-19.7)	12.6 (-13.7)	34.3 (-10.9)	8.0 (+3.8)	45.3	25.9
T_6 Mustard + Pea	149	4	13	3	12.5 (-8.7)	11.1 (-23.4)	30.8 (-20.0)	8.1 (+80.0)	43.3	22.3
T_7 Mustard + Fenugreek	163	27	17	10	11.6 (-15.3)	8.3 (+43.0)	-21.7 (-47.6)	19.5 (+43.0)	31.7	24.5
T_8 Mustard + Desi chickpea	135	37	18	1	12.6 (-1.4)	13.7 (+8.7)	44.9 (+16.5)	15.6 (-26.7)	57.4	26.7
CD (p=0.05)	-	-	-	-	-	-	-	-	-	8.7

Figures in parenthesis shows percentage of increase or decrease in yield of mustard and associated crops

Table 3. Cost of cultivation, gross return, net income, B:C ratio and profitability of mustard-based intercropping systems

Treatments	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net return (Rs/ha)	B:C ratio	Profitability (Rs/ ha /day)
T_0	34,4267	92,556	58,129	2.7	447.
T_1	32,934	96,944	64,011	2.9	492.
T_2	32,434	81,929	49,496	2.5	381
T_3	33,320	103,337	70,017	3.1	538
T_4	33,200	84,331	51,131	2.5	393.
T_5	38,400	145,038	106638	3.7	820.
T_6	37,134	126,599	89,465	3.4	688.
T_7	46,300	151,772	105472	3.5	850.
T_8	39,200	149,752	110552	3.8	888.
CD (p=0.05)	3265	44462	45,626	NS	351

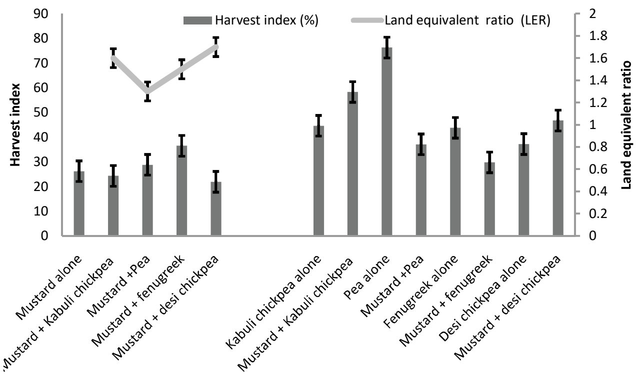

Fig. 1. Effect of associated crops on harvest index, and LER of mustard and associate crops

Net return: Significantly maximum net return of Rs. 110552 ha^{-1} (Table 3) was obtained when mustard was intercropped with desi chickpea compared to sole crop of mustard, field pea and kabuli chickpea, but it was statistically at par with rest of the treatments. Similar findings were also reported byTichy et al (2001).

Benefit: cost ratio (B: C Ratio): The benefit-cost ratio was maximum (3.8) (Table 3) when mustard was intercropped with desi chickpea compared to sole crop of mustard while it was minimum (2.7) in treatment mustard alone. The findings are in conformity with Singh et al (2000) and Abraham et al (2010).

Profitability (Rs ha^{-1} day^{-1}) : Significantly highest profitability (888 Rs ha^{-1} day^{-1}) (Table 3) was obtained when mustard was intercropped with desi chickpea compared to sole crop of mustard, field pea, fenugreek and kabuli chickpea but it was statistically at par with rest of the treatments as also reported by Mandal et al (1996).

CONCLUSION

It may be concluded that the component crop had an adversely effect on mustard's growth and yield compared to grown alone but intercropping treatments had greater comparable yields. Desi-chickpea was identified to be most suitable companion crop of mustard and Mustard + Desi chick pea intercropping system using skip-row system was found to be most suitable. Therefore, it is advisable to the farmer of Bundelkhand to practice intercropping of mustard with desi chickpea in skip row to sustained production and productivity of both mustard and desi-chickpea and also to ensure higher productivity and profitability in organic farming system.

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Growth Dynamics and Yield of Cotton-Wheat in Relation to Nutrient Use and Irrigation Regimes under Sub-Surface Drip Irrigation System

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Abstract: The present study was conducted to evaluate growth dynamics and yield of cotton-wheat cropping system under sub-surface drip irrigation at Punjab Agricultural University, Ludhiana during 2019-2020 and 2020-2021. The experiment was conducted with the combination of 3 irrigation regimes (60 80,100% ET_c), 2 fertility levels (80% recommended dose of nitrogen (RDN),100 % RDN) and 3 methods of application of nutrients (M_{foliar} i.e. foliar application of nutrients, M_{soil} i.e. soil application of nutrients). These 12 combinations were compared with further three controls; control1: surface drip + 100% RDN + M_{foliar}; control 2: surface drip + 100% RDN+ M_{soil}; control 3: Flood irrigation + soil RDN + M_{foliar}. The highest growth, seed cotton, grain yieldwere recorded at 100% ET_c which was at par with 80% ET_c but significantly higher than 60% ET_c. Among N levels, 100% RDN remained at par with 80% RDN in both the crops. Further, M_{foliar} resulted in higher growthand yield in cotton over M_{soil}, however, residual effect of M_{soil} was more in wheat. Both The control 1 and 2 were better over control 3, in terms of growthand yield. Therefore, foreseeing the impeding water resources, sub-surface drip at 80% ET_c, 80% RDN and M_{foliar}seems to be a better preposition in terms of water and fertilizer saving than conventional practice of cultivation.

Keywords: ET_c, Foliar feeding, Nutrients, Residual, Water productivity

Irrigation has been a key factor behind intensifying agricultural production to fulfill the world's growing demand for food, fiber and fuel. Under the pressure of increasing population and economic development, the available resources of water are being exploited at a faster rate. Cotton-wheat cropping system is the major cash and grain cropping system occupies an area of about 4.5 M ha in South-Asia and 2.6 M ha in India (Rajpoot et al 2021). Cotton is sown April-May under north Indian conditions when evaporative demand of atmosphere from April to June remains very high due to high temperature & low relative humidity (Rajpoot et al 2021). Early phase of the cotton and later phases of wheat both coincides with high evaporative demand atmosphere. The maintenance of sufficient moisture in soil through irrigation is an essential requirement to ensure rich harvest of any crop. Hence, it becomes important to investigate the different methods of irrigation to emphasize the efficient water resources utilization to attain higher water productivity.

Adoption of micro-irrigation systems like surface and sub-surface drip irrigation over wasteful method i.e. flood irrigation, embark a promising proposition as we look to the future, where water availability would become more scarcer (Singh et al 2021 and Rao et al 2016). These modern strategies, contributes immensely by site-specific water and nutrients utilization through the root zone of the crop plant (Hanson and May 2004). However, in surface drip, removal of laterals during harvesting and sowing of crop, make it labor intensive (Enciso-Medina et al 2011). Therefore, a more efficient form of precision irrigation would be sub-surface drip irrigation (SSDI), which supplies water through buried plastic tubes with embedded emitters spaced at regular intervals in the soil at some depth. In sub-surface drip, soil surface remains dry which minimizes evaporation (Valentin et al 2020), infiltration, weed problem and also it creates no hinderance in sowing and harvesting of crop. Therefore, this system improves labour intensity and increases lifespan of system. Fertigation is necessary for utilizing micro-irrigation to its greatest capacity. In addition to lowering the amount of fertilizer applied, fertigation may prove beneficial for Indian agriculture (Sivanappan and Ranghaswami 2005) and may open the door to the effective use of expensive fertilizers. Therefore, foreseeing the impeding water constraints, cropping systems in water-scarce regions must be redesigned to increase water productivity and growers' profitability.

MATERIAL AND METHODS

The present study was conducted at Punjab Agricultural University, Ludhiana for two consecutive years 2019-2020 and 2020-2021. The experiment was conducted in factorial randomized complete block design with combination of 2 nitrogen fertigation levels (F_{80}: 80% and F_{100}: 100% of recommended dose of nitrogen (RDN), 3 sub-surface drip irrigation levels based on crop evapo-transpiration (ET_c) (I_{60}: 60%; I_{80}: 80% & I_{100}: 100% ET_c) and two methods of nutrient application i.e. M_{foliar} (foliar spray of 2% KNO_3 & 1% $MgSO_4$) and M_{soil} (soil application of KNO_3@ 20 kg ha^{-1}& $MgSO_4$@ 5 kg ha^{-1}. These 12 combinations further compared with three controls i.e. control 1 (surface drip irrigation with 100% RDN and M_{foliar}), control 2 (surface drip with 100% RDN and M_{soil}) and control 3 (flood irrigation with 100% RDN and M_{foliar}). Application of KNO_3 & $MgSO_4$, was done to cotton crop at flower initiation and boll opening stages and its residual effect was observed on succeeding wheat crop. Cotton crop was sown on well-prepared seed bed by keeping row to row spacing of 67.5 cm and plant to plant spacing 75 cm whereas wheat was sown keeping row to row distance of 22.5 cm. Fertilizer and irrigation was applied to both the crops according to treatment. Thinning of the cotton was done on 30 days after sowing to obtain the optimum plant population.

Irrigations on the basis of crop evapo-transpiration were applied through polyethylene drip pipes placed at depth of 20 cm with 30 cm emitter spacing and 67.5 cm between the laterals such that one row of cotton and three rows of wheat at 22.5 cm spacing could be irrigated. Daily reference evapotranspiration (ET_o) was calculated from weather data using ET_ocalculator available on the website of the Food and Agriculture Organization. This ET_o, further multiplied with crop coefficient to calculate crop evapotranspiration (ET_c). Fertigation of N in cotton was done @ 112 kg ha^{-1} in 10 splits from 35 days after sowing onwards. Whereas, in wheat, 1/5th RDN i.e. 125 kg ha^{-1} was applied at sowing whereas remaining was fertigated in 8 splits starting from crown root initiation. In flood control 3, 50% RDN was applied at sowing, whereas remaining was applied at flower initiation. In wheat, RDN was applied in three splits, first at time of sowing and second & third with first and second irrigation. Data on growth attributes like leaf area index, dry matter accumulation, crop growth rate & relative growth rate and yield were recorded at different stages in both cotton and wheat. Crop growth rate was calculated using formula: $CGR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{P}$; Where, W_1 = Dry weight (g) at time T_1 (days), W_2 = Dry weights (g) at time T_2 (days), P= Ground area (m^2). Relative growth rate was calculated by formula: $RGR = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$; W_1 = dry weight at time T_1 (days); W_2 = dry weight at time T_2 (days); ln = Natural log

Statistical analysis: Data recorded were subjected to analysis of variance using Proc GLM procedure of SAS version 9.4.

RESULTS AND DISCUSSION

Periodic leaf area index: Interception of solar radiation, photosynthesis and finally the yield is directly related to leaf area index. Rate of increase in leaf area index was slow up to 45 DAS in both cotton and wheat. Thereafter, a rapid increase was observed and later on, it decreased towards maturity (Tables 1 to 4). Leaf area index (LAI) decreased with increase in moisture stress from I_{100} to I_{60}, at all stages of growth of cotton, except at 45 DAS. The effect of irrigation and fertilization remained non significant at 45 DAS, as the treatments were imposed at 35 DAS in cotton. However, at 90, 135 DAS and maturity, significantly higher LAI (5.62, 7.55 and 3.99) was observed under I_{100} over I_{60}, while I_{80} remained at par with both the levels, during 2019. During 2020, difference due to I_{100} and I_{80} was not significant, but it was significantly lowest at I_{60}, at all stages of growth. In wheat, LAI was not significantly influenced by irrigation regimes as well as fertilization levels (Tables 3 and 4) at 45 and 90 DAS due to sufficient rainfall, leading to non application of irrigation at these stages, during 2019-2020. During 2020-2021, LAI was significantly affected by irrigation regimes at all stages. Higher LAI of 1.26, 4.84 and 3.92 were observed under I_{100}, which was statistically at par with 1.22, 4.79 and 3.82 under I_{80} and both these levels were significantly better than 1.10, 4.57 and 3.68 under I_{60} at 45, 90 and 135 DAS, respectively. The higher LAI might be due to due to better availability of water for longer period (Ihsan et al 2016 and Asif et al 2010).

Graded doses of fertilizer didn't show any pronounced variation in LAI at all stages in both cotton and wheat. However, higher dose of N resulted in more growth components and yield which is in agreement with the findings of Wassie et al (2022). Further, significant difference due to method of application of nutrients at all stages except at 45 DAS in cotton. From 90 DAS upto maturity, significantly more leaf area index was recorded with M_{foliar} over M_{soil}. Increase in LAI due to readily availability of nutrients through foliar application resulted in increase in LAI (Channakeshava et al 2013). Among various controls, control 1 and 2 being at par with each other were significantly superior than control 3 at all stages except at 45 DAS during both the years in cotton and at all stages in wheat, during 2020-2021. Singh et al (2018) also found better crop growth under surface drip over flood irrigation in cotton.

Interaction among different irrigation, fertigation levels and KNO_3 & $MgSO_4$ application methods was non-significant in both cotton and wheat. Comparison of different irrigation with fertigation regimes and controls were also non significant at 45 DAS, however, it became significant afterwards in cotton. However, in wheat, comparison of controls with various combinations of irrigation regimes and fertilization levels were significant at135 DAS, during 2019-2020 and at all stages during 2020-2021.

Table 1. Leaf area index of cotton as affected under irrigation regimes, varied N levels and method of application of KNO_3 & $MgSO_4$ (2019)

	Leaf area index DAS**									
	45**					90**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	2.67	2.66	2.67	2.57	2.64	5.03	4.63	5.12	4.90	4.92
I_{80}=80% ET_c	2.90	2.78	2.63	2.75	2.76	5.60	5.15	5.78	5.22	5.43
I_{100}=100% ET_c	2.62	2.87	2.94	2.80	2.80	5.92	5.27	5.97	5.33	5.62
Mean	2.72		2.74		2.73	5.26		5.38		5.32
	M_{foliar}=2.73; M_{soil}=2.75					M_{foliar}=5.58; M_{soil}=5.07				
	Control 1=2.74; Control 2=2.78; Control 3=2.72			Mean of all controls=2.74		Control 1= 5.56; Control 2=5.42; Control 3=4.67			Mean of all controls=5.21	
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =0.54; F = NS ; M =0.45; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.67; Among control = 0.72				
	135**					Maturity**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	6.93	6.50	6.99	6.77	6.79	3.33	2.93	3.49	3.20	3.23
I_{80}=80% ET_c	7.55	7.04	7.71	7.09	7.34	3.97	3.57	4.18	3.50	3.79
I_{100}=100% ET_c	7.85	7.16	7.93	7.21	7.55	4.34	3.54	4.42	3.66	3.99
Mean	7.17		7.28		7.22	3.61		3.74		3.67
	M_{foliar}=7.50; M_{soil}=6.94					M_{foliar}=3.96; M_{soil}=3.40				
	Control 1=7.51; Control 2=7.33; Control 3=6.57			Mean of all controls=7.13		Control 1=3.92; Control 2=3.75; Control 3=2.97			Mean of all controls=3.54	
LSD (p=0.05)	I =0.56; F = NS ; M =0.48; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control =0.61; Among control = 0.65					I =0.58 ; F = NS ; M =0.45; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.69; Among control = 0.71				

Table 2. Leaf area index of cotton as affected under irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ during 2020

	Leaf area index DAS**									
	45**					90**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	2.23	2.24	2.28	2.22	2.24	4.17	3.70	4.25	4.10	4.05
I_{80}=80% ET_c	2.50	2.38	2.23	2.36	2.36	4.93	4.42	5.04	4.54	4.76
I_{100}=100% ET_c	2.22	2.46	2.53	2.43	2.40	5.25	4.64	5.32	4.79	5.01
Mean	2.33		2.35		2.33	4.52		4.69		4.60
	M_{foliar}=2.33; M_{soil}=2.32					M_{foliar}=4.85; M_{soil}=4.36				
	Control 1=2.33; Control 2=2.38; Control 3=2.32			Mean of all controls=2.34		Control 1= 4.63; Control 2=4.49; Control 3=3.73			Mean of all controls=4.28	
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =0.51; F = NS ; M =0.40; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.55; Among control = 0.61				
	135**					Maturity**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	6.03	5.37	6.12	5.77	5.82	3.23	2.57	3.29	2.67	2.94
I_{80}=80% ET_c	6.80	6.12	6.94	6.25	6.53	3.97	3.39	4.03	3.40	3.67
I_{100}=100% ET_c	7.05	6.39	7.13	6.61	6.79	4.10	3.72	4.23	3.82	3.96
Mean	6.29		6.48		6.38	3.47		3.59		3.52
	M_{foliar}=6.69; M_{soil}=6.07					M_{foliar}=3.84; M_{soil}=3.23				
	Control 1=6.49; Control 2=6.37; Control 3=5.40			Mean of all controls =6.08		Control 1=3.67; Control 2=3.52; Control 3=2.73			Mean of all controls =3.30	
LSD (p=0.05)	I =0.61; F = NS ; M =0.49; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control =0.57; Among control = 0.63					I =0.52; F = NS ; M =0.42; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.54; Among control = 0.58				

Table 3. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on periodic leaf area index of wheat (2019-2020)

Leaf area index (DAS**)										
	45**					90*				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	1.27	1.29	1.32	1.36	1.31	4.80	4.82	4.89	5.07	4.89
I_{80}=80% ET_c	1.30	1.33	1.33	1.43	1.34	4.83	4.93	4.97	5.18	4.97
I_{100}=100% ET_c	1.31	1.35	1.40	1.42	1.37	4.87	5.04	5.06	5.09	5.01
Mean	1.30		1.37		1.34	4.89		5.03		4.95
	M_{foliar}=1.32; M_{soil}=1.36					M_{foliar}=4.90; M_{soil}=5.02				
	Control 1=1.35; Control 2=1.37; Control 3=1.31			Mean of all controls=1.34		Control 1= 4.92; Control 2=4.97; Control 3=4.87			Mean of all controls=4.92	
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =NS ; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS;I*F*M = NS; Treatment v/s control = NS; Among control = NS				

135**					
Irrigation regimes (I)	Fertilization regimes				Mean
	F_{80}		F_{100}		
	Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	3.53	3.56	3.57	3.68	3.58
I_{80}=80% ET_c	3.77	3.80	3.83	3.87	3.81
I_{100}=100% ET_c	3.82	3.83	3.91	3.97	3.88
Mean	3.72		3.80		3.76
	M_{foliar}=3.73; M_{soil}=3.78				
	Control 1= 3.77; Control 2= 3.83; Control 3= 3.54			Mean of all controls=3.71	
LSD (p=0.05)	I =0.14 ; F = NS ; M =; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.07; Among control = 0.08				

Table 4. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on periodic leaf area index of wheat (2020-2021)

Leaf area index (DAS**)										
	45**					90**				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	1.05	1.12	1.08	1.15	1.10	4.53	4.57	4.58	4.62	4.57
I_{80}=80% ET_c	1.18	1.22	1.23	1.26	1.22	4.74	4.76	4.81	4.85	4.79
I_{100}=100% ET_c	1.23	1.25	1.27	1.29	1.26	4.79	4.83	4.87	4.89	4.84
Mean	1.17		1.21		1.19	4.70		4.76		4.73
	M_{foliar}=1.17; M_{soil}=1.22					M_{foliar}=4.72 M_{soil}=4.75				
	Control 1=1.21; Control 2=1.26; Control 3=1.11			Mean of all controls=1.19		Control 1= 4.77; Control 2=4.82; Control 3=4.56			Mean of all controls=4.71	
LSD (p=0.05)	I =0.07; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.04; Among control = 0.07					I =0.08; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.13; Among control = 0.18				

135**					
Irrigation regimes (I)	Fertilization regimes				Mean
	F_{80}		F_{100}		
	Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	3.60	3.71	3.64	3.74	3.68
I_{80}=80% ET_c	3.76	3.86	3.79	3.88	3.82
I_{100}=100% ET_c	3.89	3.91	3.93	3.95	3.92
Mean	3.78		3.85		3.80
	M_{foliar}=3.75; M_{soil}=3.84				
	Control 1= 3.84; Control 2= 3.88; Control 3= 3.70			Mean of all controls=3.80	
LSD (p=0.05)	I =0.12 ; F = NS ; M =; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 0.08; Among control = 0.10				

Table 5. Periodic dry matter of cotton as influenced by irrigation regimes, N levels and method of application of KNO_3& $MgSO_4$ during 2019

Irrigation regimes (I)	Dry matter (g plant^{-1}) DAS**									
	45**					90**				
	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	85.28	83.14	86.07	83.50	84.49	297.0	290.0	302.0	295.3	296.1
I_{80}=80% ET_c	83.26	85.10	84.79	85.47	84.65	319.0	299.0	323.3	303.3	311.1
I_{100}=100% ET_c	84.19	85.19	86.47	86.27	85.53	329.3	309.3	335.6	315.6	322.5
Mean	84.35		85.43		84.89	307.2		312.5		309.9
	M_{foliar} =85.00; M_{soil} =84.77					M_{foliar} =317.7; M_{soil} =302.1				
	Control 1=84.90; Control 2=83.63; Control 3=83.50			Mean of all controls=84.01		Control 1= 317.6; Control 2=311.0; Control 3=292.0			Mean of all controls=306.8	
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =15.5; F = NS ; M =11.1; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 16.75; Among control = 18.2				
	135**					Maturity**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	844.3	818.3	850.3	823.3	834.0	1029	1021	1032	1026	1027
I_{80}=80% ET_c	862.3	833.3	865.0	838.3	850.2	1051	1034	1060	1038	1046
I_{100}=100% ET_c	873.6	846.0	879.0	852.3	862.7	1067	1044	1072	1047	1057
Mean	846.3		851.7		848.9	1041		1046		1043
	M_{foliar} =862.7; M_{soil} =835.2					M_{foliar} =1052; M_{soil} =1035				
	Control 1=853.3; Control 2=844.3; Control 3=820.0			Mean of all controls=839.2		Control 1=1050; Control 2=1044; Control 3=1023			Mean of all controls=1039	
LSD (p=0.05)	I =15.66; F = NS ; M =12.76; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 21.90; Among control = 23.52					I =17.35 ; F = NS ; M =14.16; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 19.31; Among control = 20.98				

Table 6. Periodic dry matter of cotton as influenced by irrigation regimes, N levels and method of application of KNO_3& $MgSO_4$ during 2020

Irrigation regimes (I)	Dry matter (g plant^{-1}) DAS**									
	45**					90**				
	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	77.62	75.16	78.40	75.83	76.75	235.0	218.3	242.0	227.0	230.5
I_{80}=80% ET_c	75.27	77.10	77.12	77.47	76.73	269.0	246.6	276.0	251.6	260.3
I_{100}=100% ET_c	76.53	77.54	77.82	78.27	77.53	279.3	257.6	285.6	264.6	271.8
Mean	76.54		77.47		77.00	251.0		257.5		254.2
	M_{foliar} =77.12; M_{soil} =76.89					M_{foliar} =264.1; M_{soil} =244.3				
	Control 1=76.90; Control 2=75.96; Control 3=75.49			Mean of all controls =76.11		Control 1= 257.6; Control 2=249.8; Control 3=228.6			Mean of all controls =245.3	
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =13.16; F = NS ; M =10.75; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 17.65; Among control = 19.50				
	135**					Maturity**				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	715.0	695.0	721.6	708.3	710.0	910.6	898.3	916.6	903.6	907.3
I_{80}=80% ET_c	762.6	736.6	766.0	742.3	752.1	958.6	931.6	969.0	937.6	949.2
I_{100}=100% ET_c	770.3	748.6	776.6	755.6	763.0	975.3	944.3	982.3	949.0	962.7
Mean	738.0		745.1		741.7	936.5		943.1		939.7
	M_{foliar} =752.0; M_{soil} =731.1					M_{foliar} =952.1; M_{soil} =927.4				
	Control 1=731.0; Control 2=724.3; Control 3=703.3			Mean of all controls =719.5		Control 1=929.0; Control 2=922.6; Control 3=900.0			Mean of all controls =917.2	
LSD (p=0.05)	I =15.72; F = NS ; M =12.83; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control =14.72; Among control = 15.78					I =16.79 ; F = NS ; M =13.71; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 16.04; Among control = 17.58				

Table 7. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on periodic dry matter of wheat (2019-2020)

Dry matter (g m^{-2}) DAS**										
	45**					90**				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	167.3	168.3	169.3	172.0	169.2	465.0	466.3	475.0	488.3	473.6
I_{60}=80% ET_c	169.3	171.6	172.0	173.67	171.6	468.3	478.3	479.6	495.6	480.5
I_{60}=100% ET_c	168.6	173.3	173.6	173.0	172.1	472.3	483.3	491.0	493.3	485.0
Mean	172.2		170.7		170.9	472.2		487.1		479.1
	M_{foliar}=170.1; M_{soil} =172.0					M_{foliar} =475.2; M_{soil} =484.2				
	Control 1=168.6; Control 2=170.3; Control 3=168.3			Mean of all controls=169.0		Control 1= 478.3; Control 2=481.6; Control 3=465.6			Mean of all controls=475.2	
LSD (p=0.05)	I =NS; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS					I =NS ; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = NS; Among control = NS				

135**					
Irrigation regimes (I)	Fertilization regimes				Mean
	F_{80}		F_{100}		
	Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	745.0	758.3	763.3	768.3	758.7
I_{60}=80% ET_c	753.3	783.3	775.0	798.3	777.5
I_{60}=100% ET_c	786.6	795.0	802.6	808.3	798.2
Mean	770.2		786.0		778.1
	M_{foliar}=771.0; M_{soil} =785.2				
	Control 1= 780.0; Control 2= 791.6; Control 3= 693.3			Mean of all controls=754.9	
LSD (p=0.05)	I =23.93 ; F = NS ; M =; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 25.0; Among control = 54.61				

Table 8. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on periodic dry matter of wheat (2020-2021)

Dry matter (g m^{-2}) DAS**										
	45**					90**				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	115.0	117.0	118.3	121.3	117.9	420.0	423.3	425.0	434.0	425.5
I_{80}=80% ET_c	135.3	136.0	136.6	138.6	136.4	440.3	443.6	450.0	454.6	447.1
I_{100}=100% ET_c	138.0	139.6	141.6	143.3	140.6	446.0	448.3	458.0	461.3	453.4
Mean	130.0		133.3		131.6	436.9		447.1		442.0
	M_{foliar}=130.6; M_{soil}=132.6					M_{foliar}=439.8; M_{soil}=444.2				
	Control 1=130.6; Control 2=134.6; Control 3=120.0			Mean of all controls=128.4		Control 1= 442.6; Control 2=449.0; Control 3=430.3			Mean of all controls=440.6	
LSD (p=0.05)	I =4.33; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 4.11; Among control = 5.44					I =16.41 ; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 14.3; Among control = 12.2				

135**					
Irrigation regimes (I)	Fertilization regimes				Mean
	F_{80}		F_{100}		
	Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	707.0	710.0	712.3	714.6	711.0
I_{80}=80% ET_c	723.0	727.0	738.0	740.6	732.1
I_{100}=100% ET_c	738.0	740.3	742.3	745.3	741.5
Mean	724.2		732.2		728.2
	M_{foliar}=726.7; M_{soil}=729.6				
	Control 1= 728.0; Control 2= 734.0; Control 3= 709.0			Mean of all controls=723.6	
LSD (p=0.05)	I =11.02 ; F = NS ; M =; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 15.80; Among control = 18.60				

Periodic dry matter accumulation: Dry matter accumulation (DMA) is directly associated with crop yield. DMA rapidly and progressively increased from 45 DAS up to maturity and was significantly affected by different treatments in both the crops. DMA at 45 DAS did not differ significantly due to irrigation regimes as well as fertilization levels during both the years in cotton, as the treatments were imposed at 35 DAS (Table 5 & 6). However, it increased with increase in water regime from I_{60} to I_{100} at 90, 135 DAS and at maturity during both the years. I_{100} combinations exhibited significant increase over I_{60}in cotton. Fertilizer levels didn't cause variation in DMA at all stages during both the years. Among controls, control 1 & 2, produced significantly higher DMA at all stages except 45 DAS, during both the years, over control 3. Further in wheat, effect of various treatments was not significant at 45 and 90 DAS during 2019-2020 (Table 7 & 8). However, DMA significantly increased with increase in irrigation regimes at all the stages during 2020-2021. Reduced water availability, limits the cellular expansion and elongation, causes stomatal closure, raises the leaf temperature and reduces the net assimilation rate of photosynthates which decreased DMA (Ihsan et al 2016).Fertilization levels and method of application of nutrients didn't cause variation in DMA during both the years. Among controls, higher dry matter (accumulated under control 2, was at par with control 1 and significantly better than control 3 at 45, 90 and 135 DAS, during 2020-2021. Higher dry matter accumulation under surface drip irrigated crop might be due to favorable moisture conditions because of light and frequent irrigation applied to the root zone of crop.

Crop growth rate: The higher CGR of cotton between 90-135 DAS and wheat during 45-90 DAS was due to more expansion of the plant at this stage during both the years (Fig. 1 & 2). Well irrigated and fertilizer regimes coupled with congenial environment resulted in higher crop growth rate during both the years. Maximum CGR in cotton was observed under $I_{100}F_{100}M_{foliar}$ during 2019 and 2020 between 45 and 90 as well as 90 and 135 DAS, respectively over other treatments. However in wheat, maximum CGR was observed under $I_{100}F_{100}M_{soil}$ between 45-90 and 90-135 DAS, respectively over other treatments. Water deficit during early growth (45 to 90 DAS) stage causes more reduction in CGR

Table 9. Effect of irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ on seed cotton yield during 2019 and 2020

Seed cotton yield (q ha^{-1})										
	2019					2020				
Irrigation regimes (I)	Fertilization levels				Mean	Fertilization levels				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	29.18	28.84	29.46	28.89	29.10	29.57	28.00	30.38	28.76	29.17
I_{80}=80% ET_c	30.90	29.53	31.29	30.18	30.46	33.21	31.07	33.71	31.67	32.41
I_{100}=100% ET_c	32.74	30.25	33.02	30.72	31.68	34.14	32.15	34.62	32.76	33.41
Mean	30.23		30.59			31.35		31.98		
	M_{foliar}=31.09; M_{soil}=29.73					M_{foliar}=32.60; M_{soil}=30.73				
LSD (p=0.05)	Control 1=30.86; Control 2=30.15; Control 3=28.91 I =1.38; F = NS ; M =0.97; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control =0.93; Among control = 1.12					Control 1= 32.76; Control 2=31.84; Control 3=28.23 I =1.21; F = NS ; M =0.99; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 1.50; Among control = 2.33				

Table 10. Grain yield of wheat as influenced by irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton during 2019-2020 and 2020-2021

	2019-2020					2020-2021				
Irrigation regimes (I)	Fertilization regimes				Mean	Fertilization regimes				Mean
	F_{80}		F_{100}			F_{80}		F_{100}		
	Applied to cotton					Applied to cotton				
	M_{foliar}	M_{soil}	M_{foliar}	M_{soil}		M_{foliar}	M_{soil}	M_{foliar}	M_{soil}	
I_{60}=60% ET_c	48.93	49.85	49.89	50.03	49.67	45.54	45.85	45.95	46.27	45.90
I_{80}=80% ET_c	50.66	51.43	51.12	51.84	51.26	48.22	48.51	49.28	49.42	48.85
I_{100}=100% ET_c	51.61	51.79	52.20	52.78	52.09	48.96	49.18	50.08	50.31	49.63
Mean	50.71		51.31			47.70		48.55		
	M_{foliar}=50.73; M_{soil}=51.28					M_{foliar} =48.00; M_{soil} =48.28				
LSD (p=0.05)	Control 1=51.31; Control 2=51.72; Control 3=49.12 I =1.57; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 1.65; Among control = 1.94					Control 1= 47.94; Control 2=48.60; Control 3=46.72 I =1.36; F = NS ; M =NS; I*F = NS; F*M = NS; I*M = NS; I*F*M = NS; Treatment v/s control = 1.21; Among control = 1.23				

in both the crops during both the years. The, control 3, resulted in lower crop growth rate over all other treatments, between 45-90 and 90-135 DAS, during both the years in both the crops. Increase in crop growth rate with irrigation levels were also observed by Saleem et al (2010).

Relative growth rate: RGR is expressed as gram of dry matter produced by a gram of existing dry matter in a day. Relative growth rate from 45 to 90 DAS was higher than that between 90 and 135 DAS, during both the yearsin both the crops (Fig. 3 and 4). Between 45 and 90 DAS, maximum RGR was observed under I_{100} combinations with fertilization followed by I_{80} and I_{60} during both the years in cotton and 2019-2020 in wheat. Whereas, from 90 to 135 DAS in cotton, trend of RGR reversed in favor of I_{60} with its higher value compared to well watered and fertilized conditions. This was because of slower growth of crop under treatment I_{60} combination with fertilization, due to water stress up to 80-90 DAS and growth was accelerated with start of rains at the end of July and resulted in higher RGR, during both the years in cotton.

Seed cotton and grain yield: Seed cotton and grain yield increased with increasing level of irrigation from 60% to 100% ET_c during both the years (Tables 9, 10). Effect of consecutive levels of irrigation was not statistically different, during 2019-2020. However, during 2020-2021, highest seed cotton and grain yield of 33.41 q ha^{-1} & 49.63 q ha^{-1} was under I_{100} which was statistically at par with I_{80} and significantly better than I_{60}. This might have resulted from the difference in

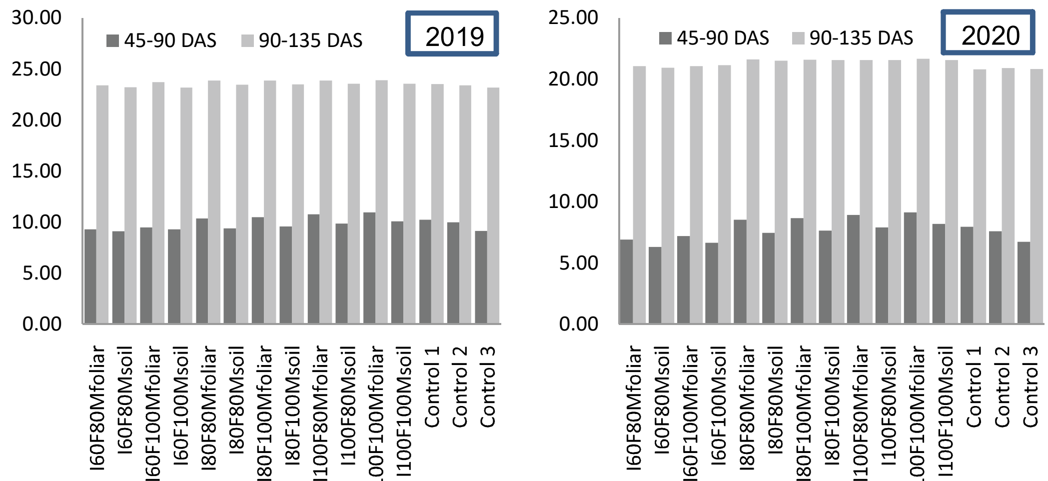

Fig 1. Effect of irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ on crop growth rate (g m^{-2}day^{-1}) of cotton during 2019 and 2020

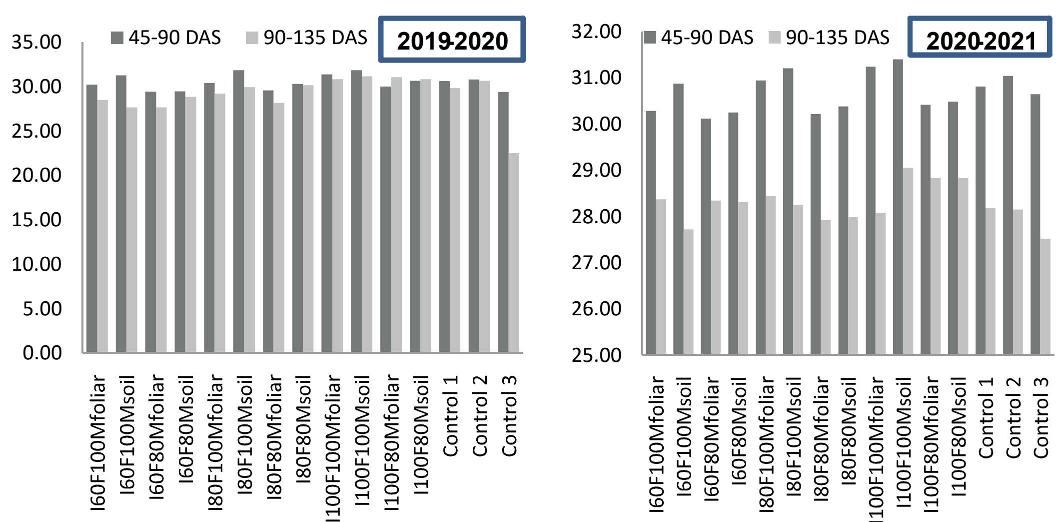

Fig. 2. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on crop growth rate (g m^{-2}day^{-1}) of wheat during 2019-2020 and 2020-2021

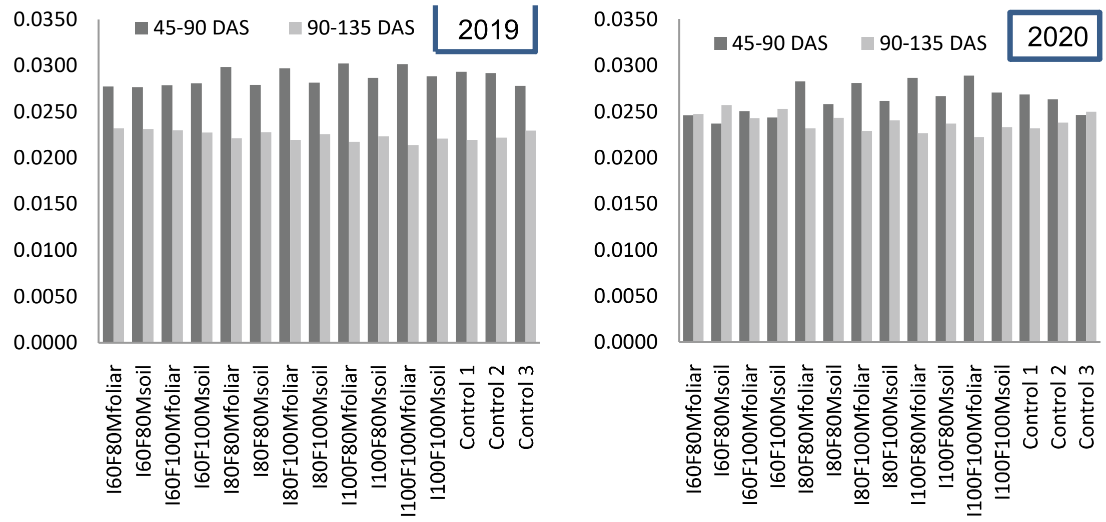

Fig. 3. Effect of irrigation regimes, N levels and method of application of KNO_3 & $MgSO_4$ on relative growth rate (g g^{-1} day^{-1}) of cotton during 2019 and 2020

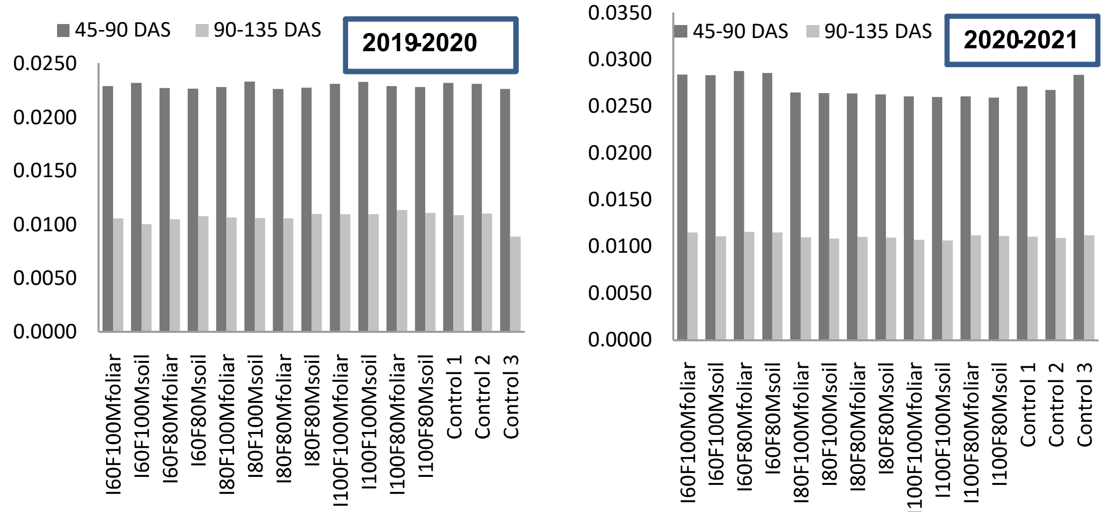

Fig. 4. Effect of irrigation regimes, fertilizer levels and residual effect of KNO_3 & $MgSO_4$ applied to cotton on relative growth rate (g g^{-1} day^{-1}) of wheat during 2019-2020 and 2020-2021

application of desired amount of water applied under different ET_c levels (Singh et al 2018). Level of fertilizer failed to cause significant variation in seed cotton as well as grain yield during both the years. M_{foliar} produced significantly higher seed cotton (31.09 and 32.60 q ha^{-1}) whereas M_{soil} resulted higher grain yield in wheat (51.28 and 48.28 q ha^{-1}) during both the years. Furthermore, among controls, seed cotton and grain yield was significantly improved under control 1 & 2 over control 3. Surface drip system supplies water and fertilizer to root zone, thereby avoids the application of water and nutrients to non target area, leading to improvement in yield over flood irrigation (Aujla et al 2005, Nuti et al 2006). The interaction between irrigation regimes and fertilization were non-significant, however, comparison of controls with combination of sub-surface drip irrigation regimes and fertilization were found to be significant in both the crops.

CONCLUSIONS

Production of crops through surface flood leads to loss of limited water resources besides leaching of nutrients, undesirable vegetative crop growth and underground water pollution. This study investigated water and nutrient management in 'cotton-wheat' cropping system and provided scientific evidence, revealing that sub-surface drip and fertigation technique leads to saving of irrigation water as well as fertilizer. Sub-surface drip irrigated at 80% ET_c has distinct advantages of saving water upto 20% without sacrificing yield and adverse effect on growth components. Fertigation of 80% RDN, resulted similar growth attributes and yield over 100% RDN, therefore saves 20% fertilizer dose. Foliar application of KNO_3 & $MgSO_4$ proved superior in cotton while residual effect of KNO_3 & $MgSO_4$ was observed in wheat. Therefore, sub-surface drip at 80% ET_c and F_{80}, proved to be valuable option over surface drip under water scarcity conditions.

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Effect of Land Configuration and Weed Management Practices on Weeds, Productivity and Profitability of Pigeon pea (*Cajanus cajan*)

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Abstract: A field experiment was conducted during *kharif* season of 2020-21 to study the performance of pigeon pea under land configuration and weed management options. The experiment was laid out in split-plot design with 3-land configurations (broad bed and furrow (BBF), ridge and furrow (RF) and flatbed (FB) in main plots and 6-weed management practices in sub plots. Broad bed and furrow planting significantly lower weed biomass and density which consequently resulted in significantly higher growth and yield attributes, seed (1.8 t/ha) and stalk yield (5.19 t/ha) of pigeon pea with the highest net returns (₹ 65,000/ha) and B:C ratio (2.53) over RF and FB land configuration. Weed management options were superior in reducing weed population and biomass and promoting crop growth and yield over weedy check but all herbicidal options remained statistically at par with each other except 2-hand weeding. Metribuzin @ 0.25 kg a.i./ha PE *fb* imazethapyr + imazamox (premix) @ 75g a.i./ha at 30 DAS fetched the highest net returns of ₹ 68000/ha with B:C ratio of 2.74. Thus, pigeon pea grown on BBF with metribuzin 0.25 kg a.i./ha (PE) *fb* imazethapyr + imazamox @ 75 g a.i./harecorded higher productivity and profitability.

Keywords: Hand weeding, Herbicides, Land configuration, Pigeon pea, Yield

Pulses have multipurpose uses *viz*., food grains, vegetables, fodder, green manure, cover crops and improving soil fertility owing to their ability to fix atmospheric nitrogen etc. More than 80% of pulses are grown with traditional practices on marginal and sub-marginal lands under rainfed conditions, resulting in low productivity and high instability in pulse production in the country (Ahlawat et al 2016). Globally, India ranks first in the pigeon pea production with 3.83 million tonnes from 4.54 million hectares and productivity of 842 kg/ha (GoI 2020). Pigeon pea is a tropical and subtropical region's crop (Saxena et al 2019). Successful cultivation of pigeon pea mainly threatened by various biotic and abiotic factors. Moisture stress and heavy weed competition were the two major bottle neck factors in enhancing pigeon pea yields (Pawar et al 2019). However, pigeon pea is a versatile deep-rooted legume and well known for drought tolerance under rainfed upland ecosystem (Sarkar et al 2020), but prolonged dry spells in the early and flowering to pod formation stages adversely affect the crop performance and growth. The heavy weed infestation elevated this extreme moisture stress via increased crop weed competition. The extent of yield loss in pigeon pea by weeds is tune of about 32-68% (Singh et al 2020). Apart from yield loss, weeds infestation also reduced inputs use efficiency of fertilizers and water, ultimately increasing the cost of cultivation. There is need to find out suitable management options to mitigate moisture stress and weed problem. Change in the current land configuration might be one of the best ways to conserve and enhance moisture availability to the crop plants throughout the growing season. In fact, the *in-situ* moisture conservation practices help to reduce soil and water erosion by increasing infiltration rate and improving the soil physico-chemical and biological properties of the soil (Kocira et al 2020). In addition, it enhances aeration in the rhizosphere region which lead to improved root growth, nodulation, and N fixation by the *Rhizobium* bacteria (Augmentation of these practices with effective weed management options may significantly improve the crop performance which results in higher qualitative crop yields. The increase in labour wage rates and labour scarcity forced the farmers to use herbicides for weed control (Singh et al 2016). Moreover, chemical weed control measures are more convenient, less time-consuming and economical, and can provide weed-free conditions from the early establishment of crop plants. However, the employment of suitable herbicides at suitable time and dose is necessary for efficient and effective control of unwanted vegetation. It was proven by past current researchers that the uses of pre- and post-emergence herbicides like pendimethalin, imazethapyr and quizalofop-ethyl have been used for effective weed control in pigeon pea (Manhas and Sidhu 2014). Thus, keeping these facts in view the present field experiment was conducted to study the effect of land configuration and weed management practices on the growth, yield and economics of pigeon pea.

MATERIAL AND METHODS

Experimental site and soil status: The field experiment was carried out at the agricultural research farm of ICAR-Indian Agricultural Research Institute, New Delhi during the *kharif* season of 2020-21, which is situated at 28.38° N latitude, 77.18° E longitude and at 228.6 m above mean sea level. The experimental site comes under semi-arid and sub-tropical climate. The soil of the experimental plot was sandy loam in texture with pH 7.79; low in soil organic carbon (0.41%) and available nitrogen (196 kg/ha); medium in available phosphorous (13.70 kg/ha) and available potassium (290 kg/ha).

Experimental design: The experiment was tested in split plot design (SPD) with three land configurations *viz.,* L_1-broad bed furrow (BBF), L_2-ridge and furrow (RF), L_3-flat-bed (FB) in main plots while, six weed management practices *viz.,* W_1-weedy check, W_2-hand weeding twice at 30 and 60 days after sowing (DAS), W_3-Metribuzin @ 0.25 kg/ha (PE) followed by (*fb)* Imazethapyr + Imazamox (premix) @ 75 g/ha at 30 DAS, W_4-Pretilachlor @ 1.0 kg/ha (PE) *fb* Imazethapyr + Imazamox (premix) @ 75 g/ha at 30 DAS, W_5-Metribuzin @ 0.25 kg/ha (PE) *fb* manual weeding at 30 DAS and W_6-Pretilachlor @ 1.0 kg/ha (PE) *fb* manual weeding at 30 DAS were allotted to the subplots. Pigeon pea variety 'Pusa Arhar-16' was sown on 27th June 2020 using a seed rate of 15 kg/ha at 45×15 cm plant spacing. Before sowing the crop, farm yard manure (FYM) @ 5 t/ha was applied and fertilized with a basal dose of 30-60-40 kg/ha N-P_2O_5-K_2O through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively.

Observations: Weed parameters were studied at 60 DAS when all herbicidal and manual weed management options were applied. Five representative plants were selected and tagged randomly to record the observations regarding plant height, number of branches per plant, number of leaves/plants and dry matter accumulation (g/plant), whereas, yield attributes *i.e.*, pods per plant, number of seeds per pod, 1000-seed weight, seed and stalk yield (t/ha) were recorded and expressed in standard units.

Statistical analysis: Data were suitably analysed using the SAS software of ICAR-Indian Agricultural Statistics Research Institute.

RESULTS AND DISCUSSION

Weeds parameters: The experimental field was invaded with 15-weed species belonging to six different families which include grasses, sedges and broad-leaved weeds. Relatively broad-leaved weeds were more dominant followed by grasses and sedges. The significantly lowest weed density and biomass at 60 DAS were in pigeon pea planted on BBF with the highest weed control efficiency (67.70%) as compared to RF and FB land configuration (Table 1). It might be due to better suppression of weeds by more vigorous crop plants, less space for weeds and more availability of nutrients and moisture to the crop with BBF as compared to other land configuration. Similar findings with BBF planting in urd bean reported by Rao et al (2022). All the weed management options significantly reduced the weed density and weed biomass accumulation and consequently resulted in higher weed control efficiency over the weedy check. However, the minimum weed density and weed biomass were recorded in two hand weeding at 30 and 60 DAS which also resulted the highest weed control efficiency. All herbicidal options were comparable with each other in suppression of weed population and weed biomass and resulted in around 78% weed control efficiency. Goud and Patil (2014) also reported that preemergence herbicide application followed by post-emergence herbicidal options were better for weed control in pigeon pea.

Effect on plant growth: All growth parameters except number of branches/plants were significantly influenced by land configuration of planting (Table 1). Broad bed and furrow planting of pigeon pea resulted in the significantly tallest plants, the highest number of leaves and dry matter accumulation over RF and FB planting system. Improvement in growth parameters under the BBF system was mainly due to the longer availability of soil moisture, nutrients and proper light and aeration as compared to RF and FB. Tomar et al (2016), Fayaz et al (2017) and Krishnaprabu (2019) also reported significantly higher growth attributes with BBF and RF land configuration over FB planting. Among the weed management options twice hand weeding resulted in significantly higher growth attributes over all other weed management options. Among the herbicidal options, both W_5 and W_6 where pre-emergence metribuzin and pretilachlor followed by one-hand weeding gave comparable growth parameters with each other and were found superior over other herbicidal options of weed management in pigeon pea. These results indicated that post-emergence herbicide application had a negative effect on plant growth characteristics. Similar findings were also reported in pigeon pea and other oilseeds and pulses (Prajapati et al 2018, Singh and Sekhon 2013 and Kaur et al 2015).

Yield attributes and yield: Number of pods per plant and pod length were mainly influenced by land configuration and weed management options which also affected the final productivity of pigeon pea (Table 2). The maximum pod length (4.3 cm), number of pods/plant (287.6), seed yield (1.71 t/ha) and stalk yield (4.83 t/ha) were recorded in BBF (L_1) and found superior over the RF and FB land configuration. The number of seeds/pod (3.9) and 1000-seed weight (72.3 g) were higher with BBF but non-significant with respect to RF and FB land configurations. The yield increased because of increased plant height, number of leaves, number of branches, number of pods/plant and 1000 grain weight, this is due to the cumulative action of soil

Table 1. Effect of land configuration and weed management practices on weeds and growth parameters of pigeon pea

Treatment	Weed density at 60 DAS (m^2)	Dry matter accumulation at 60 DAS (g m^{-2})	Weed control efficiency at 60 DAS (%)	Plant height at harvest (cm)	No. of branches/ plant at harvest	No. of leaves/ plant at harvest	Dry matter accumulation (g/plant) at harvest
Land configuration							
L_1 (BBF)	6.62 (49.72)	5.84 (39.41)	67.70	127.9	37.2	172.0	191.0
L_2 (RF)	6.90 (53.28)	6.00 (40.84)	66.27	122.8	36.3	167.2	167.8
L_3 (FB)	7.03 (54.22)	6.13 (42.28)	64.50	118.3	29.6	164.7	147.9
LSD ($P \leq 0.05$)	0.11	0.10	2.24	3.1	NS	3.6	9.6
Weed management options							
W_1 (Weedy check)	12.49 (155.11)	11.45 (130.15)	0.00	117.3	34.1	161.2	147.2
W_2 (Twice HW)	5.18 (26.11)	4.68 (20.94)	83.07	129.8	35.3	177.9	195.7
W_3 (Metribuzin (PE) *fb* Imazethapyr + imazamox)	5.86 (33.33)	4.97 (23.72)	78.42	120.7	33.8	166.8	165.2
W_4 (Pretilachlor (PE) *fb* Imazethapyr + imazamox)	5.89 (33.67)	5.02 (24.18)	78.25	119.8	34.1	162.9	163.4
W_5 (Metribuzin (PE) *fb* HW at 30 DAS)	5.76 (32.22)	4.87 (22.79)	79.15	126.2	34.6	170.0	172.6
W_6 (Pretilachlor (PE) *fb* HW at 30 DAS)	5.91 (34.00)	4.92 (23.27)	78.06	124.4	34.3	169.0	169.1
LSD ($P \leq 0.05$)	0.18	0.07	1.14	4.1	0.9	4.7	8.5

Table 2. Effect of land configuration and weed management practices on yield attributes, yield and economics of pigeon pea

Treatment	No. of pod/plant	Pod length (cm)	No. of seeds/pod	1000-seed weight (g)	Seed yield (t/ha)	Stalk yield (t/ha)
Land configuration						
L_1	287.6	4.3	3.8	72.3	1.71	4.83
L_2	283.7	4.1	3.9	72.1	1.67	4.74
L_3	280.0	4.2	3.7	71.6	1.59	4.63
LSD ($P \leq 0.05$)	3.7	0.1	NS	NS	0.02	0.11
Weed management options						
W_1	261.3	3.8	3.8	71.4	1.28	3.80
W_2	299.7	4.4	3.9	72.7	1.80	5.19
W_3	282.5	4.1	3.7	72.0	1.70	4.74
W_4	280.2	4.1	3.9	72.0	1.70	4.80
W_5	292.7	4.3	3.9	72.3	1.74	4.97
W_6	286.2	4.2	3.8	71.4	1.72	5.00
LSD ($P \leq 0.05$)	12.5	0.2	NS	NS	0.06	0.26

See Table 1 for treatment details

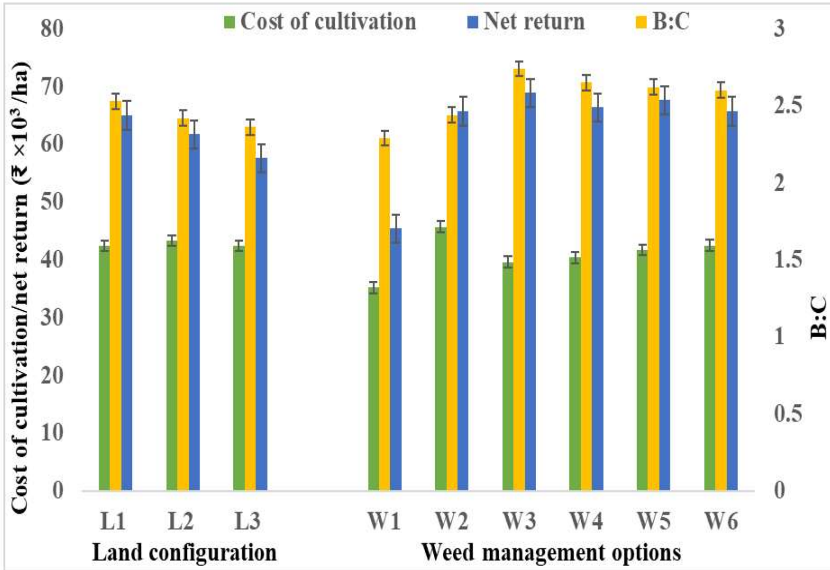

Fig. 1. Effect of land configuration and weed management practices on the economics of pigeon pea cultivation

moisture, aeration and nutrients in optimum quantity under broad bed and furrow, and ridge and furrow practice compared to conventional practice (flatbed). Similar findings were reported by earlier researchers (Pandey et al 2014, Mankar et al 2013 and Rao et al 2022).

Among the weed management options, the maximum number of pods/plant (299.7), pod length (4.4 cm), seed yield (1.80 t/ha) and stalk yield (5.19 t/ha) were recorded with W_2 (twice hand weeding at 30 and 60 DAS) and found superior over rest of the weed management options except W_5. Both W_1 and W_5 (metribuzin + hand weeding at 30 DAS) were statistically at par with respect to the number of pods/plants, pod length, seed and stalk yield. The stalk yield was statistically at par among W_1, W_5 and W_6. The number of seeds/pod and 1000-seed weight were non-significant pertaining to different weed management practices. The minimum seed yield was in a weedy check due to severe weed competition faced by the crop. Similar results were reported by Choudhary et al 2012, Bhowmick et al 2015 and Yadav et al 2015.

Economics: Cost of cultivation, net returns and benefit: cost ratio of pigeon pea also reflected the treatments effects (Fig. 1). The cost of production was almost similar in BBF (L_1) and FB (L_3) land configuration systems of pigeon pea sowing, however, net returns and benefit: cost ratio were the highest with BBF (L_1) followed by RF (L_2) and FB (L_3). The cost of cultivation was the highest with L_2 than the rest of other land configurations. The higher profitability with BBF was mainly due to higher seed and stalk yield resulting in more benefits in terms of net return (₹ 65000/ha) and B:C ratio (2.53) with BBF. Similar results were also obtained by Garud et al (2018) and Joshi et al (2020). In weed management options, the maximum cost of production was obtained in W_2 (twice hand weeding at 30 and 60 DAS) which is mainly due to more labour required for manual weeding with higher wages. The highest net returns (₹ 68900 /ha) and benefit: cost ratio (2.74) was obtained with metribuzin as PE *fb* Imazethapyr as POE (W_3) followed by metribuzin as PE *fb* hand weeding at 30 DAS (W_5). The maximum net returns and B:C ratio with W_3 due to the lowest cost of cultivation. The lowest cost of cultivation, net return and benefit: cost ratio was obtained under weedy check (W_1). Similar results were also reported by Padmaja et al (2013) and Singh et al (2020).

CONCLUSION

The broad bed and furrow (BBF) sowing of pigeon pea was the most productive and profitable land configuration while among weed management options, pre-emergence application of metribuzin 0.25 kg/ha + Imazethapyr + imazamox 75 g/ha at 30 DAS was the most profitable in terms of net returns and B:C ratio. However, two-hand weeding at 30 and 60 days after sowing proved superior in respect of increasing growth, yield attributing parameters and yield by reducing the maximum weed infestation, but involved a higher cost of cultivation.

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Effect of Different Planting Geometry and Nitrogen Levels on Growth and Yield of Rice Crop (*Oryza sativa* L.)

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Abstract: A field experiment was conducted during *kharif* 2020 at research farm of College of Agriculture, Kaul (Kaithal) of CCS Haryana Agricultural University, Hisar to investigate the response of transplanted rice (*Oryza sativa* L.) to nitrogen levels and planting geometry in rice variety HKR-128. The experiment was laid out in RBD factorial design consisting of three planting geometry *i.e.* 20 cm x 15 cm, 20 cm x 20 cm, and random transplanting as main plot treatments and five different levels of nitrogen (0, 50,100,150, and 200 kg/ha) in sub-plots with three replications. Plants attained significantly higher plant height, tillers and dry matter under 20 cm x 15 cm than other two planting geometry at all the growth stages. Number of panicles/m^2 and grains/panicle were significantly higher in 20 cm x 15 cm planting geometry as compared to other two planting geometry but panicle length and 1000-grain weight was not affected by planting geometry. Grain yield was recorded significantly higher in 20 cm x 15 cm planting geometry as compared to other plant spacing. Plant height, no. of tillers/m^2 and dry matter accumulation/m^2 enhanced significantly with successive increase in nitrogen dose up to 200 kg/ha, which was at par with 150 kg N/ha. Various yield attributing characters such as number of panicles/m^2, number of grains per panicle were significantly improved up to 200 kg N/ha being at par with 150 kg /ha.

Keywords: Growth parameters, Nitrogen levels, Planting geometry, Yield

Rice (*Oryza sativa* L.) is most important food cereal of India and second most important cereal crop of world after wheat. The area under rice cultivation in India is about 44 m ha with a production of 118.9 mt (Anonymous 2020). To obtain a high yield, it is imperative to determine the optimum plant population per unit area, spacing, and nitrogen. Through efficient use of solar radiation and nutrients, optimal plant spacing ensures the improvement in plants physiology both above and below ground and hence improper plant spacing reduces the yield. As a result, it is imperative to examine the best planting geometry to obtain maximum rice crop yield. Nitrogen (N) is the utmost important plant nutrient that governs the productivity of crop especially under intensive cultivation. It is a most important input for rice production as the soils are often low in organic nitrogen. Due to continuous raising of nutrient exhaustive cropping pattern such as rice- wheat in the state have further highlighted the vitality of nitrogenous fertilizers. Excess amount of nitrogenous fertilizer application can effect in lodging of the plants, pest susceptibility and reduction of yield. Similarly deficiency of N causes reduction in the yield. Therefore, application of nitrogenous fertilizers in adequate amount is important for obtaining higher crop yield. Planting geometry and crop nitrogen requirements can affect each other and therefore, the amount of nitrogen need of the crop can differ depending on the planting geometry. Furthermore, farmers often use higher fertilizer doses, especially nitrogenous fertilizers to compensate for the insufficient plant density obtained under traditional manual transplanting with the aim of boost productivity. As a result, there is urgent need to determine proper nitrogen dose for different planting geometries, as well as the level to which the higher N dose compensates for the inadequate plant density in the farmer's field.

MATERIAL AND METHODS

Field experiment was conducted during *kharif* 2020 at College of Agriculture, Kaul of CCS Haryana Agricultural University, Hisar. Soil of the experimental field was sandy clay loam in texture, which was medium in organic carbon (0.53%), low in available nitrogen (174 kg/ha), medium in phosphorus (30 kg/ha), high in potassium (382 kg/ha) and slightly alkaline in reaction (8.2) with EC 0.27 dS/m. Rice variety HKR-128 was sown. The experiment was laid out in RBD factorial design consisting of three planting geometry *i.e.* 20 cm x 15 cm, 20 cm x 20 cm, and random transplanting as main plot treatments and five different levels of nitrogen (0, 50,100,150, and 200 kg/ha) in sub-plots with three replications.

Data of various growth factors of crop was taken at different growth stages of crop. Height of plant was documented of the tagged hills in all the plots at 30, 60, 90 DAT and at harvest stage. Height was recorded by measuring the longest tiller from the base of the plant to highest terminal point. Number of tillers per plot were counted from five selected hills at 30, 60, 90 DAT and at harvest. Mean number of tillers per hill were computed by averaging the tillers of selected hills. Treatments $P_{1,}$ $P_{2,\ \text{and}}$ P_3 the mean number of tillers per hill were multiplied with $_{33.3,}$ 25.0 and 17.5, respectively to count the number of tillers per m^2. Dry matter per m^2 in grams was assessed at 30, 60, 90 DAT and at harvest stage. Randomly three hills in each plot were cut down from ground level, then sun dried and later dried in an oven at 70^0C for 48 hours. After averaging dry matter obtained from these three hills, mean dry matter accumulation per m^2 was calculated for each plot for statistical analysis. The mean dry matter per hill was multiplied with 33.3, 25.0 and 17.5 to estimate dry matter accumulation in g/m2 in plots under P1, P2, and P3 treatments,respectively.

Data on yield attributes and yield was recorded at maturity. Panicle length was measured from five panicles collected from each plot at the time of harvesting. The length of each panicle was taken from the base of the panicle to the terminal point. Number of panicles at the time of harvesting was recorded from randomly selected five hills per plot as per the procedure followed for counting number of tillers and were converted into number of panicles per m^2. At the time of harvesting number of grains were counted from ten randomly selected effective panicles taken from each plot. Then for each plot mean number of grains per panicle was computed by averaging the number of grains in all selected panicles. After harvesting, paddy was threshed separately in each plot and then weighted separately (at 14% moisture level) which was then converted to grain yield (kg/ha). The straw from threshed crop of each plot was dried in the sun for three days and weighed. The yield of straw per plot was then converted to straw yield in kg per hectare.

The data were analyzed using the software "OPSTAT" floated /available on official website of CCS Haryana Agricultural University, Hisar for ready use.

RESULTS AND DISCUSSION

Growth Parameters

Plant height: The highest plant height was recorded in 20 cm x15 cm planting geometry at all growth stages. The maximum plant height was recorded with application of 200 kg N/ha which was closely followed with the application of 150 kg N/ha but significantly higher than the other three treatments. The plant height increased in closer spacing due to better

Table 1. Plant height of transplanted rice as affected by planting geometry and nitrogen levels

Treatments	Plant height (cm)			
Planting geometry	30 DAT	60 DAT	90 DAT	At harvest
P_1 (20 cm x 15 cm)	71.3	121.9	135.4	137.0
P_2 (20 cm x 20 cm)	70.8	114.4	126.5	128.3
P_3 (Random)	68.7	106.7	118.9	122.1
CD (p=0.05)	NS	6.1	7.8	5.9
Nitrogen levels (kg ha^{-1})				
N_1=0	69.2	100.2	114.6	120.0
N_2=50	69.5	110.5	124.9	126.6
N_3=100	70.4	116.8	128.3	131.0
N_4=150	70.9	120.7	133.0	133.6
N_5=200	71.3	123.5	133.9	134.4
CD (p=0.05)	NS	3.2	3.9	2.3

Table 2. Number of tillers/m^2 of transplanted rice as affected by planting geometry and nitrogen levels

Treatments	No. of tillers/m^2			
Planting geometry	30 DAT	60 DAT	90 DAT	At harvest
P_1 (20 cm x 15 cm)	257.2	402.0	329.4	327.0
P_2 (20 cm x 20 cm)	213.9	330.4	266.2	259.3
P_3 (Random)	191.8	284.5	229.9	222.4
CD (p=0.05)	9.4	17.4	9.0	7.7
Nitrogen levels (kg ha^{-1})				
N_1=0	177.3	258.8	208.6	206.5
N_2=50	209.6	312.4	252.1	251.2
N_3=100	229.8	350.4	286.2	279.1
N_4=150	244.1	380.1	310.6	300.8
N_5=200	244.0	393.0	318.2	310.2
CD (p=0.05)	12.2	22.4	11.7	9.9

Table 3. Dry matter accumulation (g/m^2) of transplanted rice as affected by planting geometry and nitrogen levels

Treatments	Dry matter accumulation (g/m^2)			
Planting geometry	30 DAT	60 DAT	90 DAT	At harvest
P_1 (20 cm x 15 cm)	78.5	249.3	423.8	515.9
P_2 (20 cm x 20 cm)	61.1	224.8	352.2	472.1
P_3 (Random)	56.2	209.6	329.6	427.1
CD (p=0.05)	4.7	13.7	15.4	27.9
Nitrogen levels (kg ha^{-1})				
N_1=0	55.3	198.8	326.5	361.4
N_2=50	62.0	221.8	354.3	454.7
N_3=100	66.4	233.9	374.1	494.1
N_4=150	70.2	241.1	388.7	519.3
N_5=200	72.4	244.0	398.9	529.1
CD (p=0.05)	3.5	6.3	13.4	21.4

utilization of solar radiation and nutrients. Similar results were recorded by Alam et al (2012) and Singh et al (2015b). In case of nitrogen, plant height increased with the addition of each levels of nitrogen and this can be explained with the fact that nutrient supply increased the photosynthesis and better utilization of photosynthates. The similar results were reported by Sharma et al (2012).

Number of tillers/square meter: The maximum no. of tillers/m^2 was in 20 cm x 15 cm planting geometry at all the stages of rice crop whereas the minimum no. of tillers/m^2 was recorded in random transplanting. The no. of tillers decreased after 60 DAT in all planting geometry. Ashraf et al (2014) and Rajput et al (2016) revealed the similar results. However, Baskar et al (2013) and Dass and Chandra (2012) found that no. of tillers per hill was maximum in wider spacing because plant got enough space below and above the ground for proper growth. In nitrogen levels the maximum no. of tillers were at 30 DAT with 150 kg N/ha which was at par with 200 kg N/ha but significantly higher than the other treatments of nitrogen application. At 60 DAT and after that the maximum no.of tillers/m^2 were recorded in 200 kg N/ha which were significantly higher than control, 50 kg N/ha, 100 kg N/ha but statistically at par with 150 kg N/ha. The minimum no. of tillers/m^2 was observed in control at all the stages of growth. Similar results were recorded by Murthy et al (2015) and Dahipahle and Singh (2018). Nitrogen metabolism and protein synthesis resulted in more vegetative growth and no. of tillers.

Dry matter accumulation: Maximum dry matter reported at harvest in all the treatments. Significantly higher dry matter was in 20 cm x 15 cm planting geometry as compared to 20 cm x 20 cm the planting geometry and random transplanting. Lowest dry matter/m^2 was in random transplanting at all stages of growth. The experiment conducted by Sultana et al (2012) also supported these results. With every increase of nitrogen level the dry matter accumulation increased from control to 200 kg N/ha. The maximum dry matter accumulation/m^2 was in 200 kg N/ha which was closely followed by 150 kg N/ha but significantly higher than the rest of three treatments. The minimum dry matter was in control. Murthy et al (2015) and Sharma et al (2012) also reported similar results. The dry matter accumulation increased with each successive levels of nitrogen due to higher meristematic activity resulted in higher plant height and no. of tillers.

Yield and yield attributes: The numbers of panicles/m^2 were higher in closer spacing *i.e.* in 20 cm x 15 cm as compared to wider spacing *i.e.* in 20 cm x 20 cm and in random transplanting. Number of panicles/m^2 was minimum in random transplanting. Similar results were obtained by Moro et al (2016). As the nitrogen doses increased from 0 to 200 kg N/ha, the number of panicles/m^2 increased considerably. The highest no. of panicles/m^2 was recorded with 200 kg N/ha which was statistically at par with 150 kg N/ha but significantly higher than the other three treatments. The lowest no. of panicles/$m^2$was recorded in control. Kumar and Mahajan (2014) recorded the similar research findings. The highest no. of grains/panicle was counted in closer spacing of 20 cm x 15 cm which was remarkably higher than wider spacing of 20 cm x 20 cm and in random transplanting. The maximum no. of grains/panicle was found at higher level of nitrogen *i.e.* 200 kg N/ha which was statically at par with 150 kg N/ha but significantly higher than the rest of three treatments. Panicle length and harvest index of the crop was

Table 4. Yield attributes and grain yield of transplanted rice as affected by planting geometry and nitrogen levels

Treatments/Planting/Geometry	Yield attributes				Grain yield (kg/ha)
	Number of panicles/m^2	Number of Grains/panicle	Panicle length (cm)	1000-grain weight (g)	
P_1 (20 cm x 15 cm)	324.0	134.8	22.6	25.5	8,412
P_2 (20 cm x 20 cm)	257.5	127.4	22.1	25.8	7,733
P_3 (Random)	221.7	122.0	22.1	25.9	7,013
CD (p=0.05)	29.6	5.5	NS	NS	185.8
Nitrogen levels (kg ha^{-1})					
N_1=0	204.7	119.1	21.6	25.2	5,971
N_2=50	254.3	125.4	22.1	25.7	7,268
N_3=100	280.7	129.8	22.4	25.9	8,105
N_4=150	295.4	132.5	22.6	26.0	8,616
N_5=200	303.6	133.5	22.7	26.0	8,637
CD (p=0.05)	13.7	2.5	NS	NS	239.9

not significantly affected by planting geometry as well as nitrogen levels. The longest panicle length (22.6 cm) was measured in the planting geometry 20 cm x 15 cm with 200 kg N/ha. Alam et al (2012) reported the same results. The maximum grain yield (8412 kg/ha) was obtained in 20 cm x 15 cm which was 19.9 % higher than random transplanting. Mahaddesi et al (2011), Moro et al (2016) recorded higher grain yield in closer spacing as compared to wider spacing. The maximum grain yield (8637 kg/ha) was recorded in 200 kg N/ha which was closely followed by 150 kg N/ha but it was significantly higher than the rest of three nitrogen treatments. With 200 kg N/ha 44.6 % higher grain yield was obtained as compared to control. The lowest grain yield (5971 kg/ha) was reported in control. This might be due to the reason of better growth parameters which ultimately led to more production and translocation of photosynthates.

CONCLUSION

Rice crop transplanted under 20 cm x 15 cm planting geometry recorded higher values of growth parameters. The grain yield of rice under aforesaid spacing also surpassed the other planting geometries tested under study. Application of 150 kg N/ha performed best among different nitrogen levels. Based on the present study it may be concluded that rice should be transplanted at 20 cm x 15 cm planting geometry and should be applied with 150 kg N/ha.

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Variation Studies in Fruit Characteristics, Seed Germination and Seedling Growth of *Diospyros montana* (Roxb.) in Himachal Pradesh

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***Abstract*:** The study was confined to 19 mother trees of *Diospyros montana* (Roxb.) distributed in Solan districts of Himachal Pradesh. Variation in fruit, seed and seedling traits were studied by collecting fruits and raising nursery of this species. There was large variation in fruit and seed traits. The maximum fruit weight, fruit length, fruit width and germination per cent was recorded for M_5 and M_7. Seedling parameters were recorded maximum for M_7. Repeatability coefficient was recorded maximum for seed length. GCV, PCV and heritability was recorded maximum for germination percent. This study revealed that fruit size and germination parameters could form a selection criterion for tree improvement in *D. montana*.

***Keywords*:** Variation, Diospyros, Repeatability, PCA, Clusters, Correlation

India is blessed with all types of vegetation ranging from tropical to subtropical, temperate to subalpine and alpine because of diversified climatic and physiographic factors. In an ecosystem forest have both productive and protective role. Productive role of the forest is not only confined to timber production but also production of non-timber forest products. Non-timber forest products (NTFPs) are the biological products, other than timber, that are harvested by humans from wild biodiversity in natural and man-made environment (Sardesh Pande and Shackleton 2019). Non-timber forest products are mainly tans, dyes, medicinal plants, bamboo etc. According to an estimate 275 million people in India are dependent on these resources. There are many products which are not extracted fully, or which go to waste because of insufficient knowledge of their use. The biodiversity of most of the species is usually poorly studied. Even their identification and classification are often unsatisfactory, leading to considerable confusion when plants or their products are traded.

Among all, genus *Diospyros* is one of the potential NTFPs. The *Diospyros*is largest genus of family Ebenaceae, around 700 species of deciduous and evergreen trees and shrubs (Akagiet al 2014). The majority are native to the tropics, with only a few extending into temperate regions. This plant is distributed all along the Western Ghats of India, Sri Lanka and Indo-China through Australia. In India its different species are distributed in the state of Kerala, Assam, Rajasthan, Uttar Pradesh, Maharashtra, Tamil Nadu and Himachal Pradesh. Several species of *Diospyros* are commercially important for their edible fruits and timber. It is commonly known as ebony tree because of its hard, heavy and dark timber. *Diospyros* species have been ubiquitous to ethnic medication throughout the tropical regions. There are mainly six species of *Diospyros* (*D. kaki, D. embryopteris, D. tomentosa, D. melanoxylon, D. lotus and D. montana*) present in Himachal Pradesh (Kumar 2014, Bhardwaj and Seth 2017). Out of which *Diospyros montana,* commonly known as Bombay ebony found in some parts of Solan, Sirmour and Una district of Himachal Pradesh.

Diospyros Montana is a small deciduous tree up to 20 m high with spiny trunk and branches. Leaves are elliptic lance-shaped, somewhat heart shaped at the base and sharp or blunt at the tip. It is a dioecious tree species. Flowering takes place from March- April. The fruits are green turning orange when ripen and it mature in October. The green fruits are rich in tannin and thus avoided by most of herbivores. It is the one of the most important medicinal plant. It's almost all parts possess good therapeutic value in traditional system of medicines. Bark extract is anti-inflammatory, antipyretic and analgesic. It contributes to socio- economic livelihood of tribal people of India.

Wild populations of plant species exhibit the complex patterns of variation (Briggs and Walters 1997), making it crucial to select superior stands for breeding purposes (Gupta and Sehgal 2000). Variability in important traits is most crucial for tree improvement. Because the expression of a character is the sum of many other genetically determined qualities so, screening and selection should be based on these factors. Variations are essential for adaptation and improvement of species through breeding program. If there is no variation, there is no possibility for tree breeding to improve the quality. Continuous development is possible if variation exists in a species. Understanding the diversity within and between tree populations is essential in order to set priorities for the conservation and enhancement of tree genetic resources. The species therefore provides an opportunity, for studying variation and also to select the superior seed sources for adaptability and growth. Due to longer rotation period of the tree, there is very less information available on its genetic improvement Therefore, an effort was made to study the genetic differentiation in superior tree progenies to identify the diverse genotype to use further in hybridization programme.

MATERIAL AND METHODS

The experiment was conducted in the laboratory and experimental field of the Department of Tree Improvement and Genetic Resources, Dr YS Parmar UHF, Nauni, Solan (HP). Total 19 mother trees from Nalagarh area of district Solan of Himachal Pradesh were selected. The physical description of nineteen mother trees is given in Table 1**.**

Statistical analysis: The data of mother trees was analyzed statistically using Random Nested Model as follows,

$$Y_{ijklm} = \mu + p_i + M\,(p)\,j_{(i)} + e_{ijk}$$

Repeatability: We couldn't accurately measure genetic variance between and within populations because genetic effects can't be isolated from environmental effects in natural populations when parental origin and environmental influences aren't controlled. As a result, we are unable to calculate the heritability coefficient at the population or individual tree level. In this case, we use the repeatability coefficient, which may be considered as the top limit of the genetic-phenotypic variance relationship (Falconer and Mackey 1996). These coefficients also show the proportion of within-population variation that contributes to total variance and the proportion of between-tree variation that contributes to total population variation.

$$\text{More tree repeatability} = \sigma^2_m = \frac{\sigma^2_m}{\sigma^2_m + \sigma^2_w(m)}$$

$$\text{Where, } \sigma^2_m = \text{Mother tree variance}$$

$$\sigma^2_{w(m)} = \text{Within mother tree variance}$$

Heritability in percentage was calculated by formula suggested by Burton and De-Vane (1953) and Johnson et al (1955). The expected genetic advance at 5 per cent selection intensity was calculated by the formula suggested by Lush (1940) and further used by Burton and De-Vane (1953) and Johnson et al (1955). Genetic gain was worked out following the method suggested by Johnson et al (1955). Principal component and cluster analysis were investigated by principal component analysis (PCA). PCA was performed using JMP pro 10software. Cluster analysis was also performed to cluster genotypes into similarity groups using the method of UPGA (Unweighted Pair Group Average) using ward method (Ward 1963).

RESULTS AND DISCUSSION

Table 2 depicts the data pertaining to fruit and seed characters. Selected plant namely M_5 had maximum fruit weight (14.99g), while M_{19} had minimum fruit weight (7.28 g). Seed weight observed maximum (1.83 g) in $M_{3,}$ whereas, minimum (1.03 g) in M_{15}. Number of seeds recorded maximum (5.63) in$M_{1,}$ whereas minimum (3.33) inM_2. Seed weight (100 seeds) was observed maximum (182.97g) in$M_{3.}$The M_{15} plant depicted smallest seed weight (102.57g). Size of seed may vary due to external and internal environmental conditions (Roy et al 2004). Priya devi et al (2022) have found variation in fruit length, seed weight. etc. among different provenances.

Variance between mother trees for fruit and seed characteristics: Repeatability coefficient was found

Table 1. Physical description of mother trees

Mother trees	Altitude (feet)	Latitude (n)	Longitude (e)
M_1	1207	30°59'909"	76°44'713"
M_2	1202	30°59'915"	76°44'710"
M_3	1205	30°59'917"	76°44'712"
M_4	1201	30°59'867"	76°44'660"
M_5	1204	30°59'867"	76°44'655"
M_6	1200	30°59'881"	76°44'646"
M_7	1203	30°59'935"	76°44'742"
M_8	1202	30°59'984"	76°44'778"
M_9	1209	30°59'939"	76°44'762"
M_{10}	1597	30°59'694"	76°44'634"
M_{11}	1673	30°59'460"	76°44'625"
M_{12}	1719	30°59'472"	76°44'769"
M_{13}	1760	30°59'493"	76°44'965"
M_{14}	1764	30°59'505"	76°44'978
M_{15}	1775	30°59'509"	76°44'019"
M_{16}	1859	30°59'668"	76°44'075"
M_{17}	1859	30°59'673"	76°44'076"
M_{18}	1862	30°59'675"	76°44'079"
M_{19}	1869	30°59'680"	76°44'085"

maximum (0.94) for seed length and was found minimum (0.19) for100 seed weight. The magnitude of differences between PCV and GCV were more indicating the major role of environment in expression of various traits. In general, all characters studied in the magnitude of phenotypic coefficient of variation were greater over the respective genotypic coefficient of variation. The characters seed length (42.28and 41.02) and fruit weight (23.82and 17.75) shows higher estimates of both PCV and GCV, respectively (Table 3). Similar findings of genetic variability have been observed and reported earlier in *Pongamia pinnata* by Sunil et al (2009) and Rawale (2020) in Kaphal tree. Genetic gain was found maximum (81.97%) in seed length, whereas, maximum (19.35) genetic advance observed in 100 seed weight.

Estimation of correlation coefficients between different fruit, seed and leaf parameters: Correlation studies help in finding out the degree of inter-relationship among various characters and in evolving selection criterion for improvement of multiple characters and shorten the selection cycle. The Fruit weight is positively correlated with fruit length (0.67) and fruit width (0.83). Similarly, Fruit length is positively correlated with fruit width *i.e.* 0.83 (Selvan and Guleria 2012). Number of seeds was negatively correlated with seed width (-0.06).

Principal component analysis (PCA): PCA is used to explain pattern of variation among the populations. This technique helps in dividing the original variables in the dataset into smaller groups. The results from the PCA conducted in this study identified that PC1, PC2 and PC3 components accounted for 73.39% of the total variation in the studied variables for *D. montana* (Table 5). In PC1, the variables with the highest factor loadings were the fruit weight, the fruit length, seed length, 100 seed weight and number of seeds. Principal component analysis has been effectively used to evaluate and characterize the germplasm of many fruit trees (Hashemi and Khadivi 2020).

Cluster analysis: The diversity exists between the clusters I, II and III may result in substantial segregates. It is revealed that the existence of substantial variation and diversity can be utilized for genetic resource conservation and further tree improvement programmers of the species. Cluster I had highest mean value for 100 seed weight (152.63) (Table 6).

Nursery Performance of Half- sib Families

Variation between germination parameters: Seed germination behavior is an important factor in the distribution of species. There is a significant relationship between mean daily germination and germination percent. The maximum germination (33.83%) and mean daily germination (1.55)

Table 2. Variation for fruit and seed characters

Mother trees	Fruit length (cm)	Fruit width (cm)	Seed length (cm)	Seed width (cm)	Fruit weight (g)	Number of seeds per fruit	100 seed weight (g)
M_1	2.98	3.24	1.55	0.79	14.47	5.63	155.34
M_2	2.92	3.24	1.43	0.91	11.78	3.33	123.18
M_3	2.90	3.22	1.41	0.84	13.33	4.43	182.97
M_4	2.96	3.35	1.48	0.86	13.6	3.83	174.83
M_5	3.09	3.46	1.41	0.79	14.99	4.90	141.94
M_6	3.06	3.40	1.42	0.68	12.61	4.33	128.97
M_7	3.08	3.42	1.39	0.8	14.47	4.90	151.60
M_8	3.01	3.09	1.40	0.89	13.38	3.40	145.47
M_9	2.85	2.94	1.41	0.83	10.67	4.73	156.37
M_{10}	2.90	3.04	1.42	0.79	10.49	3.93	127.70
M_{11}	2.95	3.23	1.32	0.73	11.66	4.77	140.40
M_{12}	2.67	3.00	1.31	0.77	9.99	4.70	106.70
M_{13}	2.78	3.07	1.32	0.78	10.2	4.37	106.37
M_{14}	3.10	3.09	4.13	0.79	11.16	4.93	161.63
M_{15}	2.85	3.10	1.27	0.69	10.36	3.97	102.57
M_{16}	3.04	3.16	1.56	0.89	11.44	4.57	152.23
M_{17}	2.85	2.94	1.22	0.63	8.96	4.23	126.77
M_{18}	2.89	3.00	1.56	0.80	9.39	5.23	168.90
M_{19}	2.87	3.00	1.31	0.68	7.28	3.33	135.33
CD (p=0.05)	0.08	0.10	0.08	0.04	0.93	0.64	22.53

was recorded for M_5 which was at par with M_4 (33.63%) and minimum values (14.95%) and (0.33) was recorded for M_{17}. However, maximum peak value (2.73) and germination value (3.74) was recorded for M_7 which was followed by M_5, M_4 and minimum values (0.48) and (0.16) was recorded for M_{17} (Table 7). The premise behind germination energy is that only seeds that germinate quickly and vigorously under favourable conditions can produce vigorous seedlings in the field (Masoodi et al 2014).

Mother trees variation for seedling growth parameters (Six months): Maximum average seedling height was recorded in M_9 (60.13 cm) and minimum was recorded in M_{10} (33.33 cm). Maximum collar diameter was observed (2.04) in M_9 whereas, minimum (1.37 mm) in $M_{11.}$ Number of branches were recorded maximum in M_2 (12.53) and minimum was recorded in M_3 (4.20). The maximum number of leaves (136.67) was recorded in M_{15} and minimum (52.60) was recorded in$M_{2.}$ Leaf width was recorded maximum for M_7 (2.6cm) and minimum (2.22 cm) was recorded for $M_{17.}$ Maximum average leaf length was recorded in M_7 (7.55 cm) and minimum (6.41 cm) leaf length was recorded inM_{10}.Petiole length was observed maximum (0.27cm) and minimum (0.22 cm) was observed inM_6, M_{13}, M_{17} and M_{18}. Maximum leaf area was recorded inM_7 (13.81cm²), which was followed by M_2 (11.84 cm²) and minimum (10.03 cm²) was recorded in M_{17}(Table 8). Growth characters of seedlings were governed by genetic makeup and seed characters (Pathak et al 1984, Thakur 2013).

Variance component and heritability: Genetic variability (Table 9) studies revealed that phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for all the characters under observations. The maximum genotypic (31.89%) and phenotypic (43.82%) variability was observed in number of branches followed by number of leaves whereas, minimum GCV (3.61%) and PCV

Table 5. Principal component analysis of fruit and seed characters

Parameters	PC1	PC2	PC3
Fruit weight	0.64	0.56	0.01
Fruit length	0.7	0.36	-0.5
Fruit width	0.06	0.48	0.66
Number of seeds	0.62	0	0.3
Seed length	0.76	0.47	-0.32
Seed width	0.04	0.56	0.2
100 seed weight	0.47	0.42	0.5
Eigen value	4.05	2.75	1.27
Percent of variance	36.84	24.98	11.58
Cumulative percent	36.84	61.81	73.39

Table 3. Variance component and repeatability coefficient for fruit and seed characteristics

Parameters	Genotypic coefficient of variation (%)	Phenotypic coefficient of variation	Repeatability	Genetic advance	Genetic gain (%)
Fruit weight	17.75	23.82	0.56	3.16	27.24
Fruit length	3.74	6.65	0.32	0.13	4.33
Fruit width	5.10	7.94	0.41	0.21	6.75
Number of seeds	13.60	31.73	0.18	0.53	12.01
Seed length	41.02	42.28	0.94	1.26	81.97
Seed width	9.81	13.28	0.52	0.11	14.92
100 seed weight	15.22	34.88	0.19	19.35	13.67

Table 4. Correlation between leaf, fruit and characters in *D. Montana*

Parameters	Fruit weight (g)	Fruit length (cm)	Fruit width (cm)	No. of seeds	Seed length (cm)	Seed width (cm)	100 seed weight (g)
Fruit weight	1						
Fruit length	0.67**	1					
Fruit width	0.83**	0.63**	1				
No. of seeds	0.14	0.18	0.28	1			
Seed length	-0.05	0.42	0.01	0.25	1		
Seed width	0.19	0.22	0.46*	-0.06	0.11	1	
100 seed weight	0.23	0.48*	0.4	0.32	0.3	0.44	1

(**) – Highly significant and correlation is significant at the 0.01 level
(*) - Significant and correlation is significant at the 0.05 level

(8.81%) was found for leaf width. Heritability may give useful indication about the relative gain from the selection (Ginwal and Gera 2000). Heritability was found maximum for germination percent (0.97) and minimum (0.04) for petiole length. Genetic advance was found maximum for number of leaves (33.07). Genetic gain was found maximum for number of branches (47.81%) and minimum (1.40%) for petiole length. Genetic gain was found maximum for all the characters as compared to genetic advance. Genetic gain was dependent on heritability of traits. These findings were supported by Kumari and Wani (2015) in *D. melanoxylan*. They concluded that leaf area and seedling height performed better, indicating additive gene action on these two variables. As a result, these two qualities would yield better outcomes for improvement by simple selection. These results are in line with Thakur (2013) in *Melia azedarach.*

Estimation of correlation coefficients between different nursery parameters: All the observed characters showed significant relationship with each other. The seedling height showed a highly significant and positive correlation with collar diameter and number of leaves which depicts the less effect of environmental factors (Table 10). Significant and

Table 6. Mean value for leaf, fruit and seed characters for the cluster analysis

Cluster	1	2	3
No. of trees in cluster count	4	5	10
Notation of trees	M_1, M_5, M_7, M_{14}	M_2, M_4, M_6, M_8,M_{16}	M_3, M_9, M_{10}, M_{11}, M_{12}, M_{13}, M_{15}, M_{17}, M_{18}, M_{19}
Fruit length	3.06	3.00	2.85
Fruit width	3.30	3.25	3.05
Fruit weight	2.12	1.46	1.36
Number of seeds per fruit	0.79	0.85	0.75
Seed length	13.77	12.56	10.23
Seed width	5.09	3.89	4.37
100 seed weight	152.63	144.94	135.41

Table 7. Variation between germination parameters

Mother trees	Germination percent (%)	Mean daily germination	Peak value	Germination value
M_1	32.79	1.31	1.55	2.01
M_2	30.44	1.28	1.33	1.71
M_3	32.79	1.47	1.63	2.39
M_4	33.63	1.53	1.92	2.94
M_5	33.83	1.55	1.94	3.01
M_6	33.00	1.48	1.65	2.45
M_7	31.52	1.37	2.73	3.74
M_8	24.83	0.88	1.82	1.58
M_9	27.74	1.08	1.55	1.68
M_{10}	24.35	0.85	0.94	0.80
M_{11}	27.96	1.10	1.16	1.28
M_{12}	25.10	0.90	0.90	0.81
M_{13}	26.80	1.02	1.07	1.09
M_{14}	27.96	1.10	1.10	1.22
M_{15}	27.26	1.05	1.05	1.11
M_{16}	25.10	0.90	1.13	1.01
M_{17}	14.95	0.33	0.48	0.16
M_{18}	26.08	0.97	1.02	0.98
M_{19}	33.21	1.50	2.31	3.46
CD (p=0.05)	1.27	0.14	0.19	0.28

Table 8. Mother tree variation in seedling growth parameters (Six months)

Mother trees	Height (cm)	Collar diameter (mm)	Number of branches	Branch length per seedling (cm)	Number of leaves	Leaf width (cm)	Leaf Length (cm)	Petiole length (cm)	Leaf area (cm²)
M_1	40.33	1.66	6.33	17.1	61.53	2.53	6.57	0.24	11.48
M_2	41.33	1.89	12.53	12.31	52.6	2.43	7.02	0.25	11.84
M_3	44.4	1.63	4.2	18.62	67.73	2.36	6.56	0.23	10.77
M_4	38.47	1.88	4.53	15.43	61.47	2.25	6.65	0.24	10.39
M_5	39.27	1.47	4.87	14.48	58.07	2.42	6.47	0.25	10.85
M_6	41.8	1.42	6	13.47	64.47	2.26	6.53	0.22	10.23
M_7	37.67	1.46	4.53	15.13	65.4	2.63	7.55	0.27	13.81
M_8	39.78	1.63	4.67	20.25	56.6	2.39	7.05	0.24	11.69
M_9	60.13	2.04	9.13	18.44	123.33	2.33	6.92	0.24	11.17
M_{10}	33.33	1.49	4.6	15.51	60.47	2.43	6.41	0.25	10.81
M_{11}	32.31	1.37	5.67	14.89	60.6	2.39	7.02	0.24	11.64
M_{12}	41.33	1.62	6.13	16.51	93.47	2.39	6.79	0.23	11.28
M_{13}	40.53	1.56	7.8	15.99	97.6	2.23	6.63	0.22	10.23
M_{14}	38.2	1.38	4.33	15.34	86.67	2.42	6.59	0.23	11.09
M_{15}	42.93	1.94	7.47	19.64	136.67	2.41	7.01	0.24	11.77
M_{16}	37.6	1.83	6.8	14.33	95.27	2.41	6.75	0.24	11.3
M_{17}	35.96	1.79	5.53	15.91	82.2	2.22	6.5	0.22	10.03
M_{18}	37.87	1.64	6.93	17.91	98.2	2.34	6.55	0.22	10.65
M_{19}	41.47	2.04	8.07	18.53	104.33	2.38	6.77	0.23	11.2
CD (p=0.05)	5.64	0.24	1.35	3.25	17.78	0.14	0.41	0.04	1.16

Table 9. Variance component, heritability, genetic gain and genetic advance of growth parameters

Parameters	Genotypic coefficient of variation (%)	Phenotypic coefficient of variation (%)	Heritability	Genetic advance	Genetic gain (%)
Germination percent	16.44	16.66	0.97	9.48	33.40
Height of seedlings	13.21	23.66	0.31	6.11	15.18
Collar diameter	11.99	22.80	0.28	0.22	12.99
Number of branches	31.89	43.82	0.53	3.02	47.81
Branch length	10.93	29.98	0.13	1.34	8.21
Number of leaves	29.14	42.50	0.47	33.07	41.16
Leaf width	3.61	8.81	0.17	0.07	3.05
Leaf length	3.54	9.33	0.14	0.19	2.76
Petiole length	3.53	18.34	0.04	0.00	1.40
Leaf area	6.55	15.86	0.17	0.62	5.58

Table 10. Correlation between different nursery traits

Parameters	Germination (%)	Height (cm)	Diameter (mm)	No. of branch	Branch length (cm)	No. of leaves	Leaf width (cm)	Leaf length (cm)	Petiole length (cm)	Leaf area (cm²)
Germination percent	1									
Seedling height	0.19	1								
Collar diameter	-0.04	0.53*	1							
Number of branch	0.01	0.43	0.59**	1						
Branch length	-0.14	0.37	0.36	-0.14	1					
Number of leaves	-0.28	0.50*	0.53*	0.32	0.49*	1				
Leaf width	0.27	-0.14	-0.2	-0.08	-0.03	-0.2	1			
Leaf length	0.06	0.12	0.12	0.21	0.09	0.07	0.53*	1		
Petiole length	0.28	-0.07	-0.05	-0.04	-0.2	-0.33	0.77**	0.60**	1	
Leaf area	0.18	-0.02	-0.05	0.06	0.03	-0.07	0.86**	0.88**	0.78**	1

(**) – Highly significant and correlation is significant at the 0.01 level
(*) - Significant and correlation is significant at the 0.05 level

positive correlation was showed by branch length with number of leaf (0.49). Similar findings were obtained in *Bauhinia vahii* (Shweta 2020) and in Kaphal (Rawale 2020).

Principal component analysis: PCA (principal component analysis) (Table 11) results showed that the first principal components (PC I) gave eigen values >1.0 and accounted for 33.99% of the total variation for leaf parameters like leaf length (0.71), leaf width (0.89), petiole length (0.89) and leaf area (0.91). Thus, the use of these characteristics will help in saving a considerable amount of time for the identification and selection of best genotypes of *D. montana*. The third component explained 12.86% of total variation. The fourth component (Fig. 1) explained 10.35% of total variation followed by germination percent (0.71). Similar types of findings were also supported by Sharma et al (2019) in *Salix*

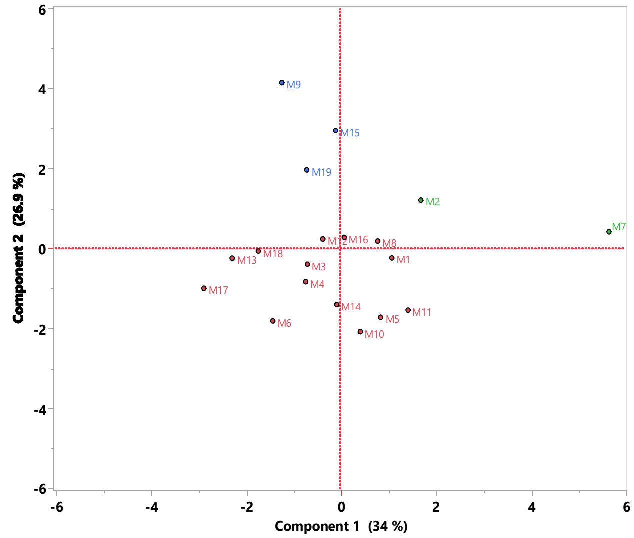

Fig. 1. Scatter plot diagram of PC1- PC2 for nursery traits

Table 11. Principal component analysis for seedling traits

Parameters	PC1	PC2	PC3	PC4
Germination percent	0.34	0.00	0.54	0.71
Height of seedlings	-0.22	0.74	0.2	0.36
Collar diameter	-0.28	0.79	0.19	-0.06
Number of branches	-0.11	0.62	0.58	-0.41
Branch length	-0.22	0.5	-0.65	0.41
Number of leaves	-0.42	0.7	-0.29	-0.07
Leaf width	0.89	0.11	-0.13	0.08
Leaf length	0.71	0.49	-0.14	-0.21
Petiole length	0.89	0.12	0.08	0
Leaf area	0.91	0.34	-0.17	-0.09
Eigen value	3.4	2.69	1.29	1.03
Percent of variance	33.99	26.86	12.86	10.35
Cumulative percent	33.99	60.84	73.71	84.06

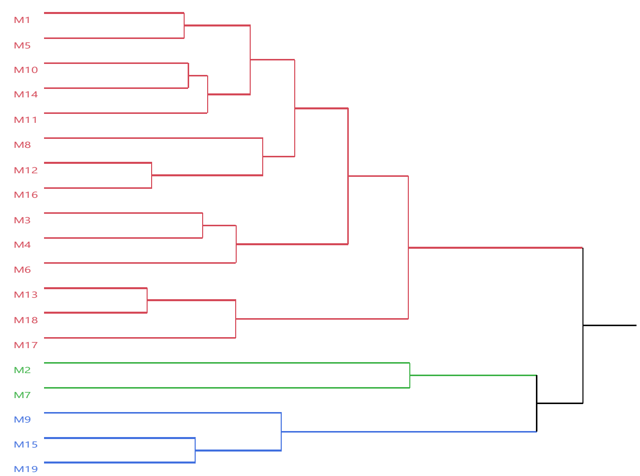

Fig. 2. Dendrogram showing clusters for seedling traits

Table 12. Mean value of seedling parameters for the clusters analysis

Cluster	1	2	3
No. of mother trees in cluster count	14	2	3
Notation of trees	M_1, M_3, M_5, M_4, M_6, M_{10}, M_{12}, M_{13}, M_{16}, M_{17}, M_{18} , M_8, M_{11}, M_{14}	M_2, M_7	M_9, M_{15}, M_{19}
Germination percent	22.21	26.50	24.22
Seedlings height	38.66	39.50	48.18
Collar diameter	1.60	1.68	2.01
Number of branches	5.60	8.53	8.22
Branch length	16.12	13.72	18.87
Number of leaves	74.60	59.00	121.44
Leaf width	2.36	2.53	2.37
Leaf length	6.65	7.29	6.90
Petiole length	0.23	0.26	0.24
Leaf area	10.89	12.83	11.38

tetrasperma, where 82.84% of variation was showed by five principal components.

Cluster analysis: In cluster analysis cluster I and II (Fig. 2) contained desirable characters. Cluster II reported maximum values for germination percent (26.50), number of branches (8.53), leaf width (2.53), leaf length (7.29), petiole length (0.26) and leaf area (12.83). Cluster III reported maximum values for seedling height (48.18), branch length (18.87), collar diameter (2.01), number of leaves (121.44) In *Myrica esculanta* six clusters were observed for seedling parameters out of which cluster IV, V and VI contained maximum values for germination percent, leaf parameters and seedling height (Rawale 2020).

CONCLUSION

The maximum fruit weight, fruit length, fruit width and germination per cent was recorded for M_5 and M_7. The higher values of PCV and GCV for germination percent indicated that further improvement can be achieved through selection based on these characters. High heritability with high genetic advance indicated that selection of this character would be more effective. Repeatability coefficient was recorded maximum for seed length. M_7 has better growth characters so further investigations should be conducted on M_7.

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Performance of Promising Okra Varieties and Fertilizers under Fruit Tree Based Agroforestry Systems

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Abstract: The performance of different varieties of Okra (*Abelmoschus esculentus* Moench) was studied under different agroforestry systems and open conditions. The treatments included 2 agroforestry systems (apricot, pear), 2 planting conditions (inside canopy and outside canopy), 3 fertilizer doses (RDF-75:50:50 NPK Kg ha^{-1} + FYM @ 15 tha^{-1}, Jeevamrut @500 l ha^{-1}, FYM @ 15 t ha^{-1}) and 3 okra varieties viz. Kranti, Nauni P-8 and Tender. The plot size was 2m x 1m. The experiment was laid out in Randomised Block design (factorial) and data was recorded in three replications for each treatment including tree and treeless plots. Plant height (63.00 cm) and internodal length (11.76 cm) were found maximum under open system as compared to agroforestry systems. Among varieties, the maximum number of nodes per plant (10.43), yield (82.10 q ha^{-1}) and number of fruits per plant (11.51) were maximum in Nauni P-8 variety. Plant height (62.03cm) was found maximum in Kranti variety. Amongst different fertilizer doses, NPK + FYM @15t ha^{-1} significantly produced maximum plant height (64.30 cm), internodal length (11.96 cm), number of fruits per plant (11.69) as compared to other fertilizers. Hence it may be concluded that among varieties, Nauni P-8 variety performed better as compared to other varieties and should be grown under the influence of NPK + FYM @15t ha^{-1} for better growth and production.

Keywords: FYM, RDF, Jeevamrut

Agroforestry is the collective name for land use system in which woody perennials (trees, shrubs etc.) are grown in association with herbaceous plants (crops, pastures) and/or livestock in spatial arrangement, a rotation, or both and in which there are both ecological and economic interactions between the tree and non-tree component of the system (Young 1989). Fruit-tree-based agroforestry systems have been only modestly studied, especially in terms of quantification of biophysical interactions occurring in mixtures of fruit trees and crops (Bellow 2004). In Himachal Pradesh temperate trees such as apple, apricot, peach, pear and plum are most commonly used in agroforestry system. The aspect and season also play a significant role in grain, straw and biological productivity of agricultural crops present in agri-horticulture and sole cropping system.

In case of sloppy land sole agricultural practices are difficult, therefore different agroforestry combinations are preferred by the farmers. Retention of fruit trees on their agricultural fields for additional monetary gain from the fruits and therefore, agri-horticulture practice is the priority of high land holding farmers as the climatic and geographical situations also permit such practices (Bijalwan 2012).

The development of agroforestry for the industrialized countries can be furthered by an understanding of the history and present functioning of traditional systems. In temperate Europe also fruit trees were traditionally grown on agricultural lands under-sown with crops or managed grasslands called Streuobst (Herzog 1998). In 1981-86, an average 74.3 per cent fruits harvested in Germany came from Streuobst and from fruit trees in gardens. In Himachal Pradesh, diversification from cereal based cropping to vegetables is gaining momentum. The temporal changes in the cropping pattern bring out the process of crop diversification towards fruits and vegetable crops in Kullu, Shimla, Kinnaur and Lahaul Spiti followed by Solan, Sirmour and Chamba. The process of diversification varies across districts depending upon agroclimatic conditions (Sharma 2011). Locally adapted niche based indigenous vegetables are consumed traditionally as special dishes based on age-old indigenous wisdom of their nutritive and medicinal values in different areas (Kumar et al 2014).

The glorious food grain production couldn't save our majority of population from malnutrition problem due to inadequate consumption of costly animal food products. Vegetables being cheap and rich source of nutrients, vitamins and carbohydrates may lead to solve this problem upto a greater extent. The present production system has endangered our health and environmental security due to abundant use of chemical fertilizers and pesticides. Organic farming has been used to develop an alternative eco-friendly technology for sustainable vegetable production (Singh et al 2000).

Okra (*Abelmoschus esculentus* L. Moench) also known as lady's finger or bhindi belongs to family Malvaceae. India is one the leading okra producer with the production of 6.346 million tonnes per year from an area of 0.532 million ha, with the productivity of 11.9 t ha^{-1} (National Horticulture Board 2014) and it is cultivated extensively round the year for its immature fruits. Higher production of this crop is possible by the cultivation of varieties or hybrids which show remarkable enhanced returns, compared to other cultivars grown at same climatic conditions and inputs applied (Javed et al 2009).

The present production system has endangered our health and environmental security due to abundant use of chemical fertilizers and pesticides. Organic farming has been used to develop an alternative eco-friendly technology for sustainable vegetable production (Singh et al 2000). Organic products fetch very high premium prices in the market from the consumers, which are often as high as 2-3 times more than that of inorganic produce which makes organic farming a highly profitable enterprise (Thakur and Sharma 2005).

MATERIAL AND METHODS

An experiment was conducted in the experimental field of the Department of Silviculture and Agroforestry, Dr. YSP University of Horticulture and Forestry, Nauni, Solan (H P) during June, 2020. The experimental site falls in mid hill zone of Himachal Pradesh at 300 51' N latitude and 760 11' E longitude, with an elevation of 1200 m amsl. The area falls in sub-tropical, sub-humid agro-climatic zone of Himachal Pradesh, India. May and June are the hottest months, whereas December and January are the coldest months and experience severe frost during winter. On an average the annual rainfall received varies from 1000-1400 mm; about 75 per cent being received during the monsoon period (June-Septmber). The soils of the area belongs to Typic Eutrochrept at subgroup level according to Soil Taxonomy of USDA.

The design used for the experiment was Randomised Block Design and treatment combinations include 2 (tree components: apricot and pear), 2 (planting condition: Inside and outside canopy), 3 varieties (Kranti, P-8, and Tender), 3 nutrient and fertilizer doses viz. RDF (75:50:50 NPK Kg ha^{-1} + FYM @15 t ha^{-1}), Jeevamrut (500 litres ha^{-1}) and FYM (15 t ha^{-1}).

The cropped area was managed in the same way as commercial crops. Open plots was an area where different bhindi varieties were sown without trees (pear and apricot), and it was established in close proximity to agroforestry systems. Bhindi varieties were sown at a spacing of 45 cm x 15 cm. Open plots were also subjected to same fertilizer doses. The data were subjected to analysis of variance (ANOVA) using IBM_ SPSS Statistics_ 26 software to evaluate difference between treatments, where ANOVA indicated that treatments effects were significant at p=0.05

The height and girth were measured with the help of calliper and tape, respectively during the two years. The crown spread (m2) was also measured with the help of measuring tape. Light Transmission Ratio of two systems pear and apricot was taken with the help of luxmeter. Fruit yield of tree was measured during the two respective years (2020-2021).

RESULTS AND DISCUSSION

Tree growth parameters: The mean tree height was 2.03 m, 2.15 m in pear based agroforestry system and 5.12 m, 5.29 m in apricot bsed agroforestry system during 2020-2021. Crown spread was found more in apricot trees during ist and 2nd year (1.24 m^2, 1.31 m^2) as compared to pear trees (0.70 m^2, 0.58 m^2). Light transmission ratio was more under pear based agroforestry system (86.74%, 87.55%) as compared to apricot (77.50%, 78.34%) during two years of study. Light is considered to be major limiting factor under agroforestry systems. Fruit yield (t ha^{-1}) was also found to be more in pear based agroforestry system (50.35 t ha^{-1}, 6.06 t ha^{-1}) as compared to apricot (45.55 t ha^{-1}, 62.53 t ha^{-1}) during 2020 - 2021.

Effect of systems, varieties and fertilizers on okra growth parameters: Various crop parameters were recorded and the performance of three okra varieties and three fertilizers doses is presented in Table 1, 2 ,3 and 4. Pooled data of both the years (2020-2021) revealed that plant height and internodal length were found to be maximum (63.00 cm, 11.76 cm) in open system and minimum (54.01 cm, 10.21 cm) under apricot based agroforestry system (Table 1 and 2). Days to first flowering (53.74 days) were found maximum under apricot based system and minimum (50.27 days) under open system. Number of nodes plant^{-1} were found maximum (10.41) under open and minimum (8.95) in apricot based system. The probable reason might be less availability of light under apricot system (Table 1). These results are in accordance with Bhusara et al (2018) while studying the performance of different okra varieties under different spacings of Melia composita based agroforestry system and found that varieties performed better under open conditions as compared to agroforestry systems. Das et al (2020) also found that yield of okra was reduced to 7.57% under agroforestry system as compared to open.

Bhindi varieties performed significantly with respect to

Table 1. Effect of systems, varieties and fertilizer doses on plant height (cm), days to Ist flowering and no. of nodes per plant of *Abelmoschus esculentus*

Treatments	Plant height (cm)			Days to Ist flowering			Number of nodes plant^{-1}		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Systems									
Apricot (S_A)	52.42^c	55.59^c	54.01^c	53.79^a	53.69^a	53.74^a	8.99^c	8.90^c	8.95^c
Pear (S_P)	56.99^b	59.32^b	58.16^b	53.29^{ab}	53.63^{ab}	53.46^{ab}	9.58^b	9.63^b	9.60^b
Open (S_O)	61.57^a	64.43^a	63.00^a	49.97^c	50.57^c	50.27^c	10.08^a	10.74^a	10.41^a
CD (p=0.05)	4.01	3.53	3.73	2.30	2.23	2.20	0.39	0.44	0.40
SE (m)	1.41	1.24	1.31	0.81	0.78	0.77	0.13	0.15	0.14
Varieties									
Kranti (V_1)	61.15^a	62.90^a	62.03^a	51.98	52.03	52.01	8.99^{bc}	9.18^{bc}	9.08^{bc}
Nauni P-8 (V_2)	56.16^b	59.12^b	57.64^b	52.78	52.88	52.83	10.29^a	10.57^a	10.43^a
Tender (V_3)	53.66^{bc}	57.33^{bc}	55.50^{bc}	52.28	52.97	52.63	9.37^b	9.53^b	9.45^b
CD (p=0.05)	4.01	3.53	3.73	NS	NS	NS	0.39	0.44	0.40
SE (m)	1.41	1.24	1.31	0.81	0.78	0.77	0.13	0.15	0.14
Fertilizers									
RDF+ FYM (F_1)	62.88^a	65.73^a	64.30^a	54.01^a	54.49^a	54.25	10.15^a	10.53^a	10.34^a
Jeevamrut (F_2)	51.92^c	54.80^c	53.36^c	51.07^c	51.22^c	51.15	9.68^{ab}	9.85^b	9.76^b
FYM (F_3)	56.18^b	58.82^b	57.50^b	51.96^b	52.18^b	52.07	8.82^c	8.89^c	8.85^c
SE (m)	1.41	1.24	1.31	0.81	0.78	0.77	0.13	0.15	0.14
CD (p=0.05)	4.01	3.53	3.73	2.30	2.23	2.20	0.39	0.44	0.40

Table 2. Effect of systems, varieties and fertilizer doses on internodal length (cm), number of fruits plant^{-1} and fruit length (cm) of *Abelmoschus esculentus*

Treatments	Internodal length (cm)			Number of fruits plant^{-1}			Fruit length (cm)		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Systems									
Apricot (S_A)	10.07^c	10.36^c	10.21^c	10.06^c	10.09^c	10.07^c	10.78^c	11.01^c	10.90^c
Pear (S_P)	11.04^b	11.58^b	11.31^b	11.04^b	11.07^b	11.05^b	11.88^b	12.12^b	12.00^b
Open (So)	11.52^a	12.01^a	11.76^a	11.52^a	11.54^a	11.53^a	12.41^a	12.85^a	12.63^a
SE (m)	0.11	0.14	0.11	0.15	0.15	0.15	0.17	0.18	0.18
CD (p=0.05)	0.31	0.39	0.33	0.43	0.43	0.43	0.50	0.53	0.51
Varieties									
Kranti (V_1)	10.80	11.18	10.99	10.05^c	10.07^c	10.06^c	10.99^c	11.27^c	11.13^c
Nauni P-8 (V_2)	10.93	11.33	11.13	11.50^a	11.52^a	11.51^a	12.17^a	12.49^a	12.33^a
Tender (V_3)	10.90	11.43	11.17	11.08^{ab}	11.10^{ab}	11.09^{ab}	11.91^{ab}	12.23^{ab}	12.07^{ab}
SE (m)	0.11	0.14	0.11	0.15	0.15	0.15	0.17	0.18	0.18
CD (p=0.05)	NS	NS	NS	0.43	0.43	0.43	0.50	0.53	0.51
Fertilizers									
RDF+ FYM (F_1)	11.82^a	12.11^a	11.96^a	11.68^a	11.70^a	11.69^a	12.47^a	12.78^a	12.62^a
Jeevamrut (F_2)	10.87^b	11.27^b	11.07^b	10.99^b	11.01^b	11.00^b	11.65^b	11.99^b	11.82^b
FYM (F_3)	9.94^c	10.56^c	10.25^c	9.97^c	9.99^c	9.98^c	10.95^c	11.21^c	11.08^c
SE (m)	0.11	0.14	0.11	0.15	0.15	0.15	0.17	0.18	0.18
CD (p=0.05)	0.31	0.39	0.33	0.43	0.43	0.43	0.50	0.53	0.51

number of nodes per plant, internodal length, and number of fruits per plant. Kranti variety showed maximum plant height (62.03 cm) and minimum (55.50 cm) in Tender variety. Nauni P-8 variety showed maximum number of nodes per plant (10.43), number of fruits per plant (11.51) as compared to other two varieties. Prasad et al 2018 also demonstrated that the maximum fruit length was found in OKHYB-15 (13.26 cm) and minimum (10.32 cm) in OKHYB-12. This is due to differences in genetic makeup and prevailing environmental conditions. Similar results have been reported by Dhankar and Singh (2008). The difference in days to flowering in different varieties may be due to differences in their genetic makeup.

Different fertilizers varied significantly with respect to their plant height, internodal length, numberof fruits per plant. Pooled data of both the years showed that fertilizer NPK + FYM @ 15 t ha^{-1} produced significantly maximum plant height (64.30 cm), internodal length (11.96) than the rest of other fertilizers used. Number of fruits per plant (11.69) were found to be maximum in NPK +FYM @ 15 t ha^{-1} and minimum (9.98) in FYM @ 15 t ha^{-1} as depicted in Table 2. Kumar et al 2011 also demonstrated that yield of *pennisetum glaucum* was 153.90% higher in treatment combination of NPK (NPK 100:60:40 + FYM @ 10 t ha^{-1} as compared to usage of FYM @ 10 tha^{-1}. These findings are also found coherent with Islam et al. (2019) and Ullah et al (2008). Inorganic fertilizers release nutrients abruptly whereas organics release nutrients slowly; therefore, plants get nutrients for a longer period of time allowing better growth and productivity.

Effect of systems, varieties and fertilizers on growth and yield attributes of okra: The fruit length, fruit diameter, fruit weight and yield were significantly influenced by the systems. The fruit diameter, fruit weight and yield were found maximum under open system (12.20 mm, 12.07 gm, 83.25 q ha^{-1}) than other agroforestry systems. Among varieties fruit length and fruit weight (12.33 cm, 11.98 gm) were maximum in Nauni P-8 variety and minimum under Kranti variety (Table 2 and Table 3).

Fruit yield per plot and yield were also found to be

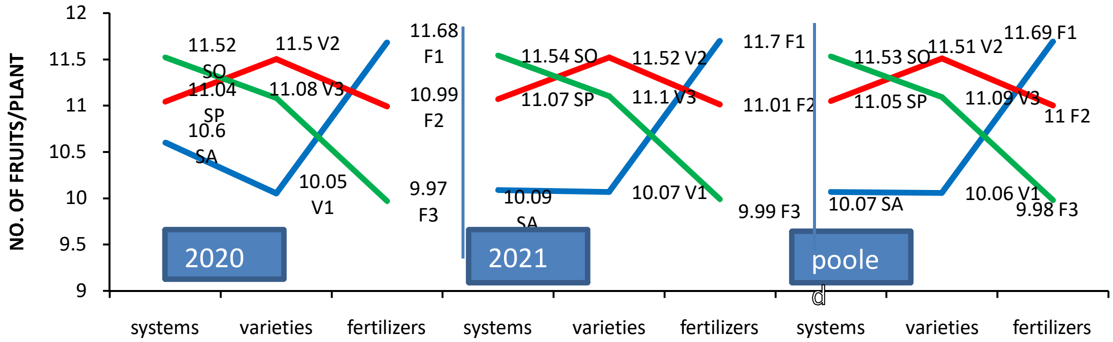

Fig. 1. No. of fruits per plant of *Abelmoschus esculentus* L. Moench as influenced by systems, varieties and fertilizer doses

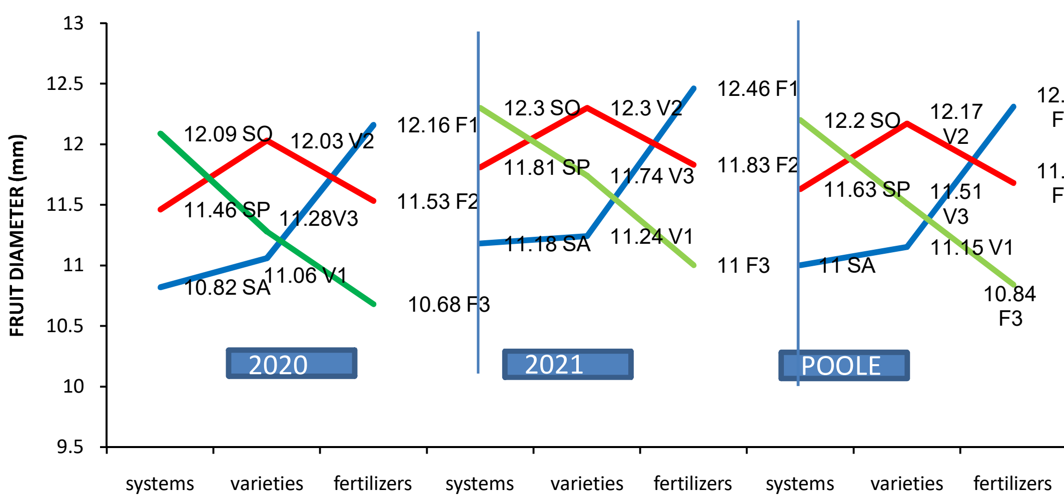

Fig. 2. Fruit diameter of *Abelmoschus esculentus* L. Moench as influenced by systems, varieties and fertilizer doses

Table 3. Effect of systems, varieties and fertilizer doses on fruit diameter (mm) and fruit weight (gm) of *Abelmoschus esculentus*

Treatments	Fruit diameter (mm)			Fruit weight (gm)		
	2020	2021	Pooled	2020	2021	Pooled
Systems						
Apricot (S_A)	10.82 c	11.18 c	11.00 c	10.67 c	10.91 c	10.79 c
Pear (S_P)	11.46 b	11.81 b	11.63 b	11.30 b	11.43 b	11.37 b
Open (S_O)	12.09 a	12.30 a	12.20 a	12.01 a	12.13 a	12.07 a
SE (m)	0.13	0.12	0.12	0.16	0.17	0.16
CD (p=0.05)	0.38	0.36	0.36	0.46	0.50	0.46
Varieties						
Kranti (V_1)	11.06 bc	11.24 c	11.15 bc	10.50 c	10.80 c	10.65 c
Nauni P-8 (V_2)	12.03 a	12.30 a	12.17 a	11.92 a	12.04 a	11.98 a
Tender (V_3)	11.28 b	11.74 b	11.51 b	11.54 ab	11.63 ab	11.59 ab
SE (m)	0.13	0.12	0.12	0.16	0.17	0.16
CD (p=0.05)	0.38	0.36	0.36	0.46	0.50	0.46
Fertilizers						
RDF+FYM (F_1)	12.16 a	12.46 a	12.31 a	12.27 a	12.37 a	12.32 a
Jeevamrut (F_2)	11.53 b	11.83 b	11.68 b	11.32 b	11.48 b	11.40 b
FYM (F_3)	10.68 c	11.00 c	10.84 c	10.38 c	10.63 c	10.50 c
SE (m)	0.13	0.12	0.12	0.16	0.17	0.16
CD (p=0.05)	0.38	0.36	0.36	0.46	0.50	0.46

Table 4. Effect of systems, varieties and fertilizer doses on fruit yield plot^{-1} and yield (q ha^{-1}) of *Abelmoschus esculentus*

Treatments	Fruit yield plot^{-1} (kg)			Yield (q ha^{-1})		
	2020	2021	Pooled	2020	2021	Pooled
Systems						
Apricot (S_A)	1.42 c	1.46 c	1.44 c	71.46 c	73.29 c	72.38 c
Pear (S_P)	1.52 b	1.57 b	1.55 b	76.35 b	78.90 b	77.63 b
Open (S_O)	1.60 a	1.67 a	1.64 a	80.46 a	86.03 a	83.25 a
SE (m)	0.02	0.02	0.02	1.33	1.50	1.34
CD (p=0.05)	0.07	0.08	0.07	3.79	4.27	3.82
Varieties						
Kranti (V_1)	1.40 c	1.45 c	1.42 c	70.18 c	72.74 c	71.46 c
Nauni P-8 (V_2)	1.59 a	1.66 a	1.62 a	79.72 a	84.48 a	82.10 a
Tender (V_3)	1.56 ab	1.60 ab	1.58 ab	78.37 ab	81.01 ab	79.69 ab
SE (m)	0.02	0.02	0.02	1.33	1.50	134
CD (p=0.05)	0.07	0.08	0.07	3.79	4.27	3.82
Fertilizers						
RDF+FYM (F_1)	1.67 a	1.72 a	1.70 a	83.88 a	86.33 a	85.11 a
Jeevamrut (F_2)	1.53 b	1.58 b	1.55 b	76.51 b	80.33 b	78.42 b
FYM (F_3)	1.35 c	1.41 c	1.38 c	67.87 c	71.57 c	69.72 c
SE (m)	0.07	0.08	0.07	3.79	4.27	3.82
CD (p=0.05)	0.02	0.02	0.02	1.33	1.50	1.34

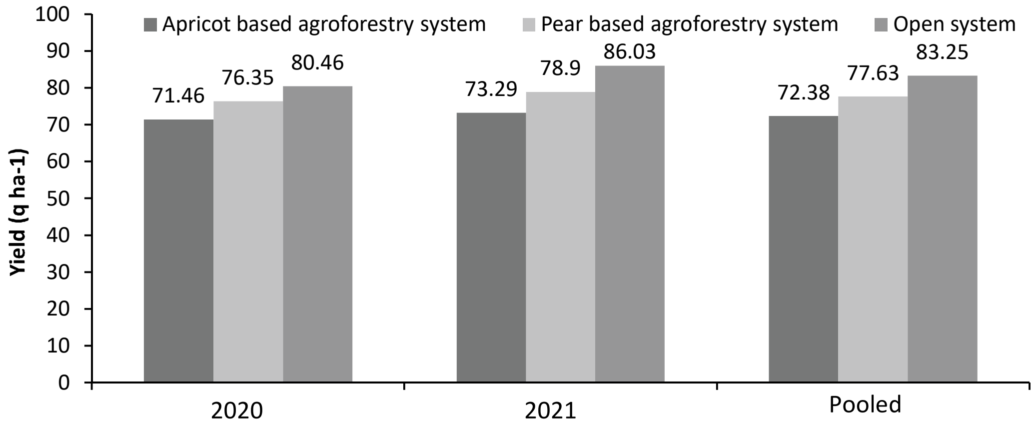

Fig. 3. Yield (q ha^{-1}) of *Abelmoschus esculentus* L. Moench influenced by systems

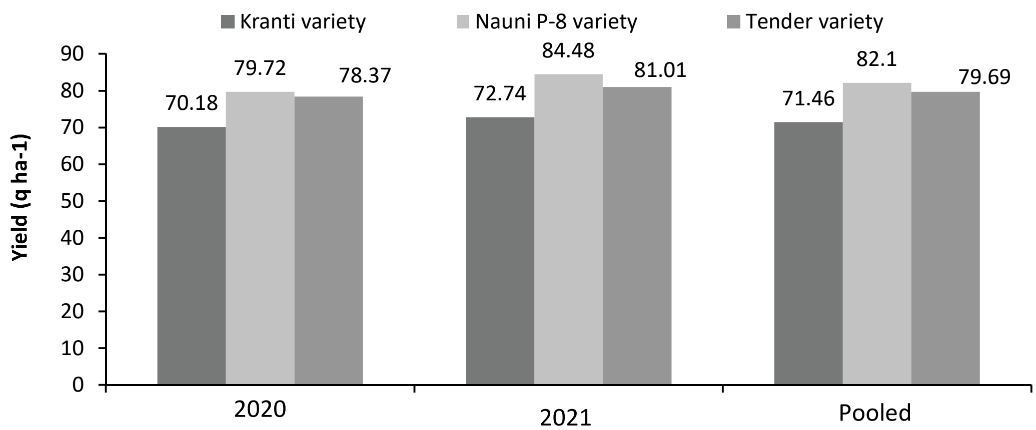

Fig. 4. Yield (q ha^{-1}) of *Abelmoschus esculentus* L. Moench influenced by varieties

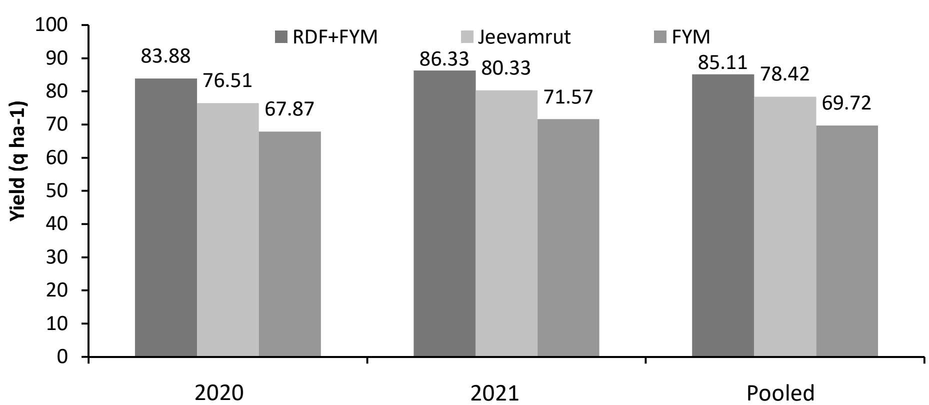

Fig. 5. Yield (q ha^{-1}) of *Abelmoschus esculentus* L. Moench influenced by fertilizer doses

maximum (1.62 Kg^{-plot}, 82.10 q ha^{-1}) in Nauni P-8 variety and minimum was found in Kranti variety as depicted in table4.

Different fertilizers revealed significant result for fruit length, yield and fruit yield per plot. The fruit length, fruit yield per plot and yield was found maximum (12.62 cm, 1.70 kg^{-plot}, 85.11 q ha^{-1}) were maximum in treatment comprising NPK + FYM @ 15 tha^{-1}. Results are found similar with Sruthi *et al.* 2020 where fruit weight, fruit diameter and fruit yield per plot were significantly higher in cucumber with the combined application of NPK + FYM as compared to other treatments. However among fertilizers maximum fruit weight (12.32 gm) was found in treatment comprising NPK 75: 50:50 Kg ha^{-1} +

FYM@ 15 t ha^{-1}) and minimum (10.50 gm) was recorded in FYM @ 15 tha^{-1}. Fruit diameter was found maximum (12.31 mm) in NPK + FYM @ 15 tha^{-1} and minimum (10.84 mm) in FYM @ 15 tha^{-1}(Table 3).

CONCLUSIONS

The results of the present study indicates that yield of okra was significantly higher under open system as compared to agroforestry systems. Varieties Nauni P-8 and tender performed better in terms of growth related attributes. Fertilizer NPK + FYM @ 15 tha^{-1} was found effective in controlling growth and yield parameters as compared to sole application of fertilizer doses.

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Effect of Pre-Harvest Treatments on Physical, Yield and Shelf-life of Sapota Fruits cv. Kalipatti

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Abstract: The pre-harvest treatments were applied during two seasons *viz.,* winter (season-1) (Salicylic acid during 1st week of October and $CaCl_2$ during 2nd week of November) and summer (season-2) (Salicylic acid during 1st week of January and $CaCl_2$during 2nd week of February) in 'Kalipatti' cultivar of sapota. The results of the study revealed that pre-harvest application of 2000 ppm salicylic acid + 1.5 % $CaCl_2$significantly influenced physical parameters like fruit weight (89.78 and 88.34g), fruit length (5.73 and 5.66cm), fruit diameter (5.61 and 5.58cm), fruit volume (83.88 and 82.76cc), pulp weight (77.80 and 76.18g), peel weight (9.59 and 9.46g) and seed: pulp ratio (0.022 and 0.022) during winter and summer seasons, respectively. Same treatment recorded highest yield (165.90 kg $tree^{-1}$) and shelf-life (10.46 and 10.35 days) during winter and summer seasons. Whereas, highest benefit:cost ratio was recorded in treatment 2000 ppm salicylic acid + 1.0 % $CaCl_2$ (1.64) which followed by 1000 ppm Salicylic acid + 1.0 % $CaCl_2$(1.60) and 2000 ppm Salicylic acid + 1.5 % $CaCl_2$(1.56).

Keywords: Shelf-life, Pre-harvest, Climacteric, Salicylic acid, Calcium chloride

Sapota [*Manilkara achras* (Mill.) Fosberg] also called as "*Chickoo*" or "Sapodilla", which is an evergreen tree and belongs to the family Sapotaceae. It is a crop of the tropical region, native to Mexico and Central America. In India, it was first time introduced at Gholwad village of Maharashtra state in 1898 (Chadha 1992). It occupies a significant position among the fruit crops in India. The states that are growing sapota on a commercial scale in India are Maharashtra, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Kerala, Uttar Pradesh, West Bengal and parts of Punjab and Haryana (Cheema et al 1954, Purseglove 1968, Singh 1969). India is considered to be the largest producer of sapota in the world occupying an area of 83 thousand ha with annual production of10.03 lakh MT (Anon. 2020a). In Gujarat, the area under sapota cultivation is 27.83 thousand ha with production of 3.1 lakh MT with productivity of 11.06 MT/ha (Anonymous 2020b). Among several varieties grown in India, Kalipatti is a leading cultivar which is grown in states like Maharashtra, Gujarat and North Karnataka. Although sapota is rich in nutritional value, lower shelf life and lack of quality production limit its' cultivation in India.

Fruit condition at harvest is essential for post-harvest performance. This necessitates an appropriate maturity stage, but also involves other aspects like nutritional status of harvested fruits. For this reason, application of pre-harvest chemical substances is considered as one of the most innovative methods to extend the commercial storage life of fruits and vegetables. Accordingly, use of particular agro-chemical substances has been found to delay ripening, decrease post-harvest losses, enhances and maintain fruit quality by reducing the speed of metabolic activities at harvest or during storage (Shafiee et al 2010). Similarly, role of some chemicals could cause an increase in shelf-life of sapota fruit and maintain its marketability for a longer term by arresting the growth and spread of micro-organisms (Sudha et al 2007). Keeping this in view, this experiment was carried out to enhance the physical properties, yield as well as post-harvest life of sapota.

MATERIAL AND METHODS

The study was carried out during 2020-21 at Instructional Farm, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari and Centre of Excellence Department of Post-Harvest Technology, Navsari Agricultural University, Navsari. Experiment was conducted on 31 years old tree planted at spacing of 10 m × 10 m with 10 treatments. Treatment comprises; T_1: 1000 ppm Salicylic acid, T_2: 2000 ppm Salicylic acid, T_3: 3000 ppm Salicylic acid, T_4: 1000 ppm Salicylic acid + 1.0 % $CaCl_2$, T_5: 2000 ppm Salicylic acid + 1.0 % $CaCl_2$, T_6: 3000 ppm Salicylic acid + 1.0 % $CaCl_2$, T_7: 1000 ppm Salicylic acid + 1.5 % $CaCl_2$, T_8: 2000 ppm Salicylic acid + 1.5 % $CaCl_2$, T_9: 3000 ppm Salicylic acid + 1.5 % $CaCl_2$ and T_{10}: Control. Four uniform trees were selected for each treatment. Treatments were applied in two consecutive seasons (Table 1).

Five randomly selected fruits from each treatment were used for estimation of physical parameters like fruit weight, length, diameter, volume, specific gravity, pulp weight, peel weight, number of seeds and weight of seeds during both seasons. Seed: pulp ratio was estimated after separation of seeds and pulp from individual ripen fruit, weight of the seeds and weight of pulp were recorded and seed: pulp ratio was calculated.

The yield was calculated at each picking and averaged of two consecutive seasons. The shelf-life of fruits was noted by keeping the fruits at room temperature and the days taken from harvesting to optimal eating stage. Fruits surviving for longest duration after harvesting were taken into consideration.

RESULTS AND DISCUSSION

Physical parameters: During the winter (season-1) and summer (season-2) seasons of investigation, treatment T_8 (2000 ppm Salicylic acid + 1.5 % $CaCl_2$) recorded highest fruit weight (89.78 g and 88.34 g), length (5.73 cm and 5.66 cm), diameter (5.61 cm and 5.58 cm),volume (83.88 cc and 82.76 cc), pulp weight (77.80 g and 76.18 g) and peel weight (9.59 g and 9.46 g) (Table 1 and Table 2).A perusal of data revealed that various pre-harvest treatments did not have a significant influence on specific gravity, number of seeds per fruit and weight of seed. Seed: pulp ratio was affected significantly by different pre-harvest treatments during winter (season-1) but during summer (season-2) was found non-significant. During winter (season-1) the minimum seed: pulp ratio (0.022) was found in T_8 (2000 ppm Salicylic acid + 1.5% $CaCl_2$) while, the maximum seed: pulp ratio (0.026) was observed in treatment T_{10} (Control) (Table 2).

The significant increase in fruit physical attributes due to pre-harvest application of salicylic acid due to this chemical act as plant growth regulator which plays a significant role in regulating stress responses and plant development processes; including chlorophyll content in leaves, photosynthesis, stomatal conductance, transpiration, ion uptake and transport, crop yield and glycolysis (Asghari and Aghdam 2010). This chemical also has reversion effects of ABA on leaf and fruit abscission and modifying the activity of some important enzymes (Hayat et al. 2010). The increase in fruit physical parameters could also be attributed due to pre harvest spray of $CaCl_2$ which affects the formation and changes of carbohydrates and carbohydrate enzymes, other reasons might be reduction in formation of abscission layer and calcium influence in maintaining the middle lamella of cells (Karemera et al 2014). The present investigation is in conformity with the results reported by Bhalerao et al (2009) and Patel et al. (2017) in sapota.

Yield attributes: The results pertaining to fruit yield (kg $tree^{-1}$) were significantly influenced by different pre-harvest treatments which is presented in Figure 1. The maximum fruit yield (165.90kg $tree^{-1}$) was observed in T_8 (2000 ppm Salicylic acid + 1.5% $CaCl_2$), which was at par with T_5 (2000 ppm Salicylic acid + 1.0% $CaCl_2$) (163.40kg $tree^{-1}$). Whereas, the

Table 1. Spraying frequencies of different treatments

Seasons	Spraying time
Season-1 (Oct.-Nov.)	Salicylic acid was sprayed in the first week of October
	$CaCl_2$ was applied in second week of November
Season-2 (Jan.-Feb.)	Salicylic acid was sprayed in the first week of January
	$CaCl_2$ was applied in second week of November

Table 2. Effect of different pre-harvest treatments on physical attributes of sapota cv. Kalipatti

Treatments	Fruit weight (g)		Fruit length (cm)		Fruit diameter (cm)		Fruit volume (cc)		Specific gravity	
	Season-1	Season -2	Season -1	Season -2	Season -1	Season -2	Season -1	Season -2	Season -1	Season -2
T_1	79.12	78.42	5.16	5.04	5.05	4.91	72.60	73.18	1.10	1.08
T_2	81.79	80.60	5.20	5.12	5.13	5.00	75.50	74.58	1.08	1.08
T_3	80.05	79.10	5.16	5.10	5.09	4.98	73.30	73.64	1.09	1.08
T_4	83.10	82.14	5.41	5.35	5.25	5.14	77.26	75.96	1.08	1.09
T_5	88.68	86.74	5.62	5.58	5.52	5.41	83.45	81.24	1.07	1.07
T_6	82.12	81.03	5.25	5.18	5.14	5.01	76.06	75.16	1.08	1.08
T_7	83.22	82.21	5.62	5.54	5.43	5.37	77.38	76.68	1.08	1.07
T_8	89.78	88.34	5.73	5.66	5.61	5.58	83.88	82.76	1.07	1.07
T_9	82.91	81.90	5.32	5.24	5.14	5.08	76.69	75.50	1.08	1.09
T_{10}	70.12	68.50	5.06	4.97	4.89	4.77	64.76	63.48	1.08	1.08
S. Em. ±	1.68	1.69	0.125	0.127	0.118	0.119	1.70	1.52	0.029	0.030
CD (p=0.05)	4.87	4.88	0.362	0.367	0.340	0.345	4.90	4.40	NS	NS

minimum fruit yield (114.97kg tree^{-1}) was recorded in T_{10} (control).

Pre-harvest application of Salicylic acid showed significant difference in yield parameters this might be due to Salicylic acid treatments are known to promote cell division and expansion (Hayat et al. 2010). The positive effect of Salicylic acid on the growth and yield may be due to its effect on plant hormones (Shakirova 2007). Salicylic acid treatment increased photosynthetic pigments and total carbohydrates (Mady 2009). In addition, it is reported that Salicylic acid treatments increased the net photosynthesis rate, intrinsic CO_2 concentration and water usage effectiveness (Fariduddin et al 2003).

The significant increase in yield due to pre-harvest $CaCl_2$ application is due to role of this chemical in photosynthesis parameters like rate of photosynthesis, transpiration rate and stomatal conductance. Calcium increases photosynthetic performance by maintaining the osmotic strength of cytoplasm in plants (Yang et al 2016).

The present findings are in accordance with results reported by Patel et al (2020) in mango, Champa et al. (2014) and Abbasi et al. (2020) in grape and Erogul and Ozsoydan (2020) in peach.

Shelf-life: During the winter (season-1) and summer (season-2) seasons of investigation, maximum shelf-life (10.46 and 10.35 days, respectively) was observed in treatment T_8 (2000 ppm Salicylic acid + 1.5 % $CaCl_2$), which was statistically at par with T_5 (2000 ppm SA + 1.0 % $CaCl_2$) (10.15 and 10.04 days) and T_7 (1000 ppm Salicylic acid + 1.5 % $CaCl_2$) (10.00 and 9.86 days). While, minimum shelf life 8.73 and 8.65 days was observed in treatment T_{10} (Control) during winter (season-1) and summer (season-2) seasons, respectively.

The present study revealed that pre-harvest spray of

Table 3. Effect of different pre-harvest treatments on physical attributes of sapota cv. Kalipatti

Treatments	Pulp weight (g)		Peel weight (g)		Number of seeds /fruit		Weight of seed (g)		Seed: pulp ratio	
	Season-1	Season -2	Season -1	Season -2	Season -1	Season -2	Season -1	Season -2	Season -1	Season -2
T_1	69.98	69.14	8.10	8.01	2.00	2.20	1.76	1.72	0.025	0.025
T_2	71.99	70.27	8.33	8.18	2.25	2.00	1.74	1.77	0.024	0.025
T_3	72.11	71.34	8.59	8.36	2.20	2.25	1.82	1.75	0.025	0.025
T_4	73.00	72.06	8.69	8.61	2.25	2.25	1.77	1.82	0.024	0.025
T_5	77.08	75.40	9.30	9.08	2.30	2.20	1.68	1.72	0.022	0.023
T_6	72.98	71.68	8.63	8.42	2.05	2.30	1.82	1.77	0.025	0.025
T_7	73.93	73.02	9.02	8.99	2.15	2.05	1.76	1.78	0.024	0.025
T_8	77.80	76.18	9.59	9.46	2.25	2.10	1.68	1.67	0.022	0.022
T_9	73.08	72.15	8.93	8.70	2.15	2.15	1.78	1.81	0.025	0.025
T_{10}	66.98	66.23	7.91	7.84	2.15	2.10	1.73	1.71	0.026	0.026
S. Em. ±	1.39	1.37	0.207	0.195	0.103	0.100	0.048	0.046	0.0008	0.0008
CD (p=0.05)	4.02	3.96	0.599	0.563	NS	NS	NS	NS	2.39	NS

Table 4. Economics of various treatments imposed

Treatments	Total cost (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Benefit: cost ratio
T_1	94354	240180	145826	1.55
T_2	98803	253220	154417	1.56
T_3	98404	244760	146356	1.49
T_4	117885	306380	188495	1.60
T_5	123998	326800	202802	1.64
T_6	117597	291720	174123	1.48
T_7	122678	308560	185882	1.52
T_8	129427	331800	202373	1.56
T_9	124983	305400	180417	1.44
T_{10}	90536	229940	139404	1.54

Total cost= cost of cultivation + treatment cost + Harvesting cost

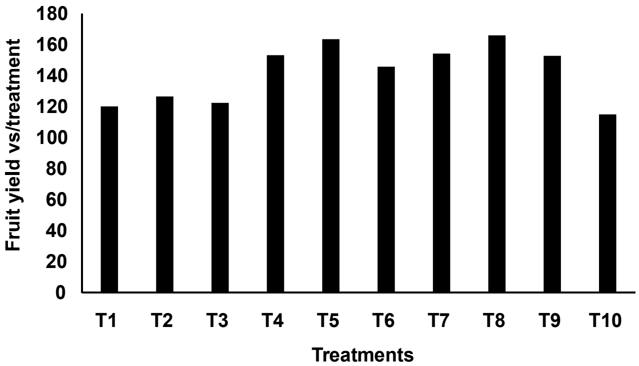

Fig. 1. Effect of different pre-harvest treatments on yield attributes of sapota cv. Kalipatti

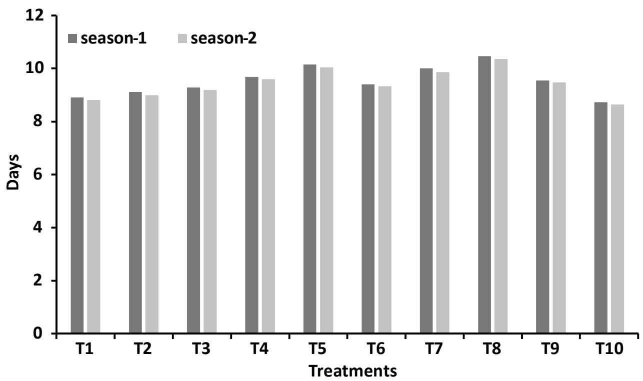

Fig. 2. Effect of different pre-harvest treatments on shelf-life of sapota cv. Kalipatti

Salicylic acid and $CaCl_2$ significantly influenced the shelf life. The positive effect of Salicylic acid which might be due to Salicylic acid slows down the process of ethylene biosynthesis and effectively reduces the transpiration and respiration rate through controlling degradation of cell wall. The exogenous Salicylic acid application also delays the ripening of apple (Yan et al 1998) and banana (Srivastava and Dwivedi 2000). Calcium also plays significant role in extending days taken to ripening and shelf life which might be due to calcium helps in structural integrity and influence cellular organization of the cell wall and plasma membrane, thereby controlling respiratory breakdown which delays ripening and extends storage life. Also, higher calcium levels in fruits leads to the reduction of respiration and ethylene production rates thus delay the ripening of fruits (Karemera et al 2014).

The present investigation is in conformity with the results reported by Sudha et al. (2007), Bhalerao et al (2009), Gondaliya (2016), Desai et al (2017), Patel et al (2017) in sapota as well as Patel et al (2020) and Vidya et al (2014) in mango and Ramesh et al (2014) in papaya.

CONCLUSION

Pre-harvest spray of 2000 ppm salicylic acid (1st week of October and 1st week of January) + 1.5 % $CaCl_2$ (2nd week of November and 2nd week of February) turned out to be the best treatment to reveal improvement in physical, yield and shelf-life of sapota during both the seasons. Salicylic acid (2000 ppm) and $CaCl_2$(1.5 %) could be utilized for enhancing the shelf-life of different cultivars of sapota.

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Population Structure, Fruit Traits Variability and Pre-sowing Seed Treatment in *Hydnocarpus pentandrus* (Buch.-Ham.) Oken. in Central Western Ghats

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Abstract: *Hydnocarpus pentandrus* (Buch.-Ham.) Oken. is a medium-sized tree belonging to Achariaceae family and commonly called as Chaulmoogra. It is one of the threatened forest tree species of Western Ghats and IUCN categorized this species as Vulnerable. Growth structure of these trees varied among studied populations. The flowering and fruiting period was observed during February to May and fruit maturation period is about 12-13 months; hence, there is an overlap in different phenophases like flowering, initial fruit set and old matured fruits in a single tree. Fruit size also vary among populations, where fruits collected from Ladghar populations are comparatively bigger than Parule population, which showed small fruit size. Seeds treated with mixture of goat manure+cocopeat (76%) and mixture of goat manure+soil (68%) resulted in higher germination than rest of the treatments.

Keywords: *Hydnocarpus pentandrus,* Stand structure, Seed oil, Germination

Hydnocarpus pentandrus (Buch.-Ham.) Oken. (Family: Achariaceae) is one of the important rare medical tree species distributed in Western Ghats of India. It is also one of the important TBOs and ecologically this species is a component of moist deciduous and semi-evergreen forests of Western Ghats and also found to grow near moist and shady localities (Joshi and Harijan 2014). *Hydnocarpus* sp. are threatened world-wide; hence, they are known for their ecological and economic significance in the tropical evergreen forest (Majumdar et al 2019). Seed oil extracted from *Hydnocarpus* sp. is commonly known as Chaulmoogra oil and mainly used in the treatment of lepromatous leprosy (Effective in early cases), decreasing the size of nodules, anaesthetic patches and skin lesions. The oil is also recommended as local application in rheumatism, sprains and bruises, sciatica and chest affections. Its seeds have long been used in South India as a remedy for leprosy, chronic skin affections, ophthalmic and as a dressing for wounds and ulcers. In fact, *H. pentandrus* is one of the potential tree species for biodiesel as seed oil meets the specifications of biodiesel (Karthikeyan et al 2013). Tree grows up to 10-12 m tall and associated with mostly *Aporosa cardiosperma* and *Syzygium stocksii* and distributed in the Western Ghats of Maharashtra. In the case of Konkan region, *H. pentendrus* is mainly occurred in Deorai/Rahat of Ratnagiri and Sindhudurg districts; however, it is more abundant in private forests of Sindhudurg district. Normally these trees are located at higher altitude above 300 m MSL and largely distributed near the bank of river and canal. *H. pentendrus* tree had some mythological value in Konkan culture. In olden days, traditionally this oil was extracted from wooden dirt and used in *Deoghar* for lighting lamp. After oil extraction the remaining cake is used on wounds sustained while working in agriculture. Being an endemic species to southern India, forest degradation coupled with over exploitation of fruits from wild leads to decrease in the 40% populations over the last 60 years (About three generations). At present, the species is not found in the type locality and is surviving with only few individuals in the Sindhudurag and Ratnagiri districts. Mostly trees occur at the farms and beside the streams. Therefore, species is assessed as Vulnerable category. Information on ecology, community structure and natural regeneration of *H. pentendrus* in the Northern Western Ghats is scanty. Therefore, present study was carried out to understand the stand structure, phenology, fruit size variation of *H. pentendrus* in the Konkan region of Maharashtra. Pre-sowing treatments were also worked out to enhance seed germination in this species.

MATERIAL AND METHODS

The distribution, population size, habitat characterization of *H. pentendrus* was assessed by conducting field surveys, visiting herbaria, studying literature and interactions with botanists and local people. *H. pentendrus* specimens were examined with the help of taxonomist in Jawaharlal Nehru Tropical Botanic Garden and Research Institute (TBGTI, Palode, Kerala). The geo-coordinates of different assessed populations (Plate 1) were recorded using global positioning system (GPS). For phenology study, monthly field visits were made and flowering and fruiting phenology were recorded. The variation in fruit quality was assessed by collecting ripen fruits during April-May, 2022. To study fruit morphology, 10 fruits were randomly selected and their length and width were measured. Weight of 10 fruits in ten replicates was determined using an analytical balance (Anamed, Model no-AA-2200DS). Apart from this, to enhance seed germination, seeds were exposed to eight different pre-sowing treatments *viz*., T_1 - Scarification (Control), T_2 - Soaking seed in water for 24 hours, T_3 - Soaking seed in GA_3 @ 300 ppm for 24 hours, T_4 - Soaking seed in GA_3 @ 350 ppm for 24 hours, T_5 - Soaking seed in H_2SO_4 1.0%, T_6 - Soaking seed in H_2SO_4 2.0%, T_7 - Goat manure + soil and T_8 - Goat manure + coco-peat (Table 3) using bulk fruits collected from natural population. After collection, fruits are break opened and de-pulped by washing in normal tap water for three to four times and then seed were extracted. Later these seeds were air dried under shade for 12 hours and exposed different pre sowing treatment.

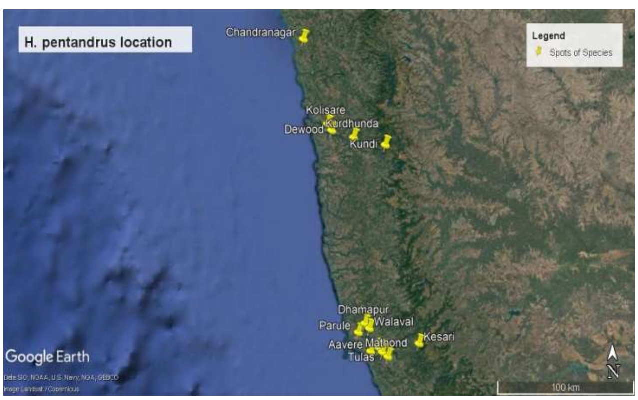

Plate 1. Location of different populations studied

RESULTS AND DISCUSSION

Stand structure and tree growth: The Konkan region of Maharashtra is highly dynamic and vibrant part of the Western Ghats and the region is divided into two agro climatic zones *viz.,* the south Konkan coastal zone with very high rainfall having lateritic soils (Ratnagiri and Sindhudurg districts) and the north Konkan coastal zone having very high rainfall zone with non-lateritic soils (Thane and Raigad districts; Haldankar et al 2014). The study was carried out in the south Konkan coastal agro-climatic region, which covers total 19 field surveys in different forest areas of Sindhudurg and Ratnagiri districts. Total eight populations of *H. pentendrus* were identified through survey. All population are found near the streams in private farms and scared grooves. The trees were located at a low elevation of 8m MSL in Dhamapur region and also at higher elevation of 283 m MSL in Kesari village of Sawantwadi region. Nearly all trees were found in the plains and hilly region with 0º to 47º slopes. However, only two identified sites were located in a moderately sloping region which had a 21º slope with a W268º aspect at Parule and a 19º slope with an S190º aspect at Dhamapur. The survey resulted in the discovery of all trees more than 140 cm GBH with 30-80 age groups. Average GBH of tree varied among population (Table 1). The highest GBH of 480 cm was at Math in Kudal and a minimum GBH of 64 cm at Kesari in Sawantwadi. The tallest trees were measured at Kalambat village in the Dapoli district with a height of 11 m with large crown spread among adult individuals (Table 1). Trees with a maximum crown spread of 37.63 m were recorded at Math, Kudal area and was minimum of 11 m in

Table 1. Population structure of *H. pentandrus* in Cenral Western Ghats

Population	Tree density (Number trees per population)	Tree height (m)	GBH (cm)	Crown spread (m)
Kalambat	04	8.25	141.25	20.83
Ansur	05	7.20	122.23	16.50
Math	06	9.50	318.66	37.63
Mathond	15	7.43	132.67	15.75
Andurle	03	7.00	105.20	11.00
Kashari	14	6.95	110.00	13.02
Ladghar	04	7.90	142.50	17.67
Parule	07	8.75	143.00	15.07
Mean	-	7.87	152.02	18.43
SD (±)	-	0.05	0.47	0.05
CV (%)	-	0.07	0.38	0.03
CD (p=0.05)	-	0.013	1.41	0.014

Andurle area. Study areas in Kesari and Parule show of 100 per cent and 70 per cent ground cover respectively, whereas Kalambat showed a minimum of 10 per cent ground cover.

Phenology and fruit size variation: The flowering and fruiting period was observed during February to May. Fruits began to ripe after the middle of April. Fruit maturation period is about 12-13 months. In this species, at a time, fruit maturation, flowering and new fruit-set were observed in same plant (Table 2). Significant variation in various fruit parameters among eight populations of *H. pentendra* was recorded and depicted in Figure 1. Fruit length varied from 70.1 (Parule population) to 84.3 mm (Ladghar population) among eight populations with overall mean of 74.10 mm. Similarly, significant variation among populations for fruit width (63.1 mm in Parule to 77.4 mm in Ladghar population), fruit thickness (9.50 mm in Parule to 14.8 mm in Ladghar population) and fruit weight (139.7g in Mathond to 325.2 gm in Ladghar population) was also recorded (Fig. 1). Among them, five genotypes recorded with smaller fruits and three genotypes recorded bigger fruits. Irrespective of populations, number of seeds per fruit ranged between 8 and 15 and a greater number of seeds per fruit was in Kalambat population and a smaller number of seeds per fruit was recorded in Ansur and Mathond populations. Seed oil per cent varied among the identified populations of *H. pentendra* and ranged from 37.83 to 40.99 per cent. Such kind of variation in fruit size and seed oil content was also reported in *H. pentendra* by Dhantri (2014) among seed sources of Uttara Kannada district of Western Ghats, where seed oil content varied from 32.35 to 49.49 per cent. Such kind of inferences in terms of variation in population structure, phenology and fruit attributes are also worked out for different forest species; further, geoclimatic variation coupled with genetic attributes resulted in great population variation in most of the morphological traits (Mirgal et al 2013, Gunaga et al 2015, Patwardhan et al 2017, Hegde et al 2018b, Gunaga et al 2020, Sukhadiya et al 2021). Similarly, population variation in fruit & seed traits and seed oil content was also documented in various TBOs like *Pongamia pinnata* (Raut et al 2011), *Garcinia talbotii* (Bansude et al 2013), *Calophyllum inophyllum* (Shinde et al 2012, Rahul and Gunaga 2017) and Mahua (Hegde et al 2018a).

Seed germination: Result showed that different pre-sowing treatments influences the seed germination and its attributes *viz.,* GRI, MDG, PV and GV in *H. pentandrus* (Table 3). Among these eight treatments, seeds treated with mixture of goat manure+cocopeat (76%) and mixture of goat manure+soil (68%) resulted in higher germination than rest of the treatments. Further these treatments also recorded higher GRI, MDG, PV and GV than rest of the treatments. Vidyasagaran (2017) observed that in *Hydnocarpus pentandra* , seed treated with 300 ppm GA_3 without seed coat, followed by 200 ppm GA_3 without seed coat shows highest germination percentage and growth attributes. In present study T8 (Goat manure + coco-peat) and T_7 (Goat manure + soil) are best for seed germination. Seed treatments are essential for orthodox types of seeds and species showing different kinds of seed dormancy. Influence of seed germination was also addressed in many forest species (Gunaga 2011, Nongmaithem et al 2018, Gunaga et al 2015). Hence, it is necessary to workout best pre-sowing treatment for each of the species for better germination and early seedling vigour.

Table 2. Maturity stages of fruiting and flowering at different population site of *H. pentandrus*

Population	Maturity stage						
	Dec-21	Jan -22	Feb-22	March -22	April-22	May-22	June -22
Kalambat	Pre-mature	Pre-mature	Pre-mature	Pre-mature + flowering starting	Pre-mature + Flowering peak period	Mature +peak flowering	New Fruit set
Ansur	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New Fruit set
Math	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature+ Flowering	Mature +peak flowering	New Fruit set
Mathond	Pre-mature	Pre-mature	Mature	Mature+ flowering starting	mature+ flowering starting	Mature +peak flowering	New Fruit set
Andurle	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New Fruit set
Kashari	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New Fruit set
Ladghar	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New Fruit set
Parule	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New Fruit set

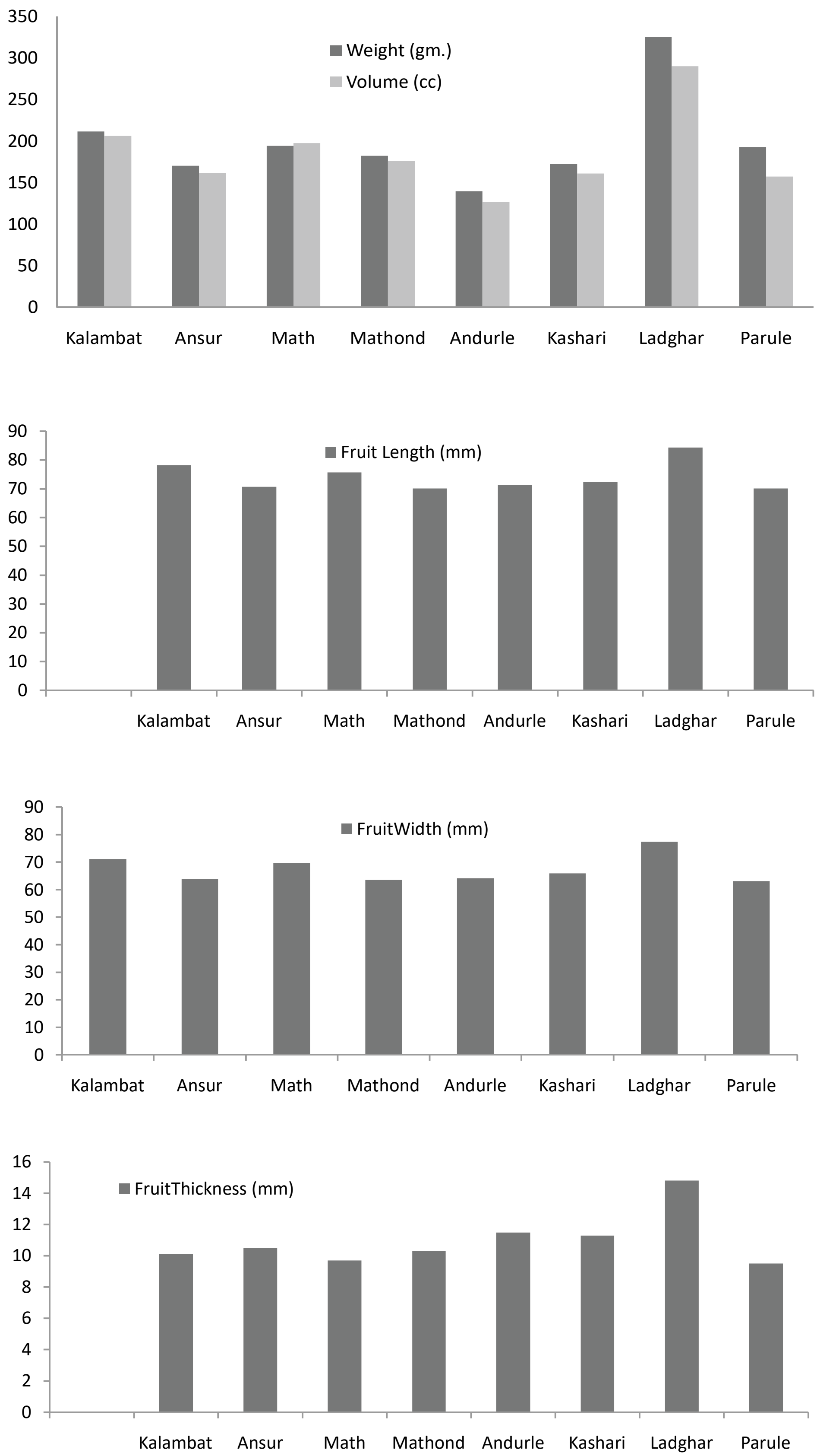

Fig. 1. Variation in fruit traits among eight populations

Table 3. Maturity stages of fruiting and flowering at different population site of *H. pentandrus*

Population	Maturity stage						
	DEC-21	JAN -22	FEB-22	MARCH -22	APRIL-22	MAY-22	JUNE -22
Kalambat	Pre-mature	Pre-mature	Pre-mature	Pre-mature + flowering starting	Pre-mature + Flowering peak period	Mature +peak flowering	New fruit set
Ansur	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New fruit set
Math	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature+ Flowering	Mature +peak flowering	New fruit set
Mathond	Pre-mature	Pre-mature	Mature	Mature+ flowering starting	mature+ flowering starting	Mature +peak flowering	New fruit set
Andurle	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New fruit set
Kashari	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New fruit set
Ladghar	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New fruit set
Parule	Pre-mature	Pre-mature	Pre-mature	Pre-mature+ flowering starting	Pre-mature +Flowering	Mature +peak flowering	New fruit set

Table 4. Effect of different pre-sowing treatments on seed germination of *Hydnocarpus pentandrus*

Pre- sowing treatment		Day of first germination (day)	Day of highest germination (%)	Germination (%)	GRI (%)	MDG (%)	PV (%)	GV (%)
T1	Control	24	47	12	1.30	0.24	0.37	0.09
T2	Soaking seed in cold water for 24 hours	23	38	20	2.37	0.4	0.76	0.30
T3	Soaking seed in GA_3 @ 350 ppm for 24 hours	14	34	32	4.88	0.64	1.6	1.02
T4	Soaking seed in GA_3 @ 300 ppm for 24 hours	15	36	52	7.81	1.04	2.47	2.57
T5	Soaking seed in H_2SO_4 1.0%	16	36	39	6.14	0.77	1.61	1.25
T6	Soaking seed in H_2SO_4 2.0%	17	37	52	7.39	1.04	2.26	2.35
T7	Goat manure + soil	18	42	68	12.24	1.36	3.09	4.20
T8	Goat manure + coco-peat	17	41	76	12.96	1.52	3.61	5.49
Mean				63.76	6.89	0.88	1.97	2.16
SD				1.12	4.19	0.45	1.11	1.90
CV (%)				21.62	0.070	0.017	0.072	0.012

CONCLUSION

The distribution of *Hydnocarpus pentandrus* trees in a population is limited, clustered and showing less density. Population variation in terms of growth structure and phenology was also recorded. Significant variation in fruit attributes among studied populations was observed and there is scope for tree selection and tree improvement in this species. Pre-sowing treatments containing goat manure mixed with either coco-peat or soil enhanced seed germination in this species.

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Nutrient Content and Uptake of Soybean (*Glycin max* L Meril) on different Fertility Levels under Guava Based Agri-horticulture System

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Abstract: A field experiment was carried out at Banaras Hindu University, Mirzapur in kharif season 2018 to study about effect of different fertility levels on nutrient content and uptake of soybean under guava based Agri horticulture system. There were five fertility levels in a randomised block design. The sources of fertilizers were urea, DAP, MOP and elemental sulphur for N, P_2O_5, K_2O, and S application, respectively. The variety of soybean was JS-2029, inoculated with rhizobium culture. Among the different fertility levels the application of 50 kg N, 100 kg P_2O_5, 60 kg K_2O, and 40 kg S ha^{-1} with rhizobium inoculation significantly enhances the nitrogen, phosphorus, potassium and sulphur content and uptake in grain and straw of soybean.

Keywords: Agri Horticulture, Fertility, Guava, Nutrient uptake, Soybean

About 42.8 % population of country relies in agricultural sector for their livelihoods, but it is under severe strain condition as an average land holding are steadily declining. In India, each person has access to 0.12 ha of land for cultivation, compared to 0.29 ha worldwide. From recent few decades agriculture become unlikely by farming community because Indian agriculture is so reliant on climate and weather conditions, less remuneration and high-risk involvement, farmers are also dealing with the critical challenges as a result of climate change (Dhyani et al 2016). As a result, a severe risk is anticipated for satisfying the requirement of increasing population for food, fibre, fuel and fodder while also expanding food grain output (Ram et al 2016). However, throughout the previous few decades, there have been a lot of expectations placed on agroforestry's contribution to climate-smart agriculture. Agroforestry is the collective name of land use system where woody perennials are integrated with agriculture crop on same land unit in such a way that is provides sustainable benefits to farmers. Guava, litchi, custard, apple, aonla, mango and bael, are some of the most popular horticulture trees used in agri-horticulture system.

Pulses offered the most affordable source of high-quality protein for human beings. In India, where the bulk of the population consumes a vegetarian diet, protein deficiency is a wide spread concern. Soybean is a prominent oil seed as well as pulse crop, grown in various parts of the world. It is an excellent source of protein, can supplement in diet. Soybean has roughly 40-45 percent protein, 18-20 percent edible oil, 24-26% carbohydrate, and 3.0-3.6% ash and also rich source of vitamins and minerals (Morshed et al. 2008). Guava is one of a various perennial fruit tree intercropped for not only to increase revenue but also to improve the use of the land by obtaining improved output and to enhance soil health by preventing soil erosion (Sharma et al 2006). Guava is one of the most significant fruits farmed in India, ranking fourth in terms of production and fifth in terms of area. Guava is great source of nutrients, dietary fibre, pectin, and ascorbic acid. Water (80-82%), protein (0.71%), fat (0.5%), carbohydrate (11-13%), and acids (2.4%) are all present in guava fruit (Uchôa et al 2014, Gupta et al 2018). Phosphorus encourages nodule formation and rhizobial activity in legumes, which aids in nitrogen fixation. Additionally, it contributes to respiration, cell growth and division, energy storage, and photosynthesis (Akter et al 2013). Sulphur is related to nitrogen metabolism and is necessary for the creation of proteins, vitamins, and important amino acids that include sulphur. Considering the above fact in view the present study was conducted to evaluate the suitable combination of nutrient to enhance the nutrient content (%) and uptake (kg/ha) of soybean under guava based agri-horticulture system.

MATERIAL AND METHODS

The present investigation was carried out during kharif season, 2018-19 at Banaras Hindu University, situated in

Vindhyan region of Mirzapur, Uttar Pradesh. The experimental site is located in $25^0 10'$ North latitude $82^0 37'$ East longitude and at altitude of 427 meter above mean sea level. This region comes under (Semi-arid eastern plain zone) agro-climatic zone III A. The experimental site was fairly uniform in topography and well drained with poor fertility status where varieties of crop like medicinal, agriculture, horticulture, plants were grown. The climate of site is semi-arid with, and characterised extremes of temperature in both summer and winter with moderate humidity and low rainfall. March to May is generally dry, maximum temperature in summer was 46^0C and minimum temperature in winter fall up to 11^0C. The normal period for onset of monsoon in this region was the third week of June and lasts up to end of September or extended to the first week of October. The annual rainfall of site was 975 mm in 2018, out of which 90 % contributed through south-west monsoon. In order to asses initial fertility status of experimental plots, soil sample from 0-15 cm were randomly collected and analysed for mechanical composition and physio-chemical properties of soil. These samples were air dried and crushed to pass through 2.0 mm sieve. The soil of experimental site was sandy loam in texture with pH 6.1, electrical conductivity 0.18 dS/m (Jackson 1973), organic carbon 0.39 percent (Walkley and Black 1934), available nitrogen 220.89 kg/ha (Subbiah and Asija 1956), available phosphorus 19.50 kg/ha (Olsen et al 1954), available potassium 266.56 kg/ha (Jackson 1973), and available sulphur 1.32 kg/ha (Chesnin and Yein 1950).

Treatment details and input application: The experiment was conducted during the kharif season of 2018-19 in a 12 yar old guava (Allahabad Safeda) based agri horticulture system, which was planted in 2007 with 7×7 meter spacing. Soybean was sown as intercrop at the seed rate 80 kg/ ka, variety JS-2029 was manually sown at 45 cm row to row spacing and planting distance of 5 cm within the row was maintained by thinning at 15 DAS. Before sowing, the seeds were treated with thiram, and rhizobium culture at the rate of 2g/kg and 5g/kg respectively. The experiment was laid out in randomised complete block design with 5 treatments viz., T_1: Control, T2: N (20 kg/ha)+P_2O_5 (40 kg/ha)+K_2O (30 kg/ha)+S (10 kg/ha), T3: N (30 kg/ha)+P_2O_5 (60 kg/ha)+K_2O (40 kg/ha)+S (20 kg/ha),T4: N (40 kg/ha)+P_2O_5 (80 kg/ha)+K_2O (50 kg/ha)+S (30 kg/ha),T5: N (50 kg/ha)+P_2O_5 (100 kg/ha)+K_2O (60 kg/ha)+S (40 kg/ha) with four replications. The data of guava height (m), canopy diameter (m) and stem diameter (cm) were recorded with the help of altimeter and tape at the time of sowing, 40 DAS and at harvesting stage. The data of guava height (m), canopy diameter (m) and stem diameter (cm) were recorded with the help of altimeter and tape at the time of sowing, 40 DAS and at harvesting stage. The different levels of fertilizers as per treatment were applied at the time of sowing. The source of fertilizer Urea, DAP, MOP, Elemental sulphur was calculated per plot and incorporated in the soil at the time of sowing.

$$\text{Fertilizer doses} = \frac{\text{Doses} \times \text{Area}}{100 \times \text{\% of nutrient available in fertilizer}}$$

Analysis of nutrient content in plant sample: The crop was harvested manually when visually observed fully matured. After harvest, the seeds and straw of soybean were dried in hot air oven at 70^0C for at least 48 hours until a constant weight was reached. After that, samples were grinded to pass through 2 mm sieve. The sieved samples were collected and used for chemical analysis viz., nitrogen was estimated by Kjeldahl method (Jackson 1973), phosphorus by di-acid digestion method by spectrophotometer, potassium by di-acid digestion method by Flame photometer, sulphur by di-acid digestion method by spectrophotometer (Bhargav and Raghupati 1993). The percentage of N, P, K, and S were multiplied with grain and stover yield in kg/ha to obtained respective nutrient uptake (kg/ha). Thereafter, nutrient by plant was calculated through following:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Dry matter yield (kg)}}{100}$$

RESULTS AND DISCUSSION

The chemical analysis of soybean showed that nutrient content and their removal significantly influenced with different nutrient management. The nitrogen content of soybean significantly increased with increasing doses of fertilizer. The application of 50 kg N, 100 kg P_2O_5, 60 kg K_2O, and 40 kg S ha^{-1} with rhizobium culture recorded highest nitrogen content in grain (6.03 %) and straw (0.92 %), over rest of the treatment. Similarly, highest nitrogen removal in grain, straw and total removal of soybean increased with increasing fertilizer level. The maximum amount of nitrogen removal (120.8 kg/ ha) was in the T_5 which is superior to rest of the treatment, while lowest was in T_1 (38.59 kg/ha). Solanki et al (2018) studied that highest nutrient uptake obtained with the application of 100 % NPK+FYM over rest of the treatment. Guava's growth metrics, such as height (5.10 m), canopy (5.95 m), and stem diameter (25.95 cm), were measured at seeding, however after harvest, the tree height, canopy, and stem diameter were 5.39 m, 6.28 m, and 26.32 cm, respectively. The increase in guava growth parameters may be caused by the advancement of tree age. The data of guava height (m), canopy diameter (m) and stem diameter (cm) were recorded with the help of altimeter and tape at the time of sowing, 40 DAS and at harvesting stage.

The highest value of P content in grain and straw were with application of (50 kg N, 100 kg P_2O_5, 60 kg K_2O, and 40 kg S ha^{-1}) with rhizobium culture which prove significantly better that rest of the treatment (Table 2). The minimum P content in grain and straw obtained under control. The total phosphorus removal in seed and straw was enhanced with treatment and highest P removal (23.81 kg/ha) in T_5 with rhizobium inoculation and minimum was in control (6.28 kg/ha). The combined application of fertilizer with rhizobium inoculation might enhanced the activity of enzymes in soil which increased availability of P to the plant uptake. Jahangir et al (2009) found that maximum P uptake was (0.72 %) in higher level of fertility management. Dhage et al (2014) also observed that uptake of phosphorus and sulphur in plants increased with increase in rate of combined application of P and S. Similar trend was also reported by Tiwari et al (2019).

The uptake of potassium by seed and straw was significantly enhanced by different fertilizer level with rhizobium inoculation. The highest potassium content in grain (2.55 %) and straw (2.83 %) were found in T_5 where lowest was in T_1. The maximum removal of potassium in grain and straw was found in 50 kg N, 100 kg P_2O_5, 60 kg K_2O, and 40 kg S ha^{-1} with rhizobium culture while minimum was in control (Table 3). Morya et al (2018) has close proximity of nutrient content uptake with the treatment 50 % RDF and 50 % vermicompost which was at par with 100 % RDF in soybean. The application of 75% RDF + Rhi + PSB+ VAM (T_{16}) provides highest K uptake in grain and straw than control (Kumar and Sharma 2018).

Table 1. Effect of NPKS and *rhizobium* on nitrogen content (%) and removal (kg/ha) of soybean under guava based agri-horticulture system

Treatment (N, P_2O_5, K_2O, S)	Nitrogen content (%)		Nitrogen removal (kg/ha)		Total (seed+straw) removal of nitrogen (kg/ ha)
	Seed	Straw	Seed	Straw	
T_1 (Control)	4.23	0.59	33.71	4.88	38.59
T_2 (20,40,30,10)	4.55	0.66	45.38	8.16	53.54
T_3 (30,60,40,20)	5.03	0.73	60.26	10.08	70.34
T_4 (40,80,50,30)	5.55	0.80	72.74	14.92	87.66
T_5 (50,100,60,40)	6.03	0.92	98.68	22.12	120.8
CD (P=0.05)	0.42	0.05	10.19	1.49	

Table 2. Effect of NPKS and *rhizobium* on phosphorus content (%) and removal (kg/ha) of soybean under guava based agri-horticulture system

Treatment (N, P_2O_5, K_2O, S)	Phosphorus content (%)		Phosphorus removal (kg/ha)		Total (seed+straw) removal of Phosphorus (kg/ ha)
	Seed	Straw	Seed	Straw	
T_1 (Control)	0.52	0.24	4.09	2.19	6.28
T_2 (20,40,30,10)	0.63	0.28	6.28	3.70	9.98
T_3 (30,60,40,20)	0.72	0.36	7.88	4.93	12.81
T_4 (40,80,50,30)	0.78	0.44	9.80	8.12	17.92
T_5 (50,100,60,40)	0.86	0.47	14.12	9.69	23.81
CD (p=0.05)	0.03	0.03	1.28	1.05	

Table 3. Effect of NPKS and *rhizobium* on potassium content (%) and removal (kg/ha) of soybean under guava based agri-horticulture system

Treatment (N, P_2O_5, K_2O, S)	Potassium content (%)		Potassium removal (kg/ha)		Total (seed+straw) removal of Potassium (kg/ ha)
	Seed	Straw	Seed	Straw	
T_1 (Control)	1.03	1.90	9.44	15.67	25.11
T_2 (20,40,30,10)	1.82	2.04	15.91	24.85	40.76
T_3 (30,60,40,20)	2.16	2.22	22.54	31.20	53.74
T_4 (40,80,50,30)	2.33	2.76	28.14	45.75	73.89
T_5 (50,100,60,40)	2.55	2.83	37.76	59.32	97.08
CD(p=0.05)	0.16	0.18	1.91	5.63	

Table 4. Effect of NPKS and *rhizobium* on Sulphur content (%) and removal (kg/ha) of soybean under guava based agri-horticulture system

Treatment (N, P_2O_5, K_2O, S)	Sulphur content (%)		Sulphur removal (kg/ha)		Total (seed+straw) removal of Sulphur (kg/ ha)
	Seed	Straw	Seed	Straw	
T_1 (Control)	0.48	0.29	3.89	2.43	6.32
T_2 (20,40,30,10)	0.52	0.32	5.17	3.97	9.14
T_3 (30,60,40,20)	0.55	0.34	6.10	4.61	10.71
T_4 (40,80,50,30)	0.61	0.35	7.71	6.51	14.22
T_5 (50,100,60,40)	0.67	0.37	11.04	8.95	19.99
CD(p=0.05)	0.04	0.03	1.07	0.74	

Sulphur content in grain and straw increased progressively with increasing fertilizer level up to (50 kg N, 100 kg P_2O_5, 60 kg K_2O, and 40 kg S ha^{-1}) with rhizobium inoculation. The highest sulphur content in grain was (0.67) and in straw was (0.37 %) in (T_5) and lowest value in grain and straw were (0.48) and (0.29) respectively in (T_1). The data presented in table (4) shows that sulphur removal was highest in (T_5) with rhizobium culture over rest of the fertility level. Whereas, lowest was recorded in (T_1). The inoculation of seed by rhizobium culture increased the nitrogen content inn seed and straw. This might be due to more nitrogen fixed by bacteria which in turn helped in better absorption and utilization of all the plant nutrients. This beneficial influence might be due to the better root establishments, nodulation and fixing atmospheric nitrogen by nitrogen fixing bacteria. Patel et al (2018) found that application of 40 sulphur kg/ ha significantly enhanced the nutrient uptake in grain and straw over rest of the treatments. The higher nutrient content and uptake was recorded under T_5 in pearl millet cultivation (Kumar et al 2022).

Increased nutrient uptake is associated with higher biomass production and nutrient assimilation in plant tissue. When inorganic fertilizer and biofertilizers are applied combined, root growth and cell division are encouraged. This enhances nutrient uptake from deeper soil layers and, as a result, increases N, P, K, and S concentrations (Bhabai et al 2019). The application of NPK and S with rhizobium culture significantly enhanced bacterial population in rhizosphere of soybean which, play crucial role in decomposition of organic matter and release nutrient for plant growth and development. Thakur et al (2022) reported that the application of 100 % dose of NPK + FYM significantly increases the nutrient content and uptake in maize grain and stover.

CONCLUSION

The combined application of 50 kg N, 100 kg P_2O_5, 60 kg K_2O, and 40 kg S ha^{-1} with rhizobium culture significantly enhanced the N, P, K and S content (%) as well as removal (kg/ha) in seed and straw of soybean under guava based agri-horticulture system. The lowest nutrient content and uptake of nutrient was in the control.

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Effect of Organic and Inorganic Nutrients Sources on Growth, Yield and Quality of Cauliflower In Mid Hills of Himachal Pradesh

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Abstract: Plant growth parameters and leaf nutrient content of plant were significantly influenced by the combined application of vermicompost and jeevamrit. The application of 100 percent recommended dose of nutrients through vermicompost + jeevamrit @ 1.5 l plot^{-1} registered a significant increase in plant growth parameters i.e. plant height, polar and equatorial diameter, dry biomass production, gross and net curd weight, curd yield, ascorbic acid content, number of days required for curd initiation and maturity. Thus, 100 percent application of vermicompost along with jeevamrit (1.5l/4.32 m^2) is a nutrient module suggested for the farmers which showed a positive effect on plant growth parameters and leaf nutrient content of the plant.

Keywords: Organic and inorganic nutrients, Recommended dose of nutrients, Vermicompost, Jeevamrit

Cauliflower is a member of the Cruciferae family and curd is the edible part of cauliflower that prevents cancer due to the high concentration of glucothiocyanate (Abd El-Rheemkh et al 2019). In India, the total area under cauliflower was about 453 thousand ha with a production of 8668 thousand MT and in Himachal Pradesh, the total area under cauliflower was about 5.5 thousand ha with a production of 131 thousand MT (Anonymous 2018). Soil organic matter is the organic substances present in the soil which arise from the decomposition of plant and animal residues. The organic matter content in soil is closely related to soil's productivity and fertility, as it governs the soil's physical, chemical and biological properties. The well decomposed organic manure is considered to be as good as lime to buffer soil acidity as it improves soil's physical and chemical properties. The presence of a large population of bacteria, actinomycetes and fungi in organic manure increases the microbiological activity, which leads to enhanced organic nitrogen mineralization and therefore nutrients becoming available to the plants (Shrestha 2008). The application of chemical fertilizers may increase the yield of crops initially however there is no sustainability of yield in long run. The productivity of cauliflower is slowly declining by the continuous use of chemical fertilizers resulting in deterioration in soil fertility. With the continuously growing demand for limited land resources to feed an increasing population, it is necessary to maintain soil health as well as environmental degradation at an optimum level for sustaining the productivity of agricultural soils. Loss of soil fertility is due to imbalanced use of chemical fertilizers which adversely impact soil fertility as well as agriculture productivity. The incorporation of organic inputs along with liquid manures is going to reduce the dependence on chemical inputs without any significant reduction in yield (Giraddi 2000 and Patil et al 2004). Therefore, it is necessary to use various nutrient sources (VC, FYM, jeevamrit, and green manure) to maintain the fertility of the soil.

Modern agriculture practices based on the utilization of organic inputs play an important role in obtaining a higher yield and good quality of cauliflower (Sharma et al 2007). Organic farming is a sustainable production system, which includes the use of organic wastes such as crop residues, green manures, animal manures, legumes and fermented liquid inputs. Organic farming maintains soil fertility, and ecological balance and reduces the cost of market-driven farm inputs. Various fermented organic inputs such as panchagavya, jeevamrit, beejamrit and vermiwash are prepared from animal origin mainly by using cow dung, cow urine, pulse flour, jaggery, live soil and local vegetation extracts, etc. These products are effective in promoting the growth and yield of different crops. These manures may not provide direct nutrients in the area of application, but they hasten the soil micro-flora and fauna activity which maintains the fertility of the soil (Yadav and Mowade 2004).

MATERIAL AND METHODS

The experiment was conducted during the year 2018-19 at the experimental farm of the Department of Soil Science and Water Management, Dr. Y S Parmar University of

Horticulture and Forestry, Nauni, Solan. The initial physico-chemical and microbiological properties of the experimental trial are presented in Table 1. The cauliflower variety "Sweta" was planted in a plot size of 2.40m×1.8m with a spacing of 60cm×45cm. There were seven treatments *i.e.* T_1- 100 per cent RDN (Recommended Dose of Nutrients) through VC, T_2- 100 per cent RDN through FYM, T_3- 100 per cent RDN through VC + jeevamrit @ 1.5 l/plot, T_4- 100 per cent RDN through FYM + jeevamrit @ 1.5 l/plot, T_5- 75 per cent RDN through VC + jeevamrit @ 3.0 l/plot, T_6- 75 per cent RDN through FYM + jeevamrit @ 3.0 l/plot, T_7- 100 per cent RD through chemical fertilizers. The RDN was calculated based on N equivalence in VC and farm yard manure. Recommended dose of nutrients N: P: K- 125:76:72 kg ha^{-1} and FYM @ 250 q ha^{-1}. A full amount of VC and FYM was applied and mixed with soil before the transplanting of seedlings. The concentrated jeevamrit was applied at 15 days intervals after transplanting as per treatment. The experimental plants were given uniform recommended cultural practices during the entire course of investigations. The Jeevamrit was prepared by adding fresh cow dung (10kg) along with cow urine (10l). After that, mixed the jaggery (2kg), pulse flour (1kg) and live soil (1kg) in 200 l of water. The solution was mixed and stir properly in the morning and evening for 4 days for 5-10 minutes. On the fifth day filter, the solution and filtrate were ready for soil drenching/spray.

RESULTS AND DISCUSSION

Growth and yield attributes: The, maximum (46.56 cm) plant height was in T_3(100% RDN through VC + Jeevamrit @ 1.5 l/ 4.32 m^2) which was statistically at par with T_5 and the lowest (39.0 cm) was in T_2 (100% RDN through FYM) (Table 2). The maximum plant height may be due to the use of vermicompost and jeevamrit which contain a large amount of nitrogen, phosphorus, and potassium. These results are in line with those of Joshi and Pal (2010) and Ramesh et al (2015). The highest (14.28 cm, 17.23 cm) polar and equatorial diameter was in T_3 (100 percent RDN through VC + Jeevamrit @ 1.5 l/ 4.32 m^2) which was statistically at par with T_5 and the lowest (8.88 cm, 9.70 cm) was in T_2 (100% RDN through FYM). Gupta and Samnotra (2004) reported that vermicompost application increased head diameter in cabbage. Arancon et al (2004) also observed that application of vermicompost increased head diameter in cabbage.

Maximum (50.09 q ha^{-1}) dry biomass production was recorded under T_3 (100 percent RDN through VC + Jeevamrit @ 1.5 l/ 4.32 m^2) was statistically at par with T_5. The lowest (27.36 q ha^{-1}) dry biomass production was recorded under T_2 (100% RDN through FYM). Joshi and Pal (2010) also recorded that the application of vermicompost significantly increases the plant biomass of tomatoes. Significantly highest (1051.67 and 469.59g) gross and curd weight was in T_3 and the lowest (814.00 g, 375.49 g) was in T_2. Maximum curd yield was highest (151.13 q/ha) under T_3 which was found statistically at par with T_5 and lowest (123.36 q/ha) curd yield was reported under T_2. The increase in gross weight, curd weight and yield may be due to the beneficial role of vermicompost and Jeevamrit. The application of vermicompost and Jeevamrit increases the activity of beneficial microorganisms in the rhizosphere and growth-promoting substances which increases the soil biomass thereby maintaining the availability and uptake of applied inputs as well as native soil nutrients resulting in better growth and yield. Earlier researchers also repoted similar findings (Arancon et al 2003, Arancon et al 2005, Natesh et al 2005, Joshi and Pal 2010Ramesh et al 2015 and Kumar 2016).

Table 1. Nutrient contents of manures

Manures	N (%)	P (%)	K (%)
Vermicompost	1.35	0.45	0.61
Farm yard manure	0.51	0.26	0.51
Jeevamrit	1.39	0.88	0.04

Table 2. Effect of different nutrient sources on growth and yield attributes of cauliflower

Treatments	Plant height (cm)	Polar diameter (cm)	Equatorial diameter (cm)	Dry biomass production (q ha^{-1})	Net curd weight (g)	Gross curd weight (g)	Curd yield (q ha^{-1})
T_1	39.66	9.30	10.70	30.50	399.38	861.00	130.27
T_2	39.00	8.88	9.70	27.36	375.49	814.00	123.36
T_3	46.56	14.28	17.23	50.09	469.59	1051.67	151.13
T_4	42.03	11.62	12.77	39.09	440.23	979.33	142.31
T_5	45.62	14.03	17.03	48.38	467.08	1041.00	148.98
T_6	41.00	10.62	11.80	35.43	434.59	954.00	141.04
T_7	44.05	12.11	14.00	42.41	443.23	991.67	144.10
CD (p=0.05)	1.35	0.28	0.25	2.57	2.84	10.35	3.52

Curd initiation, maturity and quality parameter: There was significant variation in the days required for curd initiation and curd maturity (Table 3). Significantly, the minimum (95 days,102 days) required for curd initiation and maturity were under T_3 (100% RDN through VC + Jeevamrit @ 1.5 l/ 4.32 m^2) which was statistically at par with T_5 while the maximum (104 days, 114 days) number of days required for curd initiation and maturity was under T_2 (100% RDN through FYM). The results showed that the increasing level of nutrients hastens the reproductive phase of growth whereas at a lower rate of nutrients reproductive phases were drastically delayed. Chaubey et al (2006) in cabbagealso reported that higher fertility levels favored the maturity time whereas the process of growth and development was slower at lower fertility levels. The maximum (69.33 mg $100g^{-1}$) ascorbic acid content was under T_3 (100% RDN through VC + Jeevamrit @ 1.5 l/ 4.32 m^2) which was statistically at par with $T_5$and minimum (55.00 mg $100g^{-1}$) observed under T_2 (100% RDN through FYM). There were non significant effect on non wrapper leaves Sharma et al (2014) vermicompost increased the spinach 14.42 percent more ascorbic acid content than chemically grown spinach. Theunissen et al (2010**)** organic manures treated plants yielded higher vitamin C content as compared to conventional ones.

Nutrient content in leaves, curd and roots: The significantly, highest (2.63%) nitrogen content was in T_3 and the minimum (2.08%) under T_2 (100% RDN through FYM). The P and K content also showed the same trend. The increased leaf nutrient content might be due to the beneficial effect of vermicompost brought about by the presence of macro and micronutrients and vital plant-promoting substances in vermicompost (Arancon et al 2006). The maximum NPK content in curd (3.43%, 0.79%, 2.13%) was recorded under T_3 (100% RDN through VC + Jeevamrit @ 1.5 l/ 4.32 m^2) and the minimum NPK content (2.84, 0.45 and 1.94%) was in T_2 (100% RDN through FYM). Weber et al (2007) observed that application of vermicompost significantly increased NPK content and also affect soil properties. The , maximum NPK in root was in T_3 and the minimum in T_2 Chander et al (2010) also reported an increase in nutrient content by the application of organic manures. This might be due to the beneficial effect of organic manures on nutrient availability in soil and improvement in soil's physical and microbiological properties.

Table 3. Effect of different nutrient sources on curd initiation, maturity and quality parameter

Treatments	No. of days required for curd initiation	No. of days required for curd maturity	Ascorbic acid (mg/100g)	No. of non-wrapper leaves
T_1	102.00	110.00	58.00	6.33
T_2	104.00	114.00	55.00	7.00
T_3	95.00	102.00	69.33	7.33
T_4	101.00	108.00	63.00	6.66
T_5	97.00	104.00	68.00	7.33
T_6	102.00	110.00	61.33	7.33
T_7	99.00	107.00	65.00	6.66
CD (p=0.05)	2.64	2.82	3.07	NS

Table 4. Effect of different nutrient sources on nitrogen, phosphorus potassium content of leaves, curd and root (%)

Treatments	Leaf			Curd			Root		
	N	P	K	N	P	K	N	P	K
T_1	2.16	0.50	1.64	2.91	0.48	1.97	1.19	0.26	1.12
T_2	2.08	0.47	1.56	2.84	0.45	1.94	1.15	0.25	1.07
T_3	2.63	0.64	1.99	3.43	0.79	2.13	1.54	0.39	1.30
T_4	2.39	0.56	1.77	3.22	0.73	2.03	1.43	0.33	1.20
T_5	2.63	0.62	1.93	3.36	0.76	2.07	1.48	0.36	1.27
T_6	2.19	0.53	1.72	3.11	0.68	2.02	1.31	0.30	1.16
T_7	2.48	0.59	1.86	3.28	0.62	2.06	1.43	0.33	1.22
CD (p=0.05)	0.08	0.02	0.03	0.04	0.02	0.02	0.06	0.02	0.01

CONCLUSION

Application of 100 percent RDN through vermicompost + Jeevamrit @ 2800 l ha^{-1} showed greater plant height, polar and equatorial diameter, dry biomass production, gross and net curd weight, curd yield, ascorbic acid content and number of days required for curd initiation and curd maturity. Thus, vermicompost along with jeevamrit can be used for sustainable yield for cauliflower without deteriorating soil health.

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Adoption of Plastic Mulching Techniques for Enhancing African Marigold (*Tagetes erecta* L.) Production

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***Abstract*:** Production of flowers under plastic mulch films helps in early sowing of the crop and the crops are healthy as the plants are provided with favourable micro climate. The present investigations were carried out at ICAR-Central Institute of Agricultural Engineering, Bhopal during *Rabi* season in 2020-21 and 2021-22 to evaluate the effect of plastic mulch film on water use and plant growth parameters of African marigold. The experiment was conducted by cultivating the crop in four treatments viz., crop cultivation under drip irrigation with silver coloured plastic mulch, black coloured plastic mulch, without mulch and furrow irrigation as conventional practice and each treatment replicated five times. The highest soil temperature was under black plastic mulch. Plant growth parameters viz., plant height, stem girth, number of branches/plants, plant spread and yield contributing characters viz., flower diameter, number of flowers per plant, average fresh and dry weight of flower were significantly higher in plastic mulched compared to no mulch condition. The highest flower yield (32.19 t/ha), water productivity (13.70 kg/m^3) and B:C ratio (4.27) was obtained under silver coloured mulch and lowest under furrow irrigation treatment. The plastic mulching is the most productive and profitable method for marigold cultivation in semi-arid areas.

Keywords: Marigold, Growth and yield parameter, Plastic mulch, Water productivity, Economics

Marigold (*Tagetes erecta* L.), a member of the family *Asteraceae* or *Compositae* is a free blooming ornamental crop has lot of demand in National as well as International flower trade (Ahmad et al 2011). Marigold is also an important natural source of xanthophyll used as natural food additive for brightening egg yolks and poultry skin. Marigold is broadly classified into two groups, viz., African marigold (*T. erecta* L.) and French marigold (*Tagetes patula* L.). African marigold (*T. erecta* L.) is a seasonal flowering plant which belonging to the family *Asteraceae* and is a native of South and Central America, especially Mexico. This flower is a prominent and popular flower in India, ranking third in popularity behind roses and chrysanthemums. The area under the marigold cultivation in India is about 64.65 thousand ha with a production of 608.97 thousand MT, whereas Madhya Pradesh is a major marigold producing a state in India with the production of 224.62 thousand MT (National Horticulture Board 2021). Marigold has gained popularity because of its adaptability to various soil and climatic conditions, longer blooming period, economical to major population of India and has good shelf life. Considering the market value, several farmers are now encouraged to cultivate gladiolus, tuberose, marigold, rose, gerbera, and orchid flowers in collaboration with some companies. However, the advanced production technologies are not being widely adopted by the farmers due to lack of knowledge and experimental investigations conducted on this crop with advanced farming techniques are limited. Various factors are to be considered for the high production of marigold, which includes; variety, planting time, amount of fertilizer, spacing of plants, cultural practices like pinching, irrigation, and most importantly having a good quality of soil. Marigold production has been reduced as a result of their lack of expertise and awareness of modern management procedures. The present study is mainly focused on enhancing the flower yield and net return to the farmers by the use of mulching technique.

MATERIAL AND METHODS

Study area: The present study was conducted at ICAR-Central Institute of Agricultural Engineering situated in North of Bhopal at 77°24'10" E, 23°18'35”N. Soils of the experimental site were heavy clay with clay content varying between 49.7 to 53.7%. Field capacity of the soil varied from 28.5 to 31 % (Rao et al 2021). pH value of the soil ranges from 6.5-8.0 (neutral), EC <1.0 (normal) ds/m. The climate of the region is classified as humid subtropical climate with cool, dry winters, a hot summer and a humid monsoon season.

Experimental details: The experiment was conducted during *Rabi* 2020-21 and 2021-22, laid out in factorial randomized block design with four treatments each replicated five times. The plot was 21 m long and width was 7 m. The dominate Marigold variety of the region “KMGH-103” was selected for experimental purpose. In treatment first (T1) and second (T2) the crop was sown on raised bed covered with silver and black coloured 25 micron plastic mulch film respectively with the row to row spacing of 40 cm and plant to plant of 30 cm. Inline drip laterals of 16 mm diameter having discharge rate of 2 lph with emitters spaced at 30 cm were used for irrigation purpose. In treatment third (T3) the crop was sown on raised beds without mulch, while all the other standard cultivation practices of T1 and T2 were followed. In treatment fourth (T4) the crop was sown in ridge and furrow system, wherein crop was sown on ridges and irrigation was provided in furrows. The recommended doses of fertilizers was followed in all the treatments (90:90:75 NPK/ha). On raised beds (treatment first, second and third) 50% of recommended doses of fertilizers were applied as a basal dose, remaining 50% was applied through fertigation using water soluble fertilizers. In treatment fourth (ridge and furrow) 50% doses of nitrogen, 100% of phosphorus and potash were applied at the time of sowing as a basal dose, remaining 50% of nitrogen was applied in two split doses during the crop growing period.

Data collection: Five randomly selected plants from each plot were used for recording different plant growth parameters and yield attributing characteristics of plants. In plant growth parameters average plant height (cm), plant spread (cm), number of branches per plant, plant canopy temperature (°c), SPAD values and stem girth (mm) were recorded. The plant height was measured from above ground portion to the flag leaf. Plant canopy temperature values were recorded with the help of infrared thermometer, SPAD values were recorded with the help of chlorophyll meter SPAD-502 plus (Konica, Minolta), which indicates that indirect value of chlorophyll content in plants). For recording stem girth digital Vernier calliper was used. Soil temperature values for each treatment were measured at 5 cm and 10 cm below the soil surface with the help of soil thermometer. These data were recorded at twenty days interval during the crop growing period.

Floral characters like days required to first flower bud emergence, days required to 100 % flowering, flower diameter (cm) and yield attributing parameters such as average number of flowers per plant, flower diameter (cm), fresh and dry weight of individual flower (g) were recorded. For recording average number of flower per plant, flowers were counted from the initial harvest to the last harvest and their mean values are presented in subsequent sections. Diameter of each flower from selected plant was taken with the help of measuring tape at successive growth stages and final mean values were worked out. Values of fresh weight (g) of flower were recorded with the help of weighing balance and dry weight of flower was measured after they were kept in hot air oven at 108^{0}C for 72 hours.

Water productivity (kg/m^3): Water productivity was also worked out.

$$\text{Water productivity} = \frac{\text{Yield (kg/ha)}}{\text{Water applied (m}^3\text{/ha)}}$$

Irrigation schedules have been finalized in each crop on the basis of crop water requirement to meet the demand of crop evapotranspiration of the study area.

Economic analysis: The cost of drip irrigation system included depreciation, interest rate and repair and maintenance cost of the system used in one season of a year was considered. The fixed cost of drip irrigation system for closely spaced crop like marigold is Rs.102879/ha. For calculating depreciation the life of overhead unit and drip laterals was considered to be 10 years and 4 years respectively with salvage values 10% and 5% respectively. Annual interest rate is considered @10% and operation & maintenance cost is considered @ 5% of the initial system cost. The variable cost of cultivation includes expenses incurred in land preparation, manure & fertilizer, plant protection measures, labour, irrigation water and electricity charges. Cost of cultivation was worked out by adding seasonal fixed cost and variable cost. Gross income from produce was calculated using average market price of marigold Rs.15/kg. Benefit-Cost ratio and net profit were determined for economic evaluation.

Statistical analysis: The data were subjected to analysis of variance and F-test for determining the significance of the treatments using IBM SPSS Statistics 20 software.

RESULTS AND DISCUSSION

Plant growth parameters: The growth parameters of marigold viz., plant height (51.20 cm), stem girth (15.07 mm) and plant spread (50.62 cm) were maximum and statistically significant under silver coloured plastic mulch over other treatments and at par with black coloured mulch treatment (Table 1). This could be due to maintaining constant soil moisture and favourable temperatures (18 to 25^{o}C) under the mulched condition which enhanced the growth and development of plants during the vegetative period. These findings are in agreement with the soil temperature and moisture recommendations of Sowmeya et al (2017) in marigold when cultivated under protected structures. Canopy temperature significantly influenced by the use of plastic mulch and was recorded highest (24.61°C) under treatment T2 with black coloured mulch followed by silver coloured mulch and lower canopy temperature was recorded under without or no mulch condition (T3, T4). The canopy temperature values were average of the entire crop growing period. Soil temperatures under black coloured mulch films are higher over silver coloured films that could be the reason for higher values of canopy temperatures under these films over other treatments (Fig. 1). SPAD values were significant under silver coloured mulch compared to other treatments. Number of branches per plants has been significantly varied with different treatments. Though, there is no significant difference in number of lateral branches per plant was observed amongst T1 and T2 treatments, but with other treatments (T3 and T4) the values are significantly different. Findings are in line with the studies conducted by researchers in other crops for example Rao et al (2017) in watermelon, Kumawat et al (2021) in chilli and Yadav et al (2023) in different crops.

In the vegetative growth stage, presence of plastic mulches during *Rabi* season has led to moderating the soil temperature compared with bare soil condition. Soil temperatures were higher under black plastic mulch as compared to other treatments. Plastic mulch increased the soil temperature at 5-10 cm depth by 0.8–2.5°C compared with no mulch condition. Similar observations are being reported by Díaz-Pérez and Batal (2002), Ibarra-Jiménez et al (2008) and Yadav et al (2023).

Flowering and yield attributing parameters: Among the different treatments, significant difference was observed in the floral characteristics and yield parameters of marigold. The minimum number of days taken for flower bud initiation (38.74 days) and 100% flowering (71.43 days) was observed under black coloured mulch (TI) and under silver coloured mulch was 39.22 and 72.11 days, respectively. Timely bud initiation may be due to better growth of plants, as result of high soil temperature and favourable moisture under plastic mulch. Solaiman et al (2008) observed similar trend. The number of flowers and yield per plant were significantly influenced by the use of plastic mulching. Number of flowers per plant and yield per plant were non-significant among T1 and T2. However, significant difference was observed when compared with T3 and T4 treatments. The results are in agreement with finding of Bajad et al (2017) in china aster. Maximum number of flowers, flower diameter and yield in case of mulching may be due to cumulative effects of favourable temperatures, soil moisture and no weed growth resulting in better plant growth and physiological activities (Kusuma and Thaneshwari 2021). The average fresh and dry weight of the flower was also significantly superior in mulching treatments (T1 & T2) than in the no mulch condition. The positive effect of mulching on morpho-physiological development of crops was observed by earlier researchers in their studies on different crops (Shinde et al 2021, Rao et al 2018).

Yield and water productivity: Combined analysis of two-year data revealed significant difference in yield of marigold under different treatments. The treatment (T1) with silver coloured mulch has maximum flower yield (32.19 t/ha) followed by treatment T2 with black coloured mulch and treatment T3 under drip without mulching. The flower yield per hectare was found to be minimum 15.27 t/ha under treatment (T4) with furrow irrigation. The average flower yield per hectare is significantly affected with use of plastic mulch and irrigation technique. Similar results were also reported by Rajablariani et al (2012) in tomato, Sihombing and Handayati (2017) in tuberose and Islam et al (2021) in different vegetable crops. Water productivity was also significantly superior under treatment T1 with silver colour mulch than rest of the treatments i.e. 13.70 kg/m^3 and was at par with T2 under black colour mulch and inferior value was recorded

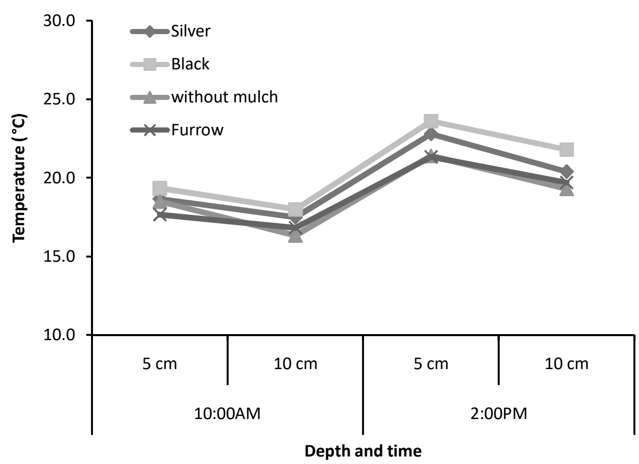

Fig. 1. Variation in average soil temperature at 5 cm and 10 cm depth under different treatments

Table 1. Growth parameters of marigold influence by use of plastic mulch

Treatments	Plant height (cm)	Canopy temperature (°C)	SPAD value	Number of lateral branches	Plant spread (cm)	Stem girth (mm)
Silver mulch (T1)	51.20	23.83	40.32	14.50	50.62	15.07
Black mulch (T2)	50.75	24.61	40.19	13.24	49.24	14.68
Without mulch (T3)	44.70	21.68	38.90	11.11	42.36	13.21
Furrow irrigation (T4)	42.40	22.00	37.83	9.20	36.21	12.75
CD (p=0.05)	2.44	1.10	1.67	1.61	3.21	1.10

under furrow irrigation system (Fig. 2). These overall 48.2% saving of irrigation water in plastic mulch condition and 34.8% in drip without mulch over conventional method. Plastic mulching shows a positive impact on yield and water productivity of plants than conventional practices by reducing evaporation from soil surface and provides protection against water loss. Silver plastic mulches are higher in reflecting PAR than black plastic mulches. Such higher reflection of PAR by silver plastic mulches reduces root zone temperature and loss of water.

Economic evaluation: The additional expenditure needs to be incurred for adoption of drip irrigation and plastic mulching under marigold cultivation as against the conventional cultivation, economic analysis has been carried out. The maximum cost of cultivation is required under plastic mulch conditions over other treatments; however, additional yields that are obtained under these conditions will compensate the initial investment (Table 3). Treatment T1 with silver mulch was most remunerative with a net return of Rs. 3,91,298/ha and B:C ratio of 4.27 followed by treatment T2. Among all the treatments conventional practices under treatment T4 showed lowest net income and benefit cost ratio. It is

Table 2. Yield attributing parameters of marigold influenced by different treatments

Treatments	Days required for first flower bud emergence	Days required for 100% flowering	Flower diameter (cm)	Number of flower per plant	Flower yield per plant (g)	Average fresh wt. of individual flower (g)	Average dry wt. of individual flower (g)	Flower yield t/ha
Silver mulch (T1)	39.22	72.11	10.16	53.63	784.32	17.38	4.38	32.19
Black mulch (T2)	38.74	71.43	9.78	52.60	749.20	16.63	4.29	30.65
Without mulch (T3)	44.80	77.80	7.43	40.25	523.40	13.84	2.76	21.34
Furrow irrigation (T4)	45.82	79.40	6.46	33.60	304.43	9.22	2.43	15.27
CD (p=0.05)	1.73	1.37	0.60	4.31	33.39	1.32	0.34	1.80

Table 3. Economics of marigold crop cultivation

Particulars	Silver mulch (T1)	Black mulch (T2)	Without mulch (T3)	Furrow irrigation (T4)
Initial fixed cost of drip irrigation system, Rs/ha	102879	102879	102879	
a. Depreciation	21165	21165	21165	
b. Interest on fixed capital @10%	10288	10288	10288	
c. Annual operation & maintenance cost @ 5% of drip system cost	5144	5144	5144	
Total Annual cost of drip irrigation system, Rs/ha	36597	36597	36597	
Seasonal cost of drip irrigation system, Rs/ha	12199	12199	12199	
Variable cost				
a. Field preparation with machine	7600	7600	7300	5500
b. Planting material	16500	16500	16500	20800
c. FYM	4500	4500	4500	4500
d. Fertilizer	2550	2550	2550	4870
e. Plant protection	1752	1752	2296	3248
f. Human labour	17066	16324	18921	21518
g. Irrigation	1880	1880	2820	4029
h. Mulching cost	26400	26400		
i. Electricity @ 6.74 Rs./unit	1105	1105	1658	3485
Total Variable cost, Rs/ha	79353	78611	56545	67950
Total cost of cultivation (B + D), Rs/ha	91552	90810	68744	67950
Yield of flower, t/ha	32.19	30.65	21.34	15.27
Gross income, Rs/ha	482850	459750	320100	229050
Net profit, Rs./ha	391298	368940	251356	161100
Benefit cost ratio (B:C)	4.27	4.06	3.66	2.37

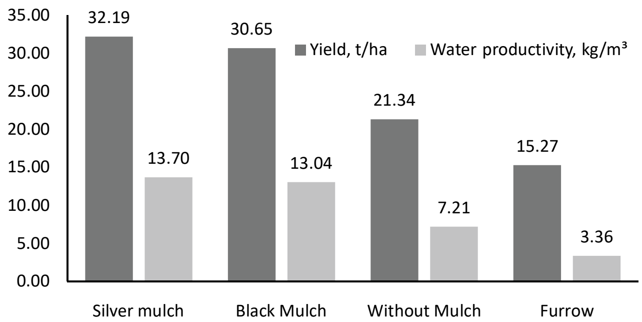

Fig. 2. Yield (t/ha) and water productivity (kg/m^3) of marigold under different treatments

observed that, the mulched treatments T1 and T2 gave more techno-economic advantage over the other treatments i.e., crop under without mulching and with conventional cultivation practice of irrigation.

CONCLUSION

Higher flower yield and net profits were observed in marigold crop when cultivated under plastic mulch films with drip irrigation. The standalone drip irrigation system also provided better techno-economic returns over conventional cultivation practice. The adoption of silver coloured mulch had significantly superior effect on the marigold crop in terms of vegetative growth, flower yield and water saving than other treatments. Marigold cultivation under silver colour mulch gave 1.4 times higher net returns over conventional practice.

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Evaluation of Indoor Ornamental Plants Suitable for Indoor Vertical Garden in Response to Different Nutrient Formulations

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Abstract: There is limited scientific information regarding the appropriate fertigation required influencing various growth and physiological parameters of indoor ornamental plant species for an indoor vertical gardening under Indian conditions. The experiment was therefore set up with the objective to determine optimum concentration of nutrient formulations for successful installation of vertical garden by using eight indoor ornamental plant species i.e. *Aglaonema angustifolium*, *Dracaena compacta* (Red), *Dracaena godseffiana, Scindapsis aureus, Schefflera arboricola variegata, Syngonium podophyllum, Philodendron selloum* and *Schefflera arboricola*. These were grown in soilless media consisting of cocopeat, perlite and vermiculite in the ratio 3:1:1 with four concentrations of Hoagland nutrient solution (25 %, 50 %, 75 % and 100 % of Hoagland's solution) and the fifth concentration was self-composed nutrient formulation. Experimental design was factorial completely randomized design (CRD) keeping three replications in each treatment. NF IV (100 % of the Hoagland's solution) proved significantly better over other treatments in terms of plant growth and physiological characters under indoor conditions. Best five species based on performance of various parameters studied were *Schefflera arboricola, Dracaena godseffiana, Philodendron selloum, Syngonium podophyllum* and *Scindapsis aureus*.

Keywords: Hoagland solution, Nutrient formulations, Indoor vertical garden, Indoor ornamental plant species

With increasing urbanization, a large population is shifting from rural to urban areas resulting in congested cities and towns leading to a limited horizontal space for greenery and landscaping. Integration of sustainable development into urbanization is anticipated as the solution of this complex situation. Vertical gardening is one such solution to this problem which is an innovative urban greening technique for limited urban spaces alternative to traditional systems of landscaping and presents substantial ecological and aesthetic opportunities. Since, most of the urban population spends most of their time indoors where air pollution can be several times higher than outdoors, hence, the quality of the indoor environment has become a major health concern. Indoor' potted-plants can remove air-borne contaminants such as volatile organic compounds (VOCs), over 300 of which have been identified in indoor air (American Lung Association 2001). Creating an indoor vertical garden can help in mitigating these and many more health related issues besides offering a high aesthetic and impact value thereby, making our cities more sustainable and help addressing environmental concerns of the citizens. As the indoor vertical gardens are grown on the walls, the growing medium other than permitting satisfactory growth of the plants and firmness to the roots, ought to be light in weight as it might influence the load capacity of the building walls hence, the use of soilless media i.e. coco peat, perlite and vermiculite possibly satisfies the essential prerequisites. Also, the nutrient supply to the indoor ornamental plants species which are to be used in the indoor vertical garden influences plant growth in many aspects. The growth of the indoor plants is not only influenced by the macronutrients but also micronutrients. Therefore, the nutrient solution which contains all necessary nutrients required for optimum plant growth would be a key factor on the growth. Hoagland solution was thus selected as it is one of the most adequate sources of macro and micro nutrients used in the soilless cultivation of plants. However, lack of scientific data related to the suitable nutritional requirement for indoor ornamental plant species for an indoor vertical garden especially under Indian conditions makes the current research of paramount significance. The importance of the study becomes more valuable as this is the first work being done on various aspects of indoor vertical gardening involving indoor ornamental plant species under Indian conditions. The experiment was thus initiated to evaluate indoor plants and to standardize their nutrient requirement for a functional indoor vertical garden.

MATERIAL AND METHODS

The study was conducted at Punjab Agricultural University, Ludhiana, Punjab which is located at 30º 54' North (latitude) and 75 º 48' East (longitude) at the height of 247 m above the sea level. Eight indoor ornamental plant species i.e. *Aglaonema angustifolium*, *Dracaena compacta* (Red), *Dracaena godseffiana, Scindapsis aureus, Schefflera arboricola variegata, Syngonium podophyllum, Philodendron selloum* and *Schefflera arboricola* were selected on the basis of their popularity and suitability among the common household for growing under indoor conditions and planted in 15 cm pots filled with media consisting of cocopeat, perlite, and vermiculite in the ratio 3:1:1. The experiment consisted of five treatments four of which included fertigation using modified Hoagland solution (Hoagland and Arnon 1950) i.e. 25 % of the Hoagland's solution (NF I) (control), 50 % of the Hoagland's solution (NF II), 75 % of the Hoagland's solution (NF III) and 100 % Hoagland solution (NF IV). The fifth treatment (NF V) included self-composed nutrient formulation (Azeezahmed 2014) (Table 1). Plants were fertigated (100 ml/plant) after every 10 days and irrigated with water alone after every 4-5 days during the entire experimental period. Irrigation frequency was doubled during hot summer months i.e. May-June. The fertigation volume was determined by adding the leaching amount to water consumed by plants i.e. 300 ml/pot. Experimental design was factorial completely randomized design (CRD) keeping three replications in each treatment.

The data on effect of different fertigation levels on plant height, plant spread, fresh and dry weight of plant canopy and roots, leaf chlorophyll content (Hiscox and Israelstam 1979), leaf carotenoid content (Kirk and Allen 1965) and relative leaf water content (RLWC) were recorded. Statistical analysis using SAS software version 9.0 was to find the best nutrient formulation as a medium of growth for these species.

RESULTS AND DISCUSSION:

Significant variability in the mean plant height and spread was observed under various nutrient solution formulations where plants fertigated with NF IV (100 % of the Hoagland solution) observed highest results among various indoor plant species under study. However, similar response w.r.t. plant height with NF V was observed (Table 2). Among the various plant species, maximum plant height was in *Dracaena godseffiana* (33.57 cm) and minimum in *Schefflera arboricola variegata* (16.58 cm) whereas maximum canopy was in *Aglaonema angustifolium* (17.23 cm) and *Schefflera arboricola* (17.89 cm) which was at par with canopy in *Syngonium podophyllum.* Kaur et al (2016) in tomato also reported maximum plant height with 100 % of the Hoagland's solution in comparison with its lower concentrations. Azeezahmed (2014) in chrysanthemum observed subsequent increase in plant height and spread with

Table 1. Hoagland nutrient formulations (NF) (mg/l)

Element	NF-I (Control) (25 % of Hoagland's solution)	NF-II (50 % of Hoagland's solution)	NF-III (75 % of Hoagland's solution)	NF-IV (100 % of Hoagland's solution)	NF-V
N	52.50	105.00	157.50	210.00	250.00
P	7.75	15.50	23.25	31.00	40.00
K	58.50	117.00	175.50	234.00	200.00
Ca	40.00	80.00	120.00	160.00	170.00
Mg	8.40	17.00	25.50	34.00	90.00
S	16.00	32.00	48.00	64.00	35.00
Fe	0.63	1.25	1.88	2.50	-
Cu	0.005	0.01	0.02	0.02	-
Zn	0.013	0.03	0.04	0.05	-

Table 2. Effect of different nutrient formulations on growth parameters of indoor ornamental plant species

Nutrient formulation	Plant height (cm)	Plant spread (cm)	Fresh canopy weight (g)	Dry canopy weight (g)	Fresh root weight (g)	Dry root weight (g)
NF I	17.41[d]	14.66[d]	13.90[e]	1.76[d]	11.35[c]	1.87[c]
NF II	21.96[c]	16.78[c]	17.17[d]	2.37[d]	13.94[b]	2.25[bc]
NF III	25.00[b]	20.17[b]	23.50[c]	3.89[c]	14.77[b]	2.53[b]
NF IV	28.82[a]	24.17[a]	33.92[a]	5.50[a]	18.95[a]	3.58[a]
NF V	28.21[a]	20.28[b]	29.71[b]	4.76[b]	19.65[a]	3.44[a]

The different letters in each column are significantly different at $P \leq 0.05$ by Duncan's Multiple Range Test (DMRT) increasing nutrient concentrations. Shorter plants at lower dose of N, P and K might have been due to their effects on cell division and elongation. Increase in plant height is attributed to an increased supply of nutrients N, Ca and S as these are the major nutrients responsible for an increase in plant height. Nutrient inadequacy often leads to lesser growth of the plants (Siddiqui and Kumar 2017). This indicates that higher nutrient concentration is required by plants to obtain longer heights.

Maximum fresh canopy weight was observed in the plants fertigated with NF IV (36.04 g) which was at par with NF V (35.10 g) whereas dry canopy weight was maximum in the plants fertigated with NF IV (5.50 g). Kang and Iersel (2002) also concluded that maximum shoot dry biomass was achieved in Alyssum, Zinnia, Celosia and Dianthus fertigated with 100 % Hoagland solution. Kang and Iersel (2004) reported that its shoot weight increased with increasing Hoagland's solution concentration and reached maximum with 100 % Hoagland solution. There was statistically non-significant difference in the mean fresh and dry root weight between species w.r.t. different fertigation treatments given except *Philodendron selloum* which showed maximum fresh (62.73 g) and dry root weight (9.38 g). However, an increase in the fresh and dry root weight with increasing nutrient concentrations was observed in the plants (Table 2). Azeezahmed (2014) also reported a significant increase in the root and shoot biomass with increasing nutrient concentrations (N, P, K, Ca, Mg and S). The increase in fresh and dry canopy biomass with increased nutrient concentration may possibly be due to increased plant photosynthetic activity leading to higher accumulation of photosynthates which led to an increase in reserved plant food material causing higher fresh and dry canopy biomass. Sublett et al (2018) proposed that nutrients are key factors influencing plant growth and biomass production in soilless culture. The study specify that optimum nutrient concentration is required by plants for their proper metabolic functioning which is responsible for positive influence on their growth and development.

A significant increase in the mean leaf chlorophyll, carotenoid and relative leaf water content was observed with increasing Hoagland solution concentration with maximum accumulation in plants fertigated with NF IV. The maximum chlorophyll and carotenoid content was observed in *Dracaena godseffiana* (3.77 and 0.32 mg/g fresh wt. respectively). Kang and Iersel (2002) attained maximum chlorophyll accumulation with 100 % Hoagland solution concentration in Alyssum, Zinnia, Celosia and Dianthus. The low fertilizer concentrations generally decreased growth and chlorophyll content, presumably because of mild nutrient

Table 4. Effect of different nutrient formulations on the mean physiological characteristics of plant species to be grown in an indoor vertical garden

Nutrient formulation	Leaf chlorophyll content (mg/g fresh wt.)	Carotenoid content (mg/g fresh wt.)	Relative leaf water content (RLWC) (%)
NF I	1.56^{c}	0.10^{e}	71.66^{d}
NF II	1.9^{d}	0.11^{d}	75.83^{c}
NF III	2.48^{b}	0.16^{b}	81.78^{ab}
NF IV	3.35^{a}	0.23^{a}	85.64^{a}
NF V	2.19^{c}	0.13^{c}	81.28

The different letters in each column are significantly different at P≤0.05 by Duncan's Multiple Range Test (DMRT)

Table 5. Response of plant species under study in terms on physiological characteristics to be grown in an indoor vertical garden

Treatments/ Indoor plant species	Leaf chlorophyll content (mg/g fresh wt.)	Leaf carotenoid content (mg/g fresh wt.)	Relative leaf water content (%)
Aglaonema angustifolium	3.47b	0.08d	86.98a
Dracaena compacta(red)	0.97f	0.22b	75.35bc
Dracaena godseffiana	3.77a	0.32a	72.51c
Scindapsis aureus	1.89e	0.14c	89.00a
Schefflera arboricola variegata	0.77g	0.05e	63.23d
Syngonium podophyllum	1.93e	0.09d	77.68b
Philodendron selloum	2.30d	0.12c	84.66a
Schefflera arboricola	3.27c	0.14c	84.19a

The different letters in each column are significantly different at P≤0.05 by Duncan's Multiple Range Test (DMRT)

Table 3. Effect of different concentrations of nutrient formulations on mean plant height, plant spread, fresh and dry canopy and root weight of indoor ornamental plant species

Treatments/Indoor plant species	Plant height (cm)	Plant spread (cm)	Fresh canopy weight (g)	Dry canopy weight (g)	Fresh root weight (g)	Dry root weight (g)
Aglaonema angustifolium	27.97^{b}	17.23^{a}	29.26^{a}	8.05^{a}	12.06^{b}	1.18^{d}
Dracaena compacta (red)	19.19^{e}	9.83^{bc}	11.04^{c}	1.39^{d}	6.70^{c}	1.12^{d}
Dracaena godseffiana	33.57^{a}	11.04^{bc}	11.60^{c}	2.74^{d}	11.80^{b}	3.26^{b}
Scindapsis aureus	21.20^{d}	11.48^{bc}	22.20^{a}	1.85^{d}	6.28^{c}	0.79^{d}
Schefflera arboricola variegata	16.58^{f}	11.61^{bc}	18.91^{b}	3.10^{d}	6.94^{c}	1.94^{c}
Syngonium podophyllum	22.11^{d}	13.97^{ab}	33.63^{a}	4.21^{c}	6.41^{c}	1.33^{cd}
Philodendron selloum	24.15^{c}	11.32^{bc}	27.68^{a}	1.91^{d}	62.73^{a}	9.38^{a}
Schefflera arboricola	29.04^{b}	17.89^{a}	34.80^{a}s	6.01^{b}	12.94^{b}	2.88^{b}

The different letters in each column are significantly different at P≤0.05 by Duncan's Multiple Range Test (DMRT)

deficiencies. Any further increase in the nutrient concentration led to decrease in the chlorophyll content. This may be possibly due to lack of micro nutrients in NF V which might have inhibited further chlorophyll production. The linear relationship between nitrogen in the nutrient solution and leaf chlorophyll content was observed. Moreover, an improved growth as well as higher fresh and dry canopy and root biomass was observed in the plants fertigated with NF IV which also had highest chlorophyll content w.r.t. lower concentrations. The increase in the chlorophyll content with increasing nutrient concentration might possibly be due to high N, P, K, Mg and Fe content which leads to its increased synthesis. Hossain et al (2010) reported an increase in chlorophyll content in *Hibiscus cannabis* L. with increasing N, P and K content. Hoagland solution (T2) recorded the maximum chlorophyll content (27.84, 29.32 and 31.51) in *Zebrina Pendula* and *Tradescantia spathacea* plants followed by T3 (Cooper solution) with 24.68, 26.12 and 27.91 at 30, 60 and 90 days (Dhanasekaran 2020). The increased chlorophyll content in *Zebrina pendula* and *Tradescantia spathacea* plants grown under Hoagland solution may be due to the increased dose of nutrition combination which contains N, K, Mg which has the beneficial effect on phloem loading and probably also on mobilization of photosynthates deposited in leaves. The findings of Li and Cheng, (2014) in cucumber, Mohidin et al (2015) in oil palm seedlings agreed with the present results. Studies conducted by Alberici et al (2008) showed an increase in the leaf chlorophyll and carotenoid content of leafy vegetables with increase in Hoagland solution concentration. Indoor ornamental plant species under our study reported maximum RLWC when fertigated with 100 % of the Hoagland's solution. This indicates that high RLWC is important in carrying out various physiological processes required for the healthy growth of the plants. This might be the reason that the plants fertigated with NF IV had better growth characteristics over other fertigation treatments as they showed maximum RLWC. RLWC is a significant indicator of water status in plants as it reflects the equilibrium between water supply to the leaf tissue and transpiration rate.

CONCLUSION

The highest concentration i.e. NF IV (100 % of the Hoagland's solution) was significantly better over other fertigation treatments in terms of growth and physiological characters of plants under indoor conditions. Among the various species evaluated on the basis of parameters under observation, the best five which were used for the indoor vertical garden were *Schefflera arboricola, Dracaena godseffiana, Philodendron selloum, Syngonium podophyllum* and *Scindapsis aureus*.

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Sustainable Production of Bell Pepper in West Bengal

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***Abstract*:** An experiment was carried at Horticultural Research Station, Bidhan Chandra Krishi Viswavidyalaya, Mondouri, Nadia, during rabi seasons of 2017-18 and 2018-2019 to study effect of intercropping on of bell pepper. Most of the growth and yield attributes were significantly influenced by intercropping system. Maximum plant height (88.06 cm) was recorded from sole capsicum followed by capsicum+ French bean treatment (85.79 cm) and lowest value was observed in capsicum + spinach intercropping system (79.10 cm). Capsicum+ French bean recorded significantly maximum capsicum equivalent yield (31.16 tons ha^{-1}). Capsicum +French bean model recorded maximum TSS, ascorbic acid and beta carotene content of capsicum i.e. 6.27^0 Brix, 181.15 mg $100g^{-1}$ and 1.90 mg $100g^{-1}$, respectively. The total and reducing sugar content of capsicum is triggered when, coriander crop grown as inter crop. Capsicum + coriander treatment recorded highest total (5.15 %) and reducing sugar (2.83 %) content. Capsicum grown with French bean valued maximum land equivalent ratio about 1.62 and minimum of 1.29 was recorded for spinach grown as intercrop in capsicum. Maximum B: C ratio (3.02) was obtained in capsicum+ French bean model .Inclusion of French bean in the interspaces of capsicum may be a viable option for sustainable production of bell pepper.

***Keywords*:** Bell pepper, Economics, Growth, Intercropping, Sustainable

Intercropping of bell pepper with different crops offers greater scope to utilize the land and other resources to maximum extend (Brintha et al 2012). Among the cropping system intercropping is the most suitable practice to stabilize the production (Kabiraj et al 2017) and two or many crops can be grown at a time from the same land having huge advantages over mono cropping (Islam et al 2021). Intercropping with vegetables is also profitable as it generates more income of the farm through increased production $unit^{-1}$ area from more number of crops in a season of a year (Dodiya et al 2018) as it provides complete and economical use of natural resources like soil, water, space, nutrients and sunlight through selection of crop combination of different duration and rooting pattern(Qinyu et al 2022). Intercropping also minimizes the cost of production attracting farmers towards intercropping cultivation (Choudhuri et al 2016). Sweet pepper, which is one of the capital earning vegetable crops for the farmers of gangetic plains of west Bengal. The soil and climatic condition of this region is mostly sandy loam in nature coupled with low organic matter and high rainfall. Cultivation of capsicum is gaining its importance among the vegetable growers of this region. But this vegetable suffers from lower productivity, frequent outbreak of pest and diseases. On the other hand capsicum is grown with wider spacing which offers ample scope for taking intercrops in between. Keeping all these present study was undertaken.

MATERIAL AND METHODS

This experiment was carried out at Horticultural Research Station, Bidhan Chandra Krishi Vishwavidyalaya, Mondouri, Nadia, during the year 2017-18 and 2018-2019. The location of the experimental site is 23.5^0 North latitude and 80^0 East longitudes with average altitude of 9.75 m above the MSL. The research work was conducted during rabi season in the randomized block design with nine (9) treatment combinations and replicated thrice, with capsicum variety Ayesha (Table 1). Seeds of capsicum were sown in plug-trays filled with coco-peat as a growing media and seedlings emerged after one week. The 30-35 days old capsicum seedlings were transplanted at the experimental plot, whereas for other intercrops direct seed sowing was done. Capsicum seedlings were transplanted at a spacing of 60 cm x 50 cm. Seeds of the intercrops i.e. spinach, radish, coriander and French bean were sown in between the rows of capsicum in 1:1 ratio i.e. in additive series and they were also transplanted in sole plot at spacing of 20 x 5 cm, 20 X 10 cm, 30 x 15 cm and 50 x 15 cm, respectively. Observations recorded are plant height (cm), plant main stem girth (cm), number of primary branches $plant^{-1}$, number of secondary branches $plant^{-1}$, number of leaves $plant^{-1}$, fruit length (cm), fruit diameter (cm), fruit yield $plant^{-1}$ (kg), fruit yield $plot^{-1}$ (kg) and total yield (tonnes ha^{-1}). Crops were raised and suitable measures and methods were adopted for fertilizer application, weed minimization, harvesting, disease and pest control following standard cultivation practices. Total soluble solids (TSS) content was estimated with the help of a digital refractometer (0 to 32°Brix). Ascorbic acid content of capsicum fruits was determined (Ranganna 1986). Beta carotene content of fruit was analyzed as per the method suggested by Davies (1976).Total and reducing sugar content were estimated by the procedure proposed by Dubois et al (1956).

In association of crop yield, Capsicum Equivalent Yield (CEY) (Verma and Modgal 1983), Land Equivalent Ratio (LER) (Mead and Willey 1980) and Relative Crowding Coefficient (K) (Hall 1974) were measured.

Capsicum Equivalent Yield measured by the formula of

Yield of capsicum in intercrop + Yield of intercrop in a mixed stand x price of intercrop

Price of capsicum

LER = ∑ Yij/Yii,

Where, Yij = yield of crop in intercropping system, Yii = yield of the crop in sole cropping system.

Relative Crowding Coefficient (K) was measured by the formula of

Kab = $Y_{ab} \times Z_{ba}$

(a and b are two crops in intercropping system)

$(Y_{aa}-Y_{ab}) \times Z_{ab}$

Where, Yab= yield of crop a in mixed stand, Yaa= yield of crop a in pure stand, Zab= sown proportion of crop a (in mixed stand with b), Zba= sown proportion of crop b (in mixed stand with crop a. Mean values of each entry in each replication for all the traits were subjected to statistical analysis by using MS Office Excel software.

Economics of capsicum production under intercropping system was calculated by computing the market price of capsicum and their intercrops and net returns and benefit cost ratios were worked out for each treatment (Zivenge et al 2013).

Net returns = Gross returns – Total production cost.

Benefit: Cost = Gross returns / Total production cost

RESULTS AND DISCUSSION

Growth parameters: Intercropping had significantly affected most of the growth parameters of bell pepper (Table 1). Maximum plant height (88.06 cm) was recorded from sole capsicum followed by capsicum+ French bean treatment and minimum plant height (79.10 cm) was observed in capsicum + spinach intercropping system preceded by capsicum + radish intercropping combination. maximum values of plant height in capsicum + French bean plots might be due lesser competition between the components crops for biological resources. This result was in conformity with the findings of Magray et al (2021) and Suresha et al (2007) in capsicum and chilli based intercropping system respectively.

Maximum stem girth (0.73 cm) was in sole capsicum and was statistically at par with all other treatment. Same trend was also observed by Thapa (2015) in garlic based intercropping system, where stem girth was maximum in sole garlic followed by garlic + garden pea intercropping system. Significantly highest number of leaves plant^{-1}(58.07) was from sole capsicum treatment and among the intercropping system, higher number of leaves plant^{-1} was found in capsicum+ French bean treatment which is supported by Morsy et al (2009), followed by capsicum+ coriander and statistically at par with each other. Lowest number of leaves plant^{-1} (46.03) was recorded from capsicum + spinach treatment. Maximum number of both primary and secondary branches plant^{-1} observed when capsicum has been grown alone. Begum et al (2015) also observed sole cropping of chilli produced maximum number of branches plant^{-1} in chili based intercropping system. This might be due to minimum competition for space and growth resources compared to growing of two or more crops in intercropping.

Yield attributing characters: Intercropping influenced yield and yield attributing characters of capsicum (Table 2). Significantly maximum fruit length (8.95 cm), fruit diameter (6.96 cm) and fruit yield (27.58 t ha^{-1}) of capsicum was from sole capsicum treatment over all other treatments. Jan et al (2016) while carrying out a field trial at Sheri Kashmir University of Agricultural Sciences and Technology, Srinagar to evaluate the nodulation behavior and other growth and yield parameters of maize and cowpea in different ratio found the similar type of results. Capsicum grown alone has no competition from intercrops for nutrients, water, sunlight,

Table 1. Effect of intercropping on growth parameters of capsicum

Treatments	Plant height (cm)	Plant main stem girth (cm)	Number of leaves plant^{-1}	Number of primary branches plant^{-1}	Number of secondary branches plant^{-1}
T_1: Sole capsicum	88.06	0.73	58.07	1.84	5.00
T_2:Capsicum+ spinach	79.10	0.63	46.03	1.54	3.93
T_3:Capsicum+radish	81.01	0.65	48.80	1.45	3.48
T_4:Capsicum+Frenchbean	85.79	0.69	54.93	1.68	4.09
T5:Capsicum+Coriander	83.58	0.66	52.71	1.59	3.58
CD (p=0.05)	1.38	0.07	3.97	0.20	0.61

space etc. that leads to maximum utilization of all the available resources by capsicum alone, which accelerated higher crop production. Higher values of fruit length (8.53 cm) and diameter (6.59 cm) were observed from capsicum+ French bean treatment followed by capsicum + coriander model. Significantly lowest fruit length and diameter (7.35 cm and 5.83 cm respectively) were obtained from capsicum+ spinach treatment. Brintha et al (2012) also reported maximum fruit length and diameter in sole chilli plots. Different levels of nitrogen, phosphorus, particularly potassium, plays dynamic role and significantly influence the production and development of good quality and length of fruits. The model Capsicum+ French bean recorded highest yield (26.20 t ha^{-1}) in intercropping combinations, which is statistically at par with capsicum+ coriander treatment and significantly lowest fruit yield about 20.90 t ha^{-1} was observed from capsicum+ spinach treatment. Koocheki et al (2021) also observed maximum values for most of the yield attributing characters in sole capsicum plots.

Capsicum+ French bean intercropping system recorded significantly maximum capsicum equivalent yield ha^{-1} (31.16 t) and lowest was observed from capsicum + spinach treatment (23.81 t ha^{-1}), preceded by capsicum + coriander intercropping system which was statistically at par with capsicum+ radish treatment. The maximum values for capsicum equivalent yield in capsicum + French bean intercropping treatment might be due the inclusion of the legume crop like French bean which might have helped in more nitrogen fixation and hence increased the nitrogen availability to the main crop. Singh et al (2019) while evaluating the efficiency of maize + pea intercropping system at Khalsa College, Amritsar, India also found that maximum maize equivalent yield was obtained from maize + pea intercropping system. Magray et al (2021) also recorded similar results in capsicum and French bean association. Kumari et al (2018) observed maximum chilli equivalent yield in chilli + fenugreek intercropping system. This may be due to ameliorative effect legume crop like fenugreek and less competition among them for water, nutrient, light etc. due to higher values of biological parameters like land equivalent ratio, relative crowding coefficient, etc and high price of French bean.

Effect of intercropping on qualitative parameters of capsicum: Biochemical parameters like TSS, ascorbic acid, beta carotene and sugar content of capsicum were also affected by intercropping (Table 3). French bean grown as inter crop recorded maximum TSS value, ascorbic acid and beta carotene content of capsicum (6.27^0 Brix, 181.15 mg 100 g^{-1} and 1.90 mg 100g^{-1}, respectively). The capsicum + coriander treatment recorded highest total and reducing sugar about 5.15 and 2.83%, respectively. Lowest values of TSS (4.58^0 Brix), ascorbic acid (89.62 mg 100g^{-1}) and beta carotene content (0.59 g 100 g^{-1}) of capsicum were observed from capsicum+ radish treatment. Significantly, lowest values of total sugar (4.19 %) and reducing sugar (2.56 %) were recorded from capsicum crop grown alone.

The higher ascorbic acid content in capsicum and French bean intercropping might be attributed to increased

Table 2. Effect of intercropping on yield and yield attributing parameters of capsicum

Treatments	Fruit length (cm)	Fruit diameter (cm)	Yield (t ha^{-1})	Capsicum equivalent yield (t ha^{-1})
T_1	8.95	6.96	27.58	27.58
$T_{2:}$	7.35	5.83	20.90	23.81
T_3	7.89	6.03	24.26	27.31
$T_{4:}$	8.53	6.59	26.20	31.16
T_5	8.30	6.26	25.38	26.80
CD (p=0.05)	0.13	0.12	1.01	1.08

Table 3. Effect of intercropping on quality parameters of capsicum

Treatments	TSS (°Brix)	Ascorbic acid (mg/100g)	β carotene (mg 100g^{-1}	Total sugar (%)	Reducing sugar (%)
T_1	5.38	159.98	1.32	4.19	2.56
$T_{2:}$	5.01	137.80	0.68	4.61	2.61
T3	4.58	89.62	0.59	4.53	2.59
$T_{4:}$	6.27	181.15	1.90	4.81	2.67
T5	4.80	106.30	1.07	5.15	2.83
CD (p=0.05)	0.29	10.05	0.92	0.14	0.08

availability of nutrients in the soil that might lead to synthesis and accumulation of more photosynthates which could have mobilized the biosynthesis of ascorbic acid. Choudhuri (2011) also found that maximum ascorbic acid content was found in okra + cowpea intercropping system. Increase in β- carotene and total sugar content of capsicum fruits may be attributed to increased vegetative growth in capsicum + French bean intercropping system due to better biological attributes like higher LER, Relative crowding coefficient, etc., which increases the efficiency of photosynthesis for the manufacture of compounds such as polysaccharides, which, when analyzed, produce acetyl COA, lycopene and β- carotene dyes (Hussein 2013). Mana and Kazem (2014) explained that the intercropping system outweighs the qualities and quality of the product. Capsicum and coriander grown together that leads to accumulation of potash in capsicum at higher quantities as coriander is less user of potash and ultimately accumulated more reducing sugar in capsicum.

Competitive functions: The observation recorded on competitive functions showed that capsicum grown with French bean recorded maximum LER value of 1.62, which indicated that about 62% of land saving and also have yield advantages, when French bean grown along with capsicum intercropping system (Table 4). It might be due to efficient utilization of natural resources viz., space, light, etc. as well as component crop having different characteristics like nutrient requirements and shading effects. Thapa, (2015) also reached the same conclusion. Capsicum + spinach recorded lowest value of LER (1.29).

All the values of relative crowding coefficient showed greater than one, which indicated yield advantage over monocropping and better land utilization efficiency by the component crops. Capsicum grown with French bean recorded maximum relative crowding coefficient (RCC) (42.16) followed by capsicum + coriander (23.65) intercropping system. RCC value obtained for all the treatment combinations in this experiment is more than one, which assumed sustainable biomass production for all treatments. Capsicum grown with French bean recorded maximum values for relative crowding coefficient which might be due to beneficial effect of legume to capsicum that leads to production of higher quantity of capsicum and French bean. Meena et al (2008) also observed same phenomena in cluster bean + sesame intercropping system.

Table 4. Effect of intercropping on competitive function of capsicum

Treatments	Land equivalent ratio	Relative crowding coefficient		Product
		K_a	K_b	
T_1:Capsicum+ spinach	1.29	3.15	1.20	3.78
T_2:Capsicum+ radish	1.45	7.46	1.35	10.07
T_3:Capsicum+ french bean	1.62	19.25	2.19	42.16
T_4:Capsicum+ coriander	1.57	11.65	2.03	23.65
T_5:Sole capsicum	1	-	-	-
T_6:Sole spinach	1	-	-	-
T_7:Sole radish	1	-	-	-
T_8:Sole french bean	1	-		-
T_9:Sole coriander	1	-	-	-

K_a – Relative crowding coefficient of capsicum, Kb- Relative crowding coefficient of intercrops

Table 5. Economics of capsicum based intercropping system

Treatments	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
T_1:Capsicum+ spinach	131063.00	309530.00	178467.00	2.36
T_2:Capsicum+ radish	132220.00	355030.00	222810.00	2.69
T_3:Capsicum+ French bean	130050.00	405080.00	271030.00	3.11
T_4:Capsicum+ coriander	120052.00	348400.00	228348.00	2.90
T_5:Sole capsicum	123120.00	358540.00	235420.00	2.91
T_6:Sole spinach	42575.00	71170.00	28595.00	1.67
T_7:Sole radish	43075.50	74060.00	30985.00	1.72
T_8:Sole French bean	45065.00	91700.00	46635.00	2.03
T_9:Sole coriander	20075.00	28015.00	7940.00	1.40

Economics: The capsicum + French bean combination was most remunerative as it recorded highest B : C ratio (3.11) followed by sole cropping of capsicum (Table 5). Among the intercropping systems, capsicum + spinach combination was recorded least economical (2.36). Among different combinations, capsicum grown with French bean was most remunerative which is due to maximum capsicum equivalent yield than all other treatments. But due to comparatively higher cost of cultivation and comparatively lower capsicum equivalent yield than most of the treatments capsicum grown with spinach was least remunerative Thapa (2015) also observed that the intercropping system garlic + garden pea combination was the most economical.

CONCLUSION

Most of the growth and yield attributes were significantly influenced due to intercropping system and economic analysis showed that capsicum+ French bean model recorded highest benefit-cost ratio. Hence, it may be concluded that inclusion of French bean with capsicum can be a profitable for a sustainable production system for the farmers of Gangetic plains of West Bengal.

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Multivariate Diversity Analysis of Tamarind (*Tamarindus indica* L.) Genotypes Arid Condition of Western Maharashtra

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Abstract: To estimate the variability among tamarind genotypes for different tree growth, flowering and fruiting parameters and to identify the potential genotypes with promising attributes, the present investigation was carried out under the arid conditions of Nashik Division of Western Maharashtra. All the reddish-brown pulp genotypes indicated reddish-brown flush colour and most of the brown pulp genotypes for the green colour flush. Most precocious flowering was in the genotype RHRTG 1 and RHRTG 9 and the most late in RHRTG 7. Minimum numbers of days taken to ripening were noted in RHRTG 13 (240 days) and RHRTG 16 (245 days), while the genotype RHRTG 1 (258 days), RHRTG 5 (258 days) and RHRTG 4 (260 days) obtained the maximum days. The major contributing trait for the diversity in the principal component one (PC1) was pulp per cent (0.333) followed by pulp weight (0.302) and pod breadth (0.251) while, in the PC2, the highest positive loading was obtained from seed weight (0.355), pod weight (0.319) and shell weight (0.315). Genotypes identified as promising in the investigation may prove to be potential genetic resource in tamarind improvement programme.

Keywords: *Tamarindus indica*, Variability, Genetic divergence

Tamarind (*Tamarindus indica* L.) is a hardy tropical tree that belongs to the Fabaceae family. It is an excellent agroforestry tree as it grows well alongside both annual and perennial crops and is deliberately retained on-farm (Okello et al 2018). Due to its capacity to withstand droughts, salinity and high temperatures, it holds greater significance in waste land development and dry land horticulture (Karale 2002). In India, tamarind is grown in an area of 44.99 thousand hectares (ha) with an annual production of 162.03 thousand MT. Tamil Nadu is the leading producer with more than 27.20% share to the total production followed by Karnataka (22.75%), and Kerala (19.94%) (NHB 2022).

Tamarind being a cross pollinated specie and predominance of propagation *via* seed provides ample opportunities for the selection of outstanding types with desirable horticultural characteristics (Pooja 2018). Thus, identifying and describing genetic variability within genotypes is a preliminary step before formulating any selection programme (Verma et al 2014). Genetic variability can be examined using a variety of methods, of which two are commonly used in the divergence studies such as principal component analysis (PCA) and hierarchical cluster analysis (HCA). The principal component analysis (PCA) is a statistical technique used to analyze data sets in order to emphasize variation and draw out strong patterns (Ayala-Silva et al 2016). It was conducted to provide a better understanding of the genetics and environmental interactions that have contributed to the genetic diversity. A hierarchical cluster analysis is also used to explain the dissimilarities among genotypes based on Euclidean distance and to investigate the relationship between them based on their potential characteristics. The multivariate analysis is an effective means of understanding genetic similarities and dissimilarities among the genotypes, where the several different traits are examined simultaneously to understand the clustering mechanism for their utility breeding, commercialization and conservation of plant genetic resources. This study aims to determine the morphological differences among the tamarind genotypes and to establish a relationship between them for their further utility in tamarind crop improvement programme.

MATERIAL AND METHODS

The field experiment was conducted at Instructional-cum-Research Farm, Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (MS), India. It is situated at 19º20′36″ North latitude and 74º39′38″ East longitudes at an altitude of 519 meters above mean sea level in the Nashik Division of Western Maharashtra. The climate of the experimental site is arid to semi-arid with dry and hot summer and receives an annual rainfall of 479.7 mm on an average. The highest average temperature ranges from 32ºC to 45ºC in summer and the lowest temperature from 8.5ºC to 10ºC in winter. The experimental material consisted of 25 years old tamarind genotypes maintained under uniform cultural practices throughout the investigation. A detailed analysis of genotypes for various tree growth, flowering and fruiting attributes was performed from the flowering month of May 2018 through the harvesting month of March 2019. The PPV&FRA (Protection of Plant Varieties & Farmer's Right Authority) test guidelines were followed to evaluate the tamarind genotypes for qualitative growth attributes (Anonymous, 2017). The observations on quantitative pod attributes were recorded as per standard procedures. The biochemical parameters *viz*. TSS, titratable acidity (%) and ascorbic acid (mg/100g) were assessed following standard methodology (AOAC 2000).

Statistical analysis: The statistical analysis for mean, standard deviation and coefficient of variation was done using IBM SPSS Statistics 19 statistical software (IBM, NY, USA). The genetic divergence among 20 tamarind genotypes was estimated using the Principal Component Analysis and Hierarchical Cluster Analysis (HCA) where the data was subjected to multivariate statistical analysis (PCA and HCA) using the R Statistical Software (2021).

RESULTS AND DISCUSSION

Out of 20 genotypes, 6 genotypes exhibited upright growth habit, 4 spreading, 10 semi-spreading (Table 1). The tree foliage density of varied from dense type (14 genotypes) to sparse (6 genotypes). For new flush colour, genotypes namely; RHRTG 1, RHRTG 3 and RHRTG 16 showed reddish brown flush and rest all displayed reddish-green flush colour (Plate 1). The differences in tree growth habit and tree morphological attributes might be due to the genotypic characteristics of the tree. Earlier workers had also reported variability in morphological attributes of different tamarind genotypes under Bangalore conditions (Nandini et al 2011, Algabal et al 2012).

Date of inflorescence emergence was early in genotype RHRTG 1 (17-05-2018) and late on 29th May, 2018 in the genotype RHRTG 7 (Fig. 1). The date of harvesting spanned from 26-02-2019 to 02-03-2019. The minimum number of days taken to maturity was estimated in RHRTG 13 (240 days) and maximum in RHRTG 4 (260 days) followed by RHRTG 5 (258 days) and RHRTG 1 (258 days) (Table 2). Previous study on tamarind also reported a high variability among genotypes for these parameters (Bhogave et al 2018). Genotype RHRTG 20 (6.60 m), RHRTG 2 (6.30 m) and RHRTG 17 (6.10 m) recorded highest tree height and the

Reddish-green flush colour **Reddish-brown flush colour**

Plate 1. Variability among the genotypes for new flush colour

Table 1. Variability among tamarind genotypes for tree growth habit, foliage type and new flush colour

Genotype	Growth habit	Tree foliage type	New flush colour
RHRTG 1	Semi-spreading	Dense	Reddish brown
RHRTG 2	Upright	Dense	Reddish green
RHRTG 3	Semi-spreading	Dense	Reddish brown
RHRTG 4	Spreading	Dense	Reddish green
RHRTG 5	Semi-spreading	Dense	Reddish green
RHRTG 6	Upright	Sparse	Reddish green
RHRTG 7	Semi-spreading	Sparse	Reddish green
RHRTG 8	Semi-spreading	Sparse	Reddish brown
RHRTG 9	Upright	Dense	Reddish green
RHRTG 10	Upright	Sparse	Reddish green
RHRTG 11	Semi-spreading	Dense	Reddish green
RHRTG 12	Spreading	Sparse	Reddish green
RHRTG 13	Upright	Dense	Reddish brown
RHRTG 14	Spreading	Dense	Reddish green
RHRTG 15	Semi-spreading	Sparse	Reddish green
RHRTG 16	Semi-spreading	Sparse	Reddish brown
RHRTG 17	Semi-spreading	Dense	Reddish green
RHRTG 18	Spreading	Dense	Reddish green
RHRTG 19	Upright	Dense	Reddish green
RHRTG 20	Semi-spreading	Dense	Reddish green

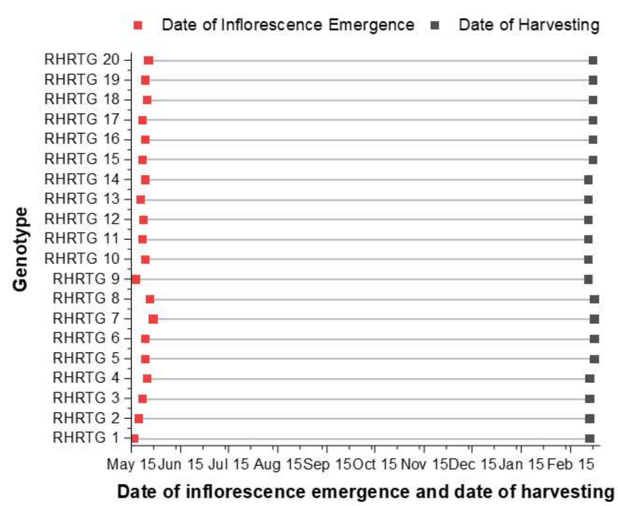

Fig. 1. Variability among tamarind genotypes for date of inflorescence emergence and harvesting

lowest was noted in RHRTG 15 (3.80 m) (Table 2). For East-West tree spread, the genotypes RHRTG 14 (7.10 m) followed by RHRTG 1, RHRTG 20 and RHRTG 11 were superior when compared with rest of genotypes and the lowest was in the genotype RHRTG 9 (3.25 m). Similarly for North-South spread genotype RHRTG 20 (6.95 m) followed by RHRTG 14 and RHRTG 12 were found superior and the lowest spread was in RHRTG 9 (3.00 m). The canopy volume ranged between 5.11 m^3 to 36.17 m^3 and the genotypes RHRTG 20, RHRTG 14 and RHRTG 1 were superior and RHRTG 9 showed the minimum (5.11 m^3). With respect to trunk girth, the genotypes RHRTG 14 (91.3 cm) followed by RHRTG 2, RHRTG 1 and RHRTG 12 estimated maximum and RHRTG 15 (45.2 cm) the minimum. Individual genotypes may have different genetic constitutions, which could explain the diversity in different metric traits of tree growth. Similar variability for plant growth attributes were reported by Tania et al (2018). Reddy et al (2022) determined the genotype NZB(S) to be best performing accessions in terms of growth, yield and quality characters.

Principal Component Analysis (PCA)

The principal component analysis of 20 tamarind genotypes based on correlation matrix of tree growth and physico-chemical traits reduced the original data set of 24 metric attributes to 18 vector or principal components. The first six components in the PCA analysis with Eigen values more than one contributed 87.48% of the total variability among the different genotypes evaluated (Table 3). The PC1 accounts for the maximum variability (30.64%) in the data, while PC2 with Eigen value of 5.03 accounted for 20.98% of the total variability observed. PC3 had Eigen value of 3.20 and contributed 13.33% to the observed variability. Meanwhile, PC4, PC5 and PC6 had Eigen value 2.745, 1.525 and 1.136 which contributed 11.44%, 6.35% and 4.74% of total variability, respectively.

In the present study, only the first 6 principal components with eigen values >1 explaining 87.48% of variation among 20 tamarind genotypes are being discussed and interpreted. For each principal component, there are several characters contributing to the total variation. Major contributing characters for the diversity in the principal component one (PC1) was pulp per cent (0.333) followed by pulp weight (0.302), pod breadth (0.251) while, seed per cent (-0.304), shell per cent (-0.303), ascorbic acid content (-0.235) had the highest negative loading (Table 3). In PCA, characteristics are analyzed in terms of their association and direction of variation. As a result of these findings, genotypes with high pulp percent and pulp weight will tend to have a greater pod breadth and lower seed/shell percents and ascorbic acid content. If the ascorbic acid content is high, then the positively correlated traits for PCI will tend to have lower values. The second PC accounted for 20.98% of the additional variability not explained by PCI. Seed weight (0.355), pod weight (0.319), shell weight (0.315) was positively correlated with PC2. Vein per cent (-0.175), pulp per cent (-0.116) and shell per cent (-0.030) decreased in PC2. Moreover in 3rd, 4th, 5th and 6th principal component, trait such as canopy volume (0.373), yield per tree (0.363), vein per cent (0.412) and days to maturity (0.588) had the highest positive loading, respectively. A positive and a negative loading of factors was observed in the above 2 major principal components, which indicate that the components and variables had both positive and negative correlations. Pulp per cent and seed weight was examined to be best choice which had the highest loading from the principal component one (PC1) and two (PC2), respectively. In principal component analysis (PCA) the amount of variation among the genotypes can be attributed to every axis of differentiation by the largest contributor. To aid the

Table 2. Days to maturity (days), tree growth and pod attributes of tamarind genotypes under the arid conditions of Western Maharashtra

Parameters	Range	Mean	CV (%)
Days to maturity (days)	240-260	248.25	2.33
Tree height (m)	3.80-6.60	5.25	13.79
Tree spread EW (m)	3.25-7.10	5.37	16.84
Tree spread NS (m)	3.00-6.95	5.29	20.21
Canopy volume (m^3)	5.11-36.17	19.06	42.04
Trunk girth (cm)	45.20-91.30	65.54	20.94
Pod weight (g)	16.85-28.07	21.55	16.79
Pod length (cm)	9.81-17.27	12.69	16.2
Pod breadth (cm)	2.05-2.95	2.48	8.71
Shell weight (g)	3.65-6.80	4.75	16.37
Pulp weight (g)	7.29-17.45	11.17	24.94
Seed weight (g)	2.37-6.67	4.44	26.5
Vein weight (g)	0.57-1.58	1.01	28.19
No. of seeds per pod	4.33-10.00	6.28	23.05
Weight of 100 seeds (g)	46.40-98.60	77.85	19.3
Shell per cent (%)	16.13-26.88	22.20	12.89
Pulp per cent (%)	37.12-62.16	51.42	13.24
Seed per cent (%)	12.32-31.34	20.75	24.56
Vein per cent (%)	2.57-6.65	4.66	22.66
Yield per tree (kg)	9.00-85	44.05	54.19
Yield efficiency (kg/m^3 CV)	0.53-5.81	2.48	58.93
TSS (°Brix)	28.68-34.80	31.20	4.58
Acidity (%)	8.08-11.18	8.76	9.2
Ascorbic acid (mg/100g)	1.35-3.54	2.06	22.86

visualization of variations among the genotypes, the score of first two principal component were represented graphically in the form of principal component biplot (Fig. 2 and Fig. 3). Biplot data revealed that the attributes displaying acute angles are positively correlated, whereas those exhibiting obtuse or parallel angles are negatively correlated and those showing right angles have no correlation at all. The graphical representation of data also reveals that the shell weight and pod length; pod weight and weight of 100 seeds are positively correlated. However, the seed per cent and pulp per cent were found to be negatively correlated. Further, PCA also helped to identify RHRTG 14, RHRTG 9 and RHRTG 12 as superior tamarind genotypes which performed well with respect to the PC1 and PC2 (Fig. 3). Using PCA, Kidaha et al (2019) assessed morphological diversity of tamarind germplasm from Eastern parts of Kenya. Trunk diameter pod weight, number of seeds per pod, height to the first branch and pod breadth showed highest variation in principal component analysis.

Hierarchical cluster analysis (HCA): Hierarchical cluster analysis also showed the dissimilarity among the tamarind genotypes and further revealed the relationship between them. The highest dissimilarity matrix was determined between the genotypes RHRTG 14 & RHRTG 9 (93.05) followed by RHRTG 7 & RHRTG 4, RHRTG 14 & RHRTG 7, however it was lowest for RHRTG 12 & RHRTG 11 (9.73) and RHRTG 14 & RHRTG 12 (Table 4). The hierarchical cluster analysis classified 20 tamarind genotypes into two major groups at 186.20 Euclidean distance and further in clusters according to their different morphological characteristics

Table 3. Eigenvalue, percentage of variance (%) and cumulative variations (%) for six major principal components among the tamarind genotypes

Character	Component					
	PC1	PC2	PC3	PC4	PC5	PC6
Days to maturity (days)	-0.122	0.128	0.107	0.200	-0.312	0.588
Tree height (m)	0.080	0.077	0.368	-0.230	0.345	-0.054
Tree spread EW (m)	0.216	0.173	0.288	0.231	-0.111	0.045
Tree spread NS (m)	0.242	0.168	0.280	0.201	0.034	0.084
Canopy volume (m^3)	0.212	0.172	0.373	0.075	0.126	0.035
Trunk girth (cm)	0.192	0.149	0.254	-0.137	0.215	0.047
Pod weight (g)	0.175	0.319	-0.214	-0.177	-0.018	-0.094
Pod length (cm)	-0.083	0.290	0.005	-0.338	-0.212	-0.005
Pod breadth (cm)	0.251	0.193	-0.058	-0.100	-0.143	0.251
Shell weight (g)	-0.093	0.315	-0.205	-0.186	-0.127	0.166
Pulp weight (g)	0.302	0.156	-0.177	-0.140	-0.091	-0.122
Seed weight (g)	-0.180	0.355	-0.042	-0.080	0.164	-0.132
Vein weight (g)	0.234	0.082	-0.315	0.018	0.308	0.188
No. of seeds per pod	-0.205	0.290	-0.034	-0.232	0.137	-0.114
Weight of 100 seeds (g)	0.148	0.260	-0.052	0.196	-0.342	-0.254
Shell per cent (%)	-0.303	-0.030	0.073	-0.028	-0.158	0.263
Pulp per cent (%)	0.333	-0.116	-0.092	-0.066	-0.165	-0.061
Seed per cent (%)	-0.304	0.168	0.110	0.070	0.194	-0.142
Vein per cent (%)	0.184	-0.175	-0.214	0.071	0.412	0.267
Yield per tree (kg)	0.117	0.267	-0.111	0.363	0.145	0.063
Yield efficiency (kg/m^3 CV)	-0.082	0.184	-0.357	0.290	0.131	0.101
TSS (°Brix)	-0.020	0.033	0.096	-0.380	0.093	0.460
Acidity (%)	-0.187	0.198	0.175	0.274	0.030	-0.055
Ascorbic acid (mg/100g)	-0.235	0.136	-0.100	0.174	0.229	0.046
Eigenvalue	7.353	5.035	3.200	2.745	1.525	1.136
Percentage of variance (%)	30.64	20.98	13.33	11.44	6.35	4.74
Cumulative variations (%)	30.64	51.62	64.95	76.39	82.74	87.48

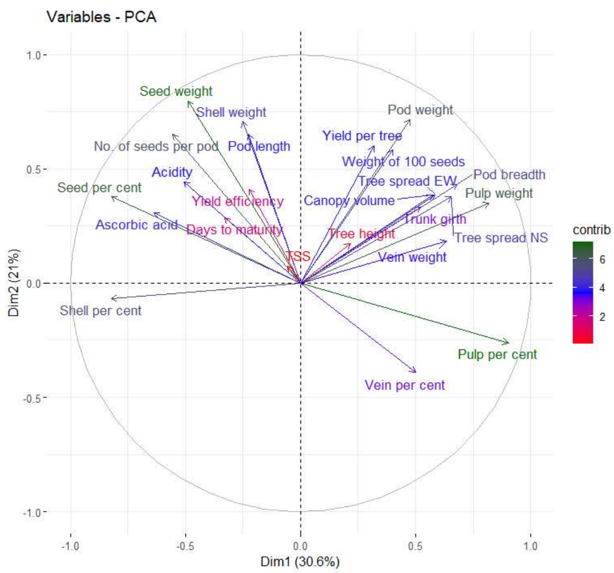

Fig. 2. Traits contribution toward genetic divergence based on PC1 and PC2

(Fig. 4). The first cluster included 14 genotypes which contributes 70.00% of the total genotypes in this population while the second group consisted 6 genotypes contributing 30% of the total genotypes. The 1st major cluster is further divided in to two sub-clusters at 90.97 Euclidean distance in

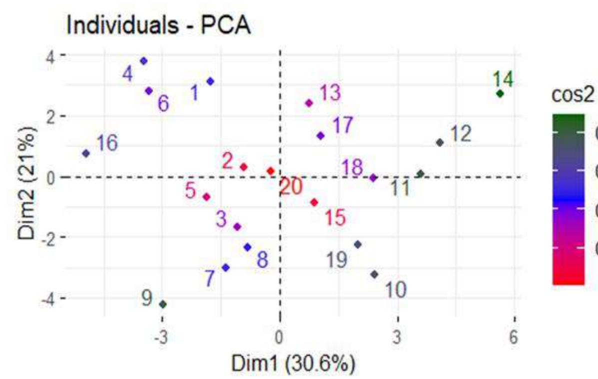

Fig. 3. Distribution of genotypes in the scatter plot along with PC 1 and PC 2

Table 4. Dissimilarity matrix among the tamarind genotypes based on Euclidean distance

Genotypes*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.00	23.79	40.88	44.21	53.14	44.75	59.46	51.26	64.48	39.73	31.01	34.08	38.96	38.67	46.56	39.46	27.48	37.39	33.31	31.17
2		0.00	40.45	60.85	51.58	36.19	40.41	40.69	47.78	26.15	43.58	48.42	33.91	51.05	54.49	45.72	36.31	37.62	26.97	22.48
3			0.00	53.14	39.22	22.70	48.65	38.04	41.81	32.81	51.14	57.20	51.29	66.97	33.78	31.93	32.30	27.28	25.08	36.48
4				0.00	73.58	63.18	91.73	78.36	88.57	69.69	39.73	38.41	69.47	52.52	35.72	29.76	37.82	48.72	57.12	67.52
5					0.00	41.53	56.62	20.75	50.07	44.09	65.30	70.89	37.87	77.03	56.21	58.55	52.75	48.73	40.51	49.49
6						0.00	38.19	34.19	30.31	30.42	59.43	65.28	47.34	72.75	47.12	41.21	42.20	34.43	29.91	37.59
7							0.00	39.37	22.33	32.59	77.93	84.65	57.55	87.60	76.34	69.74	65.43	58.02	45.70	35.58
8								0.00	34.89	31.48	64.96	71.28	33.01	75.99	59.21	58.47	51.85	44.96	32.71	39.80
9									0.00	36.77	80.65	87.18	59.42	93.05	70.39	63.99	64.88	55.56	45.08	44.80
10										0.00	49.17	56.80	39.51	60.48	50.75	51.52	40.77	32.03	20.20	30.00
11											0.00	9.73	48.74	19.74	35.75	42.12	24.45	33.05	38.54	53.46
12												0.00	52.41	15.73	40.17	44.57	28.12	39.56	44.97	58.34
13													0.00	53.21	58.06	57.58	43.60	43.57	34.29	43.58
14														0.00	53.39	57.82	38.21	48.17	51.17	61.32
15															0.00	25.67	24.48	22.92	36.10	58.56
16																0.00	25.79	31.17	37.42	50.63
17																	0.00	17.84	23.82	40.55
18																		0.00	17.32	42.35
19																			0.00	30.21
20																				0.00

Genotypes*

1.	RHRTG 1	5.	RHRTG 5	9.	RHRTG 9	13.	RHRTG 13	17.	RHRTG 17
2.	RHRTG 2	6.	RHRTG 6	10.	RHRTG 10	14.	RHRTG 14	18.	RHRTG 18
3.	RHRTG 3	7.	RHRTG 7	11.	RHRTG 11	15.	RHRTG 15	19.	RHRTG 19
4.	RHRTG 4	8.	RHRTG 8	12.	RHRTG 12	16	RHRTG 16	20.	RHRTG 20

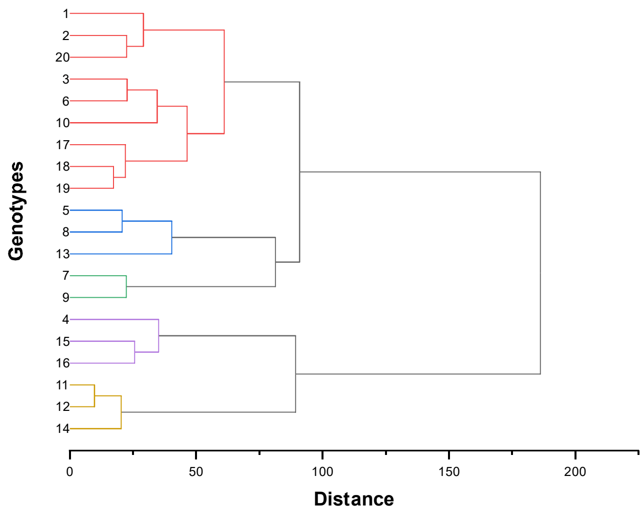

Fig. 4. Dendrogram grouping of 20 tamarind genotypes

which first sub cluster comprised 9 genotype and second sub-cluster consisted 5 genotypes. The 1st sub cluster is again divided into the two- cluster further at 61.10 Euclidean distance and 2nd at Euclidean distance of 81.33 and consisted of three and six genotypes, respectively. The 2nd major cluster is further divided in to two sub-clusters at 89.38 and consisted of RHRTG 4, RHRTG 15, RHRTG 16 in 1st sub cluster and RHRTG 11, RHRTG 12 and RHRTG 14 in 2nd sub cluster. Based on 18 qualitative and quantitative traits, Ayala-Silva et al (2016) analyzed pomological diversity of 13 tamarind genotypes at Miami, Florida. Cluster analysis grouped all tamarind genotypes into three major clusters where the semi-sour genotypes were grouped in cluster 'A' and the sour genotype in cluster 'C'. Cluster 'B' contained genotypes predominantly characterized by sweet, dark pulp, and smaller fruit size.

CONCLUSIONS

Tamarind germplasm maintained at Instructional-cum-Research farm of Department of Horticulture, MPKV., Rahuri exhibits considerable variations in terms of different metric and non-metric parameters. In conclusion, the PCA was able to capture 87.48% of the variations present in the 20 genotypes of tamarind taken into consideration. PCA study revealed the RHRTG 14, RHRTG 9 and RHRTG 12 to be superior tamarind genotypes that outperformed PC1 and PC2 based on the quality of representation of these genotypes on the factor map. The genotypes that have demonstrated superiority in a number of key attributes can be exploited more efficiently in the tamarind crop improvement programme..

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Eco-friendly Management of *Phytophthora* Root Rot and Gummosis in Mandarin

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***Abstract*:** The oomycete *Phytophthora nicotianae* causes root rot, foot rot, crown rot, and gummosis in the mandarin crop throughout India. Most mandarin root stocks grown in country is susceptible, or at best moderately susceptible, and necessitates frequent fungicide applications to avoid heavy yield losses. Four years of field trials in three different locations (Akola, Ludhaina and Tinsukia) investigated the effect of different conventional and one non-conventional chemical integration with bio-agents on *Phytophthora* root rot and gummosis. The foliar spraying of potassium phosphonate (potassium salt of phosphonic acid) at 3 g/liter water was superior in terms of average reduction in lesion oozing (51.54%), minimum feeder root rot index (1.07), increase in canopy volume (7.93%), and higher fruit yield (17.84 t/ha). Potassium phosphonate is known to induce defense responses in mandarin as well as to have direct toxic effects on oomycetes, which in turn inhibits the development of root rot and gummosis. The use of potassium phosphonate in mandarin crops has been promoted as a feasible method as part of the integrated disease management strategy for *Phytophthora* root rot and gummosis management.

***Keywords*:** Gummosis, Mandarin, Potassium phosphonate and Phytophthora

The mandarin (*Citrus reticulata* Blanco) is the most important commercial Citrus cultivar in India, with a total production of 13976MT (NHB 2019). Commercially, Nagpur mandarin is grown in the Vidarbha region of Maharashtra and adjoining areas of Madhya Pradesh; Khasi mandarin in the north eastern region; Kinnow mandarin in Punjab, Haryana, the western part of Rajasthan, Uttar Pradesh and Himachal Pradesh. Commercial citrus cultivars grown in different regions require different soil and climate conditions to thrive. It demonstrates wide adaptability of Citrus to wide range of soil and climatic conditions. The problems of various citrus cultivation belts differ according to region. The disease has a global distribution, affecting all citrus varieties in tropical and subtropical Citrus production regions, especially in warm, humid climates. Root rot and gummosis caused by *Phytopthora parasitica* var. *nicotianae* have been reported as a major constraint in maintaining optimum production in citrus, resulting in a 46% reduction in annual plant yield). It is responsible for 10-30% yield loss in citrus cultivation around the world (Timmer et al 2000). Naqvi (2003) recorded 20% yield losses in the citrus industry in Central India. Potassium salt of phosphonic acid, also known as potassium phosphonate (H_3PO_3), have been promoted and used as resistance inducers as well as direct inhibitors of oomycetes growth and sporulation with lower risk to human health and the environment when compared to conventional fungicides (Kromann et al 2012). Potassium phosphonate has a high level of symplastic ambimobility or movement in both xylem and phloem. Translocation in phloem allows the chemical to move from leaf tissues to the crowns and roots . Histological and biochemical studies confirmed that potassium phosphonate application increased host resistance to pathogen invasion (Jackson et al 2000, Daniel and Guest 2006). Previously, the efficacy of potassium phosphonate against black pepper foot rot (*Phytophthora capsici*) and Arecanut nut rot (*Phytophthora arecaea*) was determined in India (Lokesh et al 2012 and Hegde 2015). However, information on the use of potassium phosphonate for the management of *Phytophthora* root rot and gummosis diseases in mandarin is needed. In this study, the effects of potassium phosphonate and conventional fungicides on the development of root rot and gummosis were investigated in four years of full-scale field trials in three Indian states (Maharashtra, Punjab and Assam).

MATERIAL AND METHODS

The field trial was conducted at multi-locations, at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (Maharashtra) on variety Nagpur mandarin; the Fruit Research Farm, Punjab Agricultural University, Ludhiana

(Punjab) on variety Kinnow mandarin and the Citrus Research Station, Tinsukia (Assam), on variety Khassi mandarin. The research trial was in Randomized Completely Block Design with eight treatments and three replicates (Table 1). The fungicides, bio-agents, and potassium phosphonate were applied twice at 45-day intervals during July to September 2018-19 to 2020-21. Fosetyl-Al @0.2% was used as a standard check, and an untreated control (absolute check) was also used. Bordeaux paste is commonly used on tree trunks up to 45-60cm above the soil level in all treatments except control as pre and post monsoon. Respective doses of fungicides and bio-agents were applied to the plants' foliar and soil regions in the appropriate amounts. The observations on trunk lesion size recovery, canopy volume, feeder root rot rating, soil disease potential and number of fruits per tree were recorded. The residue analysis was also conducted.

The trunk lesion size was noticed on the experimental plants (main stem/side branches) before and after the second the application of treatments.

Trunk lesion size recovery = (Initial trunk lesion size - Final trunk lesion size)/Initial trunk lesion size x 100

The feeder root rot rating was determined by using Grimm and Hutchinson's scale (1973). The root rot rating scale (1-5) was: 1= No visible symptoms, 2= A few roots with symptoms (1-25%), 3= Majority of roots with symptoms (26-50%), 4= All roots infected, cortex sloughed from major roots (51-75% rotted), and 5= Majority roots dead or missing (>76% rotted). The canopy volume was estimated using the formula proposed by Westwood et al (1993), and the increase canopy volume was calculated.

Percent increase in canopy volume= (Final canopy volume -Initial canopy volume)/ Initial canopy volume X 100.

The soil disease potential of *Phytophthora* soil population was estimated by serial dilution of soil and using specific bait to trap *Phytophthora* according to procedure described by Grimm and Alexander (1973). Fruit samples for residue analysis were collected from 03 months after the second application and sent to the Pesticides Residue Analysis Laboratory at the National Horticultural Research and Development Foundation, Nasik (Maharashtra). Fungicides residues in fruits samples were quantified using the Liquid Chromatography with tandem Mass Spectrometry (LCMS/MS) technique. The experimental data were subjected to analysis for variance for various treatments by using WASP 2.0 software.

RESULTS AND DISCUSSION

The trunk lesion size was measured before the first application of treatments, and the final trunk lesion size was measured 45 days later. There were significant differences in trunk lesion size recovery compared to control observed with different concentration of fungicides and bio-agent's application (Table 2). Among the different treatments, foliar application of potassium phosphonate @ 3g/liter at 45 days' interval significantly exhibited the maximum percent trunk lesion size recovery (51.54%) over the three locations and was at par with treatment T5 (dimethomorph (50WP) + mancozeb (75WP) {1g + 2g/ l water tank mix} + *T. harzianum* + *P. fluorescens* (each 100g/plant with FYM 1kg 25 days of interval) and T7: (Fosetyl -Al @0.2%) where it was 44.17 and 42.47%, respectively. In the absolute control, there was no tree trunk recovery of oozing lesions recorded. It is clearly demonstrated that the application of fungicides and bio-agents through foliar and soil combinations aids in the reduction of lesions oozing from tree trunks.

Subsequent to final application of treatments, feeder root rot index, which included both infected and healthy roots, was observed from the basin of treated plants and was found in the range of 1.07 to 3.12 (Table 2). The untreated control had the highest feeder root rot index (3.12). The lowest feeder root rot index (1.07) was in treatment T6 (Foliar spray of potassium phosphonate @ 3 g/l water). The results showed that the respective fungicides and bio-agents were effective in reducing pathogen infections in the roots. The soil disease potential index is expressed as the highest dilution at which

Table 1. List of fungicides and bio-agents used in study

Treatment	Trade name	Formulation
Cymoxanil 8 % + Mancozeb 64 % @2.5g/l	Curzate M8	Combi product in WP formulation
Dimethomorph 50 WP @ 1g/l + Mancozeb 75 WP 2g/l	Lurit and Dithane M45	Both in WP formulation (Tank mix application)
Trichoderma harzianum(10^7CFU/g) 100g/tree	Respective University formulations	Talc powder base formulation 100 g each mix with 1 kg FYM
Pseudomonas fluorescence(10^8CFU/g) 100g/tree		
Potassium phosphonate (Potassium salt of phosphonic acid 98% Inert compounds 02%)	Chemical grade powder	Water soluble powder base formulation
Fosetyl –Al 80%	Aliette	WP formulation

sporangia are observed. Treatment T6, had the lowest soil disease potential (12.83). This was followed by treatment T5 and T2 and T3 soil application of *Trichoderma harzianum* + *Pseudomonas fluorescens* (100g/plant each) with carrier material of FYM 1kg and T4 with carrier material of FYM 1kg where soil disease potential was recorded 15.89, and 17.11, respectively (Table 3). Maximum soil disease potential was recorded in untreated control (63.17).

It is evident from the pooled data of all the locations that among all the treatments, the maximum canopy volume increase (7.93%) was in T6, where foliar spray of potassium phosphonate @ 3g/l water was undertaken (Table 3). Treatment T7 was the next best treatment, with increase in canopy volumes of 6.79. The maximum fruit yield of 17.84 t/ha was in the plots sprayed with foliar spray of potassium phosphonate @ 3g/l water (T6), The minimum yield of 9.43 t/ha was recorded in the untreated plots (T8) i.e. absolute control (Table 4).

Economics of the treatments was computed by considering the additional cost of applying treatments only (Table 4). The highest incremental cost benefit ratio (ICBR) 4.01 was in treatment T6 (Twice application of potassium phosphonate @ 3g/l water). Residue analysis was performed, and in treatment T1, T2, T4, T5, and T7, residues

Table 2. Effect of various treatments on recovery from trunk lesion and feeder root rot index of citrus (Pooled data for 4 years)

Treatments	Trunk lesion size recovery (%)			Pooled mean	Feeder root rot index			Pooled mean
	Akola	Ludhiana	Tinsukia		Akola	Ludhiana	Tinsukia	
T1: Cymoxanil + mancozeb (8 + 64 WP) 2.5g/l water (combi product)	26.62	45.92	35.90	36.15	1.67	2.00	1.59	1.75
T2: Dimethomorph (50WP) + mancozeb (75WP) (1g + 2g/ l water tank mix)	28.92	40.73	40.42	36.69	1.50	3.00	1.28	1.93
T3:*T. harzianum* + *P. fluorescens* (100g/plant) with FYM 1kg	22.20	29.28	27.10	26.19	1.70	3.00	1.57	2.09
T4: T1 followed by T3 after 25 days interval	32.86	52.57	33.17	39.53	1.20	2.00	1.32	1.51
T5: T2 followed by T3 after 25 days interval	33.77	48.65	50.10	44.17	1.13	2.00	1.15	1.43
T6: Potassium phosphonate @ 0.3% foliar spray (two spray pre and post monsoon)	38.26	65.55	50.80	51.54	0.93	1.00	1.27	1.07
T7:Fosetyl -Al 0.2% (two spray pre and post monsoon)	34.16	62.36	30.89	42.47	1.00	1.00	1.44	1.15
T8: Control	0.00	0.00	0.00	0.00	2.50	4.00	2.86	3.12
CD (p= 0.05)	7.45	12.46	7.92	11.95	0.24	1.04	0.32	0.72

Table 3. Effect of various treatments on soil disease potential and canopy volume increase (Pooled data for 4 years)

Treatments	Soil disease potential			Pooled mean	Canopy volume increase %			Pooled mean
	Akola	Ludhiana	Tinsukia		Akola	Ludhiana	Tinsukia	
T1	25.50	22.33	32.0	26.61	3.56	7.68	3.90	5.05
T2	24.63	23.00	32.0	26.54	3.68	5.63	3.81	4.37
T3	26.25	27.67	32.0	28.64	2.69	3.66	1.78	2.71
T4	19.00	16.33	16.0	17.11	5.60	9.68	3.26	6.18
T5	20.00	17.67	10.0	15.89	6.43	8.23	4.64	6.43
T6	18.50	10.00	10.0	12.83	7.81	11.23	4.75	7.93
T7	21.50	10.33	32.0	21.28	7.07	10.61	2.70	6.79
T8	63.50	62.00	64.0	63.17	0.93	-	0.53	0.49
CD (p= 0.05)	9.38	16.66	6.42	8.83	0.31	1.03	0.51	2.68

See Table 1 for treatment details

were below the quantification level. In treatment T6, where a chemical spray of potassium phosphonate @ 3 g/l water foliar spray was applied with peel 0.547mg/kg and without peel 0.275 mg/kg residue was observed. However, that was below the MRL (90 mg/kg). When compared to the control and different fungicides, the application of potassium phosphonate significantly increased the tree trunk lesion size recovery from oozing lesions. After Bordeaux paint and treatments applications, trees with gummosis symptoms initiated signs of recovery. The recovery was manifested as new flushes that turned dark green and grew normally. The use of Bordeaux paste painted trees and potassium phosphonate foliar application resulted in faster and more recovery from trunk lesions. It appears that gummosis affected trees recovered from infections and were able to absorb proper nourishment for their development after treatment application. The tree in the control plots had small chlorotic flushes, twig dieback, gummosis and bear few number of fruits. This could attribute to poor growth and disruption of normal transport in gummosis-infected plants (Gade and Koche, 2012).

Foliar applications of potassium phosphonate induced a systemic defense response in plants, including an increase in phytoalexins, lignin and chitinase contents as well as enhanced peroxidase and polyphenol-oxidase activities as part of the phosphonate induced defense mechanism (Smith *et al.,* 1997). Treatment T6(Foliar spray of potassium phosphonate @ 3g/l water) had the highest increase in canopy volume (7.93%) and the highest yield (17.84 t/ha). Canopy volume represents plant growth in response to continuous nutrient uptake without affecting any deviation in plants. *Phytophthora* infections in mandarin plants cause a gradually decline in foliage due to decay of feeder roots and oozing of gums from the tree trunk. The highest tree trunk lesion recovery, the least feeder root rot, and the least soil disease potential of *Phytopthora* sporangia were recorded in treatment T6, which resulted in an increase in canopy volume and provided the highest fruit yield.

The observations were in conformity with those of Hegde and Mesta (2014), who reported that spraying with potassium phosphonate @ 6 ml/l and soil drench @ 4 ml/l water reduced the incidence of pod rot caused by *Phytophthora theobromae* in cocoa. Similarly, Ingle et al (2020) found that treating infected mandarin plants with foliar spray + soil drenching of potassium phosphonate @ 3 ml/l water resulted in a lower average number of lesion with oozing (28.39%), a minimum feeder root rot index (2.17), an increase in canopy volume (11.15%), and a higher fruit yield (65.89 kg/ per tree). They also reported that the potassium phosphonate at three different concentrations against *P. nicotianae in vitro* and found that the potassium phosphonate was effective in arresting *P. nicotianae* growth, with complete (100%) inhibition observed in tested doses. The results were also in accordance with those described by Lokesh et al (2012) in respect of potassium phosphonate @ 0.3 % as spraying and drenching with soil application of *Trichoderma harzianum*, @ 50 g/vine along with neem cake (1 kg/vine) to the black pepper vines against *Phytophthora* foot rot being highly effective in reducing the population of *Phytophthora* and increasing yield when compared to the farmers practice with use of 1 % Bordeaux mixture as spray. Furthermore, the current findings are in agreement with the report of Hegde (2015), where potassium phosphonate effectively protected areca nut plants from *Phytophthora arecae* -induced nut rot disease. In comparison to fosetyl-Al, potassium phosphonate applied as a foliar spray or soil drench resulted in less *Phytophthora citricola* stem infection of *Persea indica* seedlings (Fenn and Coffey 1987).

Table 4. Effect of various treatments on fruit yield and economics of treatments (pooled data for 4 years)

Treatments	Fruit yield (t/ha)			Pooled mean	ICBR			Pooled mean
	Akola	Ludhiana	Tinsukia		Akola	Ludhiana	Tinsukia	
T1	15.66	15.22	16.07	15.65	2.32	2.53	1.73	2.19
T2	15.97	14.84	18.09	16.30	2.20	2.35	1.86	2.14
T3	14.46	11.83	15.23	13.84	0.46	1.88	1.56	1.30
T4	16.46	16.16	17.75	16.79	1.96	3.74	1.83	2.51
T5	17.14	15.56	18.19	16.96	2.60	3.07	2.13	2.60
T6	18.16	16.94	18.42	17.84	5.78	4.12	2.14	4.01
T7	17.30	16.36	14.61	16.09	4.30	3.80	1.64	3.25
T8	13.31	7.68	7.30	9.43				
CD (p= 0.05)	1.08	3.10	2.53	2.52				

See Table 1 for treatment details

The potassium phosphonate quickly absorbed and translocated in the xylem then moves into and translocated in the phloem, where its distribution is subjected to normal source sink relationship in the plants. The radioactive ^{32}P was used to demonstrate the translocation of phosphonate to different parts of the black pepper plant (Anil Kumar et al 2009). Graham (2011) also demonstrated that potassium phosphonate is highly systemic, rapidly absorbed by leaves and transported to fruits, where it protects against citrus brown rot *caused* by *Phytophthora palmivora*. By disrupting pathogen metabolism and activating their own defense mechanisms, potassium phosphonate-treated plants appeared to be capable of creating an antimicrobial environment more effectively than non-treated chemical fungicide plants (Daniel and Guest 2006). The active constituent working against the pathogen is phosphonate (phosphate) or phosphonic acid, which is a dynamic component of this chemical within plants. According to Lovatt (1998), a single foliar application of phosphonate promoted agronomically important traits in citrus and avocado, such as fruit size, fruit yield, anthocyanin content, floral intensity, and total soluble solids. The effects of phosphonate on fruit production and quality have been documented (Lovatt, 1999 and Rickard 2000) for example, foliar sprays improved orange tree yield.

Potassium phosphonate residue was determined using LCMS/MS on fruit samples with peel, and the results confirmed that phosphonic acid was present in treated plants. Potassium phosphonate has been found to be remarkably persistent in plants. Using high performance liquid chromatography (HPLC) and ion chromatography, Saindrenan et al (1985) and Fenn and Coffey (1989) determined the phosphate and phosphonate concentrations in higher plants. Potassium phosphonate has high phloem mobility, and is translocated to various parts of the plant including the tubers (Cohen and Coffey 1986). Even after three months, potassium phosphonate residues were found in fruits from plants treated during the fruit bearing season. Concentrations of potassium phosphonate in fruits can be used safely at levels lower than the MRL (the MRL for phosphonic acid in the EU is 90mg/kg for citrus fruits; EFSA 2021).

CONCLUSIONS

The disease has significantly reduced with increase in trunk lesion recovery, maximum per cent canopy volume, highest fruit yield, and lowest soil disease potential in potassium phosphonate (0.3%). This potassium phosphonate based management technology is more ecologically friendly than conventional management practices, resulting in economic benefits for farmers.

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Soil Nematofauna Diversity of Paddy Fields of Goa, India

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Abstract: Paddy field is a specialized habitat in which the soil has a very high water-holding capacity. Many nematode taxa are present in paddy fields including those that are specific parasites of the roots, stem and leaves of rice plants. Twenty-five species of nematodes were identified, belonging to five orders, 15 families and 19 genera. Nematodes were aggregated, not randomly or uniformly distributed. Herbivores belonging to order Tylenchida were most abundant. Peak densities and high diversity were in *morod* lands (rain-fed uplands) and in *kher* lands (rain-fed midlands) than in *khazan* lands (coastal saline lowlands). Higher densities and diversity were in the soil samples collected prior to paddy harvesting and lower in soil samples collected before transplant and after harvest. *Hirschmanniella oryzae* and *H. mucronata* were the dominant plant parasites**.**

Keywords: Agro-ecosystem, Different land types, Soil nematodes, Diversity, Density, Different stages of paddy cultivation

Paddy fields are biodiversity hotspots, nurturing a wide variety of organisms including nematodes. Nematodes are important pests of rice, but they often have gone unnoticed because of difficulties in identification. Among the significant species that attack rice, *Ditylenchus angustus* (Ufra) and *Aphelenchoides besseyi* (white-tip nematode) are main pests of deep-water rice in several countries (Varaprasad et al 2006). In irrigated rice, infections by *Hirschmanniella* spp. and *Aphelenchoides besseyi* are common, whereas upland rice is regularly diseased by *Meloidogyne* and *Pratylenchus* species. In India, losses in grain yield are estimated to be 16-32%. Yield loss due to rice stem nematode may vary from year to year depending on variety, time of infection, degree of infection and the environmental condition during crop season. The entire State of Goa is in the 12th agro-ecological zone of India viz., the west coast plains and Ghat region (http://farmech.dac.gov.in/06035-04-ACZ12-15052006.pdf). Total area under rice cultivation in Goa is 49,966 hectares comprising 12 talukas (townships). (Korikanthmath et al 2011). Rice cultivation occurs on 27.4% of this total area. While upland rice cultivation dominates rice plantations in talukas adjacent to Western Ghats, lowland rice and salt-tolerant rice cultivation predominates in the coastal ecosystem. Extensive work has been done on the fauna of Goa (Anonymous 2008). However, invertebrates have been largely ignored and unrecorded in biodiversity studies. The Goa Foundation, one of the best known of Goa's environmental action groups, has listed 10 known Goan nematode species (http://goafoundation.org/biodiversity-in-goa/). Further perusal of the literature reveals very few published and unpublished reports on nematodes of Goa (Koshy and Sosamma 1988, Ahmad and Ahmad 1992, Pai and Gaur 2010). No specific literature is available on the nematofauna of the paddy fields of Goa. The objectives of this study were to document density, diversity and distribution of soil nematodes in paddy fields and compare the nematofaunal diversities in the three different land types *(khazan, kher and morod*).

MATERIAL AND METHODS

Kharif crop or Sorod crop cultivation (monsoon crop) occurs from the first week of June to early July and the harvesting is done in September to October. The study was carried out in July, September and November 2013 to collect nematodes at three different times during paddy cultivation season. Soil samples were collected from different paddy fields chosen randomly in both districts of Goa (North Goa and South Goa). The samples were taken from three different land types: khazan (coastal saline / alluvial soils, lowlands), kher (arable, sandy to sandy loam soils, rain-fed midlands) and morod (lateritic soils, rain-fed uplands). Khazan lands or lowlands (32%) consist of low-lying areas, often below sea level and along the estuaries. They are mostly used for monsoon paddy crop. Kher lands or midlands (32%) are flatlands at low and have a high water table. The arable, sandy to sandy loams soils are suitable for multiple cropping through irrigation. Morod lands or uplands (16.4%) refer to lateritic uplands or terraced fields with a single rain-fed crop of rice.

A total of 30 soil samples for each of the land types were collected when the saplings were about 25 cm high. The ten sample each before transplanting ,at pre-paddy harvesting

(10 samples) and at post-harvesting of paddy were collected The samples were taken in the rhizosphere area 5-25 cm beneath the soil surface by taking precaution to avoid the top soil of about 1–5 cm depth. Each sample was placed in a self-sealing plastic bag with a label covering the required field information. They were either processed immediately after being brought to the laboratory or stored in the refrigerator at 4°C to be processed later. Samples were soaked in water for a few minutes then nematodes were concentrated by means of Cobb's sieving and decanting method (Cobb 1918, Ahmad 1996) and isolated in modified Baermann funnels (Thorne 1961). Nematodes were fixed in warm 4% formalin and processed with a slow glycerine method (Seinhorst 1959) to pure glycerine, then mounted on permanent slides and used for identification of nematode species.

The nematodes were identified and classified using the available literature (Goodey 1963, Jairajpuri and Khan 1982, Jairajpuri and Ahmad 1992, Andrassy 1999, Siddiqi 2000). Information was also retrieved for identification and classification from the websites of NEMAPLEX and Nema Species Masterlist A-Z (http://nematode.unl.edu/masterlist A-Z. htm). Shannon (H'), Simpson (D) and Brillouin's Evenness (J) Indices were analyzed for the nematode species using a standard statistical package (PAST version software).

Density, diversity and distribution of nemafauna: In this investigation, a total of 25 nematode species were identified in five orders, 15 families and 19 genera (Table 1). The order Tylenchida had the highest number of families (5), genera (7) and species (11) followed by Dorylaimida with four families, six genera and eight species. Mononchida was represented by three families, three genera and three species while Araeolaimida had only one family, one genus and one species (Fig. 1). Among the trophic groups, in genera as well as in abundance, herbivores dominated with 47.4% of genus diversity and 60% abundance diversity followed by the other four groups: omnivores, predators and fungivores and bacterivores (Fig. 2). Among orders for diversity of genera

Table 1. Taxonomic status of soil nematodes of paddy fields of Goa

Orders	Families	Scientifc names
Dorylaimida	Xiphinematidae	*Xiphinema insigne* Loos 1949
		X. brevicolle Lordello & da Costa 1961
	Dorylaimidae	*Dorylaimus stagnalis* Dujardin 1845
		Laimydorus uterinus Loof 1995
		Thornenema mauritianum (Williams 1959) Baqri & Jairajpuri 1969
	Nordiidae	*Lenonchium oryzae* Siddiqi 1965
		L. macrodorus Ahmad & Jairajpuri 1988
	Qudsianematidae	*Ecumenicus monohystera* (De Man 1880) Thorne 1974
Tylenchida	Hoplolaimidae	*Hoplolaimus indicus* Sher 1963
		Helicotylenchus dihystera (Cobb 1893) Sher 1961
		H. abunaamai Siddiqi 1972
		H. indicus Siddiqi 1963
	Meloidogynidae	*Meloidogyne graminicola* Golden & Birchfield 1965
	Criconematidae	*Criconemella onoesis* (Luc 1959) Luc & Raski 1981
		C. xenoplax (Raski 1952) Luc & Raski 1981
		Ditylenchus angustus (Butler 1913) Filipjev 1934
	Belonolaimidae	*Tylenchorhynchus annulatus* (Cassidy 1930) Golden 1971
	Pratylenchidae	*Hirschmanniella oryzae* (Van Breda de Haan1902) Luc & Goodey 1963
		H. mucronata (Das 18891960) Luc & Goodey 1963
Araeolaimida	Plectidae	*Plectus cirratus* Bastian 1865
Aphelenchida	Aphelenchoididae	*Aphelenchoides besseyi* (Christie 1942) Allen 1952
	Aphelenchidae	*A. avenae* Bastian 1865
Mononchida	Mylonchulidae	*Mylonchulus minor* (Cobb 1893) Andrássy 1958
	Iotonchidae	*Iotonchus trichurus* (Cobb 1916) Andrássy 1958
	Mononchulidae	*Oionchus obtuses* Cobb 1913

and abundance, Tylenchida dominated (36.84% and 44 %) followed by Dorylaimida (Mononchida, Aphelenchida and Araeolaimida , respectively (Fig. 2). Species densities per 100 gm of dry soil were 96-116 individuals (Table 2). *Oionchus obtuses* (116) and *Aphelenchoides besseyi* (116) had the maximum density while *Laimydorus uterinus* and *Lenonchium oryzae* the minimum (Table 2).

Nemafauna diversity of land types: Nematodes were most diverse in morod land type with 22 taxa and least diverse in the khazan land type (13 species) (Table 3, Fig. 3). Five species (*Lenonchium oryzae, Lenonchium macrodorum, Meloidogyne graminicola, Criconemella onoesis* and *Plectus cirratus*) were present in all three land types. Four of these five common species are herbivores while *Plectus cirratus* is a bacterivore (Table 2). Besides the five (20% of all species) common to the three land types, 32% were common to khazan and kher, 68% were common to kher and morod land type and 40 % were common to khazan and morod land types (Fig. 4). Fungivores were absent in khazan land type (coastal saline/alluvial soils) but present in the other two land types. Predators were more diverse in kher land type (flatlands with high water table) compared to khazan and morod (upland/terraced) land types (Table 5). Species diversity was highest in morod land (22) and lowest in khazan land (13) while kher land had 20 species. Abundance was highest in morod land (299) and lowest in khazan land (163). Dominance values were low in all three land types and evenness values were very high. The Shannon and Fisher diversity indices were highest in morod land and lowest in khazan land (Table 4, Fig. 3).

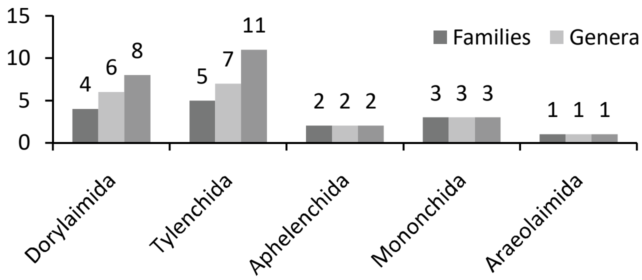
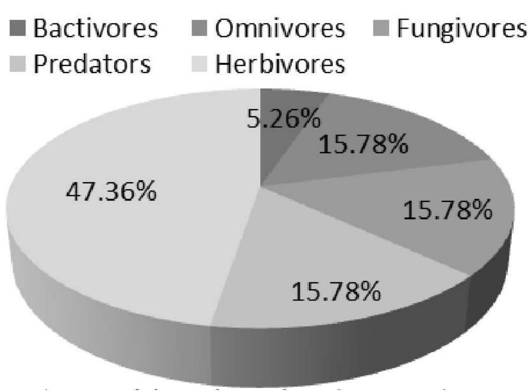
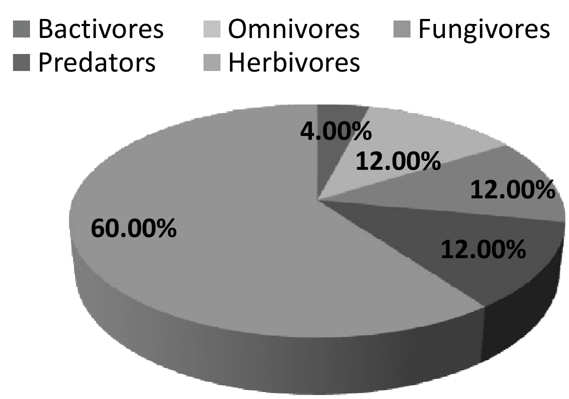


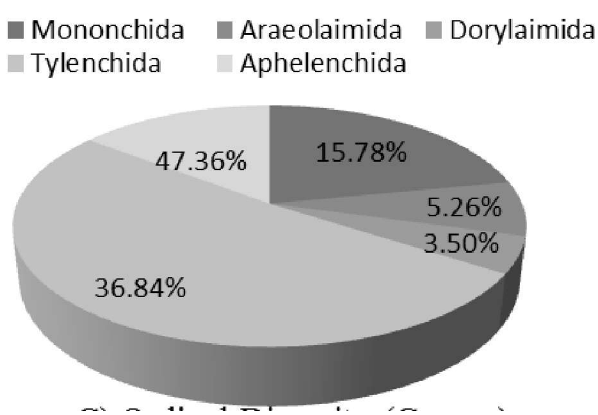
Fig. 1. Order-wise soil nematode diversity of paddy fields of Goa



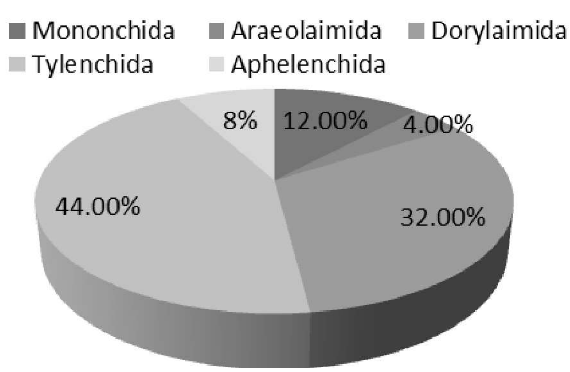
A) Trophic diversity (Genera)



B) Trophic diversity (Abundance)



C) Ordinal diversity (Genera)



D) Ordinal diversity (Abundance)

Fig. 2. Community Structure of soil nematodes of paddy fields of Goa (A, B, C & D)

Soil nematofaunal diversity at different stages of paddy crop: In all three land types, nematode densities were higher prior to harvesting and lower before transplanting and post harvesting season. *Hirschmanniella oryzae* was not observed in khazan land type (Table 6) while *Hirschmanniella mucronata* was not found in Kher land type (Table 3, 6), but both species had their highest densities in the morod land type samples collected prior to harvest . The khazan land type had the highest numbers of *Dorylaimus stagnalis* and *Lenonchium oryzae* and the lowest numbers of *Laimydorus uterinus, Helicotylenchus abunaamai* and *Criconemella onoesis, Laimydorus uterinus* and *Dorylaimoides constrictus* were lowest in the kher land type prior to harvesting. Densities of *Aphelenchoides besseyi* were highest in samples collected before transplanting in both kher and morod, but this species was absent in khazan . In kher *Mylonchulus minor* (8/100 gm dry soil) numbers were lowest in samples collected after harvesting while *Laimydorus uterinus* densities were lowest before transplanting.

Table 2. Diversity and density (no. of individuals / 100 gms of moist soil) of different tropic groups of soil nematodes of paddy fields of Goa

Trophic group	Order	Scientific names	Species density/ 100 gm of moist soil (m)
Omnivores	Dorylaimida	*Dorylaimus stagnalis*	103
		Ecumenicus monohystera	108
		Laimydorus uterinus	96
Predators	Mononchida	*Mylonchulus minor*	112
		Iotonchus trichurus	105
		Oionchus obtuses	116
Fungivores	Dorylaimida	*Thornenema mauritianum*	102
	Aphelenchida	*Aphelenchus avenae*	97
		A. besseyi	116
Herbivores	Dorylaimida	*Xiphinema brevicolle*	109
		X. insigne	115
		Lenonchium oryzae	96
		L. macrodorum	101
	Tylenchida	*Hoplolaimus indicus*	98
		Helicotylenchus dihystera	114
		H. abunaamai	106
		H. indicus	97
		Meloidogyne graminicola	108
		Criconemella onoesis	98
		C. xenoplax	111
		Ditylenchus angustus	107
		Tylenchorhynchus annulatus	99
		Hirschmanniella oryzae	104
		H. mucronata	112
Bactivores	Araeolaimida	*Plectus cirratus*	100

In this study, a total of 25 species were reported. Species belonging to the order Tylenchida which mostly represents plant feeders were more. The genera and the abundance in the ordinal diversity were dominated by the order Tylenchida (McNeely et al 1995). The present investigation also had similar results. The present also agrees with Háněl (2003) that omnivore nematodes with their versatile feeding habits would probably intervene in the soil food web resulting in the absence of the species that are dependent on undisturbed habitats. The free space that is created might be utilized by the herbivores and their population increases. So the species density among the herbivores was more. Fungivores were minimum in density, this is in agreement with Yeates et al (1993) and Yeates (1999), that omnivores are multi-feeders thus affecting adversely the population of fungal feeders. Species belonging to omnivores had maximum density as these are versatile feeders, increase in the population of hyphae, bacteria, microfaunal prey might result in the increase in the growth of their population. Herbivores showed high value of H' (2.74) which almost agrees with the values recorded by Háněl (1995). In this study, khazan lands had the fewest number of species. Conditions in khazans pose

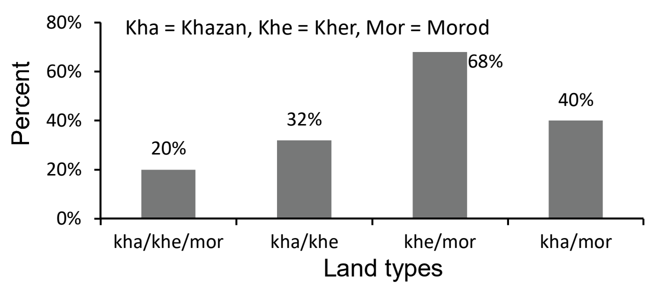


Fig. 3. Percent occurrence of common species of soil nematodes in different land types

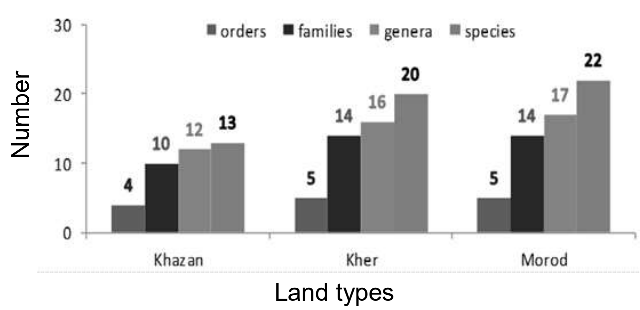


Fig. 4. Taxonomic hierarchy of soil nematodes present in different land types

Table 3. Nematode diversity in different land types

Presence or absence of species in the different land types

Orders	Families	Scientific names	Khazan Lowland land	Kher Midland	Morod Upland
Dorylaimida	Dorylaimidae	*Dorylaimus stagnalis*	+	+	-
	Qudsianematidae	*Ecumenicus monohystera*	-	+	+
	Dorylaimidae	*Laimydorus uterinus*	+	-	+
	Dorylaimidae	*Thornenema mauritianum*	-	+	+
	Xiphinematidae	*Xiphinema brevicolle*	+	-	+
	Xiphinematidae	*X. insigne*	-	+	+
	Nordiidae	*Lenonchium oryzae*	+	+	+
	Nordiidae	*L. macrodorum*	+	+	+
Mononchida	Iotonchidae	*Iotonchus trichurus*	-	+	+
	Mononchulidae	*Oionchus obtuses*	+	+	-
	Mylonchulidae	*Mylonchulus minor*	-	+	+
Aphelenchida	Aphelenchidae	*Aphelenchus avenae*	-	+	+
	Aphelenchoididae	*Aphelenchoides besseyi*	-	+	+
Tylenchida	Hoplolaimidae	*Hoplolaimus indicus*	+	-	+
	Hoplolaimidae	*Helicotylenchus dihystera*	-	+	+
	Hoplolaimidae	*H. abunaamai*	+	+	-
	Hoplolaimidae	*H. indicus*	-	+	+
	Meloidogynidae	*Meloidogyne graminicola*	+	+	+
	Criconematidae	*Criconemella onoesis*	+	+	+
	Criconematidae	*C. xenoplax*	-	+	+
	Criconematidae	*Ditylenchus angustus*	-	+	+
	Belonolaimidae	*Tylenchorhynchus annulatus*	+	-	+
	Pratylenchidae	*Hirschmanniella oryzae*	-	+	+
	Pratylenchidae	*H. mucronata*	+	-	+
Araeolaimida	Plectidae	*Plectus cirratus*	+	+	+
		Total	13	20	22

+ = present, - = absent

Table 4. Diversity indices of nematofauna for different land types

Diversity indices	Khazan	Kher	Morod
Species Richness	13	20	22
Abundance	163	265	299
Simpson's Dominance_D	0.07915	0.05148	0.04683
Shannon_H	2.55	2.981	3.076
Evenness_e^H/S	0.9854	0.9853	0.9847
Equitability_J	0.9943	0.9951	0.995
Fisher alpha	3.322	5.018	5.475

Table 5. Percent occurrence of genera and species based on trophic structure in different land types

Trophic groups	Khazan land		Morod land		Kher land	
	Genera	Species	Genera	Species	Genera	Species
Omnivores	16.66	15.38	12.00	9.09	12.50	10
Predators	8.33	7.69	11.76	9.09	18.75	15
Fungivores	-	-	17.64	13.63	18.75	15
Herbivores	66.66	69.00	53.00	63.63	44.00	55
Bactivores	8.33	7.69	5.88	4.54	6.25	5.0

Table 6. Species density of nematodes in all the three land types at three different stages of paddy cultivation

Species	Different stages of paddy cultivation in different land types								
	Khazan			Kher			Morod		
	B.T.	Pre H.	Post H.	B.T.	Pre H.	Post H.	B.T.	Pre H.	Post H.
Xiphinema insigne	-	-	-	25	34	29	20	42	37
X.brevicolle	26	45	31	-	-	-	28	39	30
Dorylaimus stagnalis	16	48	32	35	49	30	-	-	-
Laimydorus uterinus	14	31	19	-	-	-	28	34	22
Thornenema mauritianum	-	-	-	10	21	13	37	53	33
Lenonchium oryzae	22	48	33	19	29	20	29	37	31
L. macrodorus	10	35	21	29	37	24	32	49	27
Ecumenicus monohystera	-	-	-	26	37	29	21	37	31
*Hoplolaimu*s *indicus*	19	37	23	-	-	-	16	23	12
Helicotylenchus dihystera	-	-	-	15	29	20	17	25	16
H. abunaamai	14	31	19	18	32	26	-	-	-
H. indicus	-	-	-	27	40	31	17	30	05
Meloidogyne graminicola	21	42	29	34	49	23	38	53	42
Criconemella onoesis	23	44	31	29	41	30	35	51	41
C.xenoplax	-	-	-	23	39	27	31	43	37
Ditylenchus angustus	-	-	-	17	29	20	27	42	38
Tylenchorhynchus annulatus	18	31	20	-	-	-	34	49	40
Hirschmanniella oryzae	-	-	-	44	52	37	44	65	50
H. mucronata	17	33	24	-	-	-	39	54	43
Plectus cirratus	27	41	30	30	49	34	31	45	39
Aphelenchoides besseyi	-	-	-	42	37	24	46	31	27
A. avenae	-	-	-	39	30	26	25	17	22
Mylonchulus minor	-	-	-	12	19	8	16	25	20
Iotonchus trichurus	-	-	-	12	15	21	15	24	17
Oionchus obtuses	16	28	17	34	58	41	-	-	-

Species density / 100 gm of moist soil
B.T. = Before Transplantation, Pre H. = Pre harvesting, Post H. = Post harvesting

special problems for agriculture as khazan soils are poorly drained and have an acidic pH, relatively high organic carbon and iron, low calcium and high salinity.These are alluvial soils with high water tables and are subjected to inundation by salt water. Salinity varies during monsoon (2–3ºBé) and non-monsoon times (4–5ºBé) (Mani et al 2012). The low pH values of khazan lands (4.8–5.3) may contribute to a reduction in nematode diversity. Morod and kher lands, with higher nematode diversity, have less acidic soils; kher lands consist of arable sandy loam soil and morod lands are upland or terraced fields suitable for horticulture as well as agricultural crops. The results are in agreement with Jairajpuri and Baqri (1991) as nematodes are the most abundant components of the mesofauna in agronomic soils. Herbivores were the dominant trophic group, comprising more than 50% of total specimens. Predators were characteristics of morod land type as these lands mostly have laterite soils and confined to upland or terraced fields. Though this is uncommon in most ecosystems but may be related to rich food web of the site (Baniyamuddin et al 2007). Kher land type showing highest number in genera and abundance of fungivores represented that these lands are arable sandy loams and are used for multiple cropping through irrigation. *Hirschmanniella* spp. have been reported to be present in all the irrigated rice fields all over the world. *H. oryzae* and *H.mucronata* are the dominant species infecting rice crops in all parts of India, including irrigated, semi-deep and deep-water rice environments (Prasad et al 1987, Varaprasad et al 1992). The highest greatest species densities of *A. besseyi* were before transplanting. Qiu et al

(1991) suggested that *A. besseyi* invades rice mainly during sowing to the 3-leaf stage.

CONCLUSION

From this study it can be concluded that at least 25 nematode species are present in the paddy fields of Goa. The paddy field ecosystem favors plant-parasitic Tylenchids. Of the three land types, species diversity was highest in the well-drained, fertile morod land type and least in the khazan land type. Khazan lands, being saline, are not as favorable for terrestrial nematodes that are adapted to rice agriculture. Morod land also had generally high densities of individual species. Soil samples at pre-harvest generally had the highest densities of nematodes regardless of trophic group or land type. Root growth is most extensive during this stage of paddy cultivation, and therefore herbivores dependent on plant roots for their food had higher numbers. Increased root mass likely stimulated other trophic groups and provided more prey for predacious species. Fertilization patterns, use of natural fertilizers or chemical fertilizers, use of pesticides and field management methodologies can be studied for their effects on nematode communities as bio-indicators of the health of paddy field ecosystem and for effective means of controlling pest species.

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Pollination Biology in Henna-Evidences from Semi-Arid Region of Rajasthan

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Abstract: A study was carried out to study the pollination system in henna at CAZRI, RRS, Pali marwar in hot semi-arid region of India. Two types of pollination systems viz., natural open pollination and pollination in controlled condition were studied. Total of 10 inflorescences borne on ten different 20-year old henna plants were selected and covered with muslin cloth bags and butter paper for controlled pollination. Simultaneously, 10 inflorescences of same plants were kept uncovered for open pollination. Out of three modes of pollination studied in henna, maximum fruit set (60.84%) was observed in natural open pollinated condition while minimum fruit set (11.78%) recorded in controlled pollination covered with butter paper followed by controlled pollination covered with muslin cloth (10.10%). The highest fruit flower ratio also registered in natural open pollinated condition (0.608) whereas lowest were recorded in controlled pollination covered with muslin cloth (0.117) followed by controlled pollination covered with butter paper (0.101). Besides, the common flower visitors also observed which may favour the cross pollination in henna flowers. This study confirms that henna is cross pollinated species.

Keywords: Henna (*Lawsonia inermis* L.), Pollination systems, Self-pollination, Cross pollination, Arid and semi-arid region

Lawsonia inermis L. belongs to the family Lythraceae commonly called as Henna or Mehndi has been commercially cultivated for promising dye yielding cash crop which is mainly used for dyeing hair, palm and feet since ancient times (Singh et al 2015). Henna cultivation is profitable under low rainfall conditions and give assured income returns at low cost investment in drought prone arid and semi-arid regions. Due to its drought hardiness, deep root system and perennial nature, it can be cultivated on lands that are drought prone, marginal or unsuitable for arable cropping. Economic production of leaves starts from the third year onwards that continues for the next 15-30 years (Chand and Jangid 2007). Globally, India has exported 2,383 tons of henna to several countries in the year 2002-03 which indicates high demand in international export market. The plants are glabrous, much branched shrub or small tree with greyish brown bark. Leaves are opposite, sub sessile, elliptical or lanceolate, entire and acute. Flowers are numerous, small white or pink coloured with fragrant and in terminal panicle cymes. Crop is propagated through seeds and vegetative propagation. Oil also extracted from leaves and flowers called "Otto of henna" and it is utilised as perfume (Jaimini et al 2005). Since leaf is economical part of henna, flowering is considered as undesirable trait. Generally from farmer's point of view flowering is an undesirable trait beyond its use in perfume industries and the fruiting have an impact on leaf yield and lawsone content. Therefore, pollination is very much essential for understanding the flowering and fruiting pattern in henna.

Pollination is an essential step in ensuring seed production and it is a critical stage in the sexual reproduction of plants. Transfer of pollen from the anther of the flower to the stigma of the same flower or of another flower is called as Pollination. It is a prerequisite for fertilization and fruit set. Some flowers develop fruits/seeds due to self-pollination (when pollen and pistils transfer from the same plant or often same flower) and some develops due to cross pollination (when pollen from one flower transfers to different plant). Many plants are self-incompatible and in this condition an animal or an insect that move pollen from the anthers to the stigmas of flowers, thus effecting pollination. This is usually as a result of their activities when visiting plants for feeding, breeding or shelter.

Plants have evolved diverse pollination strategies ranging from complete selfing to obligate outcrossing (Richards 1986). Except fully self-incompatible and dioecious species, most of the others show a mixed mating system permitting both self- and cross-pollinations. The proportion of each is highly variable between populations and species depending on the structure of the flower, breeding system and pollination environment (Shivanna 2015). Autogamy happens to be the most frequently evolved strategy in different groups of plants (Kalisz and Vogler 2003, Goodwillie et al 2005, Eckert et al 2006, Levin 2012, Wright et al 2013). Many of the species show flexibility in their pollination strategy and show a mixed mating system. Apart from self-pollination they permit cross pollination when the pollinators are available (Goodwillie et al 2005). According to Miczak 2001, henna is a self-pollinating species; its seeds are so hardy that they must be soaked in water to facilitate germination. And also, Roy and Jindal (2009) mentioned that henna is self-pollinated woody shrub. No genetic improvement or biodiversity conservation programme can be success in absence of precise information on degree of selfing or out crossing. However, studies on mode of pollination of henna are still unclear and very limited. This study aims to study the mode of pollination of henna to improve the fruit set.

MATERIAL AND METHODS

The effect of pollination control on fruit setting in henna was studied in henna experimental field, at ICAR-Central Arid Zone Research Institute (CAZRI), Regional Research Station (Pali-Marwar, Rajasthan) in hot semi-arid region of India during 2017-18 to 2020-21. The annual average rainfall of the experimental site is 460 mm with annual maximum mean temperature of 42°C and minimum 7°C. The experimental site of henna is located between 25°47′-25°49′N and 73°17′-73°18′E at 217-220 m msl. The soils were shallow in depth (30-45 cm) with sandy clay loam to sandy loam texture, 1.35-1.5 Mg m^{-3} bulk density, 7.7-8.4 pH, 0.15–0.55 dSm^{-1} electrical conductivity and a dense underlying layer of murrum (highly calcareous weathered granite fragment coated with lime). The meteorological data for the study period has been given in Figure 1.

Uniform and healthy plants were selected randomly from the middle portion of the plantation. Two types of pollination systems were studied. These were i. natural open pollination, where buds were tagged and allowed to pollinate naturally; ii) controlled pollination, where whole inflorescence was bagged as such with muslin cloth and butter paper. Total of 10 inflorescences borne on ten different 20-year old henna plants were selected and covered with muslin cloth bags and butter paper for controlled pollination. Simultaneously, 10 inflorescences of same plants were kept uncovered for open pollination. The inflorescences were tagged and already opened flowers occurring at the basal end and the young floral buds at the distal end were clipped off in all the selected inflorescences. The number of remaining floral buds and the fruits formed on the inflorescences were recorded and the fruit set calculated under both pollination conditions. And also, length of inflorescence (cm), number of flowers per inflorescence, length of fruits (mm), width of the fruits (mm) and flower to fruit ratio was recorded on ten well developed inflorescence on each of the ten plants. The observation was made to record the floral visitors for understanding of the mode of pollination in henna inflorescence.

RESULTS AND DISCUSSION

Inflorescence and fruit characteristics of henna: Flowering in henna was observed with creamy white colour flowers during September in most of the plants. Flowering started in July after the onset of monsoon and continues till mid-September in Pali district of Rajasthan. The number flowers in inflorescence and length of inflorescence were recorded on ten well developed inflorescence on each of the ten henna plants. The length of inflorescence varied from 4.72 cm to 8.13 cm with mean value 6.42 cm. Maximum numbers of flowers per inflorescence was 218 and minimum was 22 with the mean 120. The berries are oval in shape and green colour berries turns into greyish black colour when it matures. The length of fruit ranged from 5 mm to 2.9mm. The maximum width recorded in berries was 8.3mm where

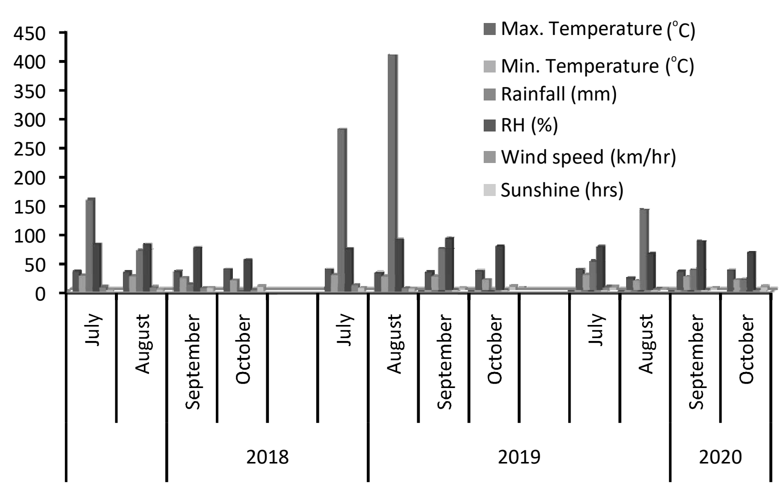

Fig. 1. Meteorological data for the study period at Pali marwar, Rajasthan

minimum was 3.8mm with the mean value 6.05mm. And the average fruit flower ratio recorded was 0.6. Maximum ratio of fruit flower recorded in the henna was 0.7 and minimum was 0.5 (Table 1).

Fruit set in henna under different pollination conditions: Ten inflorescences were selected and recorded the observations for the fruit set under open pollinated condition and controlled pollination condition (covered with muslin and butter paper). Maximum number of fruits (618 fruits) was recorded in open pollinated condition from 1015.6 flowers (Table 2). Fruit produced under controlled pollination, where the inflorescence covered with muslin cloth produced 136.6 fruits out of 1160 buds (Table 3). Minimum number of fruit set (105.6 fruits) out of 1045.6 buds was registered in controlled pollination, where the inflorescence covered with butter paper (Table 4). The same trend was observed throughout the study period in all types of pollination in henna. Similar study of the mixed pollination biology of *Oreocereus*

Table 1. Flower and fruit characteristics of Henna

	Minimum	Maximum	Mean	SD
Length of inflorescence (cm)	4.72	8.13	6.42	2.41
No. of flowers per inflorescence	22.0	218.0	120.0	138.5
Length of fruits (mm)	2.90	5.00	3.95	1.48
Width of the fruits (mm)	3.80	8.30	6.05	3.18
Flower to fruit ratio	0.50	0.70	0.60	0.14

Table 2. Fruit set in henna under open pollination conditions

No. of Inflorescence	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set
	2018		2019		2020		Mean	
1	99.00	46.00	180.0	99.00	118.0	77.00	132.3	74.00
2	28.00	21.00	73.00	57.00	179.0	124.0	93.33	67.33
3	60.00	42.00	80.00	62.00	41.00	26.00	60.33	43.33
4	22.00	13.00	147.0	80.00	127.0	86.00	98.66	59.66
5	96.00	75.00	94.00	47.00	67.00	39.00	85.66	53.66
6	47.00	20.00	77.00	51.00	122.0	79.00	82.00	50.00
7	50.00	21.00	343.0	181.0	97.00	66.00	163.3	89.33
8	56.00	18.00	63.00	36.00	66.00	39.00	61.66	31.00
9	38.00	17.00	136.0	87.00	119.0	78.00	97.66	60.66
10	107.0	67.00	150.0	84.00	165.0	116.0	140.6	89.00
Total	603.0	340.0	1343.0	784.0	1101.0	730.0	1015.6	618.0

Table 3. Fruit set in henna under controlled pollination (covered with muslin cloth) conditions

No. of Inflorescence	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set
	2018		2019		2020		Mean	
1	88.00	29.00	213.0	13.00	97.00	4.000	132.6	15.30
2	28.00	16.00	108.0	24.00	179.0	18.00	105.0	19.30
3	93.00	22.00	194.0	5.000	93.00	25.00	126.6	17.30
4	64.00	22.00	161.0	9.000	75.00	12.00	100.0	14.30
5	132.0	7.000	143.0	0.000	61.00	2.000	112.0	3.000
6	26.00	16.00	85.00	2.000	85.00	3.000	65.33	7.000
7	95.00	4.000	81.00	4.000	173.0	11.00	116.3	6.300
8	36.00	3.000	208.0	16.00	210.0	18.00	151.3	12.30
9	78.00	4.000	294.0	36.00	101.0	20.00	157.6	20.00
10	42.00	3.000	159.0	52.00	78.00	10.00	93.00	21.60
Total	682.0	126.0	1646.0	161.0	1152.0	123.0	1160.0	136.6

celsianus (Cactaceae) mating breeding system has been reported for globose cactus species in northern tropics (Nassar and Ramirez 2004, Nassar et al 2007).

Fruit set (%) and fruit flower ration in henna under different pollination condition: Pollination and fertilization is the two important process of annual cycle for fruit setting in henna. In henna, significant differences were observed between the different pollination condition in fruit set (%) and fruit flower ratio. Out of three modes of pollination studied in henna, maximum fruit set (60.84%) was observed in natural open pollinated condition. Minimum fruit set (11.78%) was recorded in controlled pollination covered with butter paper followed by controlled pollination covered with muslin cloth (10.10%) (Table 5). Similarly, a decrease in the percentage of fruit from the controlled crossing over time was observed in this argane tree orchard (Ait Aabd et al 2022).

Fruit flower ratio was also calculated in henna under different pollination conditions. The highest fruit flower ratio was registered in natural open pollinated condition (0.608) whereas lowest were recorded in controlled pollination covered with muslin cloth (0.117) followed by controlled pollination covered with butter paper (0.101) (Table 6). The data showed that one fruit is produced out of two flowers when it is pollinated under natural open condition while one fruit is produced out of ten flowers when it is pollinated under controlled condition. The exploitation of knowledge on self-incompatibility mechanisms in flowering plants is very useful. Since Darwin's (1876) studies, considerable knowledge has been acquired about these mechanisms of self-incompatibility. Recently, for other species, incompatibility systems create barriers to avoid self-fertilization and promote cross-pollination (Dutta et al 2013, Pereza et al 2016). In this study, minimum fruit set during controlled pollination suggested that the lack of self-incompatibility and pollination even in the absence of flying insects in controlled pollination. As cross pollination by insect or air-borne pollen is checked by muslin cloth and butter paper cover, the fruiting observed under the controlled condition is apparently due to self-pollination. The fruiting observed under open conditions is considered to be the result of cross pollination. Similar study was also conducted by Shivanna 2015 on pollination strategies of perennial weeds particularly of Indian species (*Cassia auriculata*, *Ipomoea obscura*, *Oxalis corniculata*, *Plumbago zeylanica* and *Dodonaea viscosa*).

Flower visitors in henna: Even though there was no separate study conducted for flower visitors, some flower visitors were observed through direct observations on several flowers during the experiment. A large numbers of insects

Table 4. Fruit set in henna under controlled pollination (covered with butter paper) conditions

No. of Inflorescence	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set	No. of buds	No. of Fruit set
	2018		2019		2020		Mean	
1	97.00	14.00	140.0	7.000	260.0	12.00	165.6	11.00
2	36.00	11.00	146.0	4.000	112.0	29.00	98.00	14.60
3	58.00	9.000	82.00	11.00	127.0	12.00	89.00	10.60
4	63.00	11.00	145.0	10.00	165.0	13.00	124.3	11.30
5	25.00	4.000	93.00	8.000	117.0	6.000	78.30	6.000
6	37.00	3.000	123.0	6.000	60.00	4.000	73.30	4.330
7	46.00	7.000	87.00	3.000	78.00	6.000	70.30	5.330
8	87.00	11.00	202.0	22.00	65.00	7.000	118.0	13.30
9	46.00	12.00	107.0	15.00	81.00	7.000	78.00	11.30
10	68.00	9.000	229.0	39.00	155.0	5.000	150.6	17.60
Total	563.0	91.00	1354.0	125.0	1220.0	101.0	1045.6	105.6

Table 5. Fruit set (%) in henna under different pollination conditions

Type of pollination	2018	2019	2020	Mean
Open pollination (Uncovered)	56.38	58.37	66.30	60.84
Controlled pollination (Covered with muslin cloth)	18.47	9.781	10.67	11.78
Controlled Pollination (Covered with butter paper)	16.16	9.231	8.278	10.10
S.Em±	1.24	1.20	1.35	1.25
CD (p=0.05)	4.30	4.14	4.66	4.34
CV(%)	9.45	10.72	10.95	10.50

Table 6. Fruit Flower ratio in henna under different pollination conditions

Type of pollination	2018	2019	2020	Mean
Open pollination (Uncovered)	0.563	0.583	0.663	0.608
Controlled Pollination (Covered with muslin cloth)	0.184	0.097	0.106	0.117
Controlled pollination (Covered with butter paper)	0.161	0.092	0.082	0.101
S.Em±	0.01	0.01	0.01	0.01
CD (p=0.05)	0.04	0.04	0.05	0.04
CV (%)	9.45	10.73	10.96	10.51

were seen around the inflorescence and plants. The insects such as honey bee, blister beetle, ants and butterflies were observed during the crossing study. The inflorescence and flowers which produces the fragrance may attracted the insects and favours the cross pollination in henna. Cross-pollination in the henna can be performed by the wind or by pollinators as reported by several studies (Benlahbil et al 2003, Nerd et al 1998, Ajerrar 2020). These studies confirm that insects play an essential role in the pollination of the henna. However, the role of vectors in pollination (wind and insects) was not well understood during our study of crosses in henna.

CONCLUSIONS

The study reveals that maximum fruit set was observed in natural open pollinated condition while minimum fruit set in controlled pollination covered with butter paper followed by controlled pollination covered with muslin cloth. And also the highest fruit flower ratio registered in natural open pollinated condition whereas lowest were recorded in controlled pollination covered with muslin cloth followed by controlled pollination covered with butter paper. Besides, the common flower visitors also observed in henna flowers. The study concluded that minimum number of fruit set in henna under controlled pollination confirms the lack of self-incompatibility and maximum number of fruits set under open pollinated condition confirms the result of cross pollination. So, the study confirms that henna is cross pollinated species.

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Diversity of Bee Flora in Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

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Abstract: Bees are crucial natural pollinators and their activities depends on availability and abundance of bee flora. The current study involved the study of foraging flora of agriculture, horticultural, forestry crops and wild plants. Here 171 plants were considered as bee flora out of which 13 are Agricultural crops, 49 are Horticulture crops, 70 are forestry crops and 34 are wild crops . All types of plants were available at study site that is nectar and Pollen and both nectar and Pollen providing. Study showed that there is highest abundance of bee flora in April month followed by May.

Keywords: Nector, Pollen, Bee-forage, Pollination

Pollination is a crucial mechanism in continuation of life process of all angiosperm and gymnosperm. In agriculture, forestry, horticulture and even in weed science pollination plays most important role in obtaining yield. It is a mechanism of continuation of all ecological processes and sustainable agriculture production (Pande and Ramkrushna 2018), where honey bees are most important and superior pollinator of all natural ecosystem as they play vital role in pollination because honey bees colony depends directly on plants ranging from cultivated crop, wild species ,ornamental crops, horticulture crops, forest crop, olericulture crops ,and even wild grasses, herbs and shrubs etc. In India there are mainly six type of species these Six species bees are of commercial importance in India; *Apis dorsata (Rock bee),* the *Himalayan species, Apislaboriosa), Apiscerana indica (Indian hive bee), Apisflorea (dwarf bee), Apis mellifera (European or Italian bee), and Tetragonulairidipennis (Dammer or stingless bee).*For commercial apiculture we can go for rearing of *Apiscerana* and *Apismallifera*, these are practicing in India for honey production. Farmers chose bee keeping as agro-bases rural industry, integrated with farming systems because it can improve livelihood of farmers. The Plant that yield nectar and Pollen are collectively referred as be flora or bee pasture (Pande and Ramkrushna 2018).

Bee flora differ from one place to another place because of change in climatological ,topographical factors and environmental factors that is way it is major prerequisite to study of abundance and availability of flora in campus area for successful beekeeping. For sound management of bee keeping study of flower duration their blooming time, span of critical darth period, availability of water sources should be studied. Critical darth period is period where there is unavaibility of flora that is nectar and pollen which serves as main qualitative and quantitative factor in final product of apiary. Hence for ease of study we created a tabular bee flora calendar which shows available of bee flora in particular month of year.

MATERIAL AND METHODS

Study sites: The present study was conducted in Dr. PDKV campus. Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Agriculture University) is situated at 77˚02'42 E longitudes and 20˚ 42' 0 N latitudes. The university has over a total 3425 hectares of land out of which the total area of the main campus of the University is 1266.03 ha. The average annual rainfall is between 700 to 950 mm and on an average, there are 53 rainy days in a year. The temperature rises rapidly after February till May, which is the hottest month of the year. In May the mean daily maximum temperature is 43.3 C means daily minimum temperature is 29.5 C. The site has predominant of black cotton soil and loamy soil and and has altitude of 307.42 from mean sea level. Major crops cultivated crops in this area are cotton, soybean, blackgram, green gram, cowpea, chickpea and some vegetables and fruits.

Identification of bee flora: During surveying for identification of bee-flora we studied the vegetation by classifying plant into different parts or groups, agricultural crops, horticultural crops, vegetable crops, forest crops and forest species, ornamental plants and weeds present at study site.

Flowers are the source of nectar and Pollen variety of plants are forage by bees. Plants are classified into nectariferous (N) polleniferous (P) or both (NP) on bee's activity during forage.

Study includes keen observation of flowers to classify them. A plant is observed for 10 minutes at least three bees should be visited to the flowers then it is called as bee flora. Plants are called as nectariferous when bee sits calmly on flowers and penetrate it's proboscis into flower for the suction of sweet nectar for some time. Plants are called as polleniferous when bees don't sit calmly on flowers but do buzzing around the flower and take pollen bath by collecting pollen on body may be in the pollen basket which is present at hind legs of bees. With the help of entomology professionals, apiary managing people, rural honey collectors and trainer we made a listing of flora species. After being collected, the documented flora was finally recognized with the aid of a plant taxonomist. The entire bee flora was divided into groups

Using the facts of the situation, identify plants that produce nectar, pollen, or both. Then, throughout the study period, plants were identified month by month as a food source, and all groups' percent contributions in each month were made for simple understanding like a floral calendar.

The percentage of abundance of bee flora was calculated by following formula:

$$\text{Percentage of abundance of bee flora} = \frac{\text{No. of bee flora species in particular month}}{\text{Total no. of bee flora species}} \times 100$$

The study of bee flora shows that the presence of total 171 species of 61 different botanical families. Among this recorded families highest number with 21 species belongs to Fabaceae family fallowed by 10 species of asteraceae family and 6 species of Malvaceae family and moderate of Lamiaceae, Verbinaceae, Caesalpinaceae, Amaranthaceae, Acanthaceae, Anacardiaceae, Rutaceae, etc. These families include Agricultural crops , Horticultural crops (Ornamental, vegetables, fruits, and medicinal) and Forest tree species (wild plants).

Bee flora classification on the basis of benefits: The plants as well as honeybees are mutually benefited from the pollination. Plants provide nector, pollen or both to honeybees and honeybees provide better pollination to plants that gives assurity of fruit/seed. Out of total bee-flora species Necteriferous are 13 and Polleniferous are 39 and both pollen and nector providing species are 110. (Table 1, 2, 3).

Accessibility of bee-flora in various months: Bee flora accessibility was counted to find out the critical darth period of bee-flora, highest flowering peak period and scarcity period in the different months. This study will help for better apiculture management and providing best pollination period in all available vegetation. Based on observation, April with 81 species, May with 75 species and March with 68 species found at selection site. The minimum bee flora available in December and January with 51 and 50 species respectively.

As per the data totally 171 plants species belonging to different botanical families, out of 13 agriculture crops highest number of flora recorded in the month of September with 9 bee-flora species followed by August, July, February and March. In May and November month only single bee-flora species is available. Highest floral abundance contribution of September month is 13.85% followed by august with 12.90%. In May month floral abundance was

Table 1. Diversity of agriculture crops in Dr. Panjabrao Deshmukh Krushi Vidyapeeth Akola

Common name	Scientific name	Family	Food source	Flowering period	Intensity of visitation
Wheat	*Titicum aestivum*	Poaceae	N	Oct-Dec	++
Jawar	*Sorghum bicolar*	Poaceae	P	Feb-Mar	++
Cotton	*Gossipium*	Malvaceae		Sep-Dec	
Gram	*Cicer arietinum*	Fabaceae	N	Dec-Mar	+++
Maize	*Zea mays*	Poaceae	P	Aug-Sep/Feb-Mar	++
Pigeon pea	*Cajanas cajan*	Fabaceae	N	July-Sept	+++
Ground nut	*Arachishypogaea*	Leguminosae	N;P	July-Oct/Apr-June	++
Soyabean	*Glycin max*	Leguminosae	N	July-Oct	+++
Green gram	*Vigna radiata*	Fabaceae	N	Aug-Sep	+++
Back gram	*Vigna mungo*	Fabaceae	N	Aug-Sep	+++
Sesame	*Sesamum indicum*	Pedaliaceae	N;P	July-Sept	+++
Sunflower	*Helianthus annus*	Compositae	N;P	Aug-Sep	+++
Safflower	Carthamus tinctoriua	Asteraceae	N;P	June-July	++

Table 2. Diversity of Horticulture crops in Dr. Panjabrao Deshmukh Krushi Vidyapeeth Akola

Common name	Scientific Name	Family	Food source	Flowering period	Intensity of visitation
a. Fruits					
Orange	*Citrus reticulate*	Rutaceae	N;P	Jan- mar/Jun-July	+++
Sapota	*Manilkara zapota*	Sapotaceae	N;P	Oct-Nov / Feb-March	++
Kaghziinimboo	-*Citrus aurantifolia*	Rutaceae	N;P	Nov-mar	+++
Papaya	Carica papaya	Caricaceae	N;P	March-april	+++
Tamarind	*Tamarind Indica*	Fabaceae	P	Apr-May/Dec-jan	+++
Aonla	*Phyllanthus emblica*	Euphorbiaceae	N;P	Mar-May	++
Dragon fruit		Cactaceae	N	June-Nov	+
Date palm	phonix dactylifera	Arecaceae	N;P	June-Dec	+++
Wood apple	limonia acidissima	Rutaceae	N;P	Feb-march	++
Pomegranate	*Punica grantum*	Punicaceae	N;P	Mar-june	++
Mango	*Mangifera indica*	Anacardiceae	P	Jan-Apr	+
Zizipus	*Zizipus jujuba*	Ramnaceae	N;P	Jul-Oct	++
Zizipus	*Zizipusmauritiana*	Ramnaceae	N;P	May-June	++
Custard apple	*Annona squamosa*	Annonacea	N;P	June-Aug	+++
Bel	*Aeglemarmilose*	Rutaceae	N;P	May-June	++
Guava	*Psidium guajava*	Myrtaceae	P	June -Sept	+++
Lemon	*Citruslinom*	Rutaceae	N;P	Oct- Jan/July-Sept	+++
b. Vegetables					
Garlic	*Allium sativum*	Liliaceac	N;P	Aug-Sep	++
Curry patta	Murray koenigii	Rutaceae	N	Mar-May	+++
Onion	*Alliumsepa*	Liliaceac	P	Dec-Feb/Mar-May	++
Chilli:	*Capsicum annum*	Solanaceae	N;P	Jan-Dec	++
Tomato:	*Lycoperesicum esculentum*	Solanaceae	N;P	Jan-Dec	+++
c) Ornamental plants					
Tulsi	*Ocimum sanctum*	Lamiaceae	N;P	July -Sept/Mar-April	+++
Gladiolus		Gladiolaceae	N;P	August	++
Marigold	*Tagetuserecta*	Asteraceae	N	Sept-Dec	+++
Basil	*Ocimumbasilium*	Labiatae	N;P	Oct-Feb	++
Zinnia	*Zinnia elegans*	Asteraceae	N;P	April-Nov	+++
Crisenthemum		Asteraceae	N;P	Oct-Nov	++
Rose	*Rosa Indica*	Rosaceae	P	Mar-Sept	+++
Gulmohar	*Delonixregia*	Fabaceae	N;P	Mar-April	+++
Tube Rose	*Polianthas tubrosa*	Asperagaceae	P	Aug-Sep	+++
Canna	*Canna indica*	Cannaceae	N;P	July-August	++
d) Medicinal plants					
Bhrami:	Adhatodavasica	Acanthaceae	N	May-Oct	++
Shatavari:	Asparagus racemosus	Asparagaceae	P	May-June	+
Brahmhi:	Bacopa monieriSSS	Scrophulariaceae	P	June -Oct	+
Tulsi	Ocimum sanctum	Lamiaceae	N;P	July -Sept/ Mar-April	+++
Sarpagandha:	Rauvoffia serpentine	Apocunaceae	N;P	March-May	++
Aloevera:	Aloe barbadensis	Asphodelaceae	N;P	March-May	+++
Lavangtulas:	Ocimum gratissimum	Lamiaceae	P	All Year	++
Indian squill:	Urgania indica	Asparagaceae	N;P	April-May	+++
Star grass lilly:	Iphiginnaia stellate	Colchicacaeae	N;P	May-july	++
Mint:	Coleus forshkohli	Lamiaceae	N;P	June-Sep	+++
Guggul:	Commiphora mukul	Burseraceae	N;P	Nov-July	
Aromatic grass:	Cymbophogon nardus	Poaceae	N;P	April-june	++
Adhulsa:	Justicia adhatoda	Acanthaceae	N;P	March-June	+++
Bibba;	seacarpus anacardium	Anacardiaceae	N;P	June-july	++
Gambheri	Gmelina arborea	Verbinaceae	N;P	Feb-April	+++
Nirgudi:	Vitex nrgundo	Laminaceae	N;P	June-August	++
Parosa pimpal		Malvaceae	N;P	All Year	+++

Table 3. The diversity of forest trees in Dr. Panjabrao Deshmukh Krishi Vidyapeeth Akola

Common name	Scientific name	Family	Food source	Flowering period	Intensity of visitation
Wild plants					
Touch Me Not	*Mimosa pudica*	Fabaceae	P	July-May	+++
Indian Catmint	*indica Anisomeles*	Labiateae	N:P	Nov-March	+
Rui	*Calatropis gigantea*	Asclepediaceae	N:P	Nov-Dec	++
Jangalimuli	*Blumealacera*	Asteraceae	N:P	Dec-Mar	+++
Wild Senna	*Cassia tora*	Ceaselpineaceae	P	Mar-July	++
Lantana	*Lantana camara*	Verbenaceae	N	Jan-April, July-Sept	+
Devils's-Horsewhip	*Achyranthes aspera*	Amaranthaceae	P	Dec-Feb	+
Ekhandi	*Tridax procumbens*	Asteraceae	N:P	Jan-Dec	+
Broad leaf button	*Borreria sp*	Rubiacae	N:P	Aug-Jan	++
Mustard	*Brassica sp.*	Brassicaceae	N	Oct-Nov	+
Dayflower species	*Commelina sp*	Commelinaceae	P:N	Aug-Dec	+
Datura sp.	*Datura stramonium*	Solanaceae	P	April-Dec	+
Wireweed	*Sida acuta*	Malvaceae	P	Jan-Dec	+
Bhumibala	*Sida cordata*	Malvaceae	N:P	Oct-Dec	+
Ilima/ flannel weed	*Sida cordifolia*	Malvaceae	N:P	Jan-Dec	+
Vernonia albicans	*Cyanthillium albicans*	Asteraceae	P	Aug-Dec	+
Milk weed	*Calatropis*	Asclepiadaceae	P	Mar-Feb	+
Field bind weed	*Convulvulus aevensis*	Convolvulus arvensis	P	Mar-Feb	++
Chinese-violet	*Asysteasis gangaetic*	Acanthaceae	N;P	Feb -March	+++
Kalsarji	*Wedelia Chinensis*		N;P	Jul-Nov	+++
Suryavarti	*Chrozophora rottleris*	Euphorbiaceae	N;P	March-May	+
Sessile joywood	*Allternanthera Sessile*	Amaranthaceae	N;P	Oct-Dec	++++
Lantana	*Lantana camera*	Verbenas	N;P	Jul-Dec	++
Tridax-daisy	*Tridax procumbence*	Asteraceae	N;P	Jul-Mar	++
Zoysia	*Zoysia spp.*	Zoysiaceae	N;P	Mae-Apr	+++
Wild mint	*Mentha arvensis*	Lamiaceae	N;P	Sept-Oct	++
Cyndrella-weed	*Syndrella nodiflora*	Asteraceae	N;P	Sept -March	+++
Devil`s horsewhip	*Achyranthus Aspera*	Amaranthaceae	P	Sept-March	+
Chickenweed	*Portulaca quadrifida*	caryophyllales	N;P	March-April	+++
Fire-weed	*Chamaenerion anguistifolium*	Onagraceae	N;P	June – Sep	++
Trida daisy	*Tridaxprocumbence*	Compositae	N;P	April-June	+++
Malabr nut	*Adhotodavasica*	Acanthaceae	N;P	Dec-June	++
Alexandrian-senna	*cassia anguistifolia*	Fabaceae	N;P	All year	+++
Mimosa	*Mimosa diplotrica*	Mimosaceae	N;P	Apr-June	++
Forest trees					
Eucalyptus	*Eucalyptus spp.*	Myrtaceae	N;P	Nov-mar	+++
Tamarind	*Tamarindus indica*	Fabaceae	P	April-May/Dec-Jan	+++
Neem	*Azadirachta indica*	Meliaceae	N;P	Mar-May	++
Babul	*Acacia nilotica*	Fabaceae	N;P	July - Sep	+++
Black Siris	*Albezialebeek*	Mimosaceae	N;P	Apr-May	++
Apta	*Bauhiniaracemose*	Caesalpinaceae	N;P	Jan-Feb	+++

Cont...

Table 3. The diversity of forest trees in Dr. Panjabrao Deshmukh Krishi Vidyapeeth Akola

Common name	Scientific name	Family	Food source	Flowering period	Intensity of visitation
Semal	*Bombax ceiba*	Bombbaceae	N;P	Jan-may	++
Khair	*Bombax ceiba*	Caesalpinaceae	N;P	Sept-Dec	+++
Palas	*Beutea monosperma*	Papilionaceae	N;P	Feb-Apr	+++
Kadamb	*Anthrocephalus cadamba*	Rubiaceae	N;P	Jan-Apr	+++
Arjun	*Terminalia Arjuna*	Combretaceae	N;P	Apr-May	++
Nimbara	*Melia Azadirach*	Meliaceae	P	Feb-May	+++
Bahava	*Casia fistula*	Caesalpinaceae	P	Apr-May	+++
Kanchan	*Bauhinia purpurea*	Caesalpinaceae	N;P	Jan-Feb	+++
Karanj	*Pongamia pinnata*	Fabaceae	N;P	Feb-May	+++
Shami	*Prosopis julifera*	Fabaceae	P	May-June/Sept-Oct	++
Jamun	*Syzigium cumimi*	Myrtaceae	N;P	Mar-May	+++
Teak	*Tectona grandis*	Verbinaceae	P	June-Sept	+
Bel	*Aegle Marmelos*	Rutaceae	N;P	Dec- Jan	++
Mango	*Magnifera indica*	Anacardiaceae	P	Jan-April	+
Ashoka	*Saracaasoca*	Leguminosae	P	Feb-april	+
Bija	*Pterocarpus marsupium*	Fabaceae	N;P	July- Oct	++
Rain tree	*Samaneae saman*	Leguminosae	P	May-june	+++
Reetha	*sapindus indica*	Sapindaceae	N;P	Oct- Dec	++
Kusum	*Scheleicheraoleosa*	Sapindacea	P	Feb-Jul	+++
Biba	*Semecarpus anacardium*	Anacardiaceae	N;P	May- Sept	+
Simaruba	*Simaruba glauca*	Simaroubaceae	P	April- Jul	+++
Bitti	*Thevetia peruviana*	Apocynaceae	N;P	April-June	+++
Nirgundi	*Vitex negundo*	Lamiaceae	N;P	March-June	++
Hirda	*Termanaliachebula*	Combretaceae	N;P	April- Oct	+++
Beheda	*Terminalia bellerica*	Combretaceae	N;P	April- Nov	++
Badam	*Terminalia bellerica*	Combretaceae	N;P	April	+
Vilayati babul	*Prosopis juliflora*	Leguminoceae	N;P	April-Jul	+++
Parijatak	*Nyctanthesarbortristis*	Oleaceae	N	Aug-Jan	+++
Tiwas	*Ougeinia dalbergioides*	Papilionace	N;P	Feb-Jul	+++
Kunda	*Paspalum scrobiculatum*	Poaceae	N	Aug-Feb	+++
Shevaga	*Moringa oleifera*	Moringaceae	N;P	Feb-Mar	+++
Khirni	*Mimusopshexandra*	Sapotaceae	N;P	Mar-May	++
Mahua	*Madhuca indica*	Sapotaceae	N;P	Feb- April	+++
Subabul	*Leucaena leucocephala*	Mimosaceae	N;P	April- Jul	++
Ghaneri	*lantana camera*	Verbenaceae	N;P	Aug-Nov	+++
Jatropa	*Jatraphacurcas*	Euphorbiaceae	P	June- Jul	++
Jungle cork tree	*Holoptelae integrifolia*	Ulmaceae	N;P	June-Jul	+++
Anjan	*Hardwickiabinata*	Caesalpiniaceae	N;P	April- May	+++
Siwan	*Gmelina arborea*	Verbanaceae	N;P	Feb- Apr	+++
Giripushp	*Gliricida maculate*	Fabeceae	N;p	Jan-Feb	+++
Dikamali	*Gliricida maculate*	Rubiaceae	N;P	Feb-Jan	++
Pipal	*Ficus religiosa*	Moraceae	N;P	Apr-May	+++

Cont...

Table 3. The diversity of forest trees in Dr. Panjabrao Deshmukh Krishi Vidyapeeth Akola

Common name	Scientific name	Family	Food source	Flowering period	Intensity of visitation
Umber	*Ficus glomerata*	Moraceae	N;P	Jan-July	+++
Nilgiri	*Ficus glomerata*	Myrtaceae	N;P	May-June	+++
Tendu	*Diospyrous melanoxylon*	Ebenaceae	N;P	Aprl-june	++
Kapok	*Ceiba pentendra*	Bombaceae	P	Jan-March	+++
Amaltas	*Cassia fistula*	leguminosae	N;P	March-Aprl	+++
Karonda	*Carissa caranthus*	Apocinaceae	P	May-Sept	++
Apta	*Carissa caranthus*	Fabaceae	N	March-June	+
Sagargoti	*Caesalpinae crista*	Fabaceae	P	April-June	+
Acher	*Buchanania lanzan*	Anacardiacea	P	April- June	++
Kanchan	*Bahunia variegata*	Fabaceae	N;P	April- June	+++
Hingan	*Balanitesa egyptiaca*	Simaroubacea	N;P	April- May	+++
Saptaparni	*Alstoni ascholaris*	Apocynaceae	P	Oct- Jan	+++
Siris	*Albizia lebback*	Fabaceae	N;P	Mar-Oct	+++
Maharukh	*Albizia lebback*	Simarobroubaceae	N;P	May- June	+++
Haldu	*Adina cordifolia*	Rubiaceae	N;P	June- Oct	+++
Adulsa	*Adhatoda vasica*	Acanthaceae	P	Oct- Feb	++
Elephant foot tree	*Adhatoda vasica*	Malvaceae	P	Oct- Dec	++
Chirchiri	*Achyranthes aspera*	Amranthaceae	P	Oct- Dec	++
Chilati	*Acacia pennata*	Fabaceae	N;P	Oct-Feb	++
Hiwar	*Acacia leucocephala*	Mimosaceae	N;P	Jul-Nov	+++
Gunj	*Abrusprecatorius*	Fabaceae	N;P	Aug-Jan	+++
Spanish cherry	*Mimusops elengi*	sapotaceae	N;P	April	++

Note: N- Necteriferrous P- Polleniferous

1.33%. In November it was 1.89%. In January with 4% , February with 7.14%, March with 5.88% (Table 5).

During the experimental period out of total 17 number of horticultural crops highest number where recorded in June with 8 bee-flora species followed by July, March, and August, with 7,7 and 6 species respectively. The floral abundance of horticultural crops in the June month was 11.94 %, March with 10.29%, July 10.45%. Least abundance was found in December month with 2 floral species having percentage abundance 3.5% (Table 5). During study period out of 5 vegetable crops same number of bee-flora available in March, April, May month with 4 bee-flora species availability, with percentage abundance 5.88%, 4.94%, and 5.33%, respectively (Table 5).

Abundance of bee-flora: The presence of plant species with particularly alluring colours was crucial for attracting pollinators and enhancing the number of times they visited. The diversity of plant species, or the amount of blossoms, and the presence of plant species that are appealing to pollinators both help to stabilise the frequency of their visits. During the experimental period out of 10 number of ornamental crops, in August 6 bee-flora species availability was present followed by September with 5 bee-flora species and 4 bee-flora species in April, July, October and November. Highest bee-flora abundance was 9.68% in August, September 7.69% least floral abundance was obtained in January with 2%, February with 1.79% (Table 6).

During the study period, Out of total 17 medicinal crops, Highest bee-flora found in June with 12 and May with 11, April and July with 10 bee-flora species available. The percentage abundance of June month is 17.91%, May 14.46% and April 12.35% July 14.93%. The least floral abundance of January and February month is 6% and 7.14%, respectively (Table 6).

During the study period, out of total 70 forest trees species, highest bee-flora found in April month with 38 and 35 in May. The least floral availability is obtained in December month with 13 forest trees species. The percentage Abundance of April month is 46.91% and that of May month 46.67% , the floral abundance of January, February, March, and June is 36%,39.29%,32.35%, and 40.30% respectively. The least floral abundance is 22.58% of August month (Table 6).

As per the above Data, out of total 34 wild plant species

Table 4. Bee-flora calender in Dr. Panjabrao Deshmukh Krishi Vidyapeet Akola campus in January 2022 to January 2023

Common name	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cereals, Pulses												
Wheat	*	*	*	*								
Jawar		*	*									
Cotton									*	*	*	*
Gram	*	*	*									*
Maize		*	*					*	*			
Pigeon pea							*	*	*			
Ground nut				*	*	*	*	*	*	*		
Soyabean							*	*	*	*		
Green gram								*	*			
Back gram								*	*			
Sesame							*	*	*			
Sunflower								*	*			
Safflower						*	*					
Fruits												
Orange	*	*	*			*	*					
Sapota		*	*							*	*	
Kaghziinimboo	*	*	*								*	*
Papaya			*	*								
Tamarind	*			*	*							*
Aonla			*	*	*							
Dragon fruit						*	*	*	*	*	*	
Date palm						*	*	*	*	*	*	
Wood apple	*	*										
Pomegranate			*	*	*	*						
Mango	*	*	*	*								
Zizipus							*	*	*	*		
Zizipus					*	*						
Custard apple						*	*	*				
Bel					*	*						
Guava						*	*	*	*			
Lemon	*						*	*	*	*	*	*
Vegetables												
Garlic								*	*			
Curry patta			*	*	*							
Onion	*	*	*	*	*							*
Chilli	*	*	*	*	*	*	*	*	*	*	*	*
Tomato	*	*	*	*	*	*	*	*	*	*	*	*
ORNAMENTAL PLANTS												
Tulsi			*	*	*		*	*	*			
Gladiolus								*				
Marigold									*	*	*	*
Basil	*	*								*	*	*

Cont...

Table 4. Bee-flora calender in Dr. Panjabrao Deshmukh Krishi Vidyapeet Akola campus in January 2022 to January 2023

Common name	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Zinnia				*	*	*	*	*	*	*	*	
Rose:			*	*	*	*	*	*	*			
Gulmohar			*	*								
Tube Rose								*	*			
Canna							*	*				
Medicinal plants												
Bhrami					*	*	*	*	*	*		
Shatavari					*	*						
Brahmhi						*	*	*				
Tulsi			*	*			*	*	*			
Sarpagandha			*	*	*							
Aloevera			*	*	*							
Lavangtulas	*	*	*	*	*	*	*	*	*	*	*	*
Indian squill				*	*							
Star grass lilly					*	*	*					
Mint						*	*	*	*			
Guggul	*	*	*	*	*	*	*				*	*
Aromatic grass				*	*	*						
Adhulsa			*	*	*	*						
Bibba						*	*					
Gambheri		*	*	*								
Nirgudi						*	*	*				
Parosa pimpal	*	*	*	*	*	*	*	*	*	*	*	*
Forest trees												
Eucalyptus	*	*	*								*	*
Tamarind	*			*	*							*
Neem			*	*	*							
Babul							*	*	*			
Black Siris				*	*							
Apta	*	*										
Semal	*	*	*	*	*							
Khair									*	*	*	*
Palas		*	*	*								
Kadamb	*	*	*	*								
Arjun				*	*							
Nimbara		*	*	*	*							
Bahava				*	*							
Kanchan	*	*										
Karanj		*	*	*	*							
Shami					*	*			*	*		
Jamun			*	*	*							
Teak						*	*	*	*			
Bel	*											*
Mango	*	*	*	*								
Ashoka		*	*	*								
Bija							*	*	*	*		
Rain tree					*	*						
Reetha										*	*	*

Cont...

Table 4. Bee-flora calender in Dr. Panjabrao Deshmukh Krishi Vidyapeet Akola campus in January 2022 to January 2023

Common name	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Kusum		*	*	*	*	*	*					
Biba					*	*	*	*	*			
Simaruba				*	*	*	*					
Bitti				*	*	*						
Nirgundi			*	*	*	*						
Hirda				*	*	*	*	*	*	*		
Beheda				*	*	*	*	*	*	*	*	
Badam				*								
Vilayati babul				*	*	*	*					
Parijatak	*							*	*	*	*	*
Tiwas		*	*	*	*	*	*					
Kunda	*	*						*	*	*	*	*
Shevaga		*	*									
Khirni			*	*	*							
Mahua		*	*	*								
Subabul				*	*	*	*					
Ghaneri								*	*	*	*	
Jatropa						*	*					
Jungle cork tree						*	*					
Anjan				*	*							
Siwan		*	*	*								
Giripushp	*	*										
Dikamali	*	*										
Pipal				*	*							
Umber	*	*	*	*	*	*	*					
Nilgiri					*	*						
Tendu				*	*	*						
Kapok	*	*	*									
Amaltas			*	*								
Karonda					*	*	*	*	*			
Apta			*	*	*	*						
Sagargoti				*	*	*	*					
Acher				*	*	*	*					
Kanchan				*	*	*	*					
Hingan				*	*	*	*					
Saptaparni	*									*	*	*
Siris			*	*	*	*	*	*	*	*		
Maharukh					*	*						
Haldu						*	*	*	*	*		
Adulsa	*	*								*	*	*
Elephant foot tree										*	*	*
Chirchiri										*	*	*
Chilati	*	*								*	*	*
Hiwar							*	*	*	*	*	
Gunj	*							*	*	*	*	*
Spanish cherry				*								
Wild plants												
Touch Me Not	*	*	*	*	*		*	*	*	*	*	*

Cont...

Table 4. Bee-flora calender in Dr. Panjabrao Deshmukh Krishi Vidyapeet Akola campus in January 2022 to January 2023

Indian Catmint	*	*	*								*	*
Rui											*	*
Jangalimuli	*	*	*									*
Wild Senna			*	*	*	*	*					
Lantana	*	*	*	*				*	*			
Devils's Horsewhip	*	*										*
Ekhandi	*	*	*	*	*	*	*	*	*	*	*	*
Borreria sp.	*							*	*	*	*	*
Brassica sp.										*	*	*
Commelina sp.								*	*	*	*	*
Datura sp.				*	*	*	*	*	*	*	*	*
Sida acuta	*	*	*	*	*	*	*	*	*	*	*	*
Sida cordata										*	*	*
Sida cordifolia	*	*	*	*	*	*	*	*	*	*	*	*
Vernonia albicans								*	*	*	*	*
Milk weed	*	*	*	*	*	*	*	*	*	*	*	*
Field bind weed	*	*	*	*	*	*	*	*	*	*	*	*
Chinese violet	*	*	*	*	*	*	*	*	*	*	*	*
Kalsarji							*	*	*	*	*	
Suryavarti			*	*	*							
Sessile joywood										*	*	*
Lantana							*	*	*	*	*	*
Tridax daisy	*	*	*				*	*	*	*	*	*
Zoysia	*	*	*	*	*	*	*	*	*	*	*	*
Wild mint									*	*		
Cyndrella weed	*	*	*						*	*	*	*
Devil`s horsewhip	*	*	*						*	*	*	*
Chickenweed			*	*								
Fireweed						*	*	*	*			
Trida daisy				*	*	*						
Malabar nut	*	*	*	*	*	*						*
Alexandrian senna	*	*	*	*	*	*	*	*	*	*	*	*
Mimosa				*	*	*						

Table 5. Bee flora abundance in agricultural and horticultural crops (Fruits & vegetables), in January 2022 to January 2023

Month	Bee flora			Total bee flora	Floral abundance (%)		
	Agriculture crops	Horticulture/ fruits crops	Horticulture/ vegetable		Agriculture crops	Horticulture/ fruits crops	Horticulture/ vegetable
January	2	6	3	50	4.00	12.00	6.00
February	4	5	3	56	7.14	8.93	5.36
March	4	7	4	68	5.88	10.29	5.88
April	2	5	4	81	2.47	6.17	4.94
May	1	4	4	75	1.33	5.33	5.33
June	2	8	2	67	2.99	11.94	2.99
July	5	7	2	67	7.46	10.45	2.99
August	8	6	3	62	12.90	9.68	4.84
September	9	5	3	65	13.85	7.69	4.62
October	3	5	2	57	5.26	8.77	3.51
November	1	5	2	53	1.89	9.43	3.77
December	2	3	3	51	3.92	5.88	5.88
Overall total	13	17	5	171	7.60	9.94	2.92

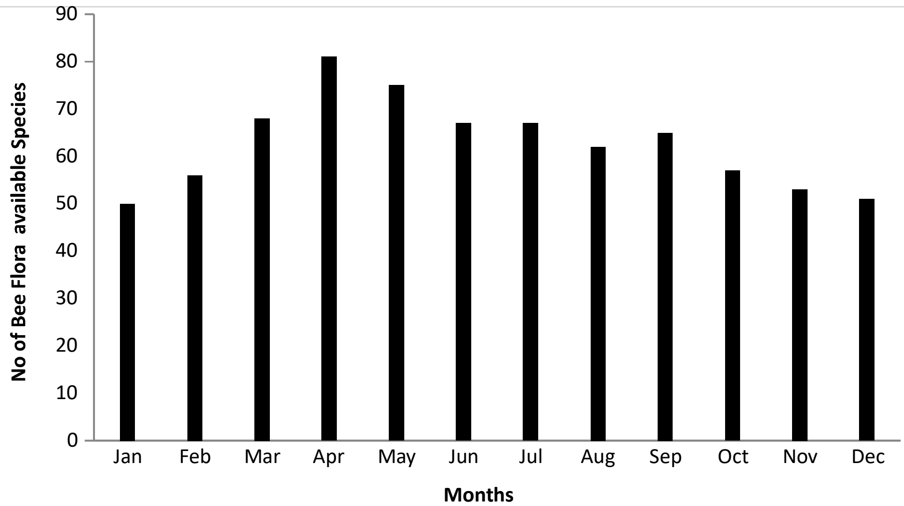

Fig. 1. Floral availability in different months

Table 6. Bee flora abundance in horticultural crops (Ornamental and medicinal crops) and forest tree species & wild plants, in January 2022 to January 2023

Month	Bee flora				Total Bee Flora	Floral abundance (%0)			
	Ornamental-crops	Medicinal-crop	Forest-Tree	Wild Trees		Ornamental-crops	Medicinal-crops	Forest tree	Wild trees
January	1	3	18	18	50	2.00	6.00	36.00	36.00
February	1	4	22	17	56	1.79	7.14	39.29	30.36
March	3	8	22	19	68	4.41	11.76	32.35	27.94
April	4	10	38	17	81	4.94	12.35	46.91	20.99
May	3	11	35	15	75	4.00	14.67	46.67	20.00
June	2	12	27	14	67	2.99	17.91	40.30	20.90
July	4	10	22	15	67	5.97	14.93	32.84	22.39
August	6	7	14	15	62	9.68	11.29	22.58	24.19
September	5	5	16	21	65	7.69	7.69	24.62	32.31
October	4	3	18	22	57	7.02	5.26	31.58	38.60
November	4	3	14	25	53	7.55	5.66	26.42	47.17
December	2	3	13	25	51	3.92	5.88	25.49	49.02
Overall total	10	17	70	34	171	5.84	9.94	40.93	19.888

(weeds, shrubs), Highest bee-flora availability found in November and December Month and Least in June Month. The percentage abundance in bee-flora in November-December Month is 47.17% and 49.02%, respectively. The least floral abundance of June Month is 20.90% (Table 6).

In conclusion the bees plays most important role in biodiversity conservation and ecological balance through pollination. It helps in sustainable agriculture development. In the above discussion Out of 171 species there are 13 agricultural crops species, 17 horticultural fruits crops species, 5 vegetable crops species, 10 ornamental plants species, 17 medicinal plants species, 70 forest trees species and 34 wild plant species included (Table 1,2,3).

CONCLUSION

From this research activity, It is proved that the study Area is full of bee-foraging flora with great percentage abundance in different months. This area is most suitable for apiculture that can benefited for farmers as well as campus for study, and honey collection. We can say there is lack of critical darth period in this study area. The bee-flora availability order is forest crops, medicinal crops, wild plants, horticultural crops fruits crops, ornamental crops, vegetables crops and agricultural crops.

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Monitoring Land Use/ Cover Dynamics of Achanakmar Tiger Reserve (ATR), India by Using Multi-Temporal Satellite Data and Future Scenario

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Abstract: The Achanakmar Tiger Reserve (ATR) has experienced various land use changes since 1975. In this study, multi-temporal land-use changes of the ATR from 2000 to 2015 were assessed using IRS-1D and P6, LISS III and Landsat OLI satellite imageries. ERDAS Imagine v 2013 and IGIS v 1.0 software was used to process satellite imageries and assess quantitative data. The maximum likelihood classification algorithm was used to derive a supervised land-use classification of the spring and autumn months for 2000, 2008, 2013 and 2015. Dense forest is the dominant land cover type covering approximately 56% of the area, followed by open forest, scrub land, agricultural land, river bed, built up land and water bodies. During 16-year period, approximately 3.20 and 2.24% of the open forest area had increased during the spring and autumn seasons, and the annual rate of change was 0.20 and 0.14%. Scrub land area has decreased by 3.53 and 2.85% during the spring and autumn seasons during this period. Areas covered under water bodies, river beds and built up lands have also reported increment. Slight variations were observed in areas of dense forest, scrub land and agricultural land. The overall accuracy for supervised images ranged from 91.84 to 94.90%. Projection modeling of ATR area was performed using TerrSet Software (v18.31) for different land use scenario. LULC projection map of 2030 shows that dense forest area will remain the dominant land cover with slight modification in built-up land, agricultural land and water bodies. ATR's land use/ land cover database will help identify the impacts of climate change on forests, water bodies and biodiversity. The results will also be helpful in planning and implementing better management decisions to conserve rich biodiversity of ATR.

Keywords: Achanakmar Tiger Reserve (ATR), Biodiversity, Classification, Accuracy assessment

The Central Indian landscape harbors a globally significant tiger population (Dutta et al 2016). The Achanakmar Tiger Reserve (ATR) is a part of Central Indian Landscape. It is the 32^{nd} tiger reserve of India and third tiger reserve of the state of Chhattisgarh. ATR owes its name to the village called "Achanakmar" (means sudden attack) that lies within the green limits of the Maikal ranges. This protected area has a long history of conservation. In recognition of its uniqueness and richness in biodiversity, Achanakmar was declared as a wildlife sanctuary in 1975 under The Wildlife (Protection) Act, 1972. Later, in 2009 it was declared as a tiger reserve due to the presence of wild tiger population. ATR is also an integral part of Achanakmar Amarkantak Biosphere Reserve (AABR) and is enriched with a rich pool of germplasm. The location of ATR is strategically important for the protection of wildlife biodiversity. It acts as a conduit for movement for tigers from many different tiger reserves and protected areas of the region, thereby promoting genetic exchange and dispersion of wild tiger population. The corridors connect ATR to many important tiger reserves of Central India such as Kanha Tiger Reserve, Pench Tiger Reserve and Bandhavgarh Tiger Reserve (Borah et al 2016, Dutta et al 2016). The ATR is also well connected to the Guru Ghasidas National Park, Phen Wildlife Sanctuary and Bhoramdev Wildlife Sanctuary.

With the advancement of science and technology, application of remote sensing and GIS plays a promising trend in the conservation and management of the environment and natural resources. This technology is widely used by different researchers for habitat assessment of different tiger reserves (Sudeesh & Sudhakar 2012, Salguna et al 2018, Khan et at 2019, Bhardwaj et al 2019). The LULCC is a dynamic and ongoing process (Mondal et al 2016) and changes in different land uses are important for overall environmental monitoring. So far, several studies evaluating floral (Shukla & Singh 2009, Sahu 2011, Singh & Sharma 2017) and faunal biodiversity (Mandal et al 2017, Chandra & Baaz 2018,) have been carried out in the ATR. Few studies have been conducted using geospatial technology of the AABR region (Karwariya et al 2017 and Karwariya & Tripathi 2012). However, little is known about the dynamics of land use/cover change in ATR (Mahato & Singh 2019) and their impact on the surrounding ecosystems. In this study the seasonal variation in land use/cover dynamics of ATR has been examined from 2000 to 2015. Another reason for choosing this period was to study the detailed dynamics of change before and after the declaration of tiger reserve. The present paper also provides the projection of various LULC categories for the year 2030 using geospatial technology.

MATERIAL AND METHODS

Study area: The geographical extent of the Achanakmar Tiger Reserve (ATR) lies between 22°17' and 22°38' North latitudes and 81°31' and 81°57' East longitude (Fig. 1). It covers an area of 914.017 km^2, of which 626.195 km^2 belongs to core zone (critical tiger habitat) and 287.822 km^2 to the buffer zone. It is a hilly-dominated area and its elevation range varies from 305-1080 m above mean sea level (Mahato & Singh 2022). Champion & Seth (1968) categorized forest vegetation into Northern Tropical Moist Deciduous and Southern Dry Mixed Deciduous Forest (Roychoudhary 2013). Sal (*Shorea robusta*) is the dominant forest type in the region, followed by Sal mixed forest which includes tree species such as Saja (*Terminalia tomentosa),* Tendu (*Diospyros melanoxylum),* Haldu (*Adina cordifolia),* Bijasal (*Pterocarpus marsupium),* Mahua (*Madhuca indica),* Dhawda *(Anogeissus latifolia),* Teak (*Tectona grandis* (plantation). Bamboo (*Dendrocalamus strictus*) is also found in higher and lower slopes with miscellaneous tree species (Mandal et al 2017). The Maniyari river which originates from Sihawal sagar inside the core zone of ATR, is its lifeline. ATR is the home of Bengal tiger, leopard, striped hyena, Indian gaur and many other endangered mammals. Few indigenous tribal groups of Baiga, Kol, Munda are the inhabitants of the study area.

Data used: Multi-date cloud free satellite data acquired by the Indian Remote Sensing (IRS) satellites 1D and P6 and LANDSAT 8 data (Table 1) were used for visual interpretation, land use/cover identification and classification. Achanakmar

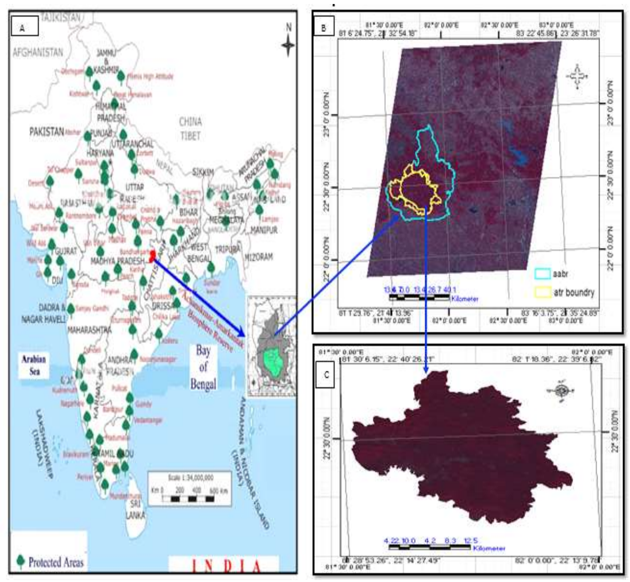


Fig. 1. Location map of ATR A-Protected Areas of India, B-Location of AABR and ATR in IRS LISS III image, C-False Colour Composite image of Achanakmar Tiger Reserve Area

Table 1. Specification of the analyzed satellite data

Satellite	Sensor	Path/row	Month and year of acquisition	Spectral bands (µm)	Spatial resolution (m)	Data source
IRS 1D	LISS 3	102/56	February 2000	0.52-0.59	23.5	NRSC
			October 2000	0.62-0.68		
				0.77-0.86	70.5	
				1.55-1.70		
IRS P6	LISS 3	102/56	March 2008			
			October 2008			
			February 2013			
			December 2013			
LANDSAT 8	OLI	142/44,	February 2015	0.435-0.451		USGS
		142/45	November 2015	0.452-0.512		(https://earthexplorer.usgs.gov)
				0.533-0.590		
				0.636-0.673		
				0.851-0.879		
				1.566-1.651	30	
				2.107-2.294		
				0.503-0.676	15	
				1.363-1.384	30	
				10.60-11.19	100*30	
				11.50-12.51	100*30	
		143/44	February 2015			
		143/45	November 2015			

LISS III- Linear Imaging and Self Scanning, OLI- Operational Land Imager, m-meter, NRSC-National Remote Sensing Centre, USGS-United States Geological Survey

Tiger Reserve boundary has been obtained from the Chhattisgarh Forest Department. The preliminary interpretation of the study area is based on topographical sheets. The Survey of India (SOI) topographic maps of 64F10, 64F11, 64 F14 and 64F15 at a scale of 1:50,000 published by SOI, Dehradun have been used for digitalization.

The imageries obtained were registered in the Universal Transverse Mercator (UTM) map projection with the WGS-84 datum, zone 43 N. Before classifying the imageries, the satellite data were reprojected into the Projected Coordinate System (PCS) to maintain consistency within the generated database. Observations made from satellite data were verified with ground thruthing and surveys in the study area. IGIS software version 1.0 was used for image pre-processing (layer stack, subset of the study area and image enhancement) and ERDAS IMAGINE version 2013 software has been used for image classification and accuracy assessment of the classified images. TerrSet software v18.31 was used for projection modelling.

Climate: The ATR area experiences tropical climate. The hottest month is May, when the maximum temperature raise to 46.7°C and drops to as low as 2°C in the winter months. The average annual precipitation of ATR is above 1200 mm and maximum precipitation falls in the month of July, August and September

Pre-processing of satellite data: The cloud free data of spring and autumn seasons have been used for the present study (Table 1). The satellite imageries acquired on different dates with path 102 and row 56 contain the spectral bands in separate files in Geo Tiff format. The files of required bands are stacked into one image using layer stacking option of the IGIS software. LANDSAT images downloaded from USGS websites having path-row 142-44, 142-45, 143-44 and 143-45 were mosaicked in GIS software. The clipping of the study area was performed from satellite imageries using the image subset function. All imageries were subjected to geometric rectification, radiometric calibration and atmospheric correction. Visual interpretations of imageries were performed on False Color Composites (FCC) using image elements such as tone, texture, pattern and location.

Image processing: Image processing and performing supervised image classification help extract information from imageries (Islam et al 2018). In present study, spring and autumn seasons were chosen to map and monitor the seasonal and temporal variation in different land use/ cover classes. Supervised classification of imageries was performed in ERDAS software v 2013 using a maximum likelihood classifier followed by accuracy assessment. A total of seven classes were identified: Dense Forest, Open Forest, Scrub Land, Agricultural Land, Built-up Land, Water Bodies and River Bed. About 100 ground locations were randomly selected in the classified imageries and accuracy assessment of the supervised imageries was performed using the Google earth synchronization tool. It includes the assessment of the overall accuracy, kappa statistics, producer's accuracy and user's accuracy of the LULC classes for the supervised imageries for years 2000, 2008, 2013 and 2015 respectively. An error matrix and kappa statistics were generated from the reference and classified data from the reports section of the software.

Change detection: For each LULC categories, the magnitude of change was assessed by subtracting the area covered in the second year from the initial year as illustrated in the equation (1)

Magnitude of change = magnitude of new year – magnitude of previous year (1)

The annual rate of change for each LULC categories was evaluated by subtracting the final year to initial year, which was further divided by number of study year i.e. 2000-2008, 2008-2013, 2013-2015 and 2000-2015 respectively using the equation (2)

$$\text{Annual rate of change} = \frac{\text{Final year – initial year}}{\text{Number of years}} \quad (2)$$

Projection modeling: Projection modeling of ATR area was performed to assess the impact of land use change on the study area. The modeling was done with the Land Change Modeler (LCM) of the TerrSet Software (Version 18.31) for different land use scenarios. The generated LULC maps were used to predict the future LULC projection map for the year 2030.

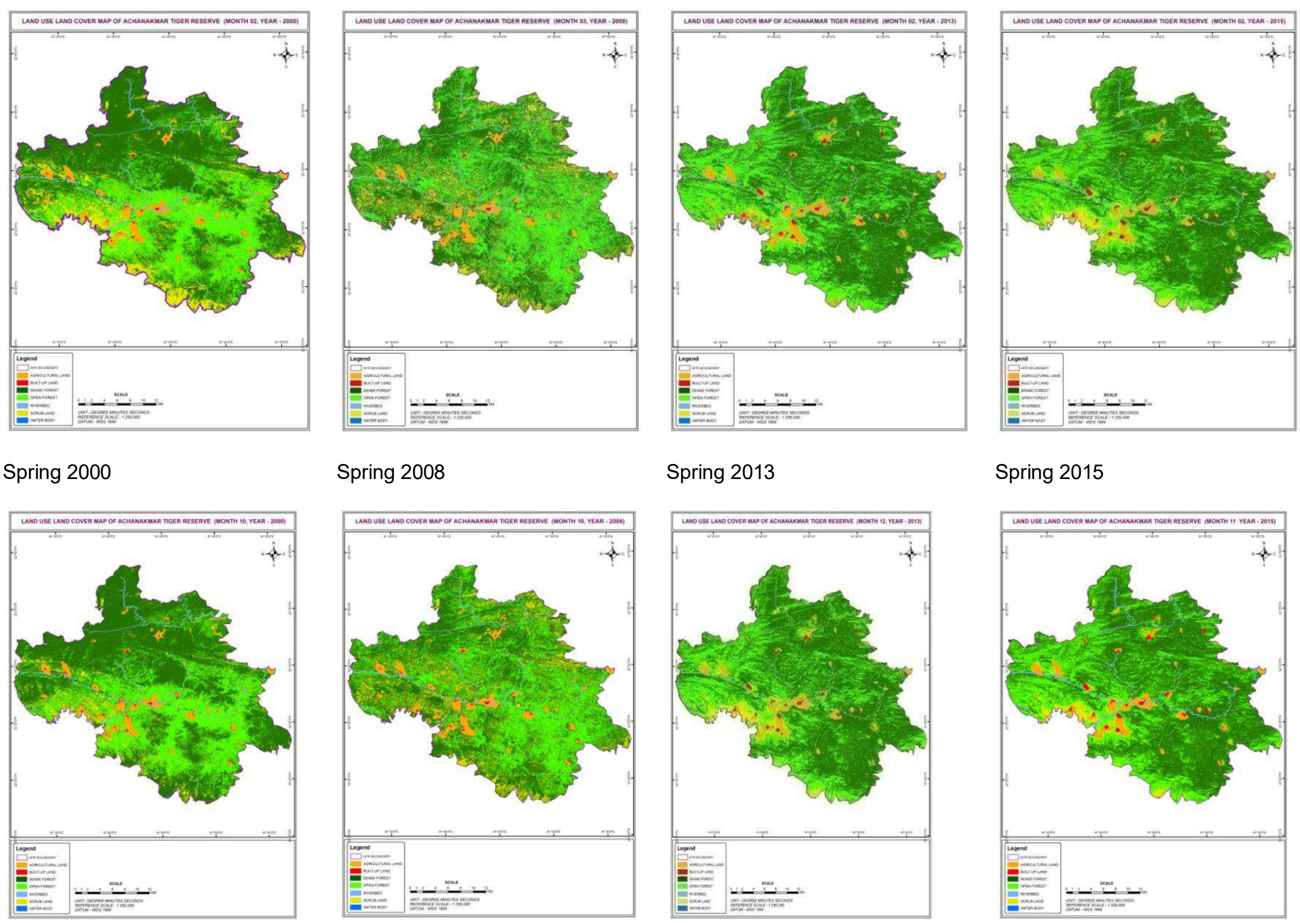
RESULTS AND DISCUSSION

LULC dynamics of ATR during spring season: The overall change assessment from 2000 to 2015 shows changes in the areas covered by different LULC classes (Table 2). The year 2000 is considered as a base year for the change detection and analysis. The main changes over the 16 year period are the 3.53 % reduction in scrub land, which has been converted to open forest cover by 3.20 % between 2000 and 2015. Slight decline in dense forest cover by 0.49 % and agricultural land area by 0.01% has been recorded during this time. Another positive change accounts from the increase in built-up area by 0.38 %. The areas covered under water bodies during spring season increased by 0.12% compared to 2000, which is due to good rainfall and increased conservation measures during recent years. The dense forest area was highest during 2000. The data also coincides with extreme climate variables in 2008 that led to the reduction in dense forest area in 2008, which also reversed in 2013.

Dynamics of land use/cover of ATR during autumn season: The overall assessment of change from 2000-2015 depicts that the dense forest area remained the dominant cover type with around 56% of the area (Fig. 2). During the autumn season, dense forest area increased by 0.09 %. The open forest area covered 32.11 % (293.49 km^2) in 2000 and increased to 34.31 % (313.96 km^2) during 2015. Scrub land area decreased by 2.85%. The built-up land area, which was 1.92 km^2 (0.21 %) in 2000, gradually increased to 2.10 km^2 (0.23 %), 4.11 km^2 (0.45 %) and 5.39 km^2 (0.59%) during the year 2008, 2013 and 2015. Utilized agricultural land area decreased by 0.03 % over a period of 16 years. The areas covered by water bodies and riverbeds showed variations depending on the precipitation received in the study area.

The general dynamics of change in the land use/ cover pattern of ATR was assessed based on the data presented in the Table 2 and magnitude of change and annual rate of change is illustrated in Table 3. The relative changes showed an irregular pattern in this study area from 2000-2015. Land use change from 2000-2008 showed slight negative changes in dense forest, scrub land and water bodies. This scenario showed a better trend in the period 2008-2013. Scrub land area had decreased by about 3.53 and 2.85% during spring and autumn between 2000 and 2015. The built-up land area covered 0.21% in 2000, increased to 0.59 % by 2015. The extent of change in area covered by water bodies varies from year to year due to variation in temperature and precipitation in the region. Riverbed area also showed fluctuation depending on the precipitation and surface runoff of the region.

Accuracy assessment: The highest accuracy for supervised imageries was reported for the autumn season (94.90% accuracy) for 2013 and the lowest for the same year during spring season (91.84% accuracy) (Table 4). The Kappa coefficient of > 0.90 for all seasons and years indicates that an observed classification of the order of 90%



Spring 2000 | Spring 2008 | Spring 2013 | Spring 2015

Autumn 2000 | Autumn 2008 | Autumn 2013 | Autumn 2015

Fig. 2. LULC map of ATR derived from satellite imageries for the year 2000, 2008, 2013 and 2015 during spring and autumn season

agrees almost perfectly. User accuracy of the dense forest and open forest classes was consistently high, ranging from 71.43 % to 100%. The producer's accuracy for the same ranged from 83.33 to 100%. The analysis shows that the classes such as dense forest, open forest, agricultural land and riverbeds were mapped unambiguously due to their distinct pattern and compactness. While the classes like scrub land and water bodies showed a slight ambiguity in classification. Factors contributing to misclassification include similar spectral information, spatial resolution of the satellite imagery, class ranges smaller than the spatial resolution of IRS P6-LISS III data etc. (Kar et al 2018).

Projected land use/ land cover map for the year 2030: The projected LU/LC for the year 2030 (Fig. 3) was generated

Table 2. Category wise LULC distribution of ATR during spring and autumn based on time frame data (2000-2015)

LULC classes	Season	2000		2008		2013		2015	
		Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)
Dense forest	Spring	518.51	56.73	507.73	55.55	516.14	56.47	514.03	56.24
	Autumn	514.22	56.26	508.55	55.64	513.12	56.14	515.04	56.35
Open forest	Spring	283.80	31.05	310.94	34.02	312.13	34.15	313.05	34.25
	Autumn	293.49	32.11	308.84	33.79	313.59	34.31	313.96	34.35
Scrub land	Spring	62.33	6.82	44.88	4.91	31.81	3.48	30.07	3.29
	Autumn	54.02	5.91	44.51	4.87	35.01	3.83	27.97	3.06
Agricultural land	Spring	31.35	3.43	31.90	3.49	31.08	3.40	31.26	3.42
	Autumn	31.72	3.47	31.90	3.49	31.17	3.41	31.44	3.44
Built-up land	Spring	1.92	0.21	2.10	0.23	4.11	0.45	5.39	0.59
	Autumn	1.92	0.21	2.10	0.23	4.11	0.45	5.39	0.59
Water body	Spring	1.92	0.21	1.10	0.12	3.56	0.39	3.02	0.33
	Autumn	2.38	0.26	1.10	0.12	3.38	0.37	3.20	0.35
River bed	Spring	14.17	1.55	15.36	1.68	15.17	1.66	17.18	1.88
	Autumn	16.27	1.78	17.00	1.86	13.62	1.49	17.00	1.86

Table 3. Magnitude and annual rate of change of LULC classes (2000-2015)

LULC classes	Season	Magnitude of change				Annual rate of change			
		2000-2008	2008-2013	2013-2015	2000-2015	2000-2008	2008-2013	2013-2015	2000-2015
		Area (%)	Area %)	Area (%)	Area (%)	Area (%)	Area (%)	Area (%)	Area (%)
DF	Spring	(-)1.18	(+)0.92	(-)0.23	(-)0.49	(-)0.131	(+)0.153	(-)0.077	(-)0.031
	Autumn	(-)0.62	(+)0.50	(+)0.21	(+)0.09	(-)0.069	(+)0.083	(+)0.070	(+)0.006
OF	Spring	(+)2.97	(+)0.13	(+)0.10	(+)3.20	(+)0.330	(+)0.022	(+)0.033	(+)0.200
	Autumn	(+)1.68	(+)0.52	(+)0.04	(+)2.24	(+)0.187	(+)0.087	(+)0.013	(+)0.140
SL	Spring	(-)1.91	(-)1.43	(-)0.19	(-)3.53	(-)0.212	(-)0.238	(-)0.063	(-)0.221
	Autumn	(-)1.04	(-)1.04	(-)0.77	(-)2.85	(-)0.116	(-)0.173	(-)0.257	(-)0.178
AL	Spring	(+)0.06	(-)0.09	(+)0.02	(-)0.01	(+)0.007	(-)0.015	(+)0.007	(-)0.001
	Autumn	(+)0.02	(-)0.08	(+)0.03	(-)0.03	(+)0.002	(-)0.013	(+)0.010	(-)0.002
BL	Spring	(+)0.02	(+)0.22	(+)0.14	(+)0.38	(+)0.002	(+)0.037	(+)0.047	(+)0.024
	Autumn	(+)0.02	(+)0.22	(+)0.14	(+)0.38	(+)0.002	(+)0.037	(+)0.047	(+)0.024
WB	Spring	(-)0.09	(+)0.27	(-)0.06	(+)0.12	(-)0.010	(+)0.045	(-)0.020	(+)0.008
	Autumn	(-)0.14	(+)0.25	(-)0.02	(+)0.09	(-)0.016	(+)0.042	(-)0.007	(+)0.006
RB	Spring	(+)0.13	(-)0.02	(+)0.22	(+)0.33	(+)0.014	(-)0.003	(+)0.073	(+)0.021
	Autumn	(+)0.08	(-)0.37	(+)0.37	(+)0.08	(+)0.009	(-)0.062	(+)0.123	(+)0.005

DF-Dense Forest, OF-Open Forest, SL-Scrub Land, AL-Agricultural Land, BL- Built up Land, WB- Water bodies, RB- River Beds, PA- Producer's Accuracy, UA- User's Accuracy, (+) sign denotes increase and (-) sign denotes decrease of change area (%) between 2000-2015 using previous supervised imageries. The projected LULC map shows that the dense forest area will cover 55.89 % (510.86 km^2). The Open Forest area will occupied 34.37 % (314.1 km^2), followed by agricultural land (3.93 %), scrub land (3.55 %), river bed (1.36 %), built up land (0.52%) and water body (0.37%). The transition probability of LULC changes in 2030 is presented in Table 5.

In the present study, spatio-temporal dynamics of LULC pattern of ATR for the years 2000, 2008, 2013 and 2015 were assessed using remote sensing and GIS technology. Rathore et al (2012) reported that land use and land cover changes are important variable factors in tiger movement as they affect the distribution of prey species, particularly when moving through a human-dominated matrix. The ATR area is predominantly covered by dense forest, followed by open forest, scrub land, agricultural land, river beds, built-up land and water bodies. Dense forest land occupied more than half of the reserve area and a slight reduction in this category was observed. Similar findings have been reported in the Kanha Tiger Reserve (Devi et al 2018) and the Pench-Satpura wildlife corridor (Banerjee et al 2020). Open forest cover was the second most common land cover type in the ATR and showed an increasing trend over a 16-year period. This is due to conversion from scrub land to open forest area, which is due to the gradual succession and changing climatic variables of ATR. Bhardwaj et al (2019) also observed that

Table 4. Accuracy and kappa statistics for 2000, 2008, 2013 and 2015 supervised imageries

LULC classes	Year	2000		2008		2013		2015	
	Season	S	A	S	A	S	A	S	A
DF	PA (%)	93.75	100.00	100.00	100.00	100.00	92.31	86.67	90.91
	UA (%)	96.77	100.00	100.00	100.00	71.43	85.71	92.86	71.43
OF	PA (%)	100.00	100.00	100.00	100.00	83.33	84.62	76.92	83.33
	UA (%)	95.45	100.00	100.00	100.00	71.43	78.57	71.43	71.43
SL	PA (%)	76.92	100.00	81.25	90.91	70.00	87.50	85.71	73.68
	UA (%)	90.91	57.14	92.86	71.43	100.00	100.00	85.71	100.00
AL	PA (%)	100.00	100.00	92.86	77.78	100.00	100.00	100.00	100.00
	UA (%)	77.78	100.00	92.86	100.00	100.00	100.00	100.00	100.00
BL	PA (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	UA (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
WB	PA (%)	100.00	57.14	100.00	100.00	100.00	100.00	100.00	100.00
	UA (%)	100.00	66.67	92.86	100.00	100.00	100.00	100.00	100.00
RB	PA (%)	100.00	100.00	91.67	92.31	100.00	100.00	100.00	100.00
	UA (%)	100.00	100.00	78.57	85.71	100.00	100.00	100.00	100.00
Overall accuracy	Spring	94.57%		94.90 %		91.84 %		92.86%	
	Autumn	94.57%		93.88%		94.90%		0.9167	
Overall Kappa statistics	Spring	0.9312		0.9405		0.9048		91.84%	
	Autumn	0.9314		0.9286		0.9405		0.9048	

DF-Dense Forest, OF-Open Forest, SL-Scrub Land, AL-Agricultural Land, BL- Built up Land, WB- Water bodies, RB- River Beds, PA- Producer's Accuracy, UA-User's Accuracy

Table 5. Transition probability of LULC changes in 2030

LU/LC classes	Scrub land	River beds	Dense forest	Built up land	Open forest	Agriculture land	Water body
Scrub land	0.6782	0.0155	0.0825	0.0257	0.1356	0.0560	0.0064
Riverbeds	0.2930	0.1432	0.2710	0.0209	0.2124	0.0518	0.0077
Dense forest	0.0997	0.0048	0.8695	0.0039	0.0107	0.0094	0.0020
Built up land	0.0110	0.0081	0.0044	0.8737	0.0021	0.0678	0.0327
Open forest	0.0014	0.0038	0.0011	0.0058	0.9738	0.0135	0.0006
Agriculture land	0.0269	0.0244	0.0125	0.1950	0.0067	0.6699	0.0644
Water body	0.3683	0.0082	0.1105	0.01	0.0366	0.0211	0.4454

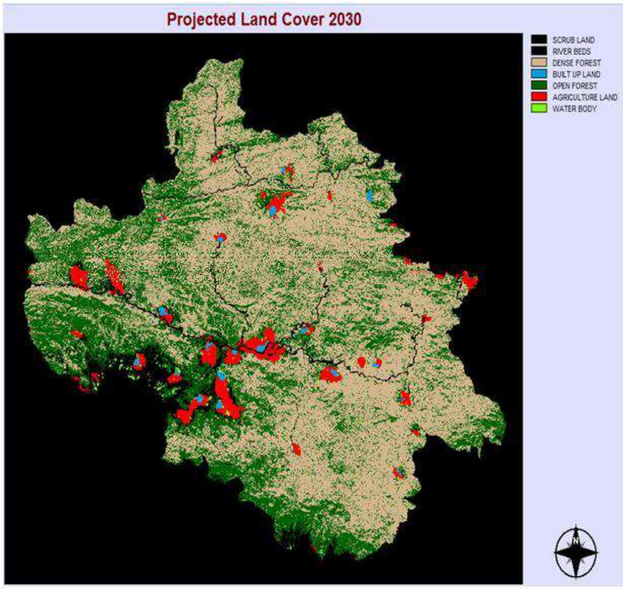


Fig. 3. Projected LU/LC map for 2030

open forest area increased by 5.76% and dense forest area decreased by 3.83% over a ten-year period (2007-2016) in Sariska Tiger Reserve, Rajasthan. Kumari et al (2020) also reported similar findings from the non-forested area of the Palamau Tiger Reserve increased by 10.40% between 1975 and 2015 due to anthropogenic impacts. In ATR, the agricultural area covered an area of approximately 3%, a similar study was reported from Nagarjunasagar-Srisailam Tiger Reserve, Andhra Pradesh, India, where the agricultural area covered 4.21% (Sudeesh & Sudhakar 2012). The area in this category was larger in the autumn months than in the spring because rainfed agriculture is practiced in the region. The slight decline in agricultural land may also be due to the relocation of six core villages from ATR that may be involved in agricultural activities. Because a very small percentage of the ATR area has agricultural land, conservation efforts may not be directly hampered. Damania et al (2003) reported that land use for agricultural purposes has negative impacts on tiger conservation.

The built-up land area witnessed a slight increase. Hund et al (2013) and Prasad et al (2012) reported that the rate of population growth and its needs, along with its natural and economic drivers, affect the conversion of land cover to land use in an area. Salghuna et al (2018) observed that in Kondapalli Reserve Forest (KRF), Andhra Pradesh, where the built-up land area increased from 1.11% in 1990 to 16.84% in 2017. This drastic increase in built-up areas near KRF is due to population growth, urban expansion and other developmental activities. The region's indigenous flora and fauna is threatened by the sprouting of built-up and inhabited areas in and around the forest (Ye et al 2015). The area covered by water bodies in ATR increased by 0.12 % in spring and by 0.09% in autumn during the 16-year period. This is due to the construction of various waterholes, anicuts etc. to conserve and capture water. The river bed occupies an area of about 1.5 % and its area varies with the rainfall in the region. In contrast, the water body in Sariska Tiger Reserve covered an area of 0.93% in 2007, which decreased to 0.32% by 2016 (Bhardwaj et al 2019).Conservation and protection of the tiger requires that its habitat be protected so viable populations can thrive and reproduce. Significant changes in the LULC through core village shifts and grassland development can create favorable habitat for ungulate species from ATR, thereby increasing the prey population for large carnivorous mammals such as tigers and leopards (Mahato & Singh 2019). Therefore, relocation of core villages, stringent restrictions on traffic and tourist movement in the core zone, regulation of developmental projects along corridors connecting other tiger reserves, and involvement of buffer and transition zone residents may be helpful in achieving the conservation goals of ATR.

CONCLUSION

ATR is recognized as one of the regions with the greatest potential for in situ conservation of tigers. Dense forests are the predominant type of land cover, followed by open forests, scrub land, agricultural land, river beds, built-up areas and water bodies. A slight variation in temporal and seasonal LULC classes was observed at ATR. The season and climate play a very important role in reflecting properties of the earth's surface, which are crucial for remote sensing applications. The present study demonstrates the potential of satellite-based temporal data and GIS techniques in analyzing the spatio-temporal dynamics of the ATR region for the management of land resources on a sustainable basis. The dynamics of LULC changes and their consequences are essential for better study and implementation planning for development projects, as well as for the sustainable survival of the biodiversity and hydrology of the area. The information gained from LULC change detection will help provide better options for effectively managing land and water resources. ATR's supervised classification depicts that dense forest is the dominant land cover type, covering approximately 56% of the area, followed by open forest, scrub land, agricultural land, river bed, built up areas and water bodies. Overall, the scrub land area decreased which are likely to be converted into open forest. The built-up land area has also increased in the period of 16 years. During the study period, water bodies have increased and require more conservation measures as the ATR area faces water shortages during the dry summer months due to the seasonal nature of the river Maniyari and its tributaries.

The ATR projection model for 2030 shows that dense forest area will cover 55.89% followed by open forest area (34.37%). This study has direct application to the conservation not only of ungulates but implicitly of large carnivores as well. The present research may provide a database of land use/ cover on spatio-temporal basis and contribute to the improvement of conservation and management plans in the near future.

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Effects of Phyto-Chemicals on Wood Modification and Dimensions Stability of *Pinus roxburghii* Wood

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Abstract: The study was carried out to examine the effects of *Acorus calamus* and *Parthenium hysterophorus* plants chemical constitute on dimension stability of *Pinus roxburghii* wood. Results of the study clearly shows the positive effects on the dimension stability of wood. However, *A. calamus* found more efficient as compare to the *P. hysterophorus*, due to the higher content of oil. In case of solvents used for extraction, petroleum ether found more effective compare to the methanol extract. Present investigation helpful for the further investigation to develop natural chemicals for wood modification which is free from the hazardous effect on environment health as well as human health.

Keywords: Dimensions stability, Shrinkage, Swelling, Plant extract, *Acorus calamus, Parthenium hysterophorus, Pinus roxburghii,* Wood modification

Wood is a renewable material and hygroscopic in nature due to the OH group. It is naturally consist with cellulose, hemicellulose, lignin, and other extractives like gum, resin and oils etc. It is described as secondary xylem, formed during the secondary growth Sharma et al (2020). Wood has been mainly utilized in furniture making, timber, fuel and shelter. In the past time wood has been utilized without any modification Rowell (2014, 2016). However, in the modern time chemical modification is involved for the increase the dimensions stability and life of wood Rowell (2016). Now a days, Humans are well aware about the utilization of wood and realized that the dimensions of wood are affected by moisture content. Wood can be damaged by different wood degrading fungi, decay and other wood degrading agencies and the ultraviolet energy is also one of the factors for wood damage. With the increase in the awareness regarding utilization of wood, effects of environmental factors on dimensions properties of wood and needs of wood durability, the new techniques have been innovated to improve the durability of wood without the using poisonous chemicals (Hill 2006, Rowell et al 2009, Rowell 2012, Gerardin 2016). Issue of chemicals with the human and environment health, ultimately put great pressure on primary timber species like; teak, sheesham, sal, deodar etc. to fulfil the demand of wood, however due to higher demand their cost is very high Meena et al (2017). In this context the utilization of secondary species is of vital importance. The main disadvantage with these lesser known timber species is less durability Gupta et al (2016). To utilize the secondary species with wood modification with environment friendly chemicals search new technologies to increase the durability and dimensions stability during the utilization of wood Rowell (2016). In addition to the progress of regulations, some wood based industries are using bio chemical products, biocide products for wood modification and to protect the wood from the biodegrading agencies Gerardin (2016). It results in an increasing use of different plants oils, extracts, thermal modification and impregnation modification for dimension stability (Hill 2006, Rowell 2012). Low durable wood can be upgraded with new modified wood properties through chemical modification with bio chemicals without any harmful effects on environment conditions and ecological biodiversity (Rowell 2014, Hill 2006). In the present study, the dimension stabilization of secondary wood species *Pinus roxburghii* has been done with environment friendly phytochemicals.

MATERIAL AND METHODS

Preparation of wood samples: Wood samples procured from the local carpenter were cut in to the dimensions of 5 ×2.5 × 2.5 cm, longitudinal, radial, and tangential respectively (±0.25, ±0.15, ±0.15 cm longitudinal, radial, and tangential respectively). Wood samples prepared from the heart wood of the selected tree species.

Collection of plant materials: *Acorus calamus* L. and *Parthenium hysterophorus* L. were selected for the study as both the plants possess antifungal property. The rhizomes of *Acorus calamus* L. were collected from Nauni and Khaltu Village, whereas the aerial parts of *Parthenium* *hysterophorus* L. were collected from the college and university campus area. The collected samples were initially dried separately in open conditions under shade condition for the 20 days. The dried material was converted into powdered in wood grinder machine and again dried in oven for 24 hours at 50±1ºC temperature and it finely powdered.

Preparation of extract for wood treatment: Prepared extract (2 % stock solution) was used to prepare 0.25, 0.50, 1.00, 1.50, and 2.0 per cent different concentrations for dip treatment and control wood samples were dipped in 5% methanol solution with distilled water. After dip treatment, the wood samples were first dried at room temperature in open condition and then dried at 105±2°C up to constant weights.

Volumetric swelling coefficient (S): The volumetric swelling coefficient (S) was calculated by using formula as given by Islam et al. (2012).

$S = (V_2 - V_1) / V_1 \times 100$

Where, S = Volumetric swelling coefficient, V_1= Wood volume of oven-dried sample before treatment, V_2 =Wood volume after treatment.

Anti-swelling efficiency (%): The anti-swelling efficiency (ASE), was calculated by using formula as given by Rowell (2005) - $ASE = (S_1 - S_2) / S_1 \times 100$

Where, S_1= Volumetric swelling coefficient of untreated wood samples, S_2=Volumetric swelling coefficient of treated wood samples

Volumetric shrinkage coefficient (S): The volumetric shrinkage coefficient (S) was calculated according to ASTM-1037 (1999) - $S = (V_2 - V_1) / V_1 \times 100$

Where, S= Volumetric shrinkage coefficient, V_1= Wood volume of oven-dried sample after treatment, V_2 = Wood volume after treatment.

Anti-shrink efficiency (%): The anti-shrink efficiency (ASE), which is the reduction in swelling resulting from a treatment, was calculated by using the methods as given by Rowell (2005) - $ASE = (S_1 - S_2) / S_1 \times 100$

Where, S_1 = Volumetric shrinkage coefficient of untreated wood samples, S_2=Volumetric shrinkage coefficient of treated wood samples

Statistical analysis: CRD One way analysis of variance (ANOVA) was used to analyze all the data with op stat CCS HAU, Hisar.

RESULTS AND DISCUSSION

Volumetric swelling coefficient (S): The results of present investigation on volumetric swelling coefficient (S) of treated and untreated wood samples are presented in Table 1. The analysed data presented in the table shows the significant variation at 1 per cent level of significance. Presented data was clearly shown the effects of plant extracts on wood modification. Volumetric swelling coefficient of untreated wood sample was recorded higher and minimum was found for treated wood samples with 2% concentrated plant extract. Volumetric swelling coefficient was increased with decreasing concentration of extract. Both of selected botanicals show the efficiency and fix the dimension properties of wood. The dimensions properties of wood were affected due to the moisture absorption. The volumetric swelling coefficients for all the treatments have shown decrease with the application of plant extracts. The volumetric swelling coefficient of wood is an important parameter to examine the dimensional stability of wood in all directions. Rowell and Ellis (1978) have reported that raise the volume of wood with the rising in added chemical. Islam et al (2012) while studying the dimensional stability of chemically modified wood noticed that there is high swelling coefficient for all the control wood samples as compared to treated wood samples. Wu et al (2012) has also reported similar results, where the eucalypt woods treated with chemicals have shown significant reduction in volumetric swelling as compared to control wood samples. Oduor et al (2013) studied the dimensional stability of *Pinus radiata* D.

Table 1. Effect of plants extracts treatment on volumetric swelling (volumetric shrinkage) coefficient on treated and untreated wood samples of *Pinus roxburghii*

Treatments	*Acorus calamus*		*Parthenium hysterophorus*	
	Methanol	Petroleum ether	Methanol	Petroleum ether
0.25	9.54 (6.85)	12.02 (10.86)	11.67 (12.33)	10.43 (10.76)
0.50	7.16 (6.79)	10.50 (10.76)	11.51 (11.66)	9.17 (9.22)
1.00	8.33 (6.77)	11.44 (11.07)	10.66 (10.23)	8.24 (8.51)
1.50	9.00 (6.71)	11.10 (11.15)	10.53 (9.53)	7.96 (8.75)
2.0	8.32 (5.15)	8.43 (8.06)	9.72 (7.55)	7.03 (6.56)
Control	11.19 (7.04)	12.14 (11.97)	15.85 (13.34)	10.72 (11.72)
CD (1%)	1.70 (1.0)	1.81 (1.42)	1.89 (0.83)	0.15 (1.74)
SE (m)	0.39 (0.23)	0.42 (0.33)	0.44 (0.19)	0.64 (0.40)

Don, impregnated with various resins. Solid wood stakes were impregnated with either an isocyanate and phenol formaldehyde resin than exposed in different three type's soil beds or two moisture contents. The treatments resulted in no effect on solid wood. Meena et al (2017) also reported significant effect on dimensional stability of *Pinus roxburghii* wood. Nampelly et al (2022) also reported that variation in swelling coefficient variation in different five wood species.

Anti-swelling coefficient (ASC): The result of dimension stability of wood in term of anti swelling coefficient of treated and untreated wood samples are presented in Table 2. Presented results was showing significant variation and data was found highly significant at 1 per cent level of significance, data related to wood samples treated with methanol extract of *A. calamus* was found non significant. Maximum ASC of treated wood was noticed at 2% concentrated treated wood samples. ASC was reduced with decreasing concentration of extract. Selected plants for the wood modification *A. Calamus* and *P. hysterophorus* was efficient to control dimension stability of wood. In case of *A. calamus* extract petroleum ether treated wood samples was shown more efficiency as compare to the methanol treated extracted treated wood samples. Similar wood samples treated with *P. hysterophorus* extract whereas methanol extracts treated wood samples was shown more efficient as compare to petroleum ether treated wood samples. Anti-swelling efficiency is a basic way to examine the dimensional stability of wood. The sample treated with plant extracts significantly improved ASE than controlled wood samples, due to restriction in movement of water molecules into the cell wall of wood Baysal et al (2004). The anti-swelling efficiency decreased with different concentrations of plant extracts. The results are similar to the study carried out by Islam et al (2012) where effects of chemical modification on different five types of tropical light hardwoods species namely, *Alstonia pneumatophora, Endospermum diadenum, Paraserianthes moluccana, Dyera costulata, Hevea brasiliensis* and and concluded that dimensional stability of wood improved by chemical modification. Sonowal and Gogoi (2010) reported that the treated wood samples showed higher dimensional stability in terms of anti-shrink efficiency (ASE), bulk co-efficient (BC) and weight percent gain (WPG). Baysal et al (2004) reported that the treated samples significantly improved ASE as compared to untreated wood samples which can be due to restriction in movement of water molecules inside the wood cell wall. Reduction in shrinking results in better dimensional stability of wood and is expressed as anti-shrink efficiency (ASE). It is considered as important measure of the dimensional stability of wood and is used to describe the degree of dimensional stability given to the wood by various treatments. Babinski (2007) investigated shrinkage of wood a little degraded, freeze dried archaeological oak-wood. Wood samples treated before drying with 10, 20, and 30% water solutions of PEG 300, PEG 4000, and sucrose and concluded that shrinkage of untreated wood samples and treated freeze dried oak-wood samples was significantly less, as compare to the wood samples was dried naturally.

Volumetric shrinkage coefficient (S): Volumetric shrinkage coefficient of wood samples treated and untreated was measured and data related to finding was presented at Table 1. Presented data showed significant variation at 1 per cent level of significance. Lowest volumetric shrinkage coefficient was noticed at treated wood samples and higher was noticed in untreated wood sample. Wood samples treated with *A. calamus* extract had high efficiency as compare to the *P. hysterophorus* treated wood samples. Due to the presence of higher oil content in *A. calamus* extract it was found more effective to fix the dimensional properties of wood and reduce the volumetric shrinkage coefficient of treated wood samples. Similar investigations were carried out by Wu et al (2012) where eucalypt wood treated with chemicals, it has been noticed that there is shrinkage of wood significantly less as compare to the untreated wood. Bazyar (2012) also reported

Table 2. Effect of plants extracts treatment on anti-swelling (anti shrinkage) coefficient of *Pinus roxburghii* wood samples

Treatments	*Acorus calamus*		*Parthenium hysterophorus*	
	Methanol	Petroleum ether	Methanol	Petroleum ether
0.25	14.28 (2.54)	0.85 (9.16)	26.25 (7.55)	2.66 (7.96)
0.50	35.48 (3.49)	13.47 (10.05)	27.35 (12.52)	14.40 (21.13)
1.00	25.12 (3.72)	5.62 (7.57)	32.64 (23.29)	23.16 (27.31)
1.50	19.18 (4.75)	8.65 (6.73)	33.52 (28.52)	25.75 (25.46)
2.0	25.54 (26.77)	30.51 (32.53)	38.78 (43.40)	34.36 (43.66)
CD (1%)	NS (13.54*)	12.81 (10.04)	NS (5.77)	5.66 (13.86)
SE (m)	5.29 (4.24)	4.01 (3.14)	2.81 (1.80)	1.77 (4.34)

*CD value at 5%

that wood samples treated with linseed oil minimum volumetric shrinkage as compared to control. Similar results treated wood samples have low volumetric shrinkage coefficient have been reported by (Salim et al 2010, Sailer et al 2000, Wang and Cooper 2005) where the oil heat treated wood samples has resulted in decline of volumetric shrinkage. Okon (2014) has reported variations in shrinkage behaviour along and across bole of 25 years old *Gmelina arborea.* Sharma et al (2020) reported that heat treatment of volumetric shrinkage coefficient of wood decrease with increasing time and temperature in case of *Toona ciliata*.

Anti-shrinkage coefficient (ASC): Result of anti-shrinkage coefficient of wood presented in Table 2. Data was showing significant variation and found significant at 1 per cent level of significance, data related to wood samples treated with methanol extract of *A. calamus* was found significant at 5 per cent level of significance. Wood samples treated with various concentrations; out of all concentration wood samples treated with 2% concentration was found highest anti shrinkage coefficient. The anti shrinkage coefficient of wood was decrease with reducing the concentration of plant extract for wood samples treated with methanol and petroleum ether extract from *A. calamus* and *P. hysterophorus* plants. Decrease in shrinking results in better dimensional stability of wood and is expressed as Anti-shrink Efficiency (ASE). It is considered as an important measure of the dimensional stability of wood and is used to describe the degree of dimensional stability given to the wood by various treatments. The plant extracts treated wood samples have shown an increase in the anti-shrink efficiency over control. ASE observed in these investigations decrease with the increasing the plant extract concentrations. Similar results have been reported by Deka et al. (2000) have shown an increase in the anti-shrink efficiency of treated wood samples over control. Yan and Morell (2014) have also reported a more pronounced increase in anti-shrink efficiency of treated wood samples over control with the increase in temperature. Wang and copper (2005) studied the effect of palm oil-, soy oil- and slack wax for different processing times and temperatures on moisture properties of treated wood and concluded that wood samples treated with wax at 100°C or 160°C improved anti-shrink efficiencies (ASE). Chloroform extracted samples treated with palm oil and soy oil treated at high temperature shown similar hygroscopicity and ASE properties than unextracted samples. The ASE values are consistent with the findings of Pavlic et al (2007). Sailer et al (2000) showed an improvement in the ASE of treated specimens at 220°C of about 40 per cent.

CONCLUSION

There was improvement in the dimensional stability of treated wood samples with respect to volumetric shrinkage coefficient, anti shrinkage efficiency, volumetric swelling coefficient and anti-swelling-efficiency. Also, the plant extracts influenced the dimension stability of wood. Improvement in the dimension stability of wood sample was more with petroleum ether as compared to methanol extract. The plant extract of *Acorus calamus* efficiently fixed the dimension stability of wood.

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Status of Medicinally Important Herbs along Canopy Disturbance in *Quercus leucotrichophora,* A. Camus Forest of Central Himalaya, India

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Abstract: The present study focuses on the structure of the herb community and the status of selected medicinal plants across the different canopies of the *Q. leucotrichophora* forest. The study revealed that 81 herbaceous species encountered in the sample and 26 species had shown IVI≥5. The maximum number of species were from Asteraceae (14 nos.), followed by Poaceae (10 nos.), Lamiaceae (9 nos.), and Acanthaceae (4 nos.) families. Around 54% of species were common across the canopies, 17% species restricted in open, 10% in moderate, and 1% in close canopy. LSD indicated significantly high species richness ($p<0.05$) in the open canopy. Most of the recorded herb communities were in the rare category in all the three canopies, while no species was under the mostly and constantly present categories among the different canopies. The frequency distribution of selected medicinal plants also indicated *Origanum vulgare* was rarely present in the moderate and close canopy, while *Hedychium spicatum* in the open and moderate canopy. Further, *Rubia cordifolia* and *Boenninghausenia albiflora* were rarely and seldom present in all the three canopies. Therefore, the conservation and management of selected medicinal plant species should be given high priority.

Keywords: Canopy, Distribution, Ecology, Himalaya, Oak Forest

The ecosystem services primarily rely on the species composition and structure of a forest community (Joshi et al 2022). Assessment of forest community's composition and structure is crucial to understand the population, regeneration, and diversity for conservation purposes (Mishra et al 2013). The study of vegetation in its totality, and the individual species as indicators are equally considered to be specific subjects for evaluating the levels of the analytical loads on ecosystems (Burianek et al 2013). It also plays an essential role in the maintenance of biodiversity (Jayakumar et al 2011) and helpful in the assessment of ground vegetation tracking, and constitutes an acknowledged basis for biodiversity assessment (Burianek et al 2013). Oak forests are an ecologically and socio-economically important late-successional forest formation of central Himalaya (Naudiyal and Schmerbeck 2021). *Quercus leucotrichophora,* is one of the keystone tree species between 1500 to 2200 m elevation in the central Himalaya which maintains the diversity of many other species (Prasad and Ram 2017). Broadleaf Oak forests are locally utilized for various provisional services viz. fuel wood, fodder for livestock, wood for agricultural implements, and many NTFPs (Negi 2022). Due to continuous dependence of local communities on oak forests, most of the species of Quercus are over-exploited and *Quercus leucotrichophora* is worst affected (Bargali et al 2015, Singh et al 2016, Naudiyal and Schmerbeck 2021).

The medicinal plants grow in different communities and a group of species is essential component of forest in Uttarakhand Himalaya (Ram et al 2010). The utilization of various medicinal plants in therapeutic drugs have also signifies the option for livelihoods and local healthcare in the country (Gakuya et al 2020). The increasing human disturbances directly or indirectly influence the medicinal plant diversity of oak forests. Due to this, the dense canopied forest converted into open canopied and, therefore, the herb species diversity has been adversely affected by these disturbances. The opening of canopy also changes the structure and distribution of species by altering the ecosystem habitats. This may lead to the addition and deletion of many species and effect the distribution of medicinal plants (Gafna et al 2017). Although such disturbances have negative effects on plant communities however, it also acts as positive force to increase the species diversity by minimizing competition among the species. Therefore, a better understanding of interactions between spatial pattern and disturbance is needed (Prasad et al 2015). The species is an important component of any ecosystem and attends as decent indicators of the ecological situations of a system (Palit and Banerjee 2014). Further, the major portion of oak forests in the hilly areas of Uttarakhand is owned by local inhabitant, therefore the nature and frequency of disturbance in these forests are under explored (Prasad et al 2015). Further, the species diversity in the Himalayan region varies from habitat to habitat, and community to community, thus location specific studies are essential for its conservation and management (Rana and Samant 2010). Keeping in view the vulnerability and significance of oak forest, the present study thus focuses on the structure of the herb community and species diversity concerning some important medicinal plants along with the canopy disturbances of *Quercus leucotrichophora* forest in the central Himalaya of India.

MATERIAL AND METHODS

Study area: The study area lies between 29°21' and 29°23'N latitude and 79° 27' and 79° 29' E longitude within an elevational range 1800 to 2000 masl in the Central Himalayan region (Fig. 1). The aspect of the study area falls in North East and East aspect with *Q. leucotrichophora* (Banj Oak) as the dominant tree species. The climate of the study area is influenced by the monsoon pattern of rainfall. The average rainfall was 2090 mm and mean annual temperature ranged from 9.1°C to 21.2°C. The rocks in the study area are mainly sandstones, conglomeration, limestone, quartzite, schists, and granites. The *Quercus leucotrichophora* (Banj Oak) is the dominant (IVI > 70%) forest forming species. The other species associated with oak are *Myrica esculenta* Buch. -Ham.ex D. Don, *Rhododendron arboreum* Sm., *Acer oblongum* Wall. Ex DC., *Pinus roxburghii* Sarg., *Cedrus deodara* (Roxb.ex D. Don) D. Don., *Quercus lanuginosa* D. Don and *Quercus floribunda* Lindl. Ex A. Camus (Prasad and Ram 2017).

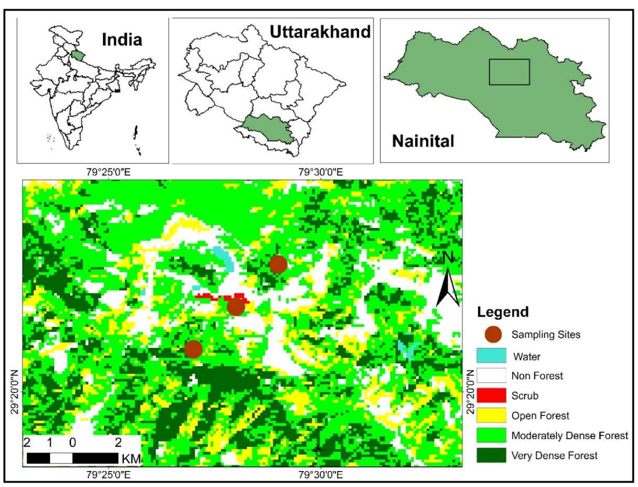

Fig. 1. Location map of the study area

Selection of important medicinal plants: Based on the ethnomedicinal uses and IUCN status, four important medicinal plant species, i.e., *Boenninghausenia albiflora* (Hk.) Reichb. Ex Meissn, *Hedychium spicatum* (Ham. Ex Smith), *Origanum vulgare* (Linn.), and *Rubia cordifolia* (Linn.) were selected (Table 1) to determine their status in the *Q. leucotrichophora* forest. *Boenninghausenia albiflora* is an erect, perennial herb, distributed in Himalayan ranges between 1000 and 2800 m above sea level (Joshi et al 1993); *Hedychium spicatum* is distributed with diverse growth habitats in sub-tropical to temperate zones (Negi et al 2014), *Origanum vulgare* is widely distributed in the subtemperate/temperate Himalaya (Mukerjee 2005) and *Rubia cordifolia* is distributed in sub-tropical and temperate regions of the world (Deshkar et al 2008).

Sampling and analysis: After thorough reconnaissance of the *Quercus leucotrichophora* forest, 10 line transects of 10 m were randomly placed to determine the canopy cover of the forest and categorized as open (< 40%), moderate (40–70%), and close (>70%) canopy (FSI 2013). In each canopy, three sites were selected for the detailed vegetation characteristics. The size and number of the sample were determined following Saxena and Singh (1982). At each site, ten quadrats of 1x1 m were randomly placed on the ground for assessment of herb vegetation and thus a total of 30 samples were present for each canopy. The herb cover was also determined by placing 10 line transects of 1 m in each site. The vegetation parameters were quantitatively analysed for density, frequency, and abundance. The Importance Value Index (IVI) for herbs was determined as the sum of

Table 1. Description of selected medicinal plant species

Species & family	Local name	Habit	Ethnomedicinal uses[#]	Status *
Boenninghausenia albiflora (Rutaceae)	Pissumar	Herb	Juice of whole plant is implemented externally to cure headache, and pain in eyes.	Common
Hedychium spicatum (Zingiberaceae)	Ban Haldi	Herb	Root stock powder or decoction is taken orally for body aches and inflammation related problems	Threatened
Origanum vulgare (Lamiaceae)	Ban Tulsi	Herb	Decoction of the whole plant is taken orally in Urinary disorder.	Rare
Rubia cordifolia (Rubiaceae)	Manjishtha	Climber	Paste of root implemented externally in leucoderma	Rare

(*IUCN 1993, [#]Kumari et al 2011)

relative density, relative frequency, and relative dominance (Phillips 1959). The presence of four medicinally important herbs was calculated and placed into their respective frequency classes in different canopy covers, Oosting (1956) gave five class scales based on presence, frequency, and constancy percentages. Thus, these were classified on the presence of species as class I (1-20%) rare, class II (21-40%) seldom present, class III (41-60%) often present, class IV (61-80%) mostly present, and Class V (81-100%) constantly present. The percent contribution of medicinal plant species from the total species present in the community was also determined. Total Species Richness was taken as a count of the number of species present in that forest type and calculated following Margalef's (1958). Species diversity was calculated based on density using the Shannon-Weaver information index (Shannon and Weaver1963). The Concentration of dominance was calculated using eq. (1) following Simpson's Index (1949).

$$C = (Ni / N)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. (1)}$$

The index of similarity was calculated after Sorenson (1948) by using in eq. (2)

$$S = \frac{2C}{A+B} \times 100 \quad \ldots\ldots \text{eq (2)}$$

Where, A and B represent the number of species in canopy A and B, respectively and C is the number of species common to both the canopy.

The percent contribution of medicinally important herb species in the community was calculated following the equations (3), (4), and (5).

$$\text{Percent cover} = \frac{\text{Cover of a plant species}}{\text{Total cover of all species}} \times 100 \quad \ldots\ldots \text{eq (3)}$$

$$\text{Percent Density} = \frac{\text{Density of a plant species}}{\text{Total density of all species}} \times 100 \quad \ldots\ldots \text{eq (4)}$$

$$\text{Percent IVI} = \frac{\text{IVI of a plant species}}{\text{Total IVI of all species}} \times 100 \quad \ldots\ldots \text{eq (5)}$$

Statistical analysis: The data were statistically analysed using IBM SPSS 20(trial version).

RESULTS AND DISCUSSION

Vegetation structure: Many species contributed to the forest floor vegetation of *Q.leucotrichophora* forest. Eighty-one (81) herbaceous species with 32 families were encountered in the oak forest. Out of the total species present in the forest, 71 species were present in the open, 61 species in the moderate, and 51species in the close canopy (Table 2). About 54 % of the species were common in all three canopies while, 10% species were common in open-moderate, 6% were common in open-close, and <1% were common in moderate-close. In comparison, 17% species were restricted in open, 10 % in moderate, and 1 % in the close canopy.

Among the species, none of the species showed its clear-cut dominance in the forest floor vegetation. There were 26 species with IVI≥ 5 in different canopies (Table 3). In open canopy, the most dominant species was *Erigeron karvinskianus* (IVI = 26.78), followed by *Capillipedium assimile*. In contrast, the most dominant species in the moderate canopy was *Arthraxon lanceolatus* (IVI = 23.61) followed by *Carex nubigena*. In the close canopy, the most prevalent species was *Carex condensata* (IVI = 29.65) followed by *Arthraxon lanceolatus*. The percent contribution of individual species to the total Importance value is low (<10%), indicating the poor dominance of the herbaceous species in the forest. However, many species contributed to the total dominance of the forest floor vegetation. Dicot families were dominant in the oak forest, while Poaceae was the only dominant monocot family. Species richness varied significantly only in the open-close canopy and was higher in the open canopy and the vegetation parameters also varied significantly for richness and density among the canopies. The opening of the canopy in the oak forest provides abundant light to the forests floor and triggers the regeneration of many species and forest floor vegetation (Arya et al 2012). The continued human pressure in grazing, leaf litter removal, fire, and other disturbances might have affected the distribution of herbaceous species. Prasad and Ram (2017) also reported similar results for *Q. leucotrichophora* forest. However, *Q. leucotrichophora* forests maintain high biodiversity for forest floor vegetation and conserve the herbaceous biodiversity in the area.

All the herb species recorded in the oak forest (Table 2) belonged to 32 families. The maximum herbs species were from the Asteraceae (14), followed by Poaceae (10 nos.), Lamiaceae (9 nos.), and Acanthaceae (4 nos.) families. The rest of the herbs were 1-3 in 28 families (Fig. 2). The Asteraceae, Poaceae, and Lamiaceae were the widely distributed family across the canopy. Among the different species, four families were restricted in the open canopy, two families were restricted in the moderate canopy, and none were restricted in the close canopy. Kharkwal et al (2005) and Pusalkar and Singh (2012) reported the dominance of the Asteraceae and Poaceae family in the Himalayan vegetation. Joshi et al (2022) also reported the dominance of Poaceae and Asteraceae for trees, shrubs, and herbs from different forests of Kumaun Himalaya. The present study revealed that Asteraceae, Poaceae, and Lamiaceae are the dominant families of herbs in the *Q. leucotrichophora* forest of Kumaun Himalaya.

Table 2. Herb species in different canopies of *Q. leucotrichophora* forest

Herb species	Family	Open	Moderate	Close
Achyranthes bidentata Blume	Amaranthaceae	+	+	+
Ageratum conyzoides (L.) L.	Asteraceae	+	-	-
Ainsliaea aptera DC.	Asteraceae	+	+	+
Ajuga parviflora Benth	Lamiaceae	+	+	-
Anaphalis busua (Buch. -Ham.) DC.	Asteraceae	+	-	+
A. contorta (D.Don)Hook.f.	Asteraceae	-	+	-
Anemone vitifolia Buch. -Ham.ex DC.	Ranunculaceae	-	-	+
Apluda mutica L.	Poaceae	+	+	+
Arisaema tortuosum (Wall.) Schott	Araceae	+	+	+
Artemisia nilagirica (C.B. Clarke) Pamp.	Asteraceae	+	+	+
Arthraxon lanceolatus (Roxb.) Hochst.	Poaceae	+	+	+
Arundinella nepalensis Trin.	Poaceae	+	+	+
Asparagus racemosus Willd.	Asparagaceae	+	+	+
Aster asperulus (DC.) Wall. Ex Hook.f.	Asteraceae	+	-	-
Barleria cristata L.	Acanthaceae	+	+	+
Begonia picta Sm.	Begoniaceae	-	+	+
Bidens biternata (Lour.) Merr. & Sherff	Asteraceae	+	+	+
B. pilosa L.	Asteraceae	+	+	+
Boenninghausenia albiflora (Hook.)Rchb.ex Meisn	Rutaceae	+	+	+
Capillipedium assimile (Steud.) A.Camus	Poaceae	+	-	+
Carex condensata Nees	Cyperaceae	+	+	+
C. nubigena D.Don ex Tilloch & Taylor	Cyperaceae	+	+	+
Chrysopogon serrulatus Trin.	Poaceae	+	-	-
Cirsium wallichii DC.	Asteraceae	-	+	-
Clinopodium umbrosum (M.Bieb.)Kuntze	Lamiaceae	+	-	-
Commelina benghalensis L.	Commelinaceae	+	+	+
Craniotome versicolor Reichb.	Lamiaceae	+	+	+
Cynodon dactylon (L.) Pers.	Poaceae	+	+	-
Cynoglossum lanceolatum Forssk.	Boraginaceae	-	+	-
Cyperus rotundus L.	Cyperaceae	+	+	+
Dicliptera bupleuroides Nees	Acanthaceae	+	+	+
Eleusine indica (L.) Gaertn	Poaceae	-	+	-
Erigeron karvinskianus DC.	Asteraceae	+	+	+
Flemingia strobilifera (L.) W.T. Aiton	Fabaceae	+	-	-
Fragaria indica Andrews	Rosaceae	+	+	+
Fragaria vesca L.	Rosaceae	+	-	-
Galinsoga parviflora Cav.	Asteraceae	+	+	-
Galium aparine L.	Rubiaceae	+	+	+
G. rotundifolium L.	Rubiaceae	+	+	+
Geranium nepalense Sweet	Geraniaceae	+	+	+
G. ocellatum Camb.	Geraniaceae	+	-	-
Gerbera gossypina (Royle) Beauverd	Asteraceae	+	-	-
Goldfussia dalhousiana Nees	Acanthaceae	+	+	+

Cont...

Table 2. Herb species in different canopies of *Q. leucotrichophora* forest

Herb species	Family	Open	Moderate	Close
Hedera nepalensis K. Koch	Araliaceae	+	+	+
Hedychium spicatum Buch. -Ham. ex Sm.	Zingiberaceae	+	+	+
Impatiens edgeworthii Hook.f.	Balsaminaceae	+	-	-
Impatiens sulcata Wall	Balsaminaceae	+	+	+
Justicia simplex D. Don	Acanthaceae	+	+	+
Lactuca lessertiana (Wall.ex DC.) C.B. Clarke	Asteraceae	-	+	-
Leucas lanata Benth.	Lamiaceae	+	+	+
Malaxis acuminata D.Don	Orchidaceae	-	+	-
Micromeria biflora Benth.	Lamiaceae	+	+	+
Microstylis wallichii Lindl.	Orchidaceae	-	+	-
Nepeta leucophylla Benth.	Lamiaceae	+	+	+
Ophiopogon intermedius D. Don	Asparagaceae	+	+	+
Oplismenus undulatifolius Roem. & Schult.	Poaceae	+	+	+
Origanum vulgare L.	Lamiaceae	+	+	+
Oxalis corniculata L.	Oxalidaceae	+	+	+
O. latifolia Kunth	Oxalidaceae	+	+	-
Phlomis bracteosa Hook.	Lamiaceae	+	-	-
Pilea scripta D. Don	Urticaceae	+	+	+
Poa annua Schur	Poaceae	+	-	-
Polygonum alatum D. Don	Polygonaceae	+	-	+
Potentilla indica (Jacks.) Th. Wolf	Rosaceae	-	+	-
Pouzolzia hirta Blume	Urticaceae	+	+	+
Ranunculus diffuses DC.	Ranunculaceae	+	+	-
Reinwardtia trigyna (Roxb.) Planch.	Linaceae	+	+	+
Roscoea procera wall.	Zingiberaceae	+	+	-
Rubia cordifolia Roxb. Ex Fleming	Rubiaceae	+	+	+
Scutellaria angulosa Benth.	Lamiaceae	+	+	+
Setaria intermedia Roem. & Schult.	Poaceae	+	-	+
Siegesbeckia orientalis L.	Asteraceae	+	-	+
Smilax aspera L.	Smilacaceae	+	+	+
Stellaria media (L.) Vill.	Caryophyllaceae	+	-	-
Swertia japonica	Gentianaceae	+	+	-
Thalictrum foliolosum DC.	Ranunculaceae	+	+	+
Tragopogon gracilis D. Don.	Compositae	+	-	-
Urtica dioica L.	Urticaceae	+	+	+
Valeriana wallichii DC.	Valerianaceae	+	+	+
Viola canescens Wall.	Violaceae	+	-	-
Vitis himalayana (Royle) Brandis	Vitaceae	+	+	-
	Total species	71	61	51

Species richness (Margalef's index) varied across the canopies and was high (10.8) in the open canopy and low (7.9) in close canopy. The opening of the canopy provides abundant light exposures to the forest floor and generate growth of ground vegetation, thus the species richness generally increased with increase in canopy gaps (Tiwari et al 2019). Shannon and Wiener Index (H) was highest (5.4) for open canopy and low for close canopy. However, the Simpson Index was high for close canopy and low for open canopy (Table 4). Similarly, the diversity was high in the open canopy as compared to close canopy and reverse for Cd. The results are well supported by the study of Joshi et al (2022) in *Q. leucotrichophora* forest, where the species richness for herb layer was in the range of 5 to 26, and species diversity H' was 3.29. The Concentration of dominance (Cd) is more or less like those reported previously for other temperate and subtropical forests of the Himalaya. Raturi et al (2012), working in the different temperate and subtropical forests of Garhwal Himalaya, reported Cd between 0.09 to 0.63. Joshi et al (2022) reported Cd values of 0.16. The Cd values is strongly affected by the importance value index of the first three relatively important species in a community. Further, H' and Cd are inversely related to each other in the study area, generally in established forests (Devlal and Sharma 2008). Among the canopies, the similarity was higher between moderate and close canopies (80.4%) compared to open-moderate (78.8%) and open-close (80.3%) canopies.

Across the canopy, the frequency distribution indicated that 62 species were rare, eight species seldom present, while only one species was often present in the open canopy. In the moderate canopy, 50 species were rare, seven species were seldom present, and four herb species were often

Table 3. Herb species importance value in different canopies

Herb species	IVI in different canopy class		
	Open	Moderate	Close
Achyranthes bidentata Blume	2.3	5.5	9.2
Anaphalis busua Buch. -Ham	5.7	-	1.6
Apluda mutica L.	5.0	8.2	4.5
Arthraxon lanceolatus Roxb. Hochst.	16.6	23.6	25.5
Arundinella nepalensis Trin.	7.6	16.9	3.5
Bidens biternata Lour. Merr. & Sherff	10.6	4.8	3.1
Boenninghausenia albiflora Hook. Rchb.ex Meisn	10.7	19.3	18.5
Capillipedium assimilie Steud. A. Camus	21.6	-	1.4
Carex condensata Nees	14.0	20.8	29.7
Carex nubigena D.Don ex Tilloch & Taylor	16.5	21.2	21.2
Cyperus rotundus L.	0.8	1.8	5.6
Erigeron karvinskianus DC.	26.8	16.0	22.0
Fragaria indica Andrews	5.2	5.8	7.0
Galium aparine L.	5.2	3.0	9.3
Geranium nepalenses Sweet	5.0	1.8	1.9
Goldfussia dalhausania Nees	3.2	6.9	12.2
Hedychium spicatum Buch. -Ham.ex Sm.	6.0	4.3	13.3
Micromeria biflora Benth.	7.1	5.7	8.0
Nepeta leucophylla Benth.	2.5	5.5	8.8
Ophiopogon intermedius D. Don	7.7	18.7	3.4
Oplismenus undulatifolius Roem. & Schult.	7.7	19.8	24.7
Origanum vulgare L.	14.0	1.6	1.2
Oxalis corniculata L.	6.6	5.6	4.9
Reinwardtia trigyna Roxb. Planch.	2.5	8.4	1.5
Rubia cordifolia Roxb. Ex Fleming	4.9	6.9	6.4
Scutellaria angulosa Benth.	5.8	5.7	3.0
Others (*)	77.7 (45)	52.2 (37)	48.7 (25)

present. Similarly, in close canopy 41 species were rare, seven species seldom present, and three herb species were often present. However, no species was available in the mostly and constantly present categories. The variation in distribution across the vegetation layers seems to relate to number of factors, particularly the microenvironment and biotic nature. Various researchers also reported the contagious distribution pattern as a common phenomenon in temperate forests (Dar and Sundarapandian 2016, Tiwari et al 2019, Prasad and Tomar 2020).

Status of selected medicinal plants in oak forest: The distribution status of four selected medicinal herbs indicated that *Boenninghausenia albiflora* was seldom present. Across the canopy, the percent density, herb cover, and IVI for *B. albiflora* were higher in the moderate and close canopy. The percent density, herb cover, and IVI for *Hedychium spicatum* showed a higher value in the close canopy, and rarity in the open and moderate canopy. Low density of *Hedychium spicatum* in moderate canopy and open canopy may be due to sciophytic nature and thus grow well in moist soil (Bisht et al 2017, Bhatt et al 2010). The occurrence of *Hedychium spicatum* in grassy slopes, shady and moist places in the Banj Oak forest (Prasad and Tomar 2020) also support our study. The natural population is easily available in shady moist and rocky habitats, near water courses or dense oak dominated forest region in the Central Himalaya (Negi et al 2014). All four medicinal plants contributed a small percentage to the total vegetation composition. *Rubia cordifolia* was rarely present in all three canopies, however showed higher vegetation parameters in the moderate and

Table 4. Diversity parameters in *Q. leucotrichophora* forest

Parameters	Canopy class		
	Open	Moderate	Close
Margalef's Index	10.8	9.3	7.9
Shannon and Weaver Index (H')	5.4	4.9	4.7
Simpson Index (Cd)	0.04	0.05	0.06

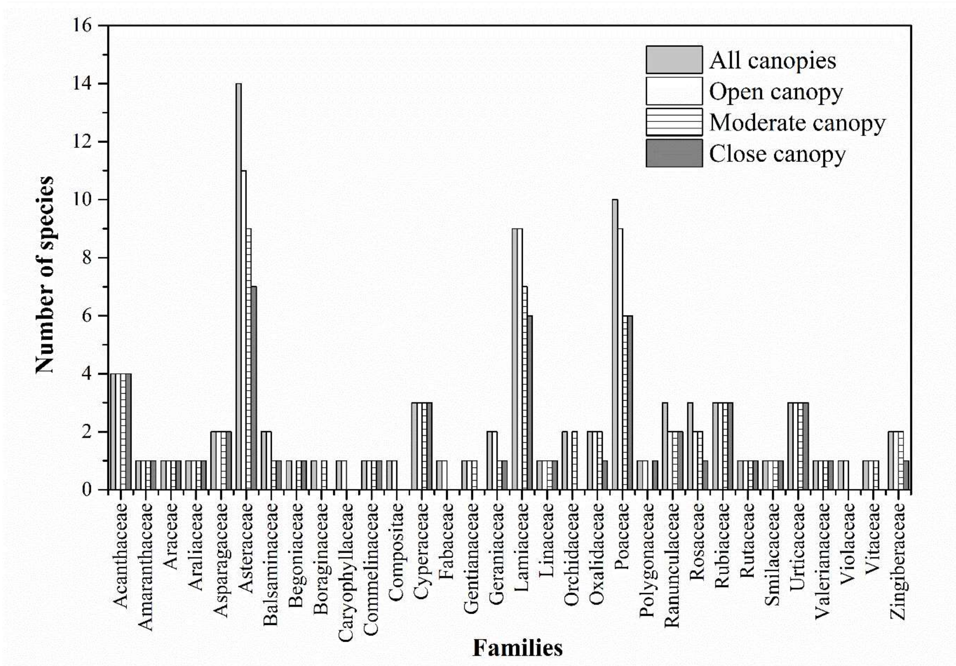

Fig. 2. Species occurrence in different families across the canopy

Table 5. Percent community contribution of selected medicinal plants in different canopies

Herb species	Parameters in different canopy class								
	Open			Moderate			Close		
	HC (%)	D (%)	IVI (%)	HC (%)	D (%)	IVI (%)	HC (%)	D (%)	IVI (%)
Boenninghausenia albiflora	4.2	2.4	3.6	10.0	4.7	6.4	8.3	5.3	6.2
Hedychium spicatum	2.6	1.4	2.0	2.8	0.8	1.4	9.9	2.2	4.4
Origanum vulgare	4.8	4.5	4.7	6.4	2.9	3.9	0.1	0.3	0.4
Rubia cordifolia	1.0	1.3	1.6	1.9	1.8	2.3	2.0	1.7	2.2

HC- Herb cover, D- Density, IVI- Importance Value Index close canopy (Table 5). *Rubia cordifolia* was rare in all three canopies and indicated the existence of this will be in danger. This may be due to frequent use and overexploitation of the species in traditional medicine in Uttarakhand (Prasad and Tomar 2020). The percent density, herb cover, and IVI for *Origanum vulgare* showed a higher value for these parameters in the open to the moderate canopy, whereas rarity in the moderate and close canopy. The species showed greater density in open canopy compared to moderate and close canopy, which also indicated that herb require abundant light for growth and development apart from other resources (Arya and Ram 2016). According to IUCN (1993), *Origanum vulgare* and *Rubia cordifolia* were in the rare category. Although changes in the herbaceous layer are dependent on length of time of woody encroachment, percent woody cover, and site productivity (Murray and Cooper 2021), however the opening of canopy favours the invasion of herbs in oak forest (Arya 2012).

CONCLUSION

The conservation and management of forest floor vegetation are essential aspects of maintaining the functioning and structure of forest ecosystem. Most of the medicinal plants are associated with the livelihood of tribal and rural communities living around the forest in the Indian Himalayan region. The forests are on the verge of different stages of degradation, which influence the frequency, abundance, and status of these selected medicinal plant species. The frequency of recorded medicinal plant species indicated that most of the species are in the rare category in all three-canopy classes. Further, none of the species fall under the mostly and constantly present category. Among the selected four medicinal plants, three are under rare category. Thus, the conservation of *Origanum vulgare*, *Rubia cordifolia,* and *Hedychium spicatum* species should be considered for their protection. Further, utilization of *B. albiflora* should be in a sustainable way to maintain the population of the species. Therefore, the in situ as well ex-situ cultivation of these species should be given high priorities for conservation and management of these species.

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Influence of Site Characteristics on Natural Regeneration of *Rhododendron campanulatum* D. Don Bearing Forests in Alpine Region

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Abstract: The present investigation was carried out on influence of site characteristics on natural regeneration of *Rhododendron campanulatum* D. Don bearing forests in alpine during 2017-19 with the aim to study the effect of site characteristics (aspect, elevation, solar influx, soil N, P and K) in Dodra Kwar and Khashdhar Forest Ranges of Himachal Pradesh India. The study area was divided into three elevation zones, E1=3000-3200 m, E2 =3200-3400 m and E3 = 3400 m above m in northern and southern aspect. Available N, P, K was highest on northern aspect as compared to southern aspect. Maximum solar influx per cent was reported on southern aspect as compared to northern aspect in both forest ranges. The main factors responsible for adequate regeneration of *R. campanulatum* were ample amount of snowfall, soil moisture, available N, P, K, solar influx, aspect, and elevation.

Keywords: Aspect, Elevation, Regeneration, Solar influx, Site characteristics

The genus *Rhododendron* (Family- Ericaceae) was first described by Carl Linnaeus in 1737 in Genera Plantarum. Over 900 species of Rhododendrons have been discovered with most of them distributed from South to Southeast Asia, ranging from the Himalaya through India, Tibet, China to Vietnam, Malaysia, Indonesia, Philippines and New Guinea. In India, there are about 80 species of Rhododendrons, mainly found in Arunachal Pradesh, Sikkim, Manipur, Nagaland, Himachal Pradesh, Jammu and Kashmir and Uttarakhand (Bhattacharya 2011). In spite of their larger distribution many Rhododendrons are classified as rare, endangered and threatened and may therefore become extinct if proper conservation initiatives are not taken up. Moist alpine forests occur throughout the Himalayas particularly on higher altitudes limited to sheltered sites on northern and western aspects. The chief site characteristics consist of ample snowfall, wet soil with thick layer of black humus. The predominant species of the herb, small tree and shrub genera varies with the effect of microclimatic conditions. Edaphic properties play an important role in determining local to regional plant distributions but are often missing from predictions of future species ranges (Lafleur et al 2010). With the view that future establishment may be constrained by non-climatic processes, our expectation was that forest soils, collected from areas where trees are already established, would be more amenable to seedling success than soils from the transition or alpine zones. In the case that transition and/or alpine soils host less successful tree seedlings, high-elevation soil properties would be viewed as limiting to future upslope tree line advance. Given that tree line expansion has the potential to modify habitat conditions (Theurillat and Guisan 2001, Greenwood and Jump 2014, and to alter ecological processes at various scales (Beniston 2003), identifying locally defined limitations to tree seedling regeneration is an important objective when considering where alpine tree line advance will occur in the future (Rosbakh et al 2015). Therefore, keeping in status of conservation and significance of this species, a study was carried out in Rohru Forest Division of Himachal Pradesh.

MATERIAL AND METHODS

The present research was conducted between 31° 12' 36" and 31° 14' 24" N latitude and 78° 01' 27" E and 77° 59' 44" E longitude in the Dodra Kwar and Khashdhar Range of Himachal Pradesh's Rohru Forest Division. The various site characteristics included were: Elevation, Aspect, Solar influx and Soil physico chemical properties.

The study area was divided into two ranges (Dodra Kwar and Khashdhar) and each range was further divided into three elevations (E_1= 3000-3200 m, E_2= 3200-3400 m and E_3= above 3400 m) and two aspects (North and South). For each study site, eighteen sample plots were laid out and samples were taken for further analysis.

Solar influx: Light illumination was recorded using luxmeter under and outside the Rhododendron canopy in selected sites of each location separately during day time and the value in percentage of light intensity under canopy to that in open canopy was calculated as under (Rao 1998).

$$\text{Solar influx (\%)} = \frac{\text{Total solar radiation beneath the canopy}}{\text{Total solar radiation in open}} \times 100$$

Soil physico-chemical properties of the site: Composite soil samples (0-30 cm) from each sampling plot at different elevations and aspects were collected. Samples were air dried in shade, grinded in iron pestle, passed through 2 mm sieve and stored in poly bags for further laboratory analysis. Available nitrogen (kg ha^{-1}), phosphorus (kg ha^{-1}) and potassium (kg ha^{-1}) were determined as suggested by Subbiah and Asija (1956), Olsen et al (1954) and Merwin and Peach (1951), respectively.

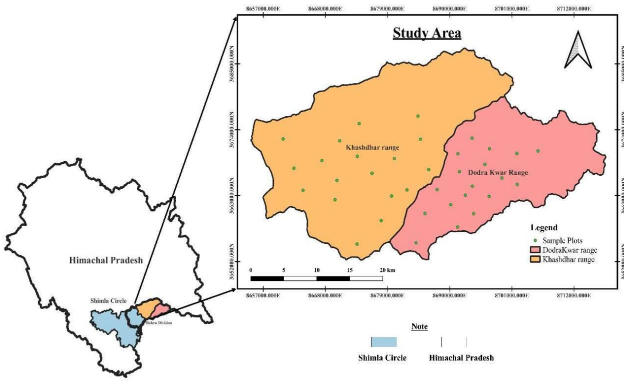

Fig. 1. Study area

RESULTS AND DISCUSSION

Solar Influx (%): The elevation, aspect and range caused significant effect on solar influx (%) (Table 1). The maximum solar influx (24.08 %) was at elevation range 3200-3400 m and minimum solar influx (13.12 %) was at elevation range above 3400 m. Among aspect, highest value for solar influx (20.16 %) was observed on southern aspect and lowest (18.07 %) was on northern aspect. In forest range, highest solar influx (19.42 %) was recorded in Dodra Kwar and minimum (18.82 %) in Khashdhar. The interaction effect of E×A showed that highest solar influx (24.94 %) at elevation range 3200-3400 m on southern aspect and lowest was reported at elevation range above 3400 m on northern aspect (11.79 %). In the interaction effect of E×R, maximum amount of solar influx (24.17 %) was at elevation range 3200-3400 m in Dodra Kwar which was statistically at par with solar influx per cent at elevation range 3200-3400 m (23.99 %) in Khasdhar. The minimum solar influx (12.44 %) was at elevation range above 3400 m in Khashdhar. In the interaction of A×R, highest solar influx (20.43 %) was on southern aspect in Dodra Kwar which was statistically at par with on southern aspect in Khashdhar. However, the interactions between E×A×R were non-significant. The present study reflects that solar influx per cent is higher on southern aspect than northern aspect. The solar influx values obtained in the current study are supported by the findings of Giertych (2000) and Mahajan (2010) for regeneration and survival of *Taxus baccata* and *Pinus roxburghii*.

Available Nitrogen (kg ha^{-1}): Available nitrogen of soil was significantly influenced due to elevation and aspect (Table 2). Significantly maximum available nitrogen (314.17 kg ha^{-1}) was at elevation range 3000-3200 m and minimum (289.26

Table 1. Solar influx (%) at different aspects along the elevations in *R. campanulatum* bearing forest

Elevation (E)	Solar influx (%)								
	Dodra Kwar			Khashdhar			Range average		
	North	South	Mean	North	South	Mean	North	South	Mean
E_1 (3000- 3200 m)	18.87	21.26	20.07	19.51	20.93	20.22	19.19	21.10	20.14
E_2 (3200-3400 m)	23.61	24.72	24.17	22.83	25.15	23.99	23.22	24.94	24.08
E_3 (Above 3400 m)	12.71	15.30	14.01	10.86	13.61	12.24	11.79	14.46	13.12
Mean	18.40	20.43	19.42	17.73	19.90	18.82	18.07	20.16	
CD (p=0.05)	Elevation (E)	0.49							
	Aspect (A)	0.40							
	Range (R)	0.40							
	E X A	0.69							
	E X R	0.69							
	A X R	0.56							
	E X A X R	NS							

kg ha^{-1}) was reported at elevation range above 3400 m. Among aspect, the highest available nitrogen (312.78 kg ha^{-1}) was on northern aspect whereas; lowest available nitrogen (281.18 kg ha^{-1}) was on southern aspect. In the interaction effect of E×A×R, the maximum available nitrogen (334.70 kg ha^{-1}) was at elevation range 3000-3200 m on northern aspect in Khashdhar. Minimum available nitrogen (280.08 kg ha^{-1}) was recorded at elevation range above 3400 m on southern aspect in Khashdhar However, the effect of R and interactions between E×A, E×R, A×R were non-significant.

The available nitrogen decreased as the elevation increased. The lower altitudes in present study were moister as compared to the higher elevation. N is mostly present in the form of nitrates in the soil, which is very mobile and gets moved freely with the moisture (Gupta and Sharma 2008). The soil organic carbon is higher in lower altitudes as compared to upper altitudes. The high amount of organic matter in the lower elevation may also be the reason for richness of N.

Available phosphorus (kg ha^{-1}): The maximum available phosphorus (27.13 kg ha^{-1}) was observed at elevation range 3000-3200 m (Table 3) and minimum (26.08 kg ha^{-1}) at elevation range above 3400 m which was statistically at par with available phosphorus (26.25 kg ha^{-1}) d at elevation range 3200-3400 m. Among aspect, highest value of available phosphorus (28.40 kg ha^{-1}) was on northern aspect whereas, lowest (24.57 kg ha^{-1}) on southern aspect. In interaction effect E×R, has highest available phosphorus (28.40 kg ha^{-1}) at elevation range 3000-3200 m in Khashdhar whereas, lowest (24.75 kg ha^{-1}) at elevation range 3200-3400 m in Khashdhar. The interaction effect of A×R, revealed that maximum

Table 2. Available nitrogen (kg ha^{-1}) at different aspects along the elevations

Elevation (E)	Available Nitrogen (kg ha^{-1})								
	Dodra Kwar			Khashdhar			Range average		
	North	South	Mean	North	South	Mean	North	South	Mean
E_1 (3000- 3200 m)	325.89	298.64	312.27	334.70	297.43	316.07	330.30	298.04	314.17
E_2 (3200-3400 m)	312.77	289.43	301.10	308.62	291.28	299.95	310.70	290.36	300.53
E_3 (Above 3400 m)	299.88	282.28	291.08	294.79	280.08	287.44	297.34	281.18	289.26
Mean	312.85	290.12	301.49	312.70	289.60	301.15	312.78	289.86	
CD (p=0.05)	Elevation (E)		2.01						
	Aspect (A)		1.64						
	Range (R)		NS						
	E X A		NS						
	E X R		NS						
	A X R		NS						
	E X A X R		4.02						

Table 3. Available Phosphorus (kg ha^{-1}) at different aspects along the elevations

Elevation (E)	Available Phosphorus (kg ha^{-1})								
	Dodra Kwar			Khashdhar			Range average		
	North	South	Mean	North	South	Mean	North	South	Mean
E_1 (3000- 3200 m)	28.10	23.60	25.85	29.40	27.40	28.40	28.75	25.50	27.13
E_2 (3200-3400 m)	29.60	25.90	27.75	26.90	22.60	24.75	28.25	24.25	26.25
E_3 (Above 3400 m)	27.90	23.70	25.80	28.50	24.20	26.35	28.20	23.95	26.08
Mean	28.53	24.40	26.47	28.27	24.73	26.50	28.40	24.57	
CD (p=0.05)	Elevation (E)		0.36						
	Aspect (A)		0.30						
	Range (R)		NS						
	E X A		NS						
	E X R		0.51						
	A X R		0.42						
	E X A X R		0.73						

available phosphorus (28.53 kg ha^{-1}) on northern aspect in Dodra Kwar which was statistically at par with available phosphorus (28.27 kg ha^{-1} on northern aspect in Khashdhar. The minimum available phosphorus (24.40 kg ha^{-1}) was d on southern aspect in Dodra Kwar which was statistically at par with available phosphorus (24.73 kg ha^{-1}) on southern aspect in Khashdhar. In the interaction effect of E×A×R, the highest value of available phosphorus (29.60 kg ha^{-1}) was at elevation range 3200-3400 m on northern aspect in Dodra Kwar which was statistically at par with available phosphorus (29.40 kg ha^{-1}) at elevation range 3000-3200 m on northern aspect in Khashdhar. The lowest available phosphorus (22.60 kg ha^{-1}) was at elevation range 3200-3400 m on southern aspect in Khashdhar. However, the effect of R and interaction between E×A was non-significant. The present study shows that lower elevation (3000-3200 m) and mid elevation (3200-3400 m) were having more density of grasses and recorded high amount of P.

Available Potassium (kg ha^{-1}): The highest amount of available potassium 234.43 kg ha^{-1} was recorded at elevation range 3000-3200 m, whereas, lowest 216.40 kg ha^{-1} was at elevation range above 3400 m (Table 4). Among aspect, maximum available potassium (233.44 kg ha^{-1}) was d on northern aspect, whereas, minimum (217.52 kg ha^{-1}) was on southern aspect. In the interaction effect of E×A×R, the highest value for available potassium (249.00 kg ha^{-1}) was at elevation range 3000-3200 m on northern aspect in Khashdhar. Lowest value for available potassium (209.08 kg ha^{-1}) was at elevation range above 3400 m on southern aspect in Khashdhar. However, the effect of R and interactions between E×A, E×R, A×R were non-significant.

Influence of site characteristics on natural regeneration of *R. campanulatum*: The maximum regeneration (52.78 %) for *R. campanulatum* was at elevation range of 3200-3400 m on northern aspect in Khashdhar (Table 5). Solar influx per cent was 22.83 and available N, P, K were 308.62, 26.90 and (234.76 kg ha^{-1}, respectively). The minimum regeneration success per cent (21.00) was at elevation range 3000-3200 m on southern aspect in Khashdhar. Here, the solar influx per cent was 20.93 and available N, P, K were 297.43, 27.40 and 227.81 kg ha^{-1}, respectively. The highest regeneration success (38.89 %) was r at all the altitudinal range on northern aspect in Dodra Kwar. The available N, P, K were 325.89, 28.10 and 239.80 kg ha^{-1}, respectively. The minimum regeneration success per cent (25.00) was at elevation range 3000-3200 m on southern aspect in Dodra Kwar. Here, the solar influx per cent was 21.26 and available N, P, K were 298.64, 23.60 kg and 221.09 kg ha^{-1}, respectively.

Available N, P, K was highest on northern aspect as compared to southern aspect. The maximum regeneration success for *Rhododendron campanulatum* was d in northern aspect as compared to southern aspect. The main factors responsible for adequate regeneration of *Rhododendron campanulatum* were ample amount of snowfall, soil moisture, available N, P, K, solar influx, aspect and elevation. In mountain ecosystems, slope- aspect plays a key role in regulating insolation, which in turn affects soil moisture, temperature regimes, hydrological precipitation pattern, erosion, species composition and distribution, photosynthetic efficiency and nutrient dynamics that can directly influence the development of local vegetation and ecosystems (Leonelli et al 2009, Sharma et al 2010, Aimme and Normaniza 2015, Yanyan et al 2017). The seasonally wet and poorly drained sites had well developed wet heath communities (Vickers and Palmer 2000). Pandey et al (2018) conducted a study on timberline structure and woody taxa regeneration towards tree line along atitudinal gradients in Khangchendzonga National Park, Sikkim and revealed that humus, elevation and slope

Table 4. Available Potassium (kg ha^{-1}) at different aspects along the elevations

Elevation (E)	Available Potassium (kg ha^{-1})								
	Dodra Kwar			Khashdhar			Range average		
	North	South	Mean	North	South	Mean	North	South	Mean
E_1 (3000- 3200 m)	239.80	221.09	230.45	249.00	227.81	238.41	244.40	224.45	234.43
E_2 (3200-3400 m)	231.65	215.89	223.77	234.76	220.14	227.45	233.21	218.02	225.61
E_3 (Above 3400 m)	227.64	211.12	219.38	217.76	209.08	213.42	222.70	210.10	216.40
Mean	233.03	216.03	224.53	233.84	219.01	226.43	233.44	217.52	
CD (p=0.05)	Elevation (E)		0.70						
	Aspect (A)		0.57						
	Range (R)		NS						
	E X A		NS						
	E X R		NS						
	A X R		NS						
	E X A X R		1.40						

Table 5. Natural regeneration of *R. campanulatum* at different aspects along the elevations

Site	Elevation (m)	Regeneration success (%)	
		N	S
Dodra Kwar	E_1 (3000- 3200 m)	38.89	25.00
	E_2 (3200-3400 m)	38.89	27.78
	E_3 (Above 3400 m)	38.89	27.78
Khashdhar	E_1 (3000- 3200 m)	38.89	21.00
	E_2 (3200-3400 m)	52.78	22.22
	E_3 (Above 3400 m)	38.89	36.11

played an important role in shaping the vegetation composition as well as timberline boundaries of the landscape.

CONCLUSION

Rhododendron campanulatum prefers cooler and moist sites. Available N, P, K was highest on northern aspect as compared to southern aspect. The regeneration status of *R. Campanulatum* was fair in both forest ranges, except in the mid elevation and northern aspect of Khashdhar range, which showed moderate regeneration success rate. The main factors responsible for adequate regeneration of *R. campanulatum* were ample amount of snowfall, soil moisture, available N, P, K, solar influx, aspect and elevation.

AUTHOR CONTRIBUTION

Ankush Moran and Mukesh Prabhakar designed the study; Nilotpal Raj, Himesh Kapoor and Kapoor collected data and developed draft of manuscript; Software- N kengoo and S Balaji Naik; Akshay Kailas Pingale, Tapan Adhikari and Vaibhav Rajesh Rao Jumale added additional data inputs and helped in laboratory.

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Novel Propagation of Fruit Species Through Mini-Cuttings and Leaves

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***Abstract*:** The main objective of the study was to standardize mini-cutting and leaf propagation in selected four fruit species locally available around College of Forestry, Sirsi. Mini-cuttings and leaves of 4 species namely *Annona muricata, Annona squamosa, Garcinia morella* and *Morinda citrifolia* were taken and planted in zip lock covers with coir pith as the rooting media inside the polyhouse. Three treatments were control, 1000 ppm of IBA and 1000 ppm of Coumarin were given. The experiment was conducted in two seasons *i.e.,* spring and rainy season. Survival per cent of all the four species was seen higher in the rainy season than the spring season. Treatment with 1000 ppm of IBA and coumarin was effective in root length (and) or number of roots in either of the seasons in both propagation methods. Three species selected for the study adapted well to mini-cutting technology which shows that it is possible to propagate genotypes with superior characteristics through mini-cutting with a greater number of seedlings per source. However, complete propagation of plant was not possible through leaves.

***Keywords*:** Clonal technology, Genotypes, Mini-cutting, Propagation

Propagation, either by sexual or asexual means, is one of the most crucial steps for the success of any tree improvement programme. Vegetative propagation plays a key role in large-scale multiplication of superior clones or tested plus trees (Palanisamy and Subramanian 2001, Prabakaran et al 2017). Most adopted methods of vegetative propagation includes cutting, grafting, budding, layering, micro-propagation and root sections/suckers (Kumar et al 2018, Thakur et al 2021). Recently, mini-cutting technology is gaining importance among commercial forestry companies to mass propagate clones of Eucalyptus (Almeida et al 2007) and is being expanded to other areas such as floriculture and fruit crops. A mini-cutting is essentially a miniature stem cutting and its length varies from two to six centimetres, depending on the size of the shoots emitted, the size of the leaves, and the phyllotaxis of the species. It is seen as an improvement of stem cutting, displaying variations for optimizing both the quality of clonal saplings and rooting (Xavier and Silva 2010). It allows a breeder to multiply any individual tree at an extremely rapid pace (up to 1,00,000 plants per year from a single individual), which is far superior when compared to the normal macro stem cutting methods. Mini-cutting in the production of forest species was first carried out with *Eucalyptus* in the 1990s (Brondani et al 2010). Today the technique has been expanded to propagate forest species such as Pine (Alcantara et al 2007), Pink cedar (Xavier et al 2003), and Ipe (Oliveira et al 2015) and in Casuarina (Palanisamy et al 2020).

Vegetative propagation through leaves is traditionally practiced in succulents such as Cactus, Bryophylum, Agave, and *Aloe-vera*. Leaf cuttings are prepared by taking a single leaf from the plant, which itself is the propagating material (Welch-Keesey and Lerner 2002). The main advantage of this leaf propagation is that, with this technique plants can be raised throughout the year, with minimal disturbance to the mother plant unlike the stem cutting method (Uday et al 2014). However, vegetative propagation through leaves is not very commonly practiced and strangely there is a lack of interest among researchers in standardizing these techniques in forestry species. Despite having a huge potential to mass propagate clones through mini-cuttings and through leaves, there is a paucity of fine-tuning the techniques in important fruit species. Hence, the main objective of the study was to assess the potentiality of propagation through mini-cuttings and leaves in four fruit species as well as to understand the influence of seasons on success rate.

MATERIAL AND METHODS

The present study was carried out in a poly-house at the College of Forestry, Sirsi, Uttara Kannada district which comes under the hill zone (Zone 9) of Karnataka State, in the Central Western Ghats of India which lies between 14° 26' N latitude, 74° 50' E longitude and at an altitude of 619 m MSL.

Mini-cuttings of 5-7 cm in length and fully expanded middle aged leaves were collected from saplings of *Annona* *muricata, Annona squamosa, Garcinia morella* and *Morinda citrifolia* growing in the College of Forestry, Sirsi campus. The experiment was conducted in two seasons of 2022 *i.e.,* spring (Feb-Mar) and rainy (Jul-Aug). The leaves and mini-cuttings from either apical or intermediary shoots were placed in zip lock covers with coir pith as the rooting media after treatment. Three treatments *viz*., T_1= Control, T_2= Indole-3-buytric acid (1000 ppm in talc form), T_3= Coumarin (quick dip method in 1000 ppm solution) were imposed to leaves and mini-cuttings. Every treatment consisted of three replications with 15 mini-cuttings/leaves each which was set in Completely Randomized Design (CRD). After 8^{th}week of planting leaves and mini-cuttings, the following observations were taken. The per cent leaves and mini-cuttings survived were estimated using formula: Per cent leaves and mini-cuttings survived=(Number of green leaves /mini-cuttings÷Total number of leaves)×100. Similarly, the per cent leaves and mini-cuttings rooted are worked out by the following formula: Per cent leaves and mini-cuttings rooted= (Number of leaves / mini-cuttings rooted÷ Total number of leaves / mini-cuttings planted)×100. Total number of roots produced and root length of each leaf/mini-cutting, were counted after the 8^{th} week of planting.

RESULTS AND DISCUSSION

Mini-cuttings of four species remained green in both spring and rainy season by the end of 8^{th}week, but *Annona muricata* and *A. squamosa* leaves showed drying in spring season. Survival per cent of all four species was good during rainy season in both mini-cutting and leaf propagation (Fig. 1). *Morinda citrifolia* is the only species which showed rooting through leaves in both the seasons (Plate 1). Three species such as *A. muricata, A. squamosa* and *M. citrifolia* showed rooting through mini-cuttings (Plate 2). There was no rooting seen in the month of spring in *Annona muricata* mini-cuttings. Callus formation was noticed in *Garcinia morella* leaves in the month of rainy season. Promising rooting was observed in *M. citrifolia* mini-cuttings and leaves when compared to other species (Fig. 2). However, three species (*A. muricata,*

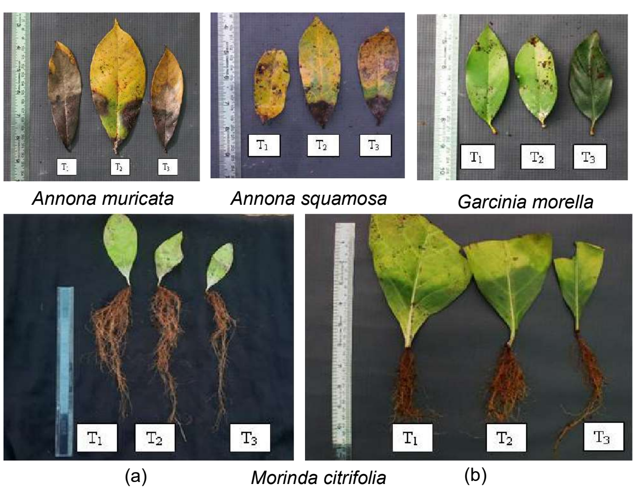

Plate 1. Influence of different treatments with plant growth regulators on rooting through leafpropagation (a-spring season, b-rainy season)

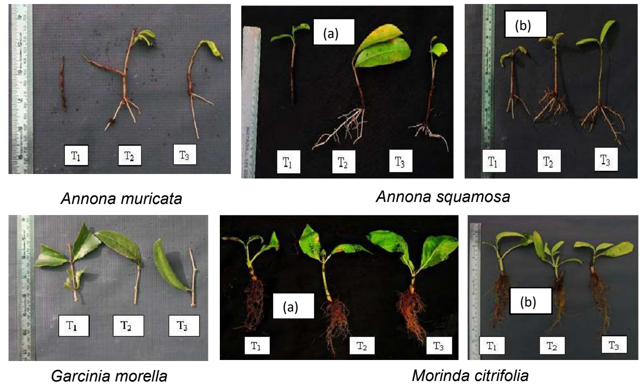

Plate 2. Influence of different treatments with plant growth regulators on rooting through mini-cutting propagation (a-spring season, b-rainy season)

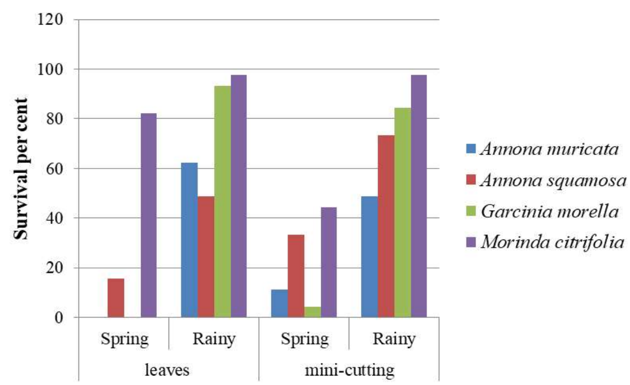

Fig. 1. Survival per cent of leaves and mini-cuttings of four fruit species in two seasons by the end of 8^{th}week

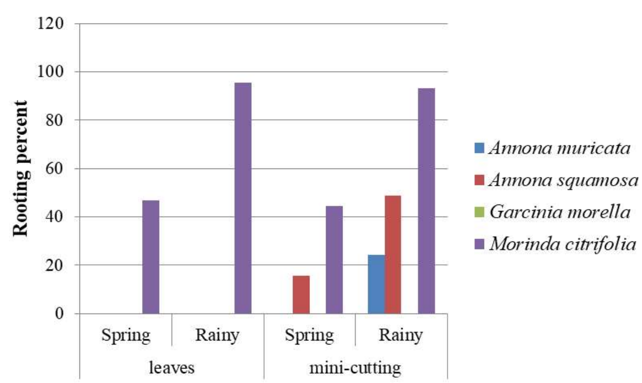

Fig. 2. Rooting per cent of leaves and mini-cuttings of four fruit species in two seasons by the end of 8^{th}week

A. squamosa and *M. citrifolia*) showed successful propagation through mini-cutting and one species *i.e. M. citrifolia* through leaf propagation, whereas one species *G. morella* showed callus formation in leaf propagation. The survival per cent of all the four species was highest during rainy season than in spring season through both leaf and mini-cutting propagation perhaps due to congenial environment. Similar results have been reported by Palanisamy et al (2020) where in *Casuarina* clones showed highest rooting (86%) in rainy season compared to spring (82%). Perhaps cuttings can hold more moisture which may help them to survive and to root vigorously in rainy season because of high humidity than any other months.

Treatment with IBA (250 mg/l) resulted in better results in terms of, number of roots (70.63), rooting per cent (80%), root length (11.13 cm) and number of leaves (5.25) per rooted mini-cuttings in *Azadirachta indica* (Gehlot et al 2014). Similar findings were found in this study where 1000 ppm of IBA was significantly effective in root length or number of roots in three species (Table 1, 2 and 3). Highest root length

Table 1. Influence of different treatments and seasons on mean number of roots and mean length of roots in *A. muricata* adopting mini-cutting propagation (The values are Mean ± SD)

Treatment	Mean number of roots		Mean root length (cm)	
	Spring	Rainy	Spring	Rainy
Control (T_1)	0	1.17 ± 2.02	0	0.33 ± 0.58
IBA 1000 ppm (T_2)	0	3.50 ± 0.50	0	3.33 ± 0.35
Coumarin 1000 ppm (T_3)	0	2.83 ± 0.29	0	3.77 ± 0.31
CD @ 1 %	0	1.80	0	0.87
P value	0	<0.01	0	<0.01

Table 2. Influence of different treatments and seasons on mean number of roots and mean length of roots in *A. squamosa* adopting mini-cutting propagation (the values are Mean ± SD)

Treatment	Mean number of roots		Mean root length (cm)	
	Spring	Rainy	Spring	Rainy
Control (T_1)	0	2.17 ± 1.89	0	2.67 ± 2.32
IBA 1000 ppm (T_2)	4.67 ± 0.58	3.93 ± 3.48	8.67 ± 0.32	4.23 ± 3.67
Coumarin 1000 ppm (T_3)	7.83 ± 1.04	3.78 ± 0.20	4.40 ± 0.30	6.60 ± 0.20
CD @ 1 %	1.40	N/S	0.52	N/S
P value	<0.01	0.60	<0.01	0.20

Table 3. Influence of different treatments and seasons on mean number of roots and mean length of roots in *M. citrifolia* adopting leaf propagation and mini-cutting propagation (The values are Mean ± SD)

Treatment	Mean number of roots		Mean root length (cm)	
	Spring	Rainy	Spring	Rainy
a. Leaf propagation				
Control (T_1)	5.42 ± 0.52	2.63 ± 0.35	27.77 ± 0.21	14.50 ± 0.20
IBA 1000 ppm (T_2)	4.08 ± 0.14	2.97 ± 0.35	31.83 ± 1.26	15.13 ± 0.15
Coumarin 1000 ppm (T_3)	3.40 ± 0.35	1.80 ± 0.20	30.97 ± 0.45	23.60 ± 0.10
CD @ 1 %	0.75	0.80	1.59	0.32
P value	<0.01	<0.01	<0.01	<0.01
b. Mini-cutting propagation				
Control (T_1)	2.87 ± 0.23	13.60 ± 0.74	6.83 ± 0.21	11.03 ± 0.15
IBA 1000 ppm (T_2)	4.87 ± 0.23	7.08 ± 0.25	6.33 ± 0.15	11.47 ± 0.45
Coumarin 1000 ppm (T_3)	6.17 ± 1.04	3.53 ± 0.31	6.77 ± 0.25	19.53 ± 0.76
CD @ 1 %	1.28	0.98	N/S	1.05
P value	<0.01	<0.01	0.05	<0.01

(31.83 cm) was observed in *M. citrifolia* through leaf propagation with IBA treatment. Highest root length in mini-cutting propagation was seen in *M. citrifolia* (19.53 cm) with treatment of 1000 ppm of coumarin. Lipecki and Selwa (1977) recorded coumarin was generally more effective than other chemicals used to observe rooting in softwood cuttings of *Prunus mahaleb* L. clones. Highest mean number of roots in leaf propagation and mini-cutting propagation was observed in *M. citrifolia i.e.* 5.42 and 13.60, respectively with control as the treatment. Rana et al (2017) reported that bamboo cuttings without any hormonal treatment exhibited 83.33% rooting, which was significantly higher (34%) than the cuttings treated with 100 ppm of IBA.

CONCLUSION

The current study, perhaps for the first time, unrevealed the potentiality of propagation of economically important fruit species through mini-cutting and leaves. Except *G. morella* all the three species showed rooting in mini-cutting in either of the season or both the seasons. *M. citrifolia* showed rooting through leaves in both spring and rainy season. *G. morella* showed callus formation through leaf propagation in rainy season. Three species selected for the study adapted well to mini-cutting technology. This shows that it is possible to propagate genotypes with superior characteristics through mini-cutting with a greater number of seedlings per source. However, in leaf propagation only rooting is achieved, which is the first and very crucial step in achieving complete regeneration, none of the rooted leaves showed signs of shoot formation during the study period. Perhaps more time is required to develop the shoots from the leaves. If leaf propagation method is perfected to achieve shooting, then it can be used for raising endangered species and it would be wonderful method to overcome tissue culture.

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Indigenous Pattern of Collection and Utilization of NWFPs and Socio-Economic Sustainability for Tribal Women of Central Chhattisgarh

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Abstract: Tribal women perform a variety of forest-based functions in their day-to-day activity at different levels but their roles and participation tend to be poorly visible and unacknowledged. Considering women's relationships with collection, utilization and processing they perform significant role and responsibility in sustainable management of NWFPs. The gathering of everyday NWFPs particularly food, medicinal plant parts and craft materials, has always fallen into the domain of women. NWFPs have widespread promotion of these products, particularly by agencies interested in sustainable development, as tools for enhancing livelihood of women. For this purpose, a review study has been conducted by reviewing of 24 relevant Research papers, articles and Forest Department office. As compared to male, female is more compatible for collection of various plant-based medicines from locally available NWFPs which includes more significant, bamboo, tendu, cocoons and mahua and so many other types of locally available known minor forest produces. Providing better support, opportunity, training and documentation on their knowledge would enhance healthcare, food sources, livelihood, involvement of women and socio-economic condition in sustainable NWFPs management.

Keywords: Tribal women, Livelihood, NWFP, Women participation, NWFP

Non-Timber Forest Products (NTFPs) are referred to as Non-Wood Forest Products (NWFPs) by FAO which has been in use since the beginning of a human civilization. In past decades these were called minor forest products due to being an insignificant economic value. According to the Food and Agricultural Organization of the United Nations (FAO), over 80% of people in underdeveloped nations have been found to use plants as a kind of traditional medicine. According to studies, on the use of non-timber forest products (NTFPs) for income production, rural households' income was generated between 20 to 60 percent in 2018-19 (Arularasan et al 2022). However, in now were days these have been spurt in demand because of common acceptance of natural products for medicines, cosmetics, dyes, chemicals, bio-pesticides, food, etc. Over 75per cent of total forest export revenue of India is accounted by NWFPs for local people and such products were always important because they are the providers for year-round source of livelihood. Social researchers and forest managers are now unambiguous about the importance of NWFPs to the living and economy of rural people (Kumar 2019). In central Chhattisgarh, collection of NWFPs consist the main source of wage labor are involved only 19 per cent and 41 percent are involved in NWFP collection as a substitute occupation. In other studies household income profile from NWFPs collection according to researchers is average as compared to another substitute occupation. From the above analyses it is clear that NTFPs plays a greater role in upgrading the social, economic and traditional lifestyle of forests dependent people particularly the tribals, women's and other rural people (Kumar 2019). The knowledge required for sustainable utilization of plants is often qualitative, based on observation and limited within a particular geographical area and these knowledges were actually accumulated by the tribal peoples and culturally transmitted from their ancestors (Gadgil 1993, Patra 2022).

This study is reviewed to understand the traditional knowledge of tribal women who practices with an emphasis on various collection of NWFPs which are locally available. Specifically, this study also made an effort to understand the support, opportunity and training on their knowledge that how it would enhance healthcare, livelihood and socio-economic condition in sustainable NWFPs management. Further, this study has assessed the role of women participation in NWFPs collection and Utilization.

In central Chhattisgarh, tribal women pursue a variety of income source, with wage labor serving as the essential part with women and men having separate domains of livelihood-related activities. Cultivating farm vegetables, manufacturing puffed rice, Bamboo crafts, weaving mats, and other similar items are there. Forests have always been a key source of food. The most prevalent source of income was timber trading, which is no longer available, at least legally. Collection and selling of non-timber forest products such as fuel wood viz., *Diospyros melanoxylon* (tendu) and *Shorea robusta* (sal), *Terminalia bellirica* (harra), *Tamarindus indica* (Tamarind), *Buchanania lanzan* (chironjee guthli), *Karria lacca* (lac, Kusumi, Rangini), *Madhuca indica* (Mahua), *Dioscorea bulbifera* (Gethi kanda), leafy vegetables and bamboo are most prevalent activity. Bamboo dead leaves are used to construct mats, which tribal women sell in the local market, in the related communities. Fuel wood, *Diospyros melanoxylon* (tendu leaves) and *Shorea robusta* (sal) leaves, bamboo, and other items are sell by rural people to generate money. In addition, the poor households ate roots and edible leaves obtained from the forest. Many tribals believed that instruction in the processing of forest products like bamboo and dead leaves was necessary. They proposed that more tree plantation in the forest due to heavy depletion and shrinking in size. In Central Chhattisgarh more than 85% of tribal women are involved directly reliant on NTFPs from the nearby forest, while other tribal women rely on NTFPs indirectly, with many households bringing forest products such as fuel wood, mushrooms, and other items as needed. According to Ghosal (2011), particularly the tribal women prefer mixed forests as it provides better support and allowed them to pursue a variety of economic options. Women in India are playing a crucial role in protection and conservation of environment.

Women in our country have brought a different perspective to the environment debate, because of their different experience base (Tiwari 2020). Women have always been the major conservers of bio-diversity. Traditionally, women have been responsible for subsistence and survival for water, food, fuel, fodder and habitat, though they rarely get the credit for nurturing these life support systems. Even today they perform duties such as seed selection, multiplication and conservation (Tiwari 2020).

Therefore, for tribal women major dependency on forest is in NTFPs as a food source and livelihood. Tribal women are getting economic benefits from the forest but in case of mushroom tribal lack behind because mushroom is a seasonal produce and at same time tribals are getting busy in their agriculture fields for crop production and due to which tribal women get less return or income from mushroom. Instead of collecting mushroom at mass level they only collect for their household needs as food option.

MATERIAL AND METHODS

We have collected the data to review from the relevant 24 research papers, articles and data collected from the forest office of Katghora forest division. The data has been collected to understand the indigenous pattern of collection and utilization of NTFPs and their socio-economic sustainability for tribal women of central Chhattisgarh.

RESULTS AND DISCUSSION

Seasonal NTFP collection: An interactive tool to explore the seasonal collection is a seasonal calendar. Knowing the kind of NTFPs and the month they are obtained is helpful. (Ushadevi et al 2022). The majority of the species may be found in the woodland from April to December. In general, tribal women and their children are active in the harvesting of NTFPs from the forest. *Shorea robusta* (Sal) leaves are harvested virtually all year, especially for use in plate manufacturing. The main season, however, is from September through November. Despite the fact that *S. robusta* (sal) leaves are abundant in the forest during the rainy season, they are rarely collected due to rice farming. Similarly, firewood is collected all year, but it is plentiful after the winter. Mushroom harvesting is limited to the late monsoon season, which runs from June to September. At the same time, tubers are harvested. One- or two-months following spring, Tendu leaf collection is prohibited. After the monsoon season, grass is grown and collected. Farmers harvest grass once or twice in the same year from the same plots of land, depending on the grass's development. The harvesting season begins in late August and lasts until the end of December. Few studies have looked at the significance of when NTFPs are collected, although it can have an impact on how useful they are as a source of revenue (Toda et al 2023).

The locals tribal people harvest NTFPs not only in the protected forests, but also in the settlements' surrounding areas. Tribals leave early in the morning to collect firewood. Tribal women are occasionally not able to gather sufficient amount of fuelwood due to which as a result tribal women enter to the deep forest. Travelling long distances inside the deep forest and return at the end of the day after gathering sufficient amount of fuel wood. Bamboo shoots, mushroom and tuber fruits are used as vegetables. Mat weaving is also done by tribal people with palm leaves and bamboo stems. *Andrographis paniculata* (Kalmegh), *Asparagus racemosus* (Satmul), *Aristolochia indica* (Ishwarmul), *Hemidesmus indicus* (Anantamul), and other therapeutic herbs are employed. Basket weaving is done with Dudhilata stems.

Table 1 shows various NTFPs collection done by tribals in central Chhattisgarh and the selling price of NTFPs per kg.

Various species mentioned in the table are collected in the priority basis and depend on the demand of the species and in the Figure 1. This shows mostly tendu and mahua are collected by the tribals. Only young people can actively collect NTFPs, probably due to collection sites are far from the village area and it is challenging for elderly persons to go about in forested areas. NTFPs are crucial for low-income households, and that's the reasons why the village youth are more interested and active for collection of NTFP as they can increase their incomes through the sale of NTFPs. (Bagal 2022). The tribal uses mostly the fruit portion of various NTFPs out of all those collections. From the present study, it can be inferred that the gathering, consumption, and sale of NTFPs are important for ensuring the tribal population's livelihoods in central Chhattisgarh. (Gupta 2017)

Socio-economic sustainability: Tribal women are directly dependent on NTFPs which are collected from the local

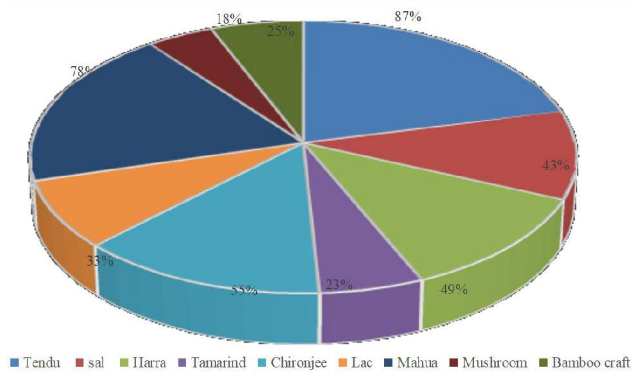

Fig. 1. Major collection of NTFPs by Tribals

Table 1. List of NTFPs collection in central Chhattisgarh

Common name	Scientific name	Family	Flowering	Fruiting	Harvesting	Selling price/kg
Tendu	*Diospyros melanoxylon*	Ebenaceae	April- May	May- June	June	-
Sal	*Shorea robusta*	Dipterocarpaceae	April- May	May	May- June	20.00
Kusum	*Schleichera oleosa*	Sapindaceae	January- February	March- April	July- August	23.00
Bahera	*Terminalia bellirica*	Combretaceae	April-May	May	November-February	17.00
Imli	*Tamarindus indica*	Fabaceae	April-June	February-March	March-April	36.00
Chironjii	*Buchanania lanzan*	Anacardiaceae	January-February	March-April	April-May	126.00
Mahua	*Madhuca indica*	Sapotaceae	March-April	April	May-June-July	29.00
Kalmegh	*Andrographis paniculata*	Acanthaceae	March- April	March- April	September	35.00
Charota	*Cassia obtusifolia*	Fabaceae	March- September	May- September	November	16.00
Harra	*Terminalia chebula*	Combretaceae	April- May	May- June	November- February	15.00
Van tulsi	*Ocimum gratissimum*	Lamiaceae	-	-	-	16.00
Honey	-	-	-	-	October/ November and February- June	225.00
Shatavari (roots)	*Asparagus racemosus*	Asparagaceae	July	September	November- December	107.00
Shikakai	*Acacia concinna*	Mimosaceae	October- November	December- January	April- May	50.00
Nagarmotha	*Cyperus rotundus*	Cyperaceae	March- July	July-September	October- November	30.00
Kusumi (Lac)	*Kerria lacca*	Kerridae	-	-	-	300.00
Rangini (Lac)	*Acacia catechu*	Fabaceae	March- September	March- September	March- September	220.00
Giloy	*Tinospora cordifolia*	Menispermaceae	May- June	September- October	November	40.00
Bhelwa	*Semecarpus anacardium*	Anacardiaceae	December- January	February- May	May- June	09.00
Dhawai (Flower)	*Woodfordia fruticosa*	Lythraceae	February- April	April- May	May	37.00
Kullu gond	*Sterculia urens*	Sterculiaceae	December- March	April- May	April- June	125.00
baelguda	*Aegle marmelos*	Rutaceae	March-April	April- June	April-May	30.00
Karanj	*Millettia pinnata*	Fabaceae	April-June	May- June	November- December	22.00
Neem	*Azadirachta indica*	Meliaceae	April	June- July	July- August	27.00
Jamun	*Syzygium cumini*	Myrtaceae	March- May	May- June	July- August	42.00

Source: Kendai Forest Range office of Katghora Forest Division forest areas, while the rest tribal women indirectly use the resources by buying forest products such as fuelwood and mushroom according to their needs. Tribal women collect NTFP like fuel wood, *Diospyros melanoxylon* (tendu) and *Shorea robusta* (sal), *Terminalia bellirica* (harra), *Tamarindus indica* (Tamarind), *Buchanania lanzan* (chironjee guthli), *Karria lacca* (lac, Kusumi, Rangini), *Madhuca indica* (Mahua). Out of which fuelwood is the most important one which is frequently collected. All tribals including male, female children they together contribute for collection of NTFPs, but the contribution from female tribals women is high. NTFPs play a vital role in supporting livelihoods in rural household community (Adhikary et al 2021). The tribal women livelihood activities of their households include crop productivity, livestock productivity, harvesting of Non-wood Forest Produces and other activities. The contribution of NTFPs to household earnings can be influenced by a wide range of circumstances. It's probable that NTFP dependence is higher among the impoverished than among the wealthy. (Lepcha et al 2022). However, the main source of income is agriculture field i.e. crop and livestock productivity and collection of NWFPs. People residing near the natural forest are depend on it for acquiring many NWFPs and timber. Although NTFPs play a vital role in rural income and employment, most tribal members only collect NTFPs from the forest on a monthly basis. Just a small number of tribal members gather NTFPs on a daily basis. (Das et al 2020). The major NWFPs, namely *Diospyros melanoxylon* (tendu) and *Shorea robusta* (sal) leaves, *Dioscorea bulbifera* (Gethi kanda), mushroom, housing materials, sal gum, sal seed play an important part in their household income. This means income of tribal women is contributed from NTFPs and NWFPs to their annual household income in the production and according to tribals agriculture is contributed slightly more than NTFPs and NWFPs (Melaku et al 2014). The level and pattern of NTFP dependency among people living near forests is influenced by various socioeconomic factors (Kar et al 2012). Therefore, tribal women are getting financial benefits from NTFPs and their knowledge related to wild fruits, food, medicines, NTFPs, forest status and conditions are high as they are more frequent visitors in the forest. Tribal women's knowledge benefits them in raising income but there are some limitations due to social structure they face the gender discrimination which negatively influence their value and role in the participation.

Role of women participation in NTFP management: The role of women's participation in NTFP activities cannot be overstated, women are primary driving force in the amount of collection and use of NTFP both of which contribute to their well-being. Women are also the active users and members of most of the community forests (Tiwari 2015). It is advised that agricultural advisory and extension services are the terms of NTFPs collection and utilization which is extended to tribal women, as involvement in crop production and agriculture is related to NTFPs utilization. Also, primary occupation of tribals is farming but by conducting various programs and making policies will increase women's participation in farm and off-farm activities and since income was positively related to NTFPs utilization, cash transfers and other forms of assistance should be provided. Also, required roadways that will assist access to forests as well as the market should be restored or built, since this will increase the sustainable use of NTFPs. It offers a potentially priceless contribution to stable economic conditions (Kaushik 2022). Also, because NTFPs use has a significant impact on well-being, rural women should be provided with extension services on how to use them effectively (Rout 2010); developing various roadways connections that connect rural communities to the nearest markets and forests should be made, as this will facilitate transportation of NTFPs from forests areas to different markets and will improve their lifestyle and facilitating credit access for rural women should be done, as this will help them expand their capital and improve their well-being. Given that the use of NTFPs benefits to women's well-being, policies and programmers aimed at increasing women's use of NTFPs should be implemented.

Sustainable management: Forest resources are in the form of NTFPs which serve a vital role in safeguarding forest inhabitants' socioeconomic and ecological safety nets. Due of its abundance in the forest, people are less aware of the need to preserve it through selective and non-destructive harvesting. (Lestari et al 2023). However, there are currently insufficient instruments and tactics available to effectively control trade, devise development strategies, and promote the sustainable use of NTFPs. In the upcoming years, it will be difficult to build the proper tools and processes for regulating NTFP trading and extraction. (Gopinath et al 2022). According to the findings, practically all forest residents rely on forest products other than timber to varied degrees. By addressing people's socioeconomic, ecological, cultural, and spiritual requirements at the local, national, and global levels, sustainable forest management (SFM) enhances human well-being. In order to promote local livelihoods, integrated SFM increases the value of forests and preserves or improves other significant local or global ecosystem services. Broad environmental and socioeconomic goals should serve as the basis for forest management, which should then use ecosystem-based approaches (EbAs) to manage the entire ecological system in a comprehensive and integrated way. (Kumar et al 2022).

Implementation of sustainable harvesting techniques at the correct time of harvest demonstrated favorable effects on resource preservation, community socioeconomic position, food quality, and financial gains. Our study clearly shows that NTFPs with higher demands are those that are harvested sustainably at the proper stage of maturity (Pandey et al 2016).

For communities in tropical areas, particularly for underdeveloped rural communities, the provision of wild non-timber forest products (NTFPs), such as food, medicines, and cultural ornaments, constitutes an important ecosystem service (Ros-Tonen and Wiersum 2005, Timko et al 2010, Shackleton and Pandey 2014, Van Andel et al 2015, Shackleton et al 2018). For the conservation of tropical NTFPs, a deeper knowledge of the connections between NTFP abundance and plant diversity is crucial because it can be used to find areas where the supply of NTFPs and current efforts to conserve biodiversity can work together, as well as to develop new conservation strategies. (Steur et al 2021). The social sustainability of a system is determined by the motivation of the people involved. Forest department make "Forest Protection Committees" (FPC), and these committees make choices for the diverse challenges that the individuals encounter. Those who make up this society which include women as the weaker sections-the silent groups. Social sustainability is also be recognized, and the societies cultural and structure are protected through significant progress which are accomplished in the district where the tribal communities are motivated for identification with the forest ecosystem where as their intrinsic love and respect for environment which provide us with a solid platform for upliftment and holding the FPC's foundation. As NTFP trade grows, there is a risk of unsustainable exploitation. This problem is made worse by the fact that local communities' ownership and access to NTFPs has rapidly decreased, leaving it as an open-access resource. India's cooperative forest management programmed, in which local people collaborate with the state forest department to share responsibilities and benefits from forests, is a promising step forward. There is little incentive to administer NTFP sustainably unless users are provided access. The close association between women and natural resources is than valid primarily in rural context especially among women of rural areas. For such women the association exists because of their social and economic role which over generations have required them to provide food, water, fuel, fodder and income from surroundings resource base (Saxena 1991). Potentially, one of the most effective and sustainable forest management strategies is the use of NTFPs in forest management and planning (Kargbo et al 2022). Thus, women are providing an important role in sustainable development of community forests. However, their role is neither properly identified nor explored (Tiwari 2015).

CONCLUSION

Participation of tribal women in social, economic and environmental activities contributes to better sustainable use of the forest resources. Involvement of women in NTFPs collection has a wide range of positive effects. The NTFPs play a vital role in improving livelihoods and satisfying the need and requirement of tribal groups, especially women in the fields of food, medicine, and poverty reduction. Non-Timber Forest Products (NTFPs) are the integral and important parts of the forest-based industry and have been long recognized as vital and viable resources for fostering sustainable livelihoods activities, conservation of resources, and developmental capacity. It is extremely important for tribal women residing in tribal zone particularly for those who are living near the forest areas. As in one hand, systematic NTFPs harvesting will expand employment prospects for them. While on the other hand, it may also lessen their anthropogenic pressure from forest which may be an effective way to address the issue of dry-deciduous forest degradation. The promotion and updating of knowledge of NTFPs for community development specially for women folk for poverty reduction, and livelihood, socio-economic betterment in tribal communities is driven by sustainable collection, use, commercialization and continuous updating of knowledge of tribal women regarding collection, cultivation, processing, value addition and marketing system also.

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Morphological and Physical Properties of Bamboo Species in South Gujarat, India

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Abstract: Bamboo, a versatile, fast-growing woody perennial grass is considered as one of the important non-timber forest products. The morphology and physical characteristics of bamboo vary between species and among the culms which influence its utilization pattern for various industrial applications. Total five (4-year-old) culms per clump of six bamboo species *i.e*. *Dendrocalamus strictus*, *D. stocksii*, *D. hamiltonii*, *Bambusa vulgaris* (Green)*, Bambusa balcooa* and *B.bambos* were selected and harvested to study the morphological and physical properties. The highest clump height and internodal length were in *B. vulgaris*, while the maximum clump girth was in *B. balcooa*. Culm mid-diameter and internodal mid-diameter were highest in *B. bambos*. However, the maximum yield per clump recorded in *D*. *strictus* followed by *B. bambos* and *B. balcooa*. The moisture content in each bamboo species varied inversely with basic density. The highest basic density and the lowest moisture content were in *B. balcooa* followed by *B. vulgaris*. The minimum and maximum hollowness proportion was in *D. stocksii* and *B. bambos*, respectively. Based on the morphological and physical properties, *D. strictus* and *B. bambos* performed better for biomass, while *B. vulgaris* and *B. balcooa* showed high basic density. Hence, bamboo culms and their clumps could be characterized by individual growth, biomass and physical variables for further utilization.

Keywords: Clump, Culm, Yield, Moisture content, Basic density

Bamboo, popularly known as 'green gold' is a fast-growing woody perennial grass and an important component of non-timber forest products that plays a key role in many stages of life and culture of people (Pathak et al 2017). The bamboo culms have been extensively used in building constructions, such as scaffoldings, housing roofs, trusses, ceiling, flooring, wall panelling, windows and doors; it is also used as structural materials for making fences, bridges and water-transportation facilities. Furthermore, it has been also processed into innumerable domestic value-added products such as, food containers, skewers, papers, hopsticks, handicrafts, furniture, flooring, boats, weapons, charcoal and musical instruments (Chaowana 2013). Hence, bamboo is called the poor man's timber in rural areas, because of its multipurpose utility in the human life. The individual upper ground part of bamboo is known as culm that comprises most of the woody fibrous material (Jiang and Peng 2007). Culm is the most utilized part of bamboo plant, its diameter tapers from the bottom to the top with the reduction in culm wall thickness (Biswas et al 2011). Bamboo culms have nodes between two internodes, its length, number and form depend on the bamboo species. Internodal length of culm is much shorter towards the base in comparison to internodal length towards the tip of the culm. Internodes of bamboo are generally hollow inside and form bamboo cavities. The culm wall thickness can vary significantly from thin walled to even solid depending on the bamboo species (Anonymous 2023). Bamboo has usually low density and high strength and stiffness compared to other plants (Osorio et al 2011). The properties of bamboo vary between species and along the culm. It is therefore, essential to study the different properties of every bamboo species for the proper end use.

The morphological characteristics such as the culms height, number of internodes per culm, internodal length, internode diameter, culm wall thickness and physical properties *viz*., moisture content, basic density and hollowness are considered as important factors in determining the strength and suitability of bamboo for various applications (Selvan et al 2017). Basic density, moisture content and hollowness proportion of bamboo are important because they reflect the amount of cell-wall materials per unit volume of culms and relate directly to strength properties. (Razak et al 2005). Hence, keeping in view of this, the present investigation was carried out on six important bamboo species such as *Dendrocalamus strictus* (Roxb.) Nees (Manvel or Bharat baans), *Dendrocalamus stocksii* (Munro.) (Goagiri baans), *Dendrocalamus hamiltonii* Gamble (Tama baans), *Bambusa vulgaris* Schrad. ex J.C. Wendl. (Green baans), *Bambusa balcooa* (Roxb.) (Beema baans) and *Bambusa bambos* (L.) Voss (Kantas baans) to evaluate the morphological and physical properties.

MATERIAL AND METHODS

Total 24 clumps of six different bamboo species *viz*., *D. strictus*, *D. stocksii*, *D. hamiltonii*, *B. vulgaris*, *B. balcooa* and *B. bambos* were selected randomly from 7 years old plantations (spacing 3.5m x 3.5m) established at the bambusetum, College of Forestry, Navsari Agricultural University, Navsari for the present study. The area is located at coastal region of South Gujarat at 20°95' N latitude, 75°90' E longitude and at an altitude of 12 m above the mean sea level. The climate of Navsari is tropical warm with fairly hot summer, moderately cold winter and warm humid monsoon with average annual rainfall of about 1600 mm. In the current study, five 4-year-old culms per clump were randomly harvested to evaluate the morphological characteristics such as clump height, clump girth, culm length, culm mid-diameter, internodal length and internodal mid-diameter of entire culm, culm weight and number of culms per clump and the yield per clump and physical characteristics such as moisture content, basic density and hollowness proportion.

The clump girth was measured at 1.5 m from the ground level. The yield per clump was calculated by multiplying average weight of randomly selected five bamboo culms per clump with number of culms in each clump. For measuring the physical properties of bamboo cross-sectional samples from each culm of bamboo species were collected from the internode of bottom (1.5 m from the ground), middle (mid of the entire culm) and top portion at the commercial height and the average value was used for further analysis. The moisture content of cross-sectional bamboo samples was calculated on the oven-dry basis, basic density was calculated by dividing oven-dry weight of the sample by green volume and hollowness was evaluated on the basis of surface area.

The data of all the parameters generated in the study were subjected to the statistical analysis using the statistical software package developed by Sheoran et al (1998).

RESULTS AND DISCUSSION

There was significant variation among the morphological properties of six bamboo species (Table 1). Among six species, the maximum culm weight (10.64 kg) was recorded in *B. bambos* followed by *B. vulgaris* while, the lowest culm weight (2.89 kg) was in *D. stocksii*. The maximum culms per clump (62.00) was in D. *strictus* followed by *D. stocksii* whereas, the minimum culms per clump (12.50) was in *B. vulgaris*. The highest biomass in terms of yield per clump was in *D. strictus* (299.9 kg) followed by *B. bambos* (Fig. 1). The highest clump height (11.25 m) and culm length (8.64 m)

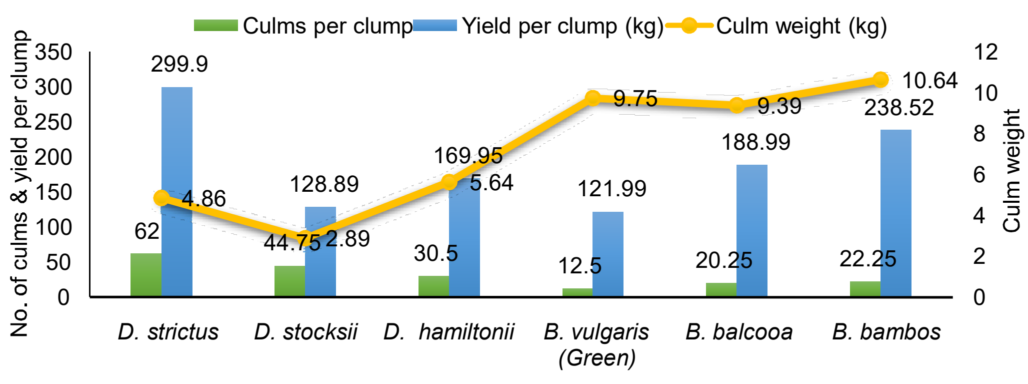

Fig. 1. Variation in culms per clump, culm weight and yield per clump of different bamboo species

Table 1. Variation in culm and clump dimensions of different bamboo species (Mean±SD)

Bamboo species	Clump height (m)	Clump girth (m)	Culm length (m)	Culm mid-diameter (cm)	Internodal length (cm)	Internodal mid-diameter (cm)
D. strictus	10.60±0.35	6.99±0.46	6.86±0.47	2.66±0.17	22.04±1.39	2.70±0.15
D. stocksii	8.99±1.39	5.06±0.34	6.59±0.40	2.03±0.14	27.16±4.51	2.20±0.16
D. hamiltonii	10.45±0.21	4.82±0.48	6.80±0.58	3.07±0.23	24.25±2.50	3.19±0.31
B. vulgaris (Green)	11.25±0.19	4.56±0.23	8.51±1.10	3.65±0.85	27.77±1.35	3.44±0.41
B. balcooa	11.23±0.50	7.38±0.72	8.64±0.89	3.17±0.17	25.82±0.43	3.37±0.23
B. bambos	11.13±0.49	4.71±0.35	6.95±0.74	3.87±0.69	23.48±1.82	4.02±0.73
CD ($p \le 0.05$)	0.98	0.68	1.11	0.71	3.55	0.58

were in *B. vulgaris* and *B. balcooa*, respectively. However, the lowest clump height (8.99 m) and culm length (6.59 m) were in *D. stocksii*. The maximum (7.38 m) and minimum (4.56 m) clump girth was in *B. balcooa* and *B. vulgaris*, respectively. The average mid-diameter of entire culm (3.87 cm) and the average internodal mid-diameter of culm (4.02 cm) were largest in *B. bambos* and smallest in *D. stocksii*. The longest internodal length (27.77 cm) was in *B. vulgaris* and shortest internodal length (22.04 cm) was found in *D. strictus*.

Generally, the clump height, clump girth, culm length, culm diameter, internodal length, internodal mid-diameter, culms per clump, culm weight and yield per clump of bamboo vary from species to species (Kumar et al 2006, Nath et al 2007, Maya et al 2013, Amlani et al 2017, Singh et al 2018). In the present study, the clump height, culm length, culm weight, culm mid-diameter and internodal mid-diameter of *B. balcooa*, *B. vulgaris* and *B. bambos* were higher than other bamboo species. Pathak et al (2015) also reported maximum clump height, culm diameter and culm length in *B. balcooa, B. bambos* and *B. vulgaris* along with *B. tulda*. The maximum clump girth was recorded in *B. balcooa*, followed by *D. strictus* and the minimum clump girth was in *B. vulgaris*. However, Singh et al (2018) reported high clump girth in *B. vulgaris* (13.28 m). This may be due to the large spacing between two clumps and locality factors. Amlani et al (2017) observed long internodal length in *D. stocksii* and *B. vulgaris* and short internodal length in *B. bambos* and *D. strictus* which were similar to the results of present study. The highest biomass in terms of yield per clump was in *D. strictus* due to high number of culms per clump and average culm weight.

Considering the physical properties of bamboo, the moisture content, basic density and hollowness proportion of six bamboo species varied significantly (Table 2). The moisture content in each bamboo species varied inversely with basic density (Fig. 2). Usually, the moisture content of any lignocellulosic material decreases with increase in the basic density of that material or *vice-versa* (Kollmann and Côté 1968, Abd. Latif and Zin 1992). The highest basic density (0.693g/cm^3) and the lowest moisture content (64.58 %) was in *B. balcooa* followed by *B. vulgaris*, while the lowest basic density (0.505 g/cm^3) and high moisture content (121.66 %) was in *B. bambos* followed by *D. hamiltonii*. Similar results were also reported by Guleria et al (2020). Similarly, Singh et al (2018) reported highest basic density in *B. tulda* followed by *B. vulgaris*, *D. strictus* and *B. balcooa*. The minimum hollowness proportion (2.35%) was in *D. stocksii* followed by *D. strictus* (2.90%), whereas the maximum hollowness proportion (27.32%) was in *B. bambos* followed by *B. vulgaris* (24.85%). Singh et al (2018) also

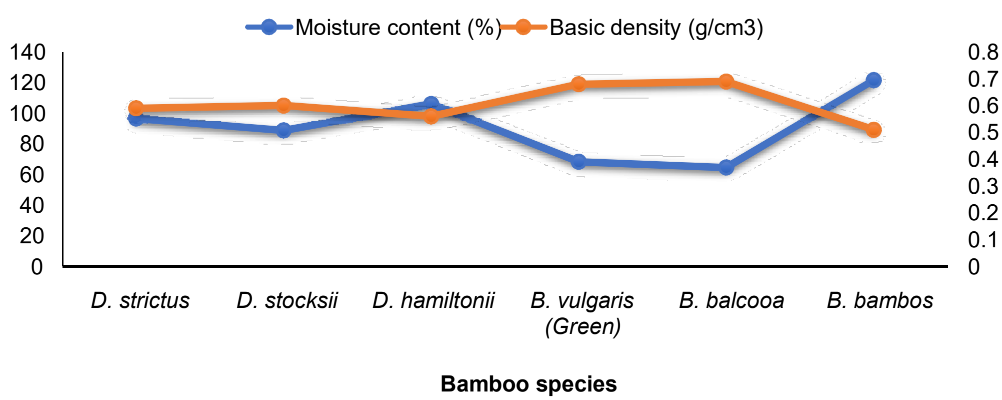

Fig. 2. Moisture content and basic density variation in different bamboo species

Table 2. Variation in physical properties of different bamboo species (Mean±SD)

Bamboo species	Moisture content (%)	Basic density (g/cm^3)	Hollowness (%)
D. strictus	96.63±5.60	0.588±0.03	2.9±3.21
D. stocksii	88.88±4.07	0.599±0.03	2.35±2.09
D. hamiltonii	106.04±3.47	0.559±0.03	11.2±2.17
B. vulgaris (Green)	68.31±3.72	0.679±0.03	24.85±3.10
B. balcooa	64.58±2.62	0.693±0.04	9.05±0.93
B. bambos	121.66±6.87	0.505±0.01	27.32±2.37
CD (p≤0.05)	6.91	0.04	3.64

reported more hollowness in *B. vulgaris, B. tulda* and *B. bambos* and less hollowness in *D. strictus* and *B. balcooa*.

CONCLUSION

Among six selected bamboo species, *D. strictus* and *B. bambos* performed better for biomass in terms of yield per clump in south Gujarat. Considering the physical properties, *B. vulgaris* and *B. balcooa* showed higher basic density than rest of the bamboo species. Hence, bamboo culms and their clumps could be characterized by individual growth, biomass and physical attributes for further utilization.

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Forest Ecosystem Soil Attributes Influence Density of *Pseudomonas fluorescens*

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Abstract: *Pseudomonas fluorescens* is a common, multi-flagellated, Gram-negative, rod-shaped bacteria, which are anti-phytopathogenic and plant growth promoting rhizo-bacteria. Study was conducted at the College of Forestry, Sirsi with the objective of measuring the bacterial copiousness in ten different forest and plantation ecosystem *i.e.,* evergreen, semi evergreen, moist deciduous, dry deciduous, myristica swamp, mangroves, scrub forest, teak, Acacia and Eucalyptus plantation; and correlated with different soil parameter *viz.,* soil p^H, electrical conductivity (EC) and soil moisture percentage (SMP). In each ecosystem plots were laid randomly; soil samples and site description were collected. *P. fluorescens* was isolated using Kings B agar as the selective media. Gram's reaction and morphological characterization were used to identify bacterial isolates. Myristica swamp had the highest 99,311.60 CFU/gm (4.997 Log (CFU/gm) bacterial abundance, followed by evergreen (4.937) and semi-evergreen (4.913). Myristica swamps with a p^H of 5.03 showed the highest levels of soil acidity, mangroves had the highest electrical conductivity (0.195 dSm^{-1}). The highest percentage of soil moisture was found in mangrove Forest (142.67%). Soil pH was negatively correlated with *P. fluorescens* abundance (r = -0.376) and soil electrical conductivity was positively correlated (r = 0.238). p^H and bacterial density were inversely correlated; EC, SMP and canopy density were directly related to bacterial density in sequentially sere ecosystems, *viz.,* Dry deciduous, Moist deciduous, Semi-evergreen, and Evergreen forests.

Keywords: *Pseudomonas fluorescens*, Density, Soil pH, Electrical conductivity, Soil moisture

Bacteria are common, largely free-living organisms that only have one biological cell. They make up a significant portion of the prokaryotic microbial world and are among the primordial life forms on earth and are typically a few micrometres in length. They can be found in most of its habitats. Gram-negative, rod-shaped *P. fluorescens* is a typical bacterium. *P. fluorescens* is a member of the *Pseudomonas* genus and has multiple flagella. It is abundant in soil and water. According to Deshwal et al (2003, 2011, 2013), plant growth promoting rhizobacteria (PGPR) are a group of bacteria that actively colonise plant roots and promote plant growth by producing a variety of plant growth hormones, P-solubilizing activity, nitrogen fixation, and biological activity. There are just a few strains of well-known PGPRs from genera including *Pseudomonas*, *Azospirillium, Azotobacter, Bacillus, Burkholderia, Enterobacter, Rhizobium, Erwinia,* and *Flavobacterium.* Some *P. fluorescens* strains, such CHA0 or Pf-5, exhibit biocontrol capabilities that shield some plant species roots against parasitic fungi like *Pythium* and *Fusarium* as well as some phytophagous nematodes.

P. fluorescence is a versatile microorganism with a major role in the environment. It is the potent biocontrol agent that protects the crop from various diseases caused by the pathogens (Ganeshan and Manoj 2005) and enhances the crop yield by facilitating the nutrient uptake and inducing systematic resistance (Vleesschauwer et al 2008) in the plants. This bacteria can degrade a wide range of organic pollutants, including hydrocarbons, pesticides, and polychlorinated biphenyls (Gutiérrez et al 2020). This ability makes them useful tools for cleaning up contaminated soil and water. The sensitivity of these bacteria to pollutant and environmental changes makes them good environmental health indicators (Nielsen and Winding 2002), and soil is a significant life support system; healthy soils are crucial for healthy development of the plant (Lehmann et al 2020). Several beneficial microorganisms ensure the soil's health and food security; *Pseudomonas* bacteria is one of them. Hence, the presence of this bacteria in the soil can be associated with the health of the soil. Absence or low abundance of these *P. fluorescences* is associated with degradation of soil health.

MATERIAL AND METHODS

Soil Sample was collected from Evergreen, Semi evergreen, Moist deciduous, Dry deciduous, Myristica swamp, Mangroves, Scrub Forest, Teak, Acacia, and Eucalyptus plantation ecosystems of Karnataka. In each forest ecosystem 3 plots (30m×30m) laid randomly in each ecosystem. Soil sampling was carried out (Parewa et al 2016) and plot descriptions such as canopy density, elevation, litter depth were recorded. Location description of sample collection site was depicted in Table 1. Lab was

Table 1. Descriptive field data of soil sampling plots (* Water depth in mangrove ecosystem)

Forest type	Sample tag	Area	Latitude and longitude	Canopy density (%)	Litter depth (cm)
Evergreen	EGP1	Gerusoppa Range, Honnavara Division, Canara Circle	14° 16' 42.83"N 74° 42' 55.44"E	85.05	1.8
	EGP2	Gerusoppa Range, Honnavara Division Canara Circle	14° 16' 52.71"N 74° 42' 53.42"E	86.5	2
	EGP3	Gerusoppa Range, Honnavara Division Canara Circle	14° 16' 54.55"N 74° 42' 49.81"E	84	2.2
Semi evergreen	SEGP1	Koppa Range, Koppa Division Chikkamagaluru Circle	13° 32' 05.22"N 75° 24' 31.52"E	83.5	1.8
	SEGP2	Siddapura Range, Sirsi Division Canara Circle	14° 16' 01.26"N 74° 48' 44.52"E	84.5	2.2
	SEGP3	Siddapura Range, Sirsi Division Canara Circle	14° 15' 36.82"N 74° 48' 30.04"E	85.5	1.4
Moist deciduous	MDP1	Banavasi Range, Sirsi Division Canara Circle	14° 34' 04.39"N 74° 56' 49.69"E	87.15	2.6
	MDP2	Banavasi Range, Sirsi Division Canara Circle	14° 39' 57.39"N 74° 52' 34.70"E	77.5	1.9
	MDP3	Banavasi Range, Sirsi Division. Canara Circle	14° 42' 19.38"N 74° 56' 51.91"E	84	1.6
Dry deciduous	DDP1	Katur Range, Yellapura Division Canara Circle	14° 45' 56.60"N 75° 01' 18.33"E	75.75	2.5
	DDP2	Katur Range, Yellapura Division Canara Circle	14° 49' 06.01"N 75° 02' 11.44"E	72.5	1.4
	DDP3	Mundgod Range, Yellapura Division Canara Circle	14° 53' 06.65"N 75° 01' 58.36"E	76.25	2.3
Myristica swamp	MYS1	Siddapura Range, Sirsi Division Canara Circle	14° 16' 26.60"N 74° 44' 50.66"E	88.5	2.8
	MYS2	Siddapura Range, Sirsi Division Canara Circle	14° 16' 21.81"N 74° 44' 40.88"E	83.75	3.8
	MYS3	Siddapura Range, Sirsi Division Canara Circle	14° 16' 23.75"N 74° 44' 43.91"E	85.25	3.2
Mangroves	MGP1	Honnavara Range, Honnavara Division Canara Circle	14° 15' 44.12"N 74° 26' 23.71"E	83	8.2*
	MGP2	Kumta Range, Honnavara Division Canara Circle	14° 25' 00.87"N 74° 24' 26.08"E	73	1.25*
	MGP3	Kumta Range, Honnavara Division Canara Circle	14° 27' 47.51"N 74° 23' 22.47"E	69	0.50*
Scrub	SFP1	Sirsi Range, Sirsi Division Canara Circle	14° 35' 44.46"N 74° 50' 38.83"E	0	0
	SFP2	Sirsi Range, Sirsi Division Canara Circle	14° 36' 46.22"N 74° 50' 42.80"E	0	0
	SFP3	Sirsi Range, Sirsi Division Canara Circle	14° 35' 50.50"N 74° 51' 03.93"E	19	0
Teak plantation	TPP1	Katur Range, Yellapura Division Canara Circle	14° 52' 38.59"N 75° 01' 57.09"E	72.5	4
	TPP2	Katur Range, Yellapura Division Canara Circle	14° 52' 28.78"N 75° 02' 03.91"E	77.25	2.4
	TPP3	Katur Range, Yellapura Division Canara Circle	14° 15' 22.72"N 75° 02' 11.95"E	71	0
Acacia plantation	APP1	Sirsi Range Sirsi Division Canara Circle	14° 35' 49.09"N 74° 50' 45.78"E	26.25	1.9
	APP2	Sirsi Range Sirsi Division Canara Circle	14° 35' 53.52"N 74° 50' 58.23"E	53.75	2.8
	APP3	Sirsi Range Sirsi Division Canara Circle	14° 35' 47.10"N 74° 50' 51.60"E	64	3.5
Eucalyptus plantation	NPP1	N R Pura Range, Koppa Division Chikkamagaluru Circle	13° 33' 58.00"N 75° 27' 09.00"E	62.5	2.3
	NPP2	N R Pura Range, Koppa Division Chikkamagaluru Circle	13° 34' 21.00"N 75° 27' 22.20"E	58.25	1.7
	NPP3	N R Pura Range Koppa Division Chikkamagaluru Circle	13° 34' 12.58"N 75° 27' 27.38"E	53.5	2.5

disinfected with 4 percent formalin solution at 50^0C**.** 42.23 grams of Kings B media (readymade dehydrated media) was mixed with 1000 ml of distilled water and heated to boil. All the glassware and media needed for plating sterilized with autoclave in 121^0C at 15 psi pressure.

Preparation of Soil dilutions and spread plates for bacterial culture: 10 g of soil sample added to conical flask containing 90 ml of distilled water. Suspension stirred well and labelled as A. Six 9ml water blank was prepared, before the soil settles, 1 ml of the suspension was removed with a sterile pipette from suspension A and transferred it to a 9-ml distilled water blank. Shaken it well and given label as “B”. This dilution was repeated five times, each time with 1 ml of the previous suspension and 9-ml distilled water blank. These Labelled sequentially as tubes C, D, E and F. This results in serial dilutions of 10^{-1} through 10^{-5} grams of soil per ml (Deshwal and Punkaj Kumar 2013) liquefied Kings B media (KBM) poured into petri plate. 0.1 ml of a serial diluted suspension solution pipetted out and spreaded on the petri plate from 10^{-3},10^{-4} and 10^{-5} dilution for each ecosystem plot soil and petri plate were sealed with cling film. All these operations carried out inside the laminar air flow under sterile condition. Culture plates were Incubated in biochemical oxygen demand (BOD) incubator for 48 - 72 hours at 28 ±2°C colonies developed in the culture plate were enumerated with digital colony counter through morphological characterization. For Gram's staining clean, grease free slide was taken. Smear of suspension prepared on the clean slide with a loopful of sample and air drying, heat fixing was carried out, Gram's crystal violet was poured and kept for about 2 minutes and rinsed with water. Gram's iodine flooded for 1 minute and washed with water. Then, washed with Gram's decolourizer for about 10-20 seconds and rinsed the slide with water. Safranin, 0.5% w/v was added after 1 minute and washed with water. Air dried and observed under microscope.

Determination of soil pH, EC and Soil moisture percentage: To determine soil p^H and Electrical conductivity (EC) 20gm of soil weighted in a clean 100ml beaker and 50ml of distilled water was added. Suspension was stirred intermittently for 30 min. p^H recorded using p^H meter. Suspension allowed to settle for an hour, EC was measured in the supernatant solution by using EC Bridge. Soil moisture content estimated by using gravimetric method.

CFU per g of soil

$$\frac{\text{No of colonies}}{\text{Wg of soil sample}} \times \text{Dilution factor} \times \frac{1}{\text{Aliquot}}$$

Soil moisture percentage

$$\text{Soil moisture (\%)} = \frac{\text{Wg of wet soil} - \text{Wg of dry soil}}{\text{Wg of dry soil}}$$

RESULTS AND DISCUSSION

Variation of canopy density (Fig. 1) and litter depth (Fig. 2) across different study plots shows wide fluctuation. The canopy density varied from zero to 88.5 per cent where in Scrub land (SFP1 and SFP2) records zero canopy density and Myristica swamps records highest canopy density (88.5 %). The litter depth varied from zero to 8.2 cm wherein Scrub land (SFP1, SFP2 and SFP3) records zero litter depth and mangroves (MGP1) records highest litter depth of 8.2 cm.

The variation of *P. fluorescence* bacterial density in ten different forest and plantation ecosystems and its relation with soil pH, electrical conductivity and moisture percentage is presented in Table 2. The highest abundance of *P. fluorescens* observed in Myristica Swamp (99,311.60 CFU/gm and 4.997 Log CFU/gm) followed by Evergreen, Semi-evergreen, Moist deciduous, Dry deciduous, Eucalyptus plantation, Mangroves, Acacia plantation, Scrub Forest and Lowest was observed in Teak plantation (5,128.61 CFU/gm and 3.710 Log CFU/gm) (Fig. 3). Highest soil p^H recorded in Mangroves (6.497) and lowest was in Myristica Swamp (5.030) (Fig. 4). Highest electrical conductivity was in Mangroves (0.195dSm^{-1}) and lowest was observed in Scrub Forest (0.044dSm^{-1}) along with Teak plantation (0.044dSm^{-1}) (Fig. 5). Maximum soil moisture percentage was observed in Mangroves (142.673%) and lowest was observed in Scrub Forest (Fig. 6).

Study revealed that Myristica swamp ecosystem having lowest p^H(5.030) with highest bacterial abundance 4.667 Log CFU/gm of soil and Mangrove Forest having Highest p^H comprising bacterial abundance 4.047 Log CFU/gm. Soil p^H was negatively correlated (Rousk et al 2009) with *P. fluorescens* bacterial abundance (r = -0.376) between the P^h range of 5.030 to 6.497 and 14.13% of variation in bacterial density is due to variation in soil p^H (Coefficient of Determination r^2 = 0.141) and the correlation was statistically significant. Mangrove Forest having Highest EC (0.195dSm^{-1}) comprising bacterial abundance 4.047 Log CFU/gm. Scrub and teak plantation having lowest soil EC (0.044 dSm^{-1}) with bacterial abundance 3.710 and 3.913 log CFU/gm respectively. Soil electrical conductivity was positively

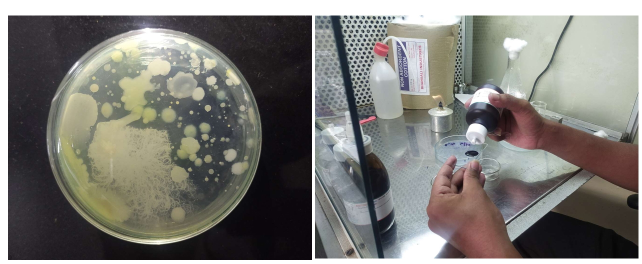

Plate 1. *Pseudomonas fluorescence* bacterial growth in KBM culture plates and Gram's staining

correlated with bacterial abundance (r = 0.238) with 5.66% of variation in bacterial density is due to variation in soil electrical conductivity (r^2 = 0.0566) and the correlation was statistically significant. Mangrove ecosystem having highest 142.67 SMP with bacterial abundance 4.047 Log CFU/gm and scrub forest contains lowest 15.22 SMP with lowest bacterial abundance 3.933 Log CFU/gm. In the monocultured plantations have lower bacterial population than in natural forest (Liu et al 2018) even its established in midst of natural forest. In sequential sere ecosystem *i.e.,* Dry

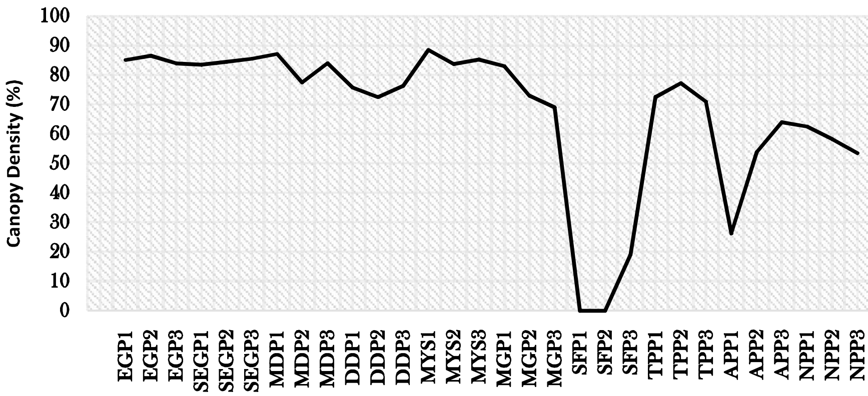

Fig. 1. Variation of canopy density across different sample plots

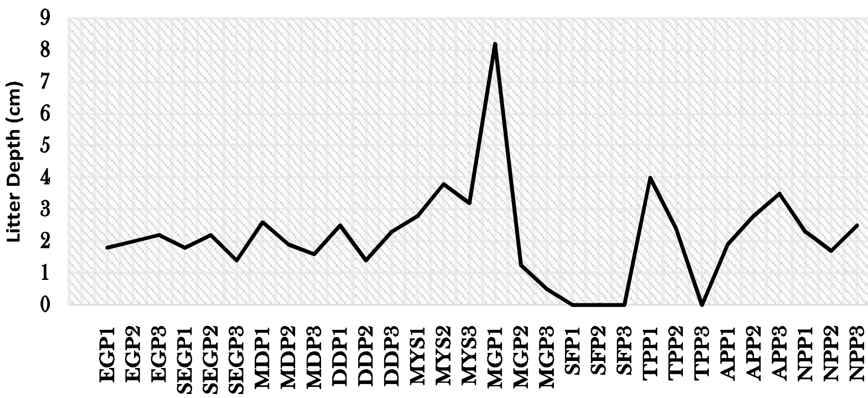

Fig. 2. Variation of Litter depth across different sample plot (Water depth in mangrove ecosystem *i.e.,* MGP1, MGP2 and MGP3)

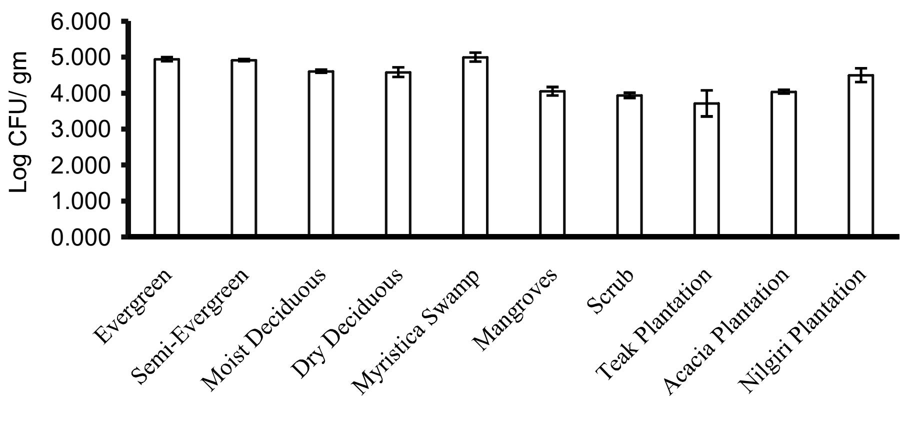

Fig. 3. Variation in mean bacterial density across different forest and plantation ecosystem (Error bars indicate 5% Standard error)

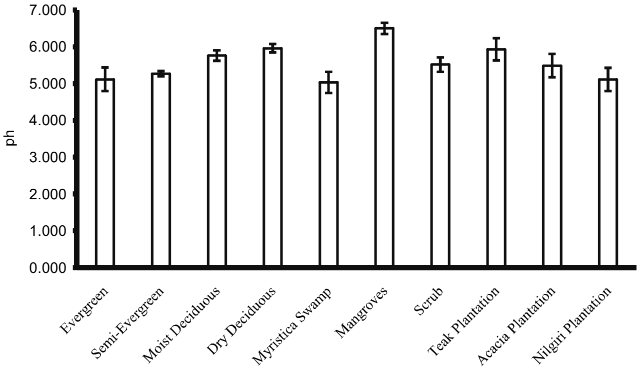

Fig. 4. Variation in mean soil pH across different forest and plantation ecosystem (Error bars indicate 5% Standard error)

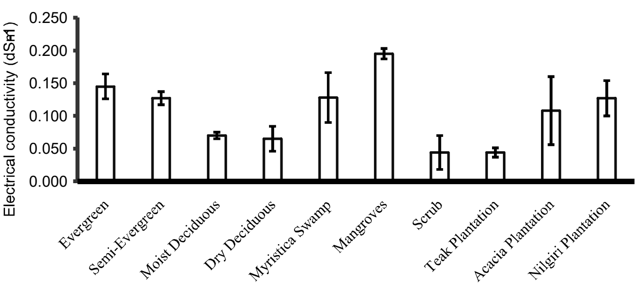

Fig. 5. Variation in mean soil electrical conductivity (dSm^{-1}) across different forest and plantation ecosystem (Error bars indicate 5% Standard error)

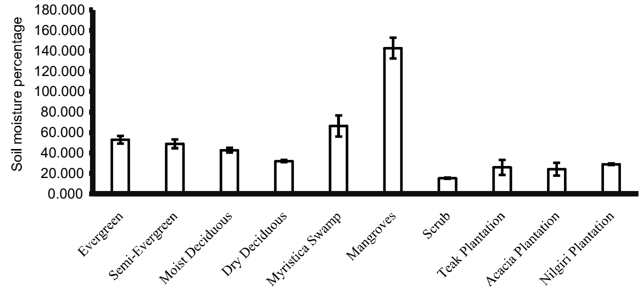

Fig. 6. Variation in mean soil moisture percentage across different forest and plantation ecosystem (Error bars indicate 5% Standard error)

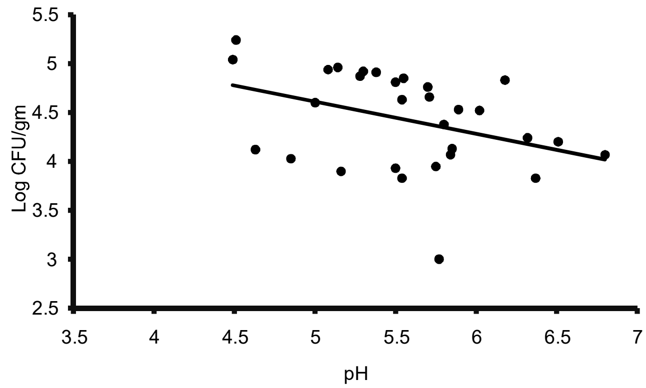

Fig. 7. Variation in bacterial abundance (Log CFU/gm) across different forest soil pH ($r = -0.376, r^2 = 0.141, p = < 0.01$)

Table 2. Variation of *P. fluorescence* bacterial density across different forest ecosystems with soil pH, electrical conductivity and moisture percentage

Ecosystem	Champion and Seth Forest Classification (Khanna 2015)	CFU/ gm	Log (CFU/ gm)	p^H	EC (dS/m)	Moisture percentage (%)
Evergreen	Southern Tropical Wet Evergreen Forest (1A)	86,496.79	4.937	5.113	0.145	52.883
Semi-Evergreen	Southern Tropical Semi-Evergreen Forest (2A)	81,846.48	4.913	5.267	0.127	48.937
Moist deciduous	Southern Tropical Moist Deciduous Forest (3A)	40,086.67	4.603	5.757	0.070	42.657
Dry deciduous	Southern Tropical Dry Deciduous Forest (5A)	38,018.94	4.580	5.957	0.065	32.107
Myristica Swamp	Myristica Swamp Forest ($4C/FS_1$)	99,311.60	4.997	5.030	0.128	66.320
Mangroves	Mangrove Forest ($4C/TS_2$)	11,142.95	4.047	6.497	0.195	142.673
Scrub	Southern Tropical thorn Forest (6A)	8,570.38	3.933	5.513	0.044	15.223
Teak plantation	-	5,128.61	3.710	5.927	0.044	25.770
Acacia plantation	-	10,889.30	4.037	5.483	0.108	24.157
Eucalyptus plantation	-	31,117.16	4.493	5.110	0.127	29.040
Mean (±SE)	-	-	4.425 ± 0.152	5.565 ± 0.24	0.105 ± 0.026	47.9767 ± 5.842
C.V.	-	-	5.94	7.463	42.053	21.09
C.D	-	-	0.451	0.712	0.076	17.355
SE(d)	-	-	0.215	0.339	0.036	8.261

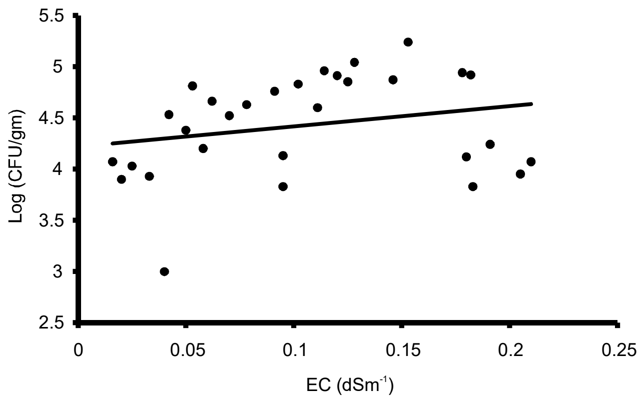

Fig. 8. Variation in bacterial abundance (Log CFU/gm) across different forest Soil electrical conductivity (dSm^{-1}) ($r = 0.238$, $r^2 = 0.0566$, $p = < 0.01$)

deciduous, Moist deciduous, Semi-evergreen and Evergreen Forest bacterial density inversely related with pH and directly related with Electrical conductivity, soil moisture percentage and canopy density. These soil properties are known to influence soil flora directly or indirectly, fauna, tree species (Rodrigues et al 2018) abundance and diversity in respective niche and ecosystems.

There are billions of soil microorganisms resides in soil. Biodegradation of pollutants, maintenance of soil structure, and circulation of biogenic elements which makes nutrients available to plants are all services supported by bacteria's (Furtak and Gajda 2018). Some are even PGPR as well as anti-phyto-pathogenic in nature. Loss of soil biodiversity is major problem due to excessive use of inorganic fertilizers, weedicides, fungicides *etc.,* (Bishtand Chauhan 2020). As the forest soils are having least anthropogenic intrusion when compared to agriculture and industrial soils. Based on studies on beneficial microbial abundance in these ecosystems minimum typical benchmark bacterial abundance can be determined and which can be retained as yardstick to measure the microbial abundance to decide health of soil. The presence of microorganisms in soil depends on their chemical composition, moisture, p^H, and structure. Many factors *viz.,* chemicals secretion, secondary metabolites (litter), decomposition, insolation *etc.,* might have influenced on bacterial density and p^H (Furtak and Gajda 2018).

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CONCLUSION

Conservation of soil health is major concern of the century and microorganisms are integral part of soil many beneficial microorganisms ensure the soil health and food security. *P. fluorescens* is one such among beneficial bacteria. *P. fluorescens* bacterial profusion varies from 99,311.60 to 5,128.61 Log CFU/gm of different forest soils. Based on present study minimum representative bacterial population can be determined which can be retained as standard to measure soil biological health status of soil.

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Melia dubia Fodder Phytochemicals: Non-Targeted Gas-Chromatography Mass-Spectrometry (GC-MS) Analysis and Corroboration for Biological Activities

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***Abstract*:** *Melia dubia* of Meliaceae family is an important agroforestry tree species indigenous to the Western Ghats region in India and is common in moist deciduous forests of south Gujarat. It has chemically diverse and structurally complex active phytochemicals with no allelopathic influence on understory crops. In present study, total 93 volatile phytochemical compounds were detected from *M. dubia* leaves from different locations of south Gujarat region in nontargeted gas-chromatography mass-spectrometry (GC-MS) analysis. The detected compounds are known to have antimicrobial, antifungal, antioxidant, anti-inflammatory, insecticidal, nematicidal, antibacterial, antiviral and other various biological properties which are beneficial to humans and animals as well.

Keywords: *Melia dubia,* GC-MS, Volatile phytochemical, Biological properties

The interest in natural products from plants and their use has increased tremendously in indigenous and unconventional plants to study bio compounds which may be beneficial to mankind (Achi et al 2017). *Melia dubia* of Meliaceae family is a large deciduous perennial tree growing from 6 to 30 meters in height. The species is indigenous to the Western Ghats region in India and is common in moist deciduous forests of the Indian states from Kerala to Gujarat (Saravanan et al 2013). *M. dubia* showed high potential as a raw material for pulp and paper industries (Sinha et al 2019) and is being planted under industrial agroforestry models. It is also reported to be an acceptable agroforestry species (Mohanty et al 2017 , Thakur et al 2018) with no allelopathic influence on understory crops (Thakuret al 2017 , Parmar et al 2019). Leaves and fruits of *M. dubia* possess a vast array of biologically active compounds which are chemically diverse and structurally complex (Paritala et al 2015, Parmar et al 2019, Sukhadiya et al 2021). Traditionally different plant part of species used as herbal medicines, such as anthelmintics, in treatment of leprosy, eczema, asthma, malaria, fevers and venereal diseases, as well as cholelithiasis, acariasis and pain (Murugesan et al 2013b). The study was conducted to unveil the various phytochemicals of *M. dubia*from south Gujarat region.

MATERIAL AND METHODS

The leaf samples of *M. dubia* were collected from distantly located eight different locations in Satpura and Shyadri ranges of Northern Western ghats in Gujarat. Various phytochemicals were detected through GC-MS partly following Murugesan et al (2013b), and Sukhadia et al (2021) as under:

One gm of the powdered sample was extracted using Hexene: Acetone (1:1) solvent in centrifuge tube and after 72 hrs of incubation the homogenate centrifuged for 20 min. at 3500 rpm and supernatant was collected. Pinch of activated charcoal was added to treat chlorophyll content. 2 ml of supernatant was collected in pre cleaned glass test tube and evaporated using cold nitrogen air drier. After drying 2 ml ACN solution was added to test tube, vortex for 2-3 min and sonicate for 2 min. The content was then filtered using injection and disk filter in to 2 ml glass sampling vile. Reading was taken in GC-MS (Thermo make trace GC ultra – ITQ 900).The GC-MS analysis was carried out on Thermo make Trace GC-ULTRA-ITQ 900 with fused silica capillary column (Rx-1-5MS) of 30 m length, 0.25 internal diameter and 0.25 µm film thickness. The injection volume was 1µl and the total run time of the sample was 33.00 minutes. Three samples per location were injected for GC-MS analysis. Total of 93 different phytochemicals were detected from the *M. dubia* leaves and out of that 20 important phytochemicals are described in this paper and corroborated for their biological activities with other studies.

RESULTS AND DISCUSSION

Non targeted gas-chromatography mass-spectrometry (GC-MS) analysis of *M. dubia* leaves from different locations of south Gujarat region revealed array of total 93 volatile phytochemical compounds (Fig. 1). Mudhafar et al (2020) reported 22 phytochemical compounds from *M. dubia* leaves using GC-MS analysis. Parmar et al (2019) reported 18 different types of phytochemicals in leaf litter of *M. dubia* through GC-MS analysis whereas; Sukhadiya et al (2022) mentioned 27 phytochemicals from fruit pulp. Murugesan et al (2013b) also reported 42 phytochemicals from the *M. dubia* leaves. Jahirhussain et al (2015) identified 33 phytochemicals as constituents with more than one peak area for 7 compounds from ethanolic leaf extract of *M. composita* using GC-MS method. Compound formula, molecular weight and peak area percentage (concentration) of the selected compounds are presented in Table 1.

Important volatile phytochemicals identified in *M. dubia* during the study have been corroborated with available literature. It is found that many of the compounds detected in *M. dubia*, in present study (Table 1), have been reported in other plant species and have one or the other beneficial biological activities (Table 2). The most common phytochemicals detected werel-(+)-Ascorbic acid 2,6-dihexadecanoate also known as vitamin C is beneficial in common cold, gum disease, acne and other skin infections, bronchitis, stomach ulcers, tuberculosis, dysentery, boils and wounds, to prevent glaucoma, cataracts, gallbladder disease, dental cavities, constipation, hay fever, asthma, arthritis, back pain, diabetes, chronic fatigue syndrome, osteoporosis and boosting the immune system, antioxidant in the skin (Nazir et al 2021 and Okenwa and Okwunodulu 2014); Phenol,2,4-bis(1,1-dimethylethyl)-,phosphite (3:1) is alkylbenzene which act as antibacterial and is a moderate cytotoxic (Ren et al 2019, Elgorban et al 2019 and Alwar et al 2014); dl-a-Tocopherol commonly known as vitamin E is an antioxidant (Wojdyłoet al 2021). Docosanal proved to be effective in treating recurrent herpes simplex labialis episodes (Shankar et al 2022) and 2,4-Di-tert-butylphenol have antioxidant, anti-inflammatory, insecticidal, nematicidal, antibacterial, antiviral and antifungal effect in various plants(Murugesan et al 2013b and Zhao et al 2020). The 3, 7, 11, 15-Tetramethyl-2-hexadecen-1-ol also exhibits anti-inflammatory, anti-diuretic, antioxidant and hypo-cholesterolemic properties (Mujeeb et al 2014, Hamid et al 2016). The Phytol is a constituent of chlorophyll and after fermentation it converted to phytanic acid and stored in fats (Murugesan et al 2013b, Hamid et al 2016 , Hossain et al 2013) (Table 2).

Table 1. Important phytochemicals detected in *M. dubia* leaf from south Gujarat, India

Compound	Formula (Molecular weight)	Peak area %
10-Heneicosene (c,t)	$C_{21}H_{42}$ (294.55)	3.92
1-Hexadecanol	$C_{16}H_{34}O$ (242.44)	4.96
2,4-Di-tert-butylphenol	$C_{14}H_{22}O$ (206.32)	12.79
2-Pentadecanone, 6,10,14-trimethyl-	$C_{18}H_{36}O$ (268.47)	3.96
3,7,11,15-Tetramethyl-2-hexadecen-1-ol	$C_{20}H_{40}O$ (296.53)	11.02
9,12,15-Octadecatrienoic acid, (Z,Z,Z)-	$C_{19}H_{32}O_2$ (278.42)	8.92
dl-a-Tocopherol (Vitamin E)	$C_{29}H_{50}O_2$ (416.68)	13.45
Docosanal	$C_{22}H_{44}O$ (326.61)	0.92
Eicosane	$C_{20}H_{42}$ (282.54)	2.69
Ethanol, 2-(dodecyloxy)-	$C_{14}H_{30}O_2$ (230.39)	2.50
Fumaric acid, cis-hex-3-enyl tetradecyl ester	$C_{24}H_{42}O_4$ (280.36)	0.01
Hexadecanal	$C_{16}H_{32}O$ (256.42)	0.53
l-(+)-Ascorbic acid 2,6-dihexadecanoate (vitamin C)	$C_{38}H_{68}O_8$ (652.9)	18.14
Neophytadiene	$C_{20}H_{38}$ (278.5)	9.87
Nonadecane, 2-methyl-	$C_{20}H_{42}$ (282.5)	5.21
n-Tetracosanol-1	$C_{24}H_{50}O$ (354.65)	2.87
n-Hexadecanoic acid (Palmitic acid)	$C_{16}H_{32}O_2$ (256.42)	1.74
Octadecanoic acid (Stearic acid)	$C_{18}H_{36}O_2$ (284.48)	4.23
Phenol, 2,4-bis(1,1-dimethylethyl)-, phosphite (3:1)	$C_{42}H_{63}O_3P$ (646.92)	13.83
Phthalic acid, hept-4-yl isobutyl ester	$C_{19}H_{28}O_4$ (320.4)	1.41
Squalene	$C_{30}H_{50}$ (422.8)	1.08

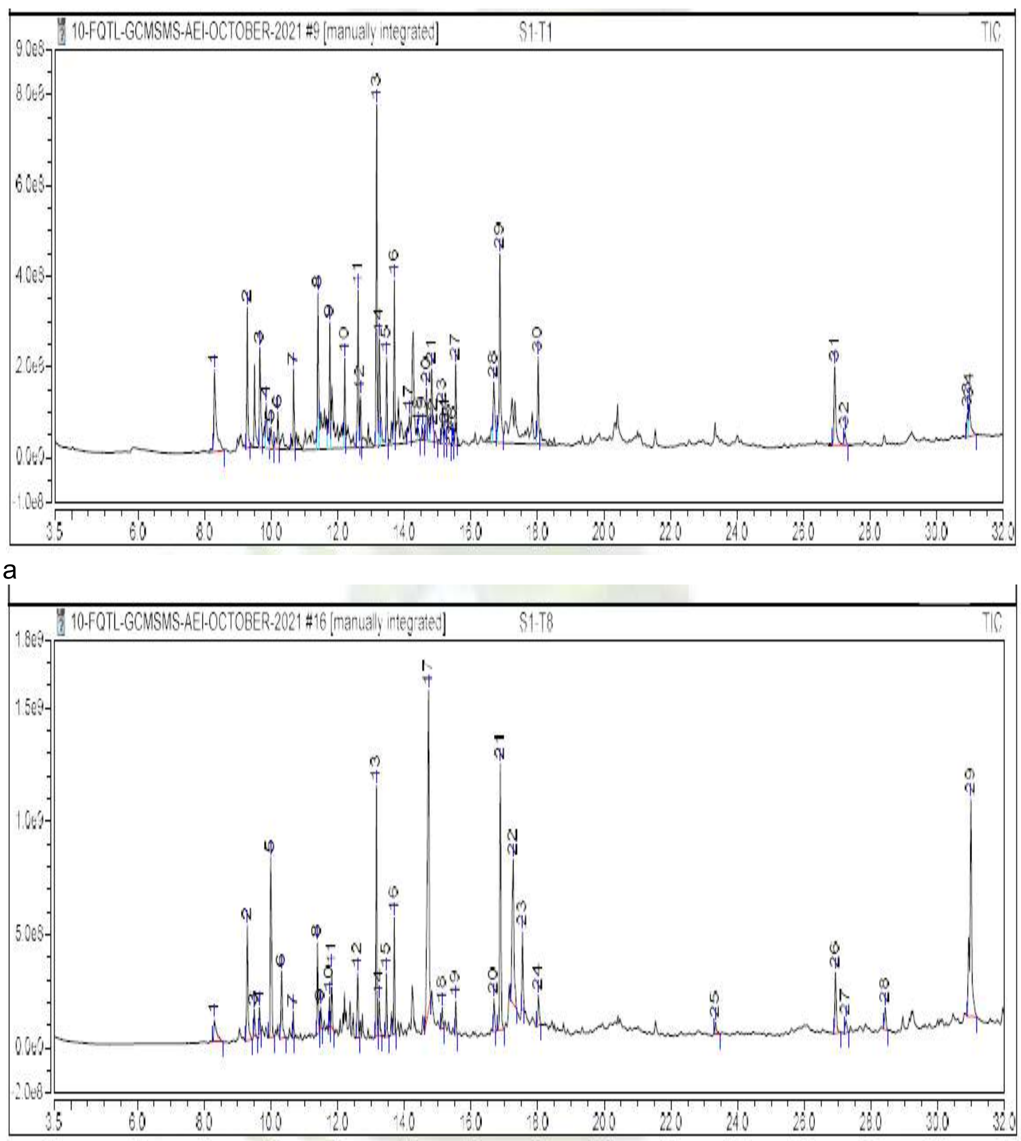
Table 2. Corroboration of *M. dubia* phytochemicals detected in present study for their beneficial biological activity

Compound	Phytochemical reported in other plants	Reported beneficial biological activity	Reference
10-Heneicosene (c,t)	*Luisia tenuifolia*	Pheromone, Antifungal	Sethuraman et al (2022)
1-Hexadecanol	*Memecylon umbellatum, Enhalusa coroides*	Antioxidant	Murugesan and Panneerselvam (2013a) Amudha et al (2018)
2,4-Di-tert-butylphenol	*M. dubia, Carica papaya Terminalia travancorensis Juglans regia, Albizia julibrissin, Eucalyptus globulus*	Antioxidant, Anti-inflammatory, insecticidal, nematicidal, antibacterial, antiviral and antifungal	Murugesan et al (2013b) Zhao et al (2020)
2-Pentadecanone, 6,10,14-trimethyl-	*Azadirachta indica, E. acoroides*	Hypocholesterolemic, antioxidant and lubrication	Kumar et al (2018) Amudha et al (2018)
3,7,11,15-Tetramethyl-2-hexadecen-1-ol (Phytol)	*Grewia pubescens, Aegle marmelos*	Anti-inflammatory, anti-diuretic, Antioxidant and hypo-cholesterolemic A constituent of chlorophyll, after fermentation converted to phytanic acid and stored in fats.	Hamid et al (2016) Mujeeb et al (2014) Murugesan et al (2013b) Hossain et al (2013)
9,12,15-Octadecatrienoic acid, (Z,Z,Z)-	*A. indica, A. occidentale, P. guajava, T. catappa, Salvadora persica, Silybum marianum*	Anticancer, anti-inflammatory, antibacterial, antioxidant	Balasubramanian et al (2014) Chikezie et al (2020), Bratty et al (2020), Padma et al (2019)
dl-a-Tocopherol (Vitamin E)	*Prunus armeniaca P. persica, P. domestica Malus domestica*	*Antioxidant*	Wojdyło et al (2021)
Docosanal	*Rhus chinensis*	Recurrent herpes simplex labialis episodes	Zhu et al (2007) Shankar et al (2022)
Eicosane	*Trichilia connaroides*, *Gymnema sylvestre*	Bronchodilators, Drug for throat disorder	Senthilkumar et al (2012) Subramanian et al (2020)
Ethanol, 2-(dodecyloxy)-	*T. connaroides*	Sclerosing agent for the treatment of esophageal and gastric varices and varicose veins	Senthilkumar et al (2012)
Fumaric acid, cis-hex-3-enyl tetradecyl ester	*Uncaria sessilifructus*	Food additive, to treat the autoimmune condition psoriasis and multiple sclerosis, feed additive to lower methane production	Wang and Huang (2012)
Hexadecanal	*Abutilon pannosum*, *Grewia tenax*	Reduce aggression, anthelmintic	Aadesariya et al (2017) Mishor et al (2021)
l-(+)-Ascorbic acid 2, 6-dihexadecanoate (vitamin C)	*Elaeagnus umbellate, Phyllanthu samarus*	Preventing and treating common cold, gum disease, acne and other skin infections, bronchitis, stomach ulcers, tuberculosis, dysentery, boils and wounds. To prevent glaucoma, cataracts, gallbladder disease, dental cavities, constipation, hay fever, asthma, arthritis, back pain, diabetes, chronic fatigue syndrome, osteoporosis and boosting the immune system.	Nazir et al (2021) Okenwa and Okwunodulu (2014)
Neophytadiene	*A. pannosum, G. tenax, Plectranthus amboinicus, Eupatorium odoratum*	Sesquiterpenoids, an anti-inflammatory agent, a plant metabolite and an algal metabolite. analgesic, antipyretic, antimicrobial, and antioxidant	Aadesariya et al (2017) Swamy et al (2017) Raman et al (2012)
Nonadecane, 2-methyl-	*A. pannosum, G. tenax T. connaroides*	Alkanes, antioxidant	Aadesariya et al (2017) Senthilkumar et al (2012) Bratty et al (2020)
n-Tetracosanol-1	*Combretum microphyllum, E. acoroides*	Antioxidant	Makhafola et al (2017) Amudha et al (2018)
n-Hexadecanoic acid (Palmitic acid)	*Entada rheedii, A. indica*	Saturated fatty *acid, a*nti-Inflammatory	Ruthisha et al (2017) Balasubramanian et al (2014) Aparna et al (2012)

Cont...

Table 2. Corroboration of *M. dubia* phytochemicals detected in present study for their beneficial biological activity

Compound	Phytochemical reported in other plants	Reported beneficial biological activity	Reference
Octadecanoic acid (Stearic acid)	*M. dubia*	lowered LDL cholesterol	Murugesan et al (2013b) Hunter et al (2009)
Phenol, 2,4-bis(1, 1-dimethylethyl)-, phosphite (3:1)	*Pseudomonas fluorescens, Alternaria* spp., *Gracilaria gracilis*	Alkylbenzene, anti-bacteria, antibacterial moderate cytotoxic	Ren et al (2019), Elgorban et al (2019), Alwar et al (2014)
Phthalic acid, hept-4-yl isobutyl ester	*Spondias mombin*	Allelopathic, antimicrobial, insecticidal	Osuntokun and Cristina (2019) Huang et al (2021)
Squalene	*Persea americana, M. domestica*	Triterpene, biochemical intermediate to sterol biosynthesis	Lewis (1972)



a

b

Fig. 1. Chromatograms showing retention time and relative abundance of phytochemical compounds detected in *M. dubia* leaf fodder in location 1 (a) and 8 (b)

Neophytadiene is sesquiterpenoid which act as an anti-inflammatory agent, a plant metabolite and an algal metabolite (Table 2). It has analgesic, antipyretic, antimicrobial, and antioxidant properties (Aadesariya, et al 2017, Swamy et al 2017 and Raman et al 2012). The 9, 12, 15-Octadecatrienoic acid, (Z,Z,Z)- is reported to have anticancer, anti-inflammatory, antibacterial, antioxidant properties (Balasubramanian et al 2014, Bratty et al 2020, Padma et al 2019). Nonadecane, 2-methyl- have aantioxidant properties *(*Senthilkumar et al 2012 Aadesariya et al 2017, Bratty et al 2020); 1-Hexadecanol hadAntioxidant properties (Murugesan 2013a and Amudha et al 2018). Octadecanoic acid reported to lower LDL cholesterol (Murugesan et al 2013b and Hunter et al 2009. Eicosane can be used as a bronchodilators, drug for throat disorder (Senthilkumar et al 2012 , Subramanian et al 2020). The Ethanol, 2-(dodecyloxy)- act as a sclerosing agent for the treatment of esophageal and gastric varices and varicose veins (Senthilkumar et al 2012) and Fumaric acid, cis-hex-3-enyl tetradecyl ester is a food additive and used to treat the autoimmune condition psoriasis, multiple sclerosis and lower methane production (Wang and Huang 2012, Gold et al 2012 and Bayaru et al 2000). The 10-Heneicosene (c,t) is a pheromone and has antifungal properties (Sethuraman et al 2022), 2-Pentadecanone, 6,10,14-trimethyl- is a hypocholesterolemic, antioxidant and used in lubrication (Amudha et al 2018). Phthalic acid, hept-4-yl isobutyl ester also known to have allelopathic, antimicrobial, insecticidal properties (Osuntokun and Cristina 2019 and Huang et al 2021) and Squalene which is a triterpene act as a biochemical intermediate to sterol biosynthesis (Lewis 1972) (Table 2).

CONCLUSION

Total 93 of biological active compound were reported from *M. dubia* leaves collected from various locations from South Gujarat. The non-volatile compounds findings through GCMS analysis inferred that *M. dubia* leaves has beneficial biological active phytochemicals which may be beneficial to human and animals.

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Innovative Technology for Preparing Value Added Product from *Mucuna Pruriens*

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Abstract: Box-Behnken Design was used for conducting 29 experiments for preparing *Mucuna pruriens* seeds powder. The experimental data was analyzed by applying Response Surface Methodology (RSM) using Design Expert 12.0.8.0 software.The optimized values for soaking, boiling, autoclaving and drying were 9h, 30min, 20 min and 50°C, respectively were responsible for recovery of 87 per cent *M. Pruriens* seed powder. The L-Dopa value of 1.09 (g $100g^{-1}$) in *M. Pruriens* seed powder was considered safe for consumption. The sensory evaluation for overall acceptability for *M. Pruriens* seed powder was 7.2. The prepared *M. Pruriens* powder is a ready to eat value added product hence, it could be used for consumption by adding to liquids, milk, salads, curries, *etc*. The developed process technology for preparing *M. Pruriens* powder may be adapted by small, medium, and large-scale farmers, self-help groups, unemployed youths to become an entrepreneur.

Keywords*: Mucuna pruriens,* Value addition, Process, Drying, Powder recovery

The plant *Mucuna Pruriens* belongs to family "*Fabaceae*". It is widely known as "velvet bean" and mostly found in the form of a vigorous annual climber. It is originally from Southern China and Eastern India. It is considered as a viable source of dietary proteins due to its high nutritional value. According to Food and Agriculture Organization (FAO) it can be used to restore soil as well as to provide food. In Kenya it is generally grown to act as rehabilitating agent for deteriorated soils also to provide animal feeds as well as human food. *M. pruriens* seeds also possess the activity of different aliments of anabolic, androgenic, analgesic, anti-inflammatory, antispasmodic, antivenom, aphrodisiac, febrifuge, cholesterol lowering, hypoglycaemic, immune modulator, antilithiatic, antibacterial, antiparasitic, cough suppressant, blood purifier, carminative, hypotensive, and uterine stimulant properties (Divya et al 2017). It is one of the most important sources of L-dopa and thus increases the levels of dopamine in the brain hence it can be used very efficiently against Parkinson's Disease (Vaish et al 2014). It has become very necessary to diversify the present-day agriculture in order to meet various daily needs of human. The plants which remain ignored or under-utilized but have a tremendous potential for commercial exploitation, offer a good scope in this context. Processing of *M. Pruriens* bean increases its nutritional value and potential to improve food security. It is reported that there is a lack of data or knowledge about the nutritive value, various value-added products from *M. Pruriens*.

The research focuses on optimization of process parameters for preparing *M. pruriens* powder. Preparation of powder reduces the volume of seeds and helps in proper storage. The process parameters selected for preparing *M. Pruriens* powder helped in reducing the level of L-Dopa and by maintaining the other nutrients values of *M. Pruriens* powder. The prepared *M. pruriens* powder is ready to eat value added product, hence could be used for consumption by adding to liquids, milk, salads, curries.. Thus, to increase the awareness among the community about its medicinal benefits and to make *M. Pruriens* available in powder form, this work was proposed with the objectives to optimize process parameters for preparing *M. Pruriens* powder, quality analysis of *M. Pruriens* powder and to access economic feasibility of *M. Pruriens* powder.

MATERIAL AND METHODS

The present research work was carried out Agriculture Engineering and Technology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. *M. Pruriens* seeds were procured from Medicinal department of Nagarjun, Dr. P.D.K.V., Akola. The various process parameters like soaking (h), boiling (min), autoclaving (min) and drying (°C) were optimized for maximum powder recovery (%) and minimum powder loss (%) of *M. pruriens*. The process parameters for the preparation of *M. pruriens* seeds powder were analyzed by Response Surface Methodology (RSM) using Design-Expert software. Based on the preliminary experiments, Box

Behnken design was finalized for conducting 29 experiments with three level and four factor. The cleaned Mucuna seeds of 200g were used for each experiment.

Experimental design for preparation *M. pruriens* powder: The design of the experiments was based on the preliminary trials conducted. The three levels of the independent variables (Soaking in water (h), Boiling (min), Autoclaving (@1.05 kg/cm^2, 121°C) (min) and Drying (°C) were finalized based on the results of preliminary experiments. The finalized experiments along with four independent parameters and three levels for preparing *Mucuna pruriens* powder Table 1.

Response Parameters (Dependent variables)

Powder yield (%): Powder recovery was calculated as ratio of the weight of the powder produced to consume feed mixture on a dry basis and expressed as percentage yield.

$$\text{Powder yield (\%)} = \frac{\text{Mucuna powder yield (g)}}{\text{Mucuna seeds (g)}} \times 100$$

$$\text{Powder loss (\%)} = \frac{\text{Mucuna powder loss (g)}}{\text{Mucuna seeds (g)}} \times 100$$

Table 1. Independent variables for preparing *Mucuna pruriens* powder

Independent parameters	X_1	X_2	X_3
Soaking in water (h)	6	9	12
Boiling(min)	20	30	40
Autoclaving (@1.05 kg/cm^2,121°C) (min)	10	20	30
Drying (°C)	40	50	60

RESULTS AND DISCUSSION

Optimization of process parameters by using response surface methodology: The recovery of powder and powder loss were affected by process variables *viz.,* soaking (h), boiling (min), autoclaving (min) and drying (°C). To avoid bias, 29 runs were performed in a random order. Total 29 experiments (Table 2) generated through Box-Behnken design were conducted. The experimental data was analyzed by applying Response Surface Methodology (RSM) using Design Expert software. The process variables *viz.,* soaking (6, 9 and 12 h), boiling (20, 30 and 40 min), autoclaving (10, 20 and 30 min) and drying (40, 50 and 60°C) were finalized for maximum recovery of powder as well as for minimum powder loss. Models for the responses were developed through regression analysis.

The Model F-value of 41.73 implies that the model was significant (Table 3). There was only a 0.01% chance that an F-value. The P-values is less than 0.0500 indicate model terms were significant. In this case A, B, C, D, AB, AC, AD, BC, BD, CD, A^2, B^2, C^2, D^2 was significant model. Values greater than 0.1 indicate the model terms was not significant. There was a 13.89% chance that a Lack of Fit F-value is not significant. Non-significant lack of fit was good and thus, the model was fit for obtaining the response.

The R^2 value was computed by a least square technique and found to be 0.9766, showing good fit of model to the data. The predicted R^2 of 0.8762 was in reasonable agreement with the Adjusted R^2 of 0.9532 i.e. the difference was less than 0.2. Adeq. precision measures the signal to noise ratio. A ratio greater than 4 was desirable. Ratio of 10.2520 indicated an adequate signal. So this model was used to navigate the design space. The recovery of powder was prominently affected by soaking (h), boiling (min), autoclaving (min) and drying (°C) (Fig 1). Drying at 50°C plays an important role as the proper drying helps to get maximum recovery of powder with less losses. The soaking of 6h is sufficient to get maximum recovery of powder with minimum losses. It was observed that, the autoclaving for 22 min and boiling for 23 min were best combination for getting maximum recovery of powder.

The loss of powder (%) of Mucuna seeds ranged between 13 to 26% within the combination of variable studied (Fig. 2). It was revealed, that the minimum loss of powder i.e. 13% was obtained with treatment having the combination of soaking in water for 6h, Boiling for 20 min, autoclaving for 20 min and drying at 50°C. Thus the minimum loss of powder were found to be dependent on process parameters viz., Soaking in water (hr), Boiling (min), Autoclaving (min) and Drying (°C).

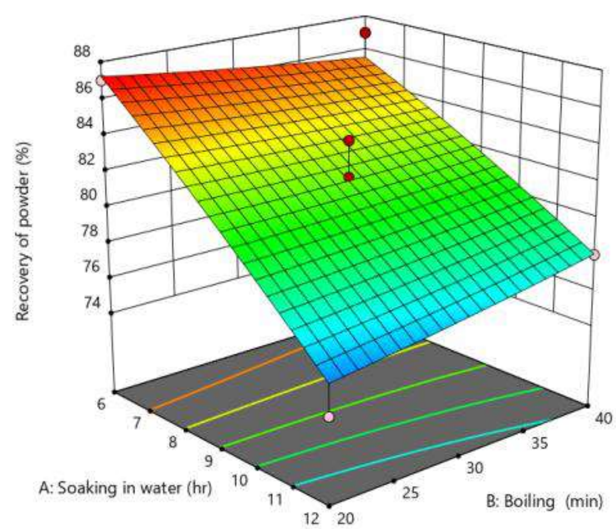


Fig. 1. Effect of boiling (B) and soaking in water (S) on recovery of powder at constant autoclaving (A= 20 min) and drying (D = 50°C)

Optimization of different process input variables for preparation *M. pruriense* powder: Numerical multi response optimization technique was carried out for the operational parameters for the preparation of Mucuna seeds powder. To perform this operation, Design Expert software of the STAT-EASE software (Statease Inc, Minneapolis, USA Trial version), was used for simultaneous optimization of the multiple responses. A stationary point at which the slope of the response surface was zero in all the direction was calculated by partially differentiating the model with respect to each variable, equating these derivatives to zero and simultaneously solving the resulting equations, thus simultaneously optimizing the multiple responses. The desirability values with optimum combinations of independent variables *viz.,* soaking (h), boiling (min), autoclaving (min) and drying (°C) and response parameter for maximum value of recovery of powder and minimum value of loss of powder were graphically presented from Figure 1 to 2 Table 2 shows that the software generated anoptimum conditions of independent variable with predicted values of responses. The solutions given in Table 5 having the maximum desirability value 1 was selected as the optimum condition for preparation of Mucuna seed powder.

Quality parameters: Average values of L-Dopa content (%) for raw and optimize Mucuna seed powder content (g $100g^{-1}$) for raw and experimentally optimized sample were 4.79 and 1.09 g 100 g^{-1}. Sensory evaluation of raw and optimized *M. pruriense* seed powder

The raw sample powder and experimentally optimized powder sample was tasted by 10 panelists with

Table 2. Recovery of powder under varying process parameters

Exp No.	Soaking in water (h)	Boiling (min)	Autoclaving (min)	Drying (°C)	Recovery of powder (%)
1	12	30	30	50	76
2	12	30	20	40	77
3	6	40	20	50	86
4	9	30	30	40	80
5	12	30	10	50	78
6	9	30	20	50	82
7	9	30	10	60	79
8	9	20	20	60	80
9	9	40	20	40	78
10	9	30	30	60	79
11	9	30	20	50	80
12	6	20	20	50	87
13	9	20	10	50	82
14	12	20	20	50	74
15	12	30	20	60	75
16	9	40	10	50	84
17	6	30	20	60	85
18	9	20	30	50	80
19	9	30	10	40	83
20	6	30	30	50	86
21	9	30	20	50	84
22	9	30	20	50	84
23	9	40	20	60	81
24	9	20	20	40	84
25	9	40	30	50	81
26	6	30	10	50	85
27	6	30	20	40	85
28	9	30	20	50	79
29	12	40	20	50	78

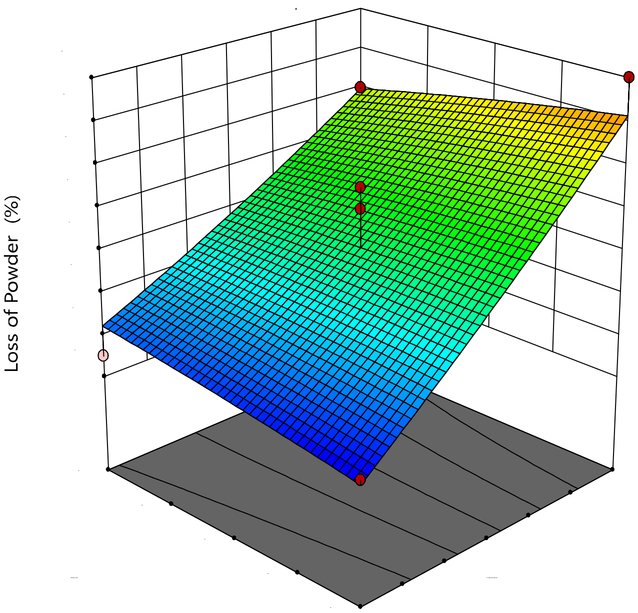
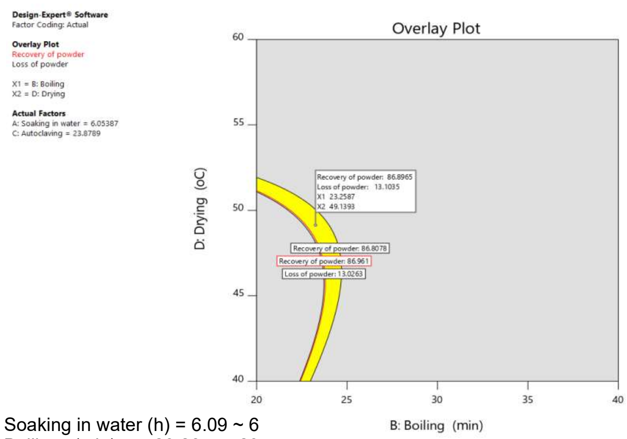


Fig. 2. Effect of soaking in water (S) and boiling (B) on loss of powder at constant autoclaving (A = 20 min) and drying (D = 50°C)

the help of 9-point Hedonic test chart overall acceptability values of raw powder sample and experimentally optimized powder sample were 7.4 and 7.2.



Soaking in water (h) = 6.09 ~ 6
Boiling (min) = 23.26 ~ 23
Autoclaving (min) = 21.84 ~ 22
Drying (°C) = 49.13 ~ 50

Fig. 3. Effect of boiling (B) and drying (D) on responses

Table 3. Analysis of Variance (ANOVA) showing the effect of process parameters on recovery of powder

Source	Sum of squares	Df	Mean square	F-value	p-value	
Model	446.54	14	31.90	41.73	< 0.0001	Significant
A-Soaking in water	80.08	1	80.08	104.78	< 0.0001	
B-Boiling	14.08	1	14.08	18.43	0.0007	
C-Autoclaving	10.08	1	10.08	13.19	0.0027	
D-Drying	10.08	1	10.08	13.19	0.0027	
AB	12.25	1	12.25	16.03	0.0013	
AC	9.00	1	9.00	11.78	0.0041	
AD	16.00	1	16.00	20.93	0.0004	
BC	6.25	1	6.25	8.18	0.0126	
BD	56.25	1	56.25	73.60	< 0.0001	
CD	1.0000	1	1.0000	1.31	0.0719	
A^2	138.25	1	138.25	180.89	< 0.0001	
B^2	53.30	1	53.30	69.74	< 0.0001	
C^2	44.41	1	44.41	58.11	< 0.0001	
D^2	109.93	1	109.93	143.83	< 0.0001	
Residual	10.70	14	0.7643			
Lack of fit	9.50	10	0.9500	3.17	0.1389	Not significant
Pure error	1.20	4	0.3000			
Cor total	457.24	28				
Std. Dev.	0.8742		R^2	0.9766		
Mean	86.52		Adjusted R^2	0.9532		
C.V. %	1.01		Predicted R^2	0.8762		
			Adeq. Precision	10.2520		

Table 4. Optimized solution generated by the software

Soaking in water (h)	Boiling (min)	Autoclaving (min)	Drying (°C)	Recovery of powder	Loss of powder	Desirability	Remarks
6.02	20.17	19.99	50.70	87.02	12.98	0.890	Selected
6.05	20.38	13.01	47.35	87.34	12.66	0.830	
6.08	23.37	15.42	44.58	87.20	12.81	0.879	
6.05	20.59	23.88	50.33	87.05	12.96	0.860	
6.02	23.09	21.66	45.04	87.24	12.76	0.872	

CONCLUSION

The optimized values for soaking, boiling, autoclaving and drying were 9h, 30min, 20 min and 50°C were responsible for recovery of 87% Mucuna seed powder. The L-Dopavalue of 1.09 (g $100g^{-1}$) in Mucuna seed powder was considered safe for consumption. The sensory evaluation for overall acceptability for Mucuna seed powder was 7.2.

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Fuel Bark Quality Evaluation of Commercial Tropical Tree Species: An Approach to Waste Utilization

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Abstract: The removal of bark from logs is creating major residue problem in wood-based industries**.** Bark contains high amount of lignin, extractives, ash, moisture and low amount of polysaccharides than wood. The most desirable properties for an optimal fuel quality of a lignocellulosic material are its high calorific value, high density, low ash and moisture content. Keeping in view of these points, an investigation was carried out to evaluate the fuel value index (FVI) of bark from ten commercial tropical tree species for their effective utilization. Total ten different tree species planted in NAU campus were selected for evaluation of FVI of bark based on their calorific value, basic density, moisture and ash content. The highest FVI of bark was recorded in *Casuarina equisetifolia* (156.80) and lowest in *Tectona grandis* (18.53). The most promising tree species for fuel bark quality were in the order of *Casuarina equisetifolia*, *Adina cordifolia* and *Acacia nilotica*. However, *Acacia auriculiformis* and *Mangifera indica* also recorded topper rank than other five species. Therefore, the waste bark of these tree species could be further utilized into the value-added product like briquettes.

***Keywords*:** Bark, fuel value index, Ash, Basic density, Moisture content, Calorific value

Fuelwood accounts approximately 90 per cent of the total wood production in India. It is still the main source of energy in rural India which indicates the scarcity of substitutes and creates a lot of pressure on the forest resources in the country (Shrivastava and Saxena 2017). Bark is one of the few renewable energy resources after wood and has negligible sulphur content when compared to coal Corder (1976). Moreover, due to increase in the price of fossil fuels and its less availability, bark could become more important energy source in future. Currently lump of bark after removal from wood is creating major residue problem in many wood conversion industries such as sawmills, pulp mills and composite wood industries. The actual production of bark residue by these wood industries depends upon the use of different tree species. Bark occupies about 10 to 22 per cent of total log volume on a dry weight basis depending upon the size and type of tree species used in wood industries (Anonymous 2019). This bark residue creates a serious waste disposal problem unless it can be converted into value added product of high energy solid fuel like briquettes.

The proximate chemical composition of bark is much more extensive than wood. Tree bark contains high amount of lignin, extractives, ash and moisture and less amount of polysaccharides in comparison to wood (Harkin and Rowe 1971). The high amount of lignin and extractives increases the calorific value of wood whereas high amount of moisture and ash content decreases the calorific value (Lunguleasa and Spirchez 2017). Much of the data available in the literatures are related to fuelwood quality of stem and branches. However, limited information is available on fuel quality of bark. Keeping in view of these points, the present paper aims to study the fuel value index of bark from ten commercial tropical tree species for their effective utilization.

MATERIAL AND METHODS

Study site: Plantations established in Navsari Agricultural University (NAU), Navsari, Gujarat were selected for the present study. The area is situated at coastal region of South Gujarat at 20°95' N latitude, 75°90' E longitude and at an altitude of 12 m above the mean sea level. The climate of Navsari is tropical warm with fairly hot summer, moderately cold winter and warm humid monsoon. Monsoon starts from second week of June and ends in September and majority of precipitation occurs in the month of July and August, receiving from south-west monsoon. Average annual rainfall of this region is about 1600 mm. Hottest months are April and May; however, the coldest months are from December to February.

Sampling: Bark of size 10 cm x 5 cm from 10 commercial tropical tree species such as *Tectona grandis* L.f. (Teak), *Gmelina arborea* Roxb. (Gamhar), *Casuarina equisetifolia* L. (Saru), *Eucalyptus* sp. (Nilgiri), *Mangifera indica* L. (Mango), *Albizia procera* (Roxb.) Benth. (Killai), *Acacia nilotica* (L.) Willd. ex Delile (Babul), *Acacia auriculiformis* A. Cunn. ex Benth. (Bengali Babul), *Adina cordifolia* (Roxb.) Brandis (Haldu) and *Leucaena leucocephala* (Lam.) de Wit (Subabul) were sampled at the breast height. Bark from three trees of each species were sampled from 15-30 cm diameter class. Fresh weight of collected bark samples was immediately recorded and green volume of sample was measured by water displacement method. Afterwards, samples were dried in a forced-air convection oven at 100 ± 2°C till constant weight achieved. The dried samples were ground to pass through 4.7 mm mesh, pelleted and burnt in an oxygen bomb calorimeter to determine the calorific value. Moisture content was determined by oven-dry method and ash content by burning the powdered samples in a muffle furnace at 600°C for 4 hours. Basic density was calculated as oven-dry weight divided by green volume of the sample. Fuel value index (FVI) was calculated following Puri et al (1994),

$$\text{Fuel Value Index (FV)} = \frac{\text{Calorific value (MJ/kg)} \times \text{Basic density (g/cc)}}{\text{Moisture content (g/g)} \times \text{Ash content (g/g)}}$$

RESULTS AND DISCUSSION

The moisture content (58.3 to 298.0%), basic density (0.277 to 0.600 g/cc), ash content (5.3 to 13.0%) and FVI (18.53 to 156.80) of bark varied significantly except calorific value (14.97 to 17.66 MJ/kg) which did not show a statistically significant difference (Table 1). High moisture content (> 150%) and low basic density (< 350 g/cc) were in the bark of *Albizia procera*, *Gmelina arborea*, *Tectona grandis* and *Eucalyptus* spp*.* The higher (> 10%) ash content was recorded in the bark of *Tectona grandis*, *Eucalyptus* spp. and *Acacia nilotica* than other studied species. However, high calorific value (>16 MJ/kg) was in *Albizia procera*, *Adina cordifolia*, *Gmelina arborea*, *Acacia nilotica, Acacia auriculiformis* and *Mangifera indica*. Puri et al (1994) recorded similar trend of variation for calorific value of bark in *Acacia nilotica* (19.47 MJ/kg)*, Acacia auriculiformis* (19.40 MJ/kg) and *Casuarina equisetifolia* (19.73 MJ/kg) which were higher than the value reported in the present study (Table 1).

For evaluating an ideal fuel value of lignocellulosic material, high calorific value, high density, low ash content and low moisture content are the most desirable characteristics (Bhatt and Todaria 1990). FVI of ten species showed highly negative relationship with moisture content and positive relationship with basic density (Fig. 1). Out of ten species evaluated, the bark of *Casuarina equisetifolia*, *Acacia nilotica, Adina cordifolia*, *Acacia auriculiformis* and *Mangifera indica* were found to have higher fuel value (FVI >75) than other species and it may mainly be due to high basic density and low moisture content. Since, the bark of *Albizia procera* contained the highest calorific value (17.66 MJ/kg) but due to its very high moisture content (298.0%), low basic density (0.277 g/cc) and average ash content (8.5%), was comparatively less suitable for fuel value (low FVI) as compared to *Casuarina equisetifolia*, *Acacia nilotica* and *Adina cordifolia*. Deka et al (2014) also reported highest calorific value in *Albizia procera* (20.64 MJ/kg) but also very high FVI (630.08) which could be due to lower moisture content and low ash content of their samples. Similarly, bark of *Tectona grandis* and *Eucalyptus* spp*.* also had high moisture content, low basic density and high ash content and they were thus less acceptable as fuel due to very low FVI (Table 1). Similar results are also reported for FVI of bark in *T. grandis* by Prasaningtyas and Sulistyo (2014). *Gmelina arborea*, although having high calorific value (17.23 MJ/kg) and low ash content (5.5%), had high moisture content (217.8%) and low basic density (0.327 g/cc) and therefore, was less suitable for fuel purpose. However, *Leucaena leucocephala* had moderately high basic density (0.427 g/cc) and average ash content but because of low calorific value (15.94 MJ/kg) and moderately high moisture content (154.6%), hence, was less suitable for fuel. Shanavas and Mohan Kumar (2003) also reported similar calorific value (15.57 MJ/kg) in the bark of *Leucaena leucocephala* and

Table 1. Fuel value characteristics of bark often tree species (Mean±SD)

Tree species	Moisture (%)	Basic density (g/cc)	Ash (%)	Calorific value (MJ/kg)	FVI
T. grandis	200.7±14.79	0.310±0.04	13.0±1.73	15.00±0.49	18.53±6.46
G. arborea	217.8±49.48	0.327±0.06	5.5±0.53	17.23±0.67	51.11±24.67
C.equisetifolia	88.3±11.61	0.600±0.06	7.0±0.01	15.79±0.27	156.80±36.27
Eucalyptus spp.	197.2±16.35	0.300±0.05	11.3±0.01	14.97±0.96	19.74±0.64
M. indica	117.1±11.68	0.447±0.04	10.6±4.75	16.22±1.81	77.74±61.62
A. procera	298.0±100.87	0.277±0.09	8.5±0.55	17.66±2.32	22.18±14.56
A. nilotica	58.3±11.29	0.580±0.03	11.3±2.21	16.94±0.72	156.21±36.67
A. auriculiformis	124.6±15.81	0.440±0.01	7.2±0.12	16.69±2.34	81.54±2.42
A. cordifolia	151.4±30.40	0.417±0.04	5.3±1.48	17.55±0.96	96.71±27.83
L. leucocephala	154.6±10.35	0.427±0.01	8.7±0.58	15.94±0.92	50.98±5.37
CD (p=0.05)	65.96	0.082	3.14	NS	48.90

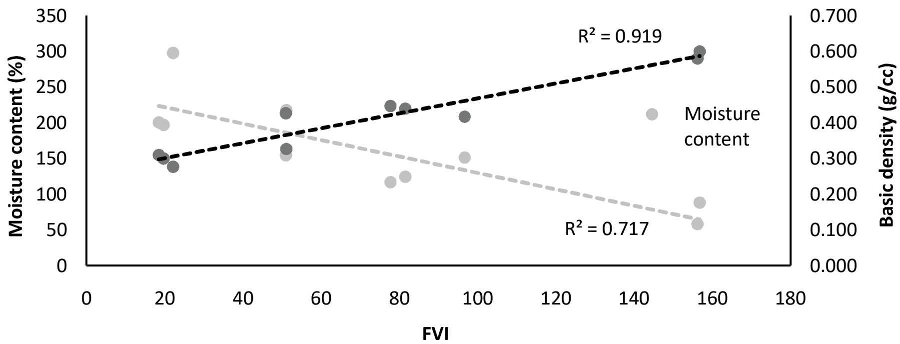

Fig. 1. Relationship between FVI with moisture content and basic density of bark of ten tree species

Table 2. Fuel value ranking of bark of ten commercial tropical tree species using calorific value, density, ash, moisture and fuel value index (FVI) (Mean±SD)

Tree species	Moisture (%)	Basic density (g/cc)	Ash (%)	Calorific value (MJ/kg)	FVI	Total	Rank
T. grandis	8	8	10	9	10	45	10
G. arborea	9	7	2	3	6	27	6
C. equisetifolia	2	1	3	8	1	15	1
Eucalyptus spp.	7	9	8	10	9	43	9
M. indica	3	3	7	6	5	24	5
A. procera	10	10	5	1	8	34	8
A. nilotica	1	2	9	4	2	18	3
A. auriculiformis	4	4	4	5	4	21	4
A. cordifolia	5	6	1	2	3	17	2
L. leucocephala	6	5	6	7	7	31	7

slightly higher calorific value (17.52 MJ/kg) in *Eucalyptus tereticornis*. Therefore, low moisture content, high basic density, moderately high calorific value and average ash content of bark played important role in determining the high fuel value.

CONCLUSION

The maximum fuel bark quality was evaluated in *Casuarina equisetifolia* followed by *Adina cordifolia* and *Acacia nilotica*. However, *Acacia auriculiformis* and *Mangifera indica* also ranked in the higher range than other five species. Therefore, the waste bark of these tree species could be further utilized into the value-added products like briquettes.

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Survival, Growth and Biomass of *Bambusa tulda* Seedlings as affected by Different Level of Saline Irrigation Water

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Abstract: The objective of this study was to evaluate the influence of saline irrigation water on the production of bamboo seedlings (*Bambusa tulda*) in nursery condition. The present investigation was carried out at Bamboo Resource Centre, College of Forestry, NAU, Navsari, Gujarat during March, 2021 to June- 2022. The experiment was carried out in nursery conditions with completely randomized design comprising five treatments and four repetitions. Seedling were irrigated with five different levels of saline irrigation water *i.e.*, S_1: 0.5 dSm^{-1}, S_2: 2.0 dSm^{-1}, S_3: 4.0 dSm^{-1}, S_4: 6.0 dSm^{-1} and S_5: 8.0 dSm^{-1} at interval of 2 days up to 120 days after imposing the treatments (DAT). Among different levels of saline irrigated water, a significant reduction in survival, growth, and biomass of *B. tulda* seedlings was observed at 8 dSm^{-1} and slight reduction 4 dSm^{-1} level in nursery condition. However, S_1: 0.5 $dSm^{-1}$and S_2: 2.0 dSm^{-1} showed less impact on seedling survival, growth and biomass parameters. Study showed that the critical limit of saline irrigation water for *B. tulda* species is 8 dSm^{-1}, however, a 4 dSm^{-1} irrigated water not drastically reducing the survival, growth and biomass parameters of *B. tulda* under nursery condition.

Keywords: *Bambusa tulda*, Salinity, Irrigation water, Survival, Growth, Biomass and Nursery condition

Bamboo is one of the fastest growing, versatile plants of immense utility and large economic benefits. Now a days bamboo is also known as green gold. Day by day demand of bamboo is increasing due to which farmers are showing interest in bamboo farming. Among different bamboo species in India, *Bambusa tulda* is now a days gaining popularity among farmers due to its versatile uses and culm characters. It is a widely used bamboo for commercial purposes in Bangladesh and India. Paper pulping industry makes substantial use of *B. tulda* as a raw material. It can be used to make wrapping, writing, scaffolding, incense stick, kite industry and printing paper. In agroforestry, *B. tulda* is often planted as a wind-break around farms and fields. Around 6.727 million ha area in India, which is around 2.1 per cent of geographical area of the country is salt-affected of which 2.956 million ha is saline having high TDS (Arora et al. 2016, Arora and Sharma 2017). Most of Bamboo species have moderate salt tolerance. Bamboo leaves are acidic in nature which reduces the salinity of the soil. Bamboos are potential species for reclamation of saline soils and water (Pulavarty and Bijaya 2018). Bamboo species which can establish and survive in high TDS water can be useful in bamboo farming in areas of high TDS water. National Bamboo Mission, in consultation with industry and states has identified 10 crucial species to be encouraged to be planted by farmers and others to make the country self-sufficient in the supply of raw material to our industry. Among these 10 species, *B. tulda* had been selected for the present study.

MATERIAL AND METHODS

The present investigation was carried out at Bamboo Resource Centre, College of Forestry, NAU, Navsari, Gujarat during the March-2021 to June-2022. The climate of experimental area is typically tropical, characterized by fairly hot summer, moderate cold winter and humid warm monsoon. In general, monsoon commences during the second week of June and ends by the second fortnight of September. Most of the precipitation is received from South West monsoon, concentrated during the months of June, July and August. The minimum and maximum temperature during the course of experiment varied from 20.3°C to 33.6°C, whereas the minimum and maximum Relative Humidity (RH) was varied from 49.93 to 88 per cent.

The experiment was carried out in nursery conditions with completely randomized design. One year old seedlings of *B. tulda* were transplanted in to polybags size 18 cm x 18 cm having a mixture of soil and vermicompost in a ratio of 3:1. Total weight of plastic bags along with media was 12 kg. The sea water was collected from nearest seacoast *i.e.*, Dandi sea coast, which is having EC 38 dSm^{-1} and was diluted with normal water as per the treatments and stored. Initially seedlings were irrigated with normal water till survival and after 15 days, seedling were irrigated with five different levels of saline irrigation water *i.e.*, S_1: 0.5 dSm^{-1}, S_2: 2.0 dSm^{-1}, S_3: 4.0 dSm^{-1}, S_4: 6.0 dSm^{-1} and S_5: 8.0 dSm^{-1} at an interval of 2 days up to 120 DAT. The observations on survival, growth and biomass of seedling were recorded at 120 DAT.

RESULTS AND DISCUSSION

The data on survival, growth and biomass of *B. tulda* seedlings as affected by various levels of saline irrigation water are furnished in Table 1.

Survival of seedling was decrease with increase in salinity level of irrigation water. The maximum survival percentage of *B. tulda* seedlings 120 DAT was found in S_1: 0.5 dSm^{-1} (89.00 %) which was followed by S_2: 2.0 dSm^{-1} (84.67 %) and S_3: 4.0 dSm^{-1} (76.67 %). The lowest survival percentage was recorded in S_5: 8.0 dSm^{-1} (39.67 %).

Seedling height was negatively affected by saline water, showing a reduction in height as increase in the salinity level of irrigation water. At 120 DAT, maximum seedling height was found in S_1: 0.5 dSm^{-1} (76.69 cm) which was at par with S_2: 2.0 dSm^{-1} (71.85 cm). In S_3: 4.0 dSm^{-1} (69.55 cm) marginal reduction in seedling height was observed. The lowest seedling height was recorded in S_5: 8.0 dSm^{-1} (47.21 cm). Reduction in seedling height could be due to high concentration of soluble salts which increase the osmotic pressure and decrease the osmotic potential of soil solution which means that the soil water is held with extra energy produced by the presence of salts in *Leucaena leucocephala, Acacia nilotica* and *Casuarina equisitifolia* (Ali et al 1987). Number of leaves per seedling was registered maximum in S_1: 0.5 dSm^{-1} (96.46) which was on same bar with S_2: 2.0 dSm^{-1} (92.78) and S_3: 4.0 dSm^{-1} (89.78) whereas lowest number of leaves per seedling (50.50) was noted in S_5: 8.0 dSm^{-1}.

Maximum number of shoots was reported in S_1: 0.5 dSm^{-1} (4.73) which was at statistically at par with S_2: 2.0 dSm^{-1} (4.53). At 120 DAT diameter of shoot registered maximum in S_1: 0.5 dSm^{-1} (5.47 mm) which was followed by S_2: 2.0 dS m^{-1} (4.16 mm) and S_3: 4.0 dSm^{-1} (4.07 mm), whereas, it was found lowest in S_5: 8.0 dSm^{-1} (3.04 mm).

As the salinity level of irrigation increase the fresh and dry biomass of shoot and root affect adversely. Fresh biomass of shoot and root were recorded maximum in S_1: 0.5 dSm^{-1} (53.11 and 37.44 g, respectively) which was at statistically at par with S_2: 2.0 dSm^{-1} (5.23 and 33.52 g, respectively). In salinity level of S_3: 4.0 dSm^{-1} (44.45 and 15.23 g, respectively) marginal reduction in biomass was observed as compare to control and it was found lowest in S_5: 8.0 dSm^{-1} (14.95 and 5.82 g, respectively). Dry biomass of shoot and root are also found maximum in S_1: 0.5 dSm^{-1} (17.69 and 20.48 g, respectively) which was on same bar with S_2: 2.0 dSm^{-1} (16.96 and 19.60 g, respectively). In saline irrigation water of S_3: 4.0 dSm^{-1} (26.46 and 15.66 g, respectively) slight reduction in biomass was noted as compare to control and it was found lowest in S_5: 8.0 dSm^{-1} (8.09 and 4.60 g, respectively) (Table 1).

The assessment of biomass clearly indicates that a significant increase in fresh and dry biomass was observed in seedlings treated with S_1: 0.5 dSm^{-1} as compared to different salinity levels. It was found that salinity stress caused significant decrease in total fresh and dry biomass at S_4: 6.0 dSm^{-1} and 8.0 dSm^{-1} as compared to seedlings treated with 0.5 dSm^{-1}.

The significant loss observed in higher salinity level could be due to the cause of wilting and leaf shedding. Similar decrease in shoot biomass production and the number of leaves was recorded in bamboo by Pulavarty and Sarangi (2018). These reductions in production are explained by the influence of salt stress, which can also alter the partitioning of photo-assimilates between the different parts of the plants

Similar decreases in number of leaves per plant, plant height, biomass and survival were reported by Samarakkody

Table 1. Survival, growth and biomass of *Bambusatulda* at 120 days after imposing treatment (DAT)

Treatments	Survival (%)	Height (cm)	Number of leaves	Number of shoot	Diameter of shoot (mm)	Fresh biomass of Shoot (g)	Dry biomass of shoot (g)	Fresh biomass of root (g)	Dry biomass of root (g)
S_1 - EC_{iw} = 0.5 dS m^{-1}	89.00	76.69	96.46	4.73	5.47	53.11	17.69	37.44	20.48
S_2 - EC_{iw} = 2.0 dS m^{-1}	84.67	71.85	92.78	4.53	4.16	50.23	16.96	36.52	19.60
S_3 - EC_{iw} = 4.0 dS m^{-1}	76.67	69.55	89.78	4.33	4.07	44.45	15.23	26.46	15.66
S_4 - EC_{iw} = 6.0 dS m^{-1}	52.67	63.82	58.63	3.13	3.28	34.13	11.89	16.23	9.40
S_5 - EC_{iw} = 8.0 dS m^{-1}	39.67	47.21	50.50	1.47	3.04	14.95	5.82	8.09	4.60
Mean	68.53	65.82	77.63	3.64	4.00	39.38	13.52	24.28	13.95
S.Em. ±	1.01	2.05	2.40	0.07	0.12	1.03	0.35	0.78	0.35
CD (0.05)	3.03	6.16	7.19	0.20	0.35	3.09	1.04	1.95	1.04

and Palihakkara (2005) in *Melia azedarach, Swietenia mahogany, Artocarpus heterophyllus* and *Acacia mangium*. The threshold tolerance limit of salinity *i.e.*, 4 $mScm^{-1}$, 0.13 $mScm^{-1}$, 8 $mScm^{-1}$ and 12 $mScm^{-1}$ were observed by them respectively for *Melia azedarach, Artocarpus heterophyllus, Swietenia mahogany* and *Acacia mangium* seedlings. The most likely factor causing these differences in salt tolerance may also be the rate of salt transport to the shoots adversely affecting the leaf expansion reducing the photosynthetic efficiency of the plant, further reducing the dry matter production. Therefore, the present study showed that survival percentage, seedling height, collar diameter, number of leaves per seedling, number of shoots per seedling, fresh and dry biomass of shoot and root were significantly influenced by different salinity levels of irrigation water. Interestingly, lower salinity levels such as S_1: 0.5 dSm^{-1}, S_2: 2.0 $dSm^{-1}$and S_3: 4.0 dSm^{-1} showed less negative influence on these survival, growth and biomass parameters and the values of S_2: 2.0 dSm^{-1} and S_3: 4.0 dSm^{-1} for growth parameters recorded to be non-significant when compared with control *i.e.* S_1: 0.5 dSm^{-1}.

CONCLUSION

The higher level of salinity significantly reduced the survival percentage, seedling height, collar diameter, number of shoots per seedling, number of leaves per seedling, fresh and dry biomass of shoot and root in *B. tulda.* Among different level of saline irrigated water, significant reduction in survival, growth and biomass of *B. tulda* was registered at S_4: 6.0 dSm^{-1} and S_5: 8.0 dSm^{-1} while marginal reduction at S_3: 4.0 dSm^{-1}. However, S_1: 0.5 $dSm^{-1}$and S_2: 2.0 dSm^{-1} showed less impact on *B. tulda* seedling's survival, growth and biomass parameters. From the present study, it is inferred that *B. tulda* can be successfully grown with slight reduction in survival, growth and biomass up to the salinity level of 4 dSm^{-1}. It is also noticed that the critical limit of saline irrigation water under nursery condition for *B. tulda* is 4 dSm^{-1} which shows less negative impact on survival, growth and biomass as compared to higher salinity levels.

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Monitoring Vegetation Health, Water Stress, and Temperature Variation through Various Indices using Landsat 8 Data

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Abstract: Remote Sensing (RS) may serve as an efficient tool to monitor and assess the water stress, vegetation health, and temperature variations in a region with both time and space. The present study was undertaken to monitor vegetation health, water stress, and temperature variation by estimating nine widely used spectral indices for seven stations (Ambala, Bhiwani, Gurugram, Hisar, Karnal, Narnaul, and Rohtak) located in Haryana State, India using the 30-m Landsat-8 data. The spectral indices were cross-verified with ground observation data collected from the seven stations. The used indices included the Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), Modified Soil-Adjusted Vegetation Index (MSAVI), Normalized Difference Built-up Index (NDBI), Normalized Difference Water Index (NDWI), Normalized Difference Moisture Index (NDMI), Normalized Difference Infrared Index for Band 7 (NDIIB7), and Surface Albedo and Land Surface Temperature (LST). The observed data for all the nine indices for different locations showed large variations throughout the study period (2013–2018). Large variations of LST values were observed during the study period in the study regions. The findings of the study exhibited the ability of RS technology in assessing and monitoring vegetation health, water stress, and temperature variations in the study area. Such a study would be helpful in long-term crop planning in a region concerning the improved monitoring and management of temperature variation and crop water stress.

Keywords: RS, GIS, LST, NDBI, MSAVI, NDWI, NDIIB7

The study of regional eco-environment should focus on economic development and ecosystem conservation (Surya et al 2020). The main reason for the accumulation and expansion of ecological vulnerability is due to the higher rate of human-socioeconomic activity and climate change (Saha et al 2021, Xu et al 2021, Boori et al 2022). RS has emerged as an important tool to measure and track the characteristics of terrestrial ecosystems at several scales due to consistent, extensive coverage and high spatial and temporal resolutions (Gu and Wylie 2015). Data of spatial, spectral and temporal resolutions are acquired for physical processes that take place on Earth using RS techniques such as Landsat Sensors, Multispectral Scanner (MSS), Thematic Mapper (TM), different satellite sensors, and aircraft cameras. In recent years, many coarse and high-resolution RS images are available free of cost to the user and are not limited to commercially available images of very high spatial resolution such as Sentinel and Landsat images. Further, such images are usually acquired with several desired spectral bands, i.e., the near-infrared and thermal bands, thus proving their applicability in natural process modeling such as vegetation health and stress. Land surface reflectance and temperature data can be used to quantify crop water stress using different vegetation and temperature indices calculated from the near-infrared, red, and thermal band (Neale et al 1990, Bausch 1993, Bausch et al 2011, DeJonge et al 2015, Dejonge et al 2016). The vegetation indices were used to estimate fractional vegetation cover add spacing (Trout et al 2008, Johnson and Trout 2012, Kumar et al 2019, Arvind et al 2020, Kumar et al 2021). During the last decades, various studies have been carried out for the assessment of eco-environmental quality. Several techniques like analytical hierarchical process (AHP), the index evaluation method, fuzzy comprehensive evaluation method, matter element analysis, and principal components analysis are used to reveal the regional eco-environmental situation (Zhang et al 2011). The vegetation indices i.e., SAVI, NDVI, MSAVI, etc. have been developed and used in the last half-century. The algebraic combination of spectral bands is the fundamental hypothesis behind the development of these indices, which can reveal useful biophysical characteristics such as vegetation or leaf structure, coverage, density, spread, water content, and mineral deficiencies (Holben 1986). In addition, factors influencing spectral reflectance's such as soil properties, atmospheric conditions, sensor viewing geometry, and solar illumination should be less susceptible to healthy vegetation indices (Tucker and Garratt 1977, Holben 1986). The leaf structure influences vegetation interactions with sunlight for photosynthesis. The leaves have two procedures, i.e., absorption and scattering of sunlight. At particular wavelengths, plant pigments and water present in the leaves absorb light. Scattering is caused by the leaves' inner composition, whereas the leaf's interior is a labyrinth of air spaces and irregularly water-filled cells. Green leaves absorb most in the blue and red regions and less in the green region (Holben 1986). There is no absorption from upper vision limit of 700 nm to more than 1300 nm. No absorption indicates high rates of reflectance of green vegetation beyond the red band (Tucker and Garratt 1977).

The normalized difference vegetation index (NDVI) value varies from ±1. The dense vegetation here is described by +1; water typically has an NDVI value less than zero (Taloor et al 2021). Here, −1 means the existence of large water bodies (Holben 1986). Specified some typical NDVI values for different types of land use/land cover, where the water value is −0.257. Dwivedi and Sreenivas (2002) considered the limit value of 0.13 of NDVI for the separation of vegetation areas from waterlogged areas using Landsat and IRS-1A (Indigenous state-of-art operating remote sensing satellites) and LISS-I (Linear Imaging Self Scanning Sensor) data. The NDWI was designed to obtain the difference in the signature for water availability in plants (McFeeters 1996, Xu 2006). The NDBI is used to obtain built-up features and ranges between −1 and +1 (Zha et al 2003). The drought index NDIIB7 is used for measuring water stress in vegetation. The interpretation of the NDMI's absolute value makes it possible to identify the farm or field areas with water stress problems instantly. NDMI can be easily interpreted using its value ranges from −1 to +1 (Taloor et al 2021). The NDMI and NDWI are satellite-derived indices to monitor soil and vegetation moisture conditions. In areas with sparse vegetation, the ability of greenness indices for evaluating vegetation is limited due to neighboring soils and sand pixels that may be showing more reflectance than vegetation (Barati et al 2011). Surrounding soils represent visible wavelengths and will continue to affect traditional vegetation indices that commonly use red wavelengths until soils are fully covered by vegetation (Jackson and Huete 1991). In order to minimize the confusing impacts of soil in the background, soil-adjusted vegetation indices were developed (Carreiras et al 2006). The SAVI was formed (Huete 1988) to minimize soil impacts on canopy spectra by integrating the NDVI denominator into soil adjustment factor (Qi et al 1994). Its results are presented based on cotton canopies measured by ground and aircraft. It has been observed that the MSAVI increases the vegetation signal's dynamic range while reducing soil background impacts, that leads to increased vegetation sensitivity as explained by a soil noise ratio of “vegetation signal” (Kasawani et al 2010). In sparsely vegetated areas, such as mangrove swamps (Kasawani et al 2010) and deserts (Barati et al 2011), SAVI has been found to work more effectively than NDVI. Taking into account the vegetation condition in Haryana, which is characterized by fairly open canopies, the soil-adapted indices have been evaluated in the present study.

The complexity of the ecological environment, however, makes the limits of typical environmental surveys and statistics apparent. The study methodologies and depth were enhanced with the use of new technologies, including RS and GIS (Geographic information system) in the eco-environmental evaluation (Zhang et al 2011). However, a few studies compared the variations and applications of these indices for the state of Haryana. The state of Haryana was chosen as the case study region for the investigation and quantitative evaluation of this work. Eco-environmental indices from 2013 to 2018 were examined and evaluated with the help of GIS and RS technology, which could be helpful for governments in formulating policies to protect the environment. The primary objective of this research was to identify the hot spots of water stress, vegetation vulnerability, and temperature variation for sustainable development with environment protection.

MATERIAL AND METHODS

Study area: The study area included seven stations located in seven different districts (Ambala Bhiwani, Gurugram, Hisar, Karnal, Narnaul, and Rohtak) of Haryana state (Fig. 1).

The site is situated between the latitudes of 27°39'20'' to 30°55'05'' N and longitudes of 74°27'08'' to 77°36'05'' E. The total geographical area of the state is 44,212 km2 and is located in the NW of India. The study region is subjected to arid to semi-arid monsoon climatic conditions with an average annual rainfall of 450 mm. In summer, the state experiences extremely hot temperatures of about 45°C (Singh 2010), whereas in winter, it becomes mild. During the Monsoon (June-Sept), approximately 80% of the rainfall is received, while the Remaining 20 % is received in winter season (Singh 2010) due to western disturbance.

Data used: The data used in this study are seven scenes of OLI (Operational Land Imager), Landsat-8 (Path 146/Row

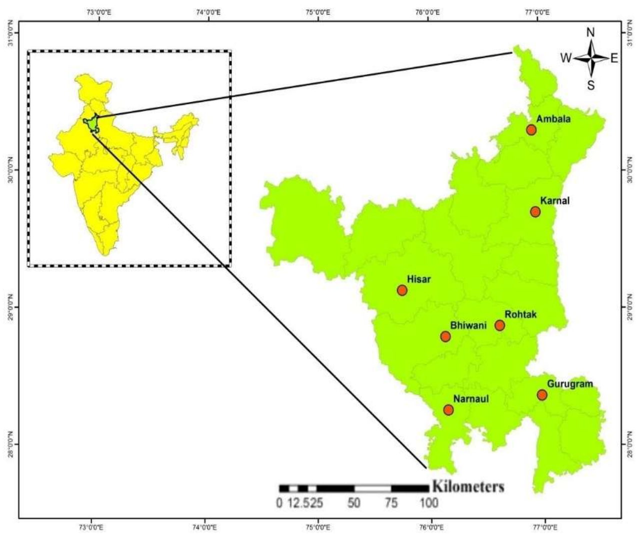

Fig. 1. Study area

40, Path 146/Row 41, Path 147/Row 39, Path 147/Row 40, Path 147/Row 41, Path 148/Row 39, and Path 148/Row 40) obtained from Earth Explorer (http://earthexplorer.usgs.gov/, accessed on 1 February 2019) with different acquisition dates ranging from 2013 to 2018, and which are cloud-free images. The Landsat-8 sensor provides 30 m spatial resolution data with 11 spectral bands.

Software used: ArcGIS was used for database creation, spatial analysis, and map preparation. ERDAS (Earth Resources Data Analysis System) Imagine was used for image processing and determination of vegetation and water indices (Islam et al 2018).

Methodology: Satellite-based images for Landsat-8 were processed for the estimation of nine indicators, namely Surface Albedo, NDVI, SAVI, MSAVI, NDBI, NDWI, NDMI, NDIIB7, and LST. These indicators were assessed for the Monitoring of vegetation health, water stress, and temperature variation, having 30 m spatial resolution for 2013 to 2018.

Vegetation/water indices: Landsat-8 OLI surface reflectance was used to calculate surface albedo and vegetation indices. Bands 1-7 surface reflectance was used to calculate vegetation indices and albedo. For generating LST, the brightness temperature of band 10 was used (Table 1).

Surface albedo estimation: The albedo (α) was calculated according (Smith 2010)'s to algorithm. The broadband surface albedo was calculated as band integration with a specified value, as shown in Equation 1:

$$\alpha = \frac{0.356B_2 + 0.130B_4 + 0.373B_5 + 0.085B_6 + 0.072B_7 - 0.0018}{0.356 + 0.130 + 0.373 + 0.085 + 0.072} \quad (1)$$

where B_2, B_4, B_5, B_6, and B_7 represent blue, red, near-infrared, middle-infrared, and far-infrared bands of multispectral Landsat-8, respectively.

Land surface temperature estimation (LST): Brightness temperature was estimated using TIR (Thermal Infrared) band 10, and NDVI was calculated using bands 4 and 5 in the optical range from the Landsat satellite images. The algorithm was executed in ERDAS Imagine, taking inputs from the metadata file available with the downloaded images. The steps involved in LST calculation are as follows:

Top of atmosphere radiance calculation: The TIR band 10 values were converted into the top of atmosphere (TOA) spectral radiance (Lλ) using the formula obtained from(Li and Jiang 2018) and given in Equation 2:

$$L\lambda = M_{\mathrm{L}} * Q_{\mathrm{cal}} * A_{\mathrm{L}} - O_{\mathrm{i}} \quad (2)$$

where M_L is the band-specific multiplicative rescaling factor, Q_{cal} is the Band 10 image, A_L is the band-specific rescaling factor, and O_i is the band 10 correction (Barsi et al 2014).

Radiance to at-sensor temperature conversion: Using the thermal constants from the metadata file, the TIR band 10DN (Digital Number) values were transformed from spectral radiance to brightness temperature (BT) using Equation 3 (Li and Jiang 2018):

$$BT = \frac{K_2}{\ln[(K_1/L\lambda) + 1]} - 273.15 \quad (3)$$

where K_1 and K_2 stand for the band-specific thermal conversion constants from the metadata (K_1 and K_2 constant for Band x, where x is the thermal band number). For obtaining the results in degrees Celsius, the radiant temperature was calculated by adding absolute zero (approx. −273.15°C) (Xu and Chen 2004).

Calculation of vegetation proportion (P_v): The vegetation proportion (P_v) was calculated according to (Wang et al 2015, Kumar et al 2021b) using Equation 4:

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad (4)$$

The NDVI values are different for each region, whereas $NDVI_{max}$ and $NDVI_{min}$ depend on the vegetation condition (Jimenez-Munoz et al 2009).

Land surface emissivity: The emissivity of the land surface (ε) must be known to estimate LST. LSE is a proportionality factor that scales black body radiance (Planck's law) to predict emitted radiance. It is the efficiency of transmitting thermal energy throughout the surface into the atmosphere (Jimenez-Munoz et al 2006). The determination of the ground emissivity is calculated using Equation 5 (Sobrino et al 2004).

$$\varepsilon_\lambda = \varepsilon_{v\lambda} \times P_V + \varepsilon_{s\lambda}(1 - P_v) + C_\lambda \quad (5)$$

where the vegetation and soil emissivity are ε_v and ε_s, respectively. C reflects the roughness of the surface (C = 0 for homogenous and flat surfaces). It was taken as a constant value of 0.005 (Sobrino and Raissouni 2000).

LST retrieval: The LST retrieval or the land surface temperature (Ts) corrected by emissivity was computed using Equation 6:

$$T_s = \frac{BT}{[1 + \{(\lambda BT/\rho)\ln \varepsilon_\lambda\}]} \quad (6)$$

where T_s is the LST in Celsius (°C), BT is Brightness Temperature (°C) at the sensor, and λ is the wavelength of radiance emitted. The maximum response and the limiting wavelength average (λ = 10.895) were used (Markham and Barker 1985).

RESULTS AND DISCUSSION

Normalized difference vegetation index (NDVI): There are wide variations in NDVI at different locations, which may be considered substantial for representing all the vegetation existing in the state (Fig. 2). The lowest NDVI value was observed for Rohtak station (0.08) in May 2015, while the maximum for Gurugram (0.35) in December 2017. The values of NDVI at different locations are used for analyzing the spatial distribution of changes in NDVI values during the Rabi and *Kharif* seasons. Similar trends in NDVI (-0.2 to 0.52) were also shown by earlier scientist (Bala et al 2015, Swain and Barik 2015, Tyagi et al 2019). NDVI variations may be due to the fallow land between the period of *Rabi* and *Kharif* crops, which is also responsible for the increase in temperature. Moreover, once the SW monsoon sets in, it leads to an increase in vegetation cover in the study area, thereby increasing NDVI values during that period Mathew et al 2016).

Soil-adjusted vegetation index (SAVI): The maximum of SAVI was observed for Karnal and Gurugram stations during September and October 2017, respectively, whereas the lowest value was obtained for Rohtak station in May 2016 (Fig. 3). The variation in SAVI may be due to higher temperatures during May month. Further, the lower rainfall

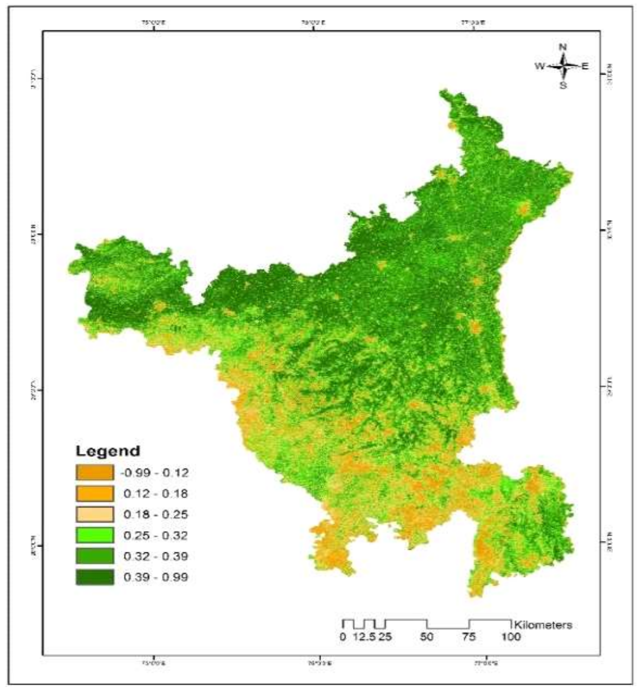

Fig. 2. Spatial variation of NDVI over the study region

Table 1. Vegetation indices evaluation formula for Landsat 8

	Acronym	Equation	Source
Vegetation Greenness Indices	SAVI	$1.5 \times \frac{B5 - B4}{B5 + B4 + 0.5}$	(Huete 1988)
	MSAVI	$\frac{2 \times B5 + 1 - \sqrt{(2 \times B5 + 1)^2 - 8 \times (B5 - B4)}}{2}$	(Qi et al 1994)
	NDVI	$\frac{B5 - B4}{B5 + B4}$	(Tucker 1979)
Vegetation Water Indices	NDMI	$\frac{B5 - B6}{B5 + B6}$	(Wilson and Sader 2002)
	NDWI	$\frac{B3 - B5}{B3 + B5}$	(McFeeters 1996)
	NDIIB7	$\frac{B5 - B7}{B5 + B7}$	(Hunt and Rock 1989)
	NDBI	$\frac{B6 - B5}{B6 + B5}$	(Zha et al 2003)

Note: B represents band and numbering indicates band number during the season led to large variations in SAVI values during these months (Swain and Barik 2015, Tyagi et al 2019).

Modified soil-adjusted vegetation index (MSAVI): The MSAVI varied from -0.38 to 0.74. The highest MSAVI was observed in the northern part of the study area while the southern part shows the lowest indices (Fig. 4). The lowest MSAVI was observed at Hisar station in June 2016 which falls under a semi-arid region and was highest for Gurugram station in September 2017. The MSAVI values were affected by the type and density of vegetation, soil texture, and the prevailing climatic conditions during the season. Tyagi et al (2019) reported a slightly higher value of MSAVI, mainly due to the difference in location and the climatic conditions.

Normalized difference moisture index (NDMI): The NDMI showed wide variations in the study area which varied from -0.99 to 0.99 (Fig. 5). The maximum value of NDMI was observed in October 2017 at Karnal station, whereas was lowest in May 2013 for Hisar station. The NDMI values varied largely due to changes in temperature, water availability (low), and vegetation conditions during the growing season (Das et al 2017). The land cover was very low in May due to the absence of any crops. Moreover, the rainfall usually arrives during the monsoon season (first week of June). Thus, there was no additional source of moisture/irrigation during the month, leading to lower values of NDMI.

Normalized difference water index (NDWI): NDWI spatial

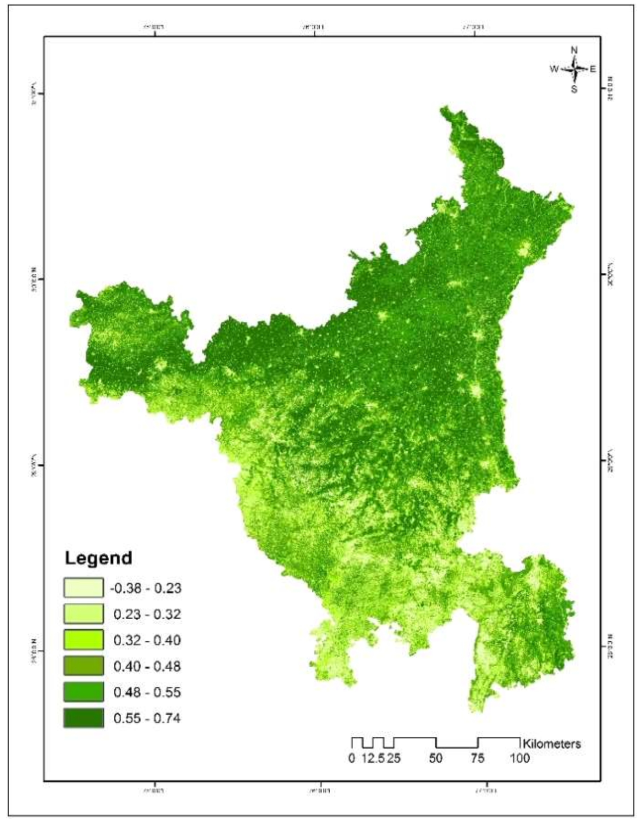

Fig. 4. Map of MSAVI

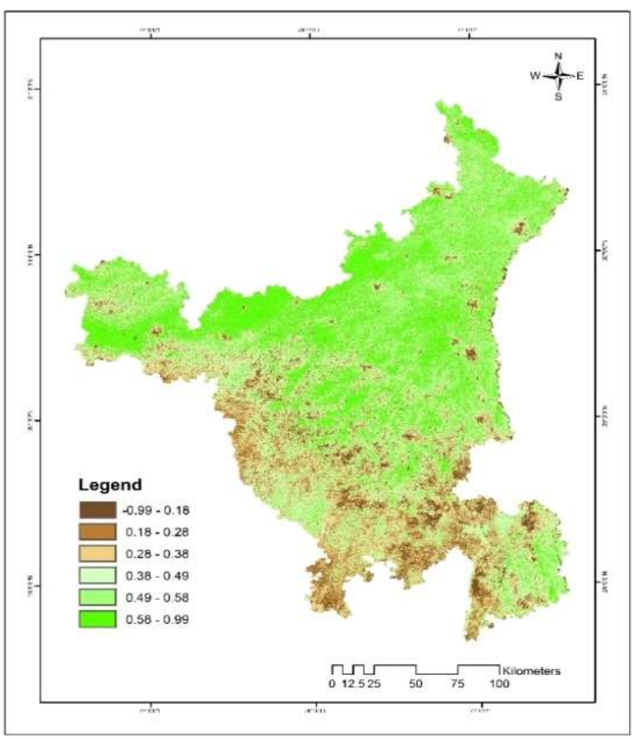

Fig. 3. Map of SAVI

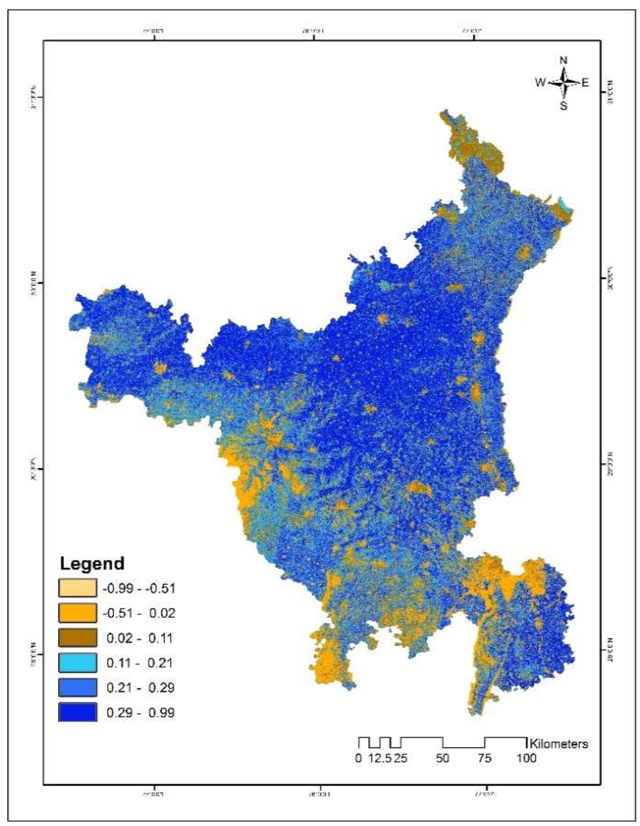

Fig. 5. Map of NDMI

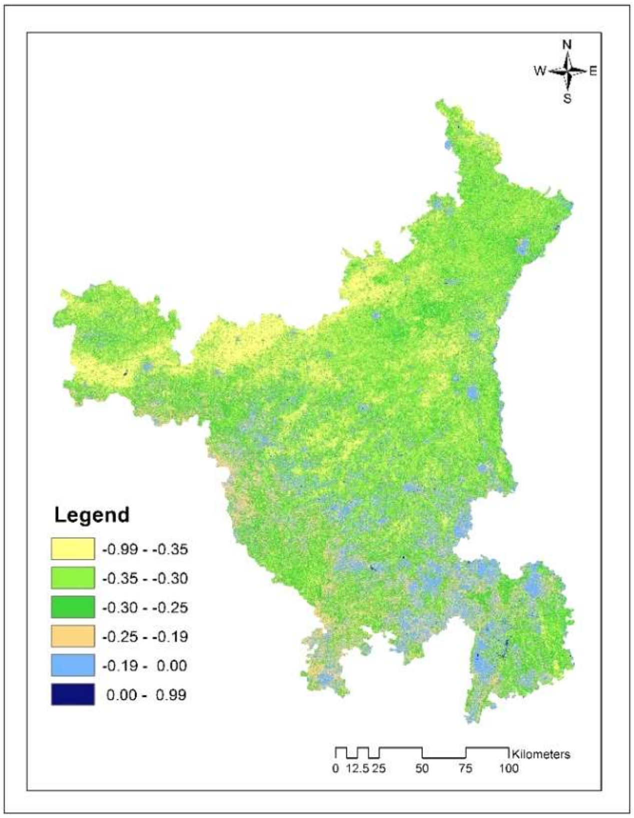

Fig. 6. Map of NDWI

variation in the study area which ranges from -0.99 to 0.99 (Fig. 6). The results indicated the lowest value of NDWI at Gurugram station in September 2017, while the highest value was at Hisar station in November 2013. The maximum study area showed negative NDWI which indicate the water scarcity during the study period. Similar observation on NDWI was observed by Bala et al 2015.

Normalized difference infrared index for band 7 (NDIIB7): NDIIB7 varied from -0.99 to 0.99 (Fig. 7). The highest and lowest was observed at Karnal station in October 2017 and Hisar station in May 2013, respectively. The variation in NDIIB7 values indicated that the vegetation was under water stress.

Normalized difference built-up index (NDBI): The spatial variation shows the small variation throughout the study area (Fig. 8). Almost all over the Haryana state, the NDBI ranged from -99 to -0.13 and negative values indicate the absence of buildings or other permanent structures in the study area (Sharma and Joshi 2015, Jangra and Kaushik 2017). The values of NDBI ranged between −0.17 and 0.00. Among the seven districts of the state, the maximum NDBI value of 0.00 was recorded for Rohtak district in December 2014, while the minimum (−0.17) was for Karnal in October 2017.

Surface albedo: The surface albedo was highest at Ambala station in September 2015, while the lowest value was at

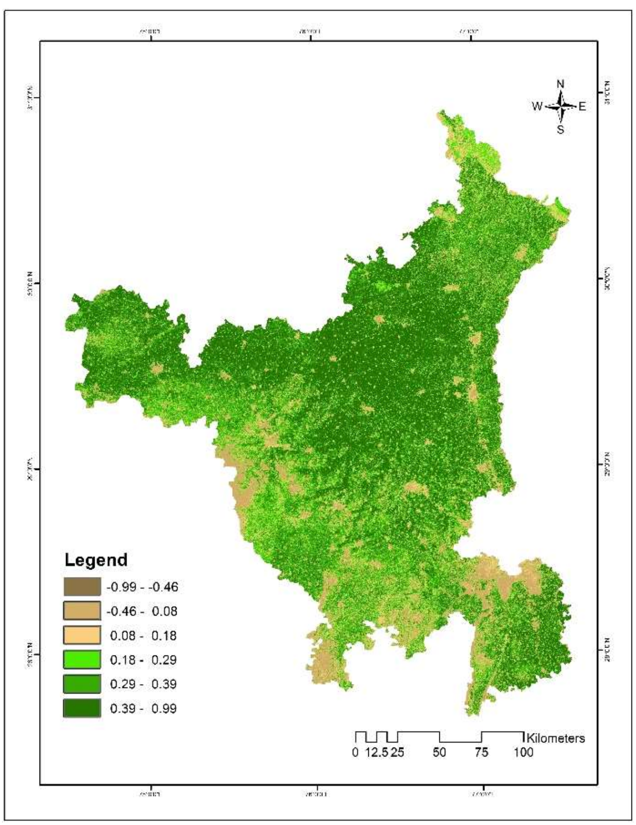

Fig. 7. Map of NDIIB7

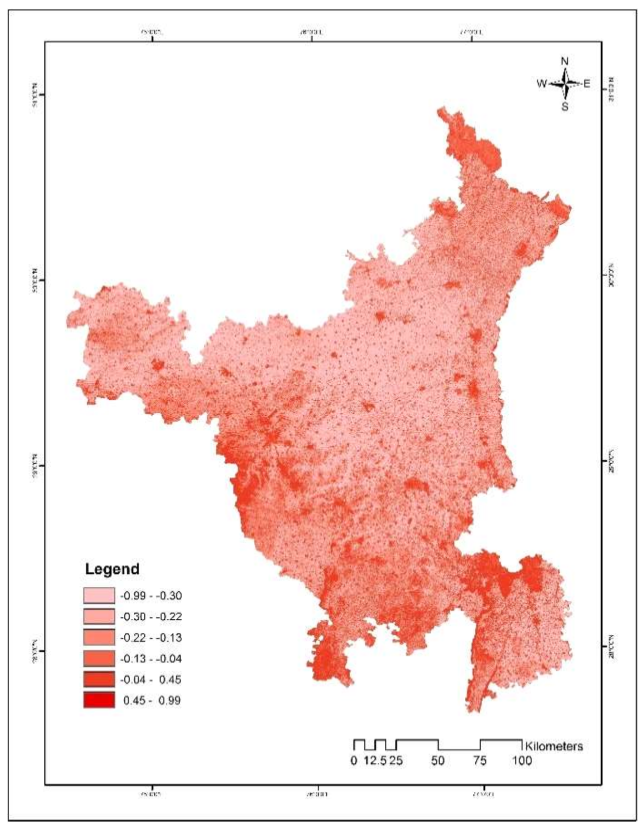

Fig. 8. Map of NDBI

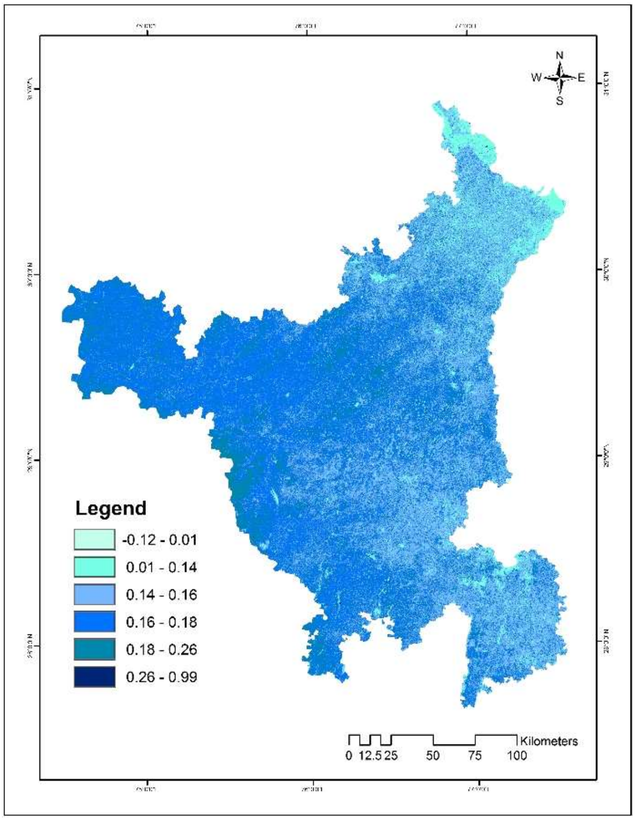

Fig. 9. Map of surface Albedo

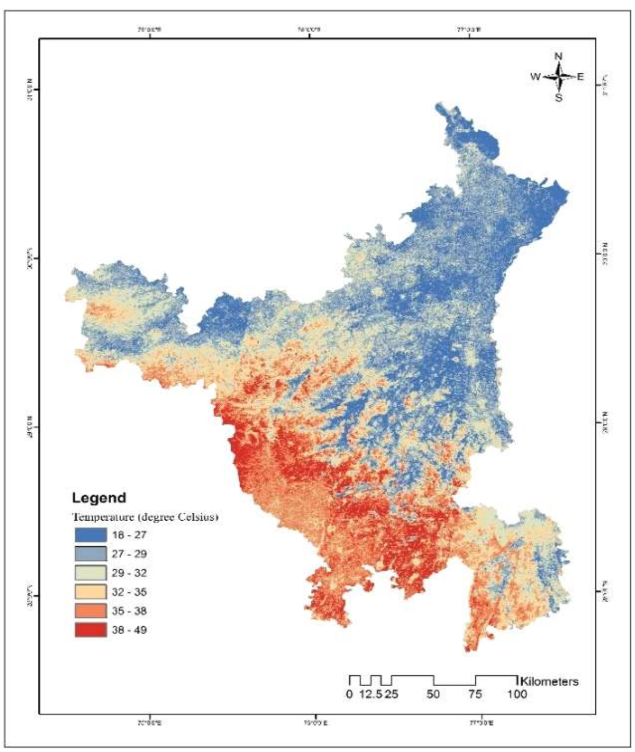

Fig. 10. Map of LST

Narnaul station in 2017 December (Fig. 9). The albedo values showed little variation due to similar climatic and geographic conditions over the whole study area. Mathew et al (2016) showed a small variation in the surface albedo values as compared to the present study.

Land surface temperature (LST) : LST varied from 18 to 49^{0}C throughout the study area (Fig. 10). The northern part of the study area shows the lowest LST while the southern part shows the highest LST. The maximum LST value was observed in May and the lowest was in December. The probable reason for this is that the heat waves flow prominently in the region during May and June which leads to an increase in LST, while cold waves are dominant in December and January when lowest the temperature was during these months.

CONCLUSIONS

There is a wide range of variation in vegetation and water indices throughout the year at different locations during the study period. This variation is mainly due to the flow of heat waves in the region during May and June, leading to an increase in temperature, while cold waves are dominant during December. The computed indices proved to be useful for assessing stress levels in different types of vegetation in the study area. The results indicated a sudden increase in LST and fall in vegetation and water indices values during May and June, as the land remained fallow intermittently after the harvesting of crops, thus leading to an increase in temperature. During the monsoon, an increase in vegetation cover and water was recorded, which in turn indicated increased vegetation and water indices. Moreover, it was observed that the indices were affected by the type and density of vegetation, soil texture, and the prevailing climatic conditions during different seasons. The variations in the values of different indices can be attributed to the varied range of temperatures, water availability, and vegetation condition during different cropping seasons. It is concluded that these indices would provide great help to monitor vegetation health, water stress, and temperature variations in the study area. Thus, the remote-sensing-based monitoring and assessment of vegetation health, water stress, and temperature variation would be helpful in long-term crop planning in a region. Such a study is not limited simply to monitoring and assessing the vegetation health, water stress, and temperature variation in a region. There exists a scope to integrate the data generated from different indices for estimating the performance of the crops grown in the region concerning the available input information.

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Influence of Induced Mutagenesis on DNA Methylation among Mutants of Groundnut (*Arachis hypogaea* L.)

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Abstract: Influence of induced mutagenesis on DNA methylation was studied among the two sets of parents and their EMS-derived mutants (first set consisting of TMV 2 and its mutant TMV 2-NLM and the second set consisting of DER and its mutant VL 1). The number of methylated sites increased in the mutants over their parents in both the sets and the rate of increase was more in the first set than in the second set. B genome accumulated a greater number of DNA methylated sites in both sets. Among the various contexts (CPG, CHG and CHH) of DNA methylation, CHG regions showed the highest number of methylated sites in the first set, while the CPG regions showed a greater number of methylated sites in the second set. The first set showed a higher rate of increase in methylated sites in the intronic and while the second set showed a higher rate of increase in methylated sites in the exonic region of mutants compared to parents. Overall, the study indicated the influence of induced mutagenesis on DNA methylation pattern among the mutants.

Keywords: Groundnut, Ethyl methanesulfonate, Mutants, DNA methylation

Groundnut (*Arachis hypogaea* L.) is an important legume food and oilseed crop worldwide, which is a cultivated allotetraploid (2n = 4X = 40). The breeding efforts mainly focus on productivity, disease resistance, insect resistance, oil quality, oleic acid content Genomics-assisted breeding has been successfully employed (Kolekar et al 2017). Varshney et al (2014) with the development of genomic resources including the genome sequence of the cultivated allotetraploid groundnut (Bertioli et al 2019). Enormous phenotypic variability despite limited genetic variability in groundnut suggests the role of epigenetic changes in generating phenotypic diversity (Bhat et al 2020). Epigenetic changes include DNA methylation, histone modification, acetylation, phosphorylation, ubiquitylation and sumoylation (Weinhold, 2006). Epigenetic factors showing transgenerational inheritance have been identified (Miryeganeh and Saze 2020). Importance of these modifications in plant growth and development has been well documented (Kumar and Mohapatra 2021). In plants, genome-wide DNA methylation modifications have been observed due to drought (Sharma et al 2016), hybridization (Liu et al 2015, Zhu et al 2017) induced and spontaneous mutations (Shen et al 2006, Ma et al 2016). Mutagenesis is known to modify the DNA methylation in Arabidopsis (Zilberman et al 2007), rice (Shen et al 2006) and pigeonpea (Junaid et al 2018). However, not much information is available on the influence of mutagenesis on DNA methylation in groundnut. Therefore, an effort was made in this study to compare the DNA methylation pattern between the parent and the mutant genotypes of groundnut.

MATERIAL AND METHODS

Plant material: Two sets of parents and mutants (EMS derived) were used; the first set consisted of TMV 2 and its mutant TMV 2-NLM and the second set consisted of DER and its mutant VL 1. TMV 2 is typical Spanish bunch variety with a wide-elliptic leaflet, while TMV 2-NLM is a Virginia runner with a linear-lanceolate leaflet.

DNA isolation and library construction: DNA of all four genotypes was isolated using Qiagen DNeasy Plant Mini Kit (Cat # 69104). Bisulfite treatment was done using Zymo EZ DNA Methylation-Gold Kit. DNA methylome library was constructed using illumine TruSeq ® DNA Methylation Kit. The quality of the library was checked using Tape Station and Qubit.

Bisulfite sequencing and analysis: DNA sequencing was carried out using Illumina Hiseq 2500 with two technical replicates and without any biological replicates. Raw fastq files were pre-processed using Adapter- Removal v2 (Schubert et al 2016) tool. Using bwa-meth (Pedersen *et al*2014) program, the preprocessed reads were aligned with the *Arachis hypogaea* reference genome downloaded from Peanut- Base (IPGI 2017). The genomic sites showing DNA methylation were identified using Methyl Dackel program. Differential methylation was analyzed using methyl kit (Akalin et al 2012) R package. The DNA methylation pattern was compared across the genotypes at *q*-value cutoff 0.01 and methylation percentage change cutoff 25 using methyl Kit.

RESULTS AND DISCUSSION

Mapping of the reads: On an average, 281,174,853 bisulfite sequencing reads were generated for each sample. These reads were mapped onto the reference genome of *Arachis hypogaea* with an average mapping rate of 98.78%. Mutant TMV 2 had a marginally higher mapping rate over TMV 2-NLM. Similarly, VL 1 had a marginally higher mapping rate than its parent DER. The number of mapped reads at each DNA methylated site ranged from 1 to 274. On an average, 280, 424, 853 DNA methylation sites were among the four genotypes. Of them, 75, 612, 348 sites showed DNA methylation with 100% reads showing methylation. The number of sites increased to 100, 460, 546 when only 50% reads showing methylation were considered. The B sub-genome exhibited higher DNA methylation sites (184, 183, 182) than the A sub-genome (121, 143, 295) across the genotypes. CHG (where H=A, C or T) region showed the highest methylation sites (121,450,697) followed by CPG (120, 529, 828) and CHH (63, 345, 952) region across all genotypes. These results are in line with the previous reports (Zemach et al 2010, Feng et al 2010) indicating that in plants DNA methylation is found both in CpG and non-CpG (CHG and CHH, where H is A, C or T) contexts, in contrast to mammals where DNA methylation occurs predominantly at CpG dinucleotides.

DNA methylation changes between TMV 2 and TMV 2 -NLM: Changes in DNA methylation between the parent (TMV 2) and the mutant (TMV 2-NLM) were compared in the first set. The number of methylation sites increased in the mutant TMV 2-NLM (25, 44, 52, 659) when compared to its parent TMV 2 (21, 90, 13, 323) when 100% reads showing methylation were considered (Table 1). Likewise, the number of methylated sites increased in the mutant TMV 2-NLM (78, 856, 996) compared to its parent TMV 2 (68, 893, 302). This increase in the methylated sites was more frequent in the B genome than in the A genome, indicating that the B genome is more prone to DNA methylation (Table 2). CHG context showed the highest increase in DNA methylation in the mutant (Table 3). Both genic and non-genic regions showed increased DNA methylation. In genic region, intronic regions (1,687,698 in TMV 2-NLM) showed higher rate of increase in DNA methylation than exonic regions (1,018,559 in TMV 2-NLM). Overall, the number of genes showing DNA methylation increased in the mutant TMV 2-NLM (54,463) over the parent (51,866) (Table 4). Further, the differentially methylated sites between TMV 2 and TMV 2-NLM (Bhat et al 2020) were reported, 37 genes exhibiting differential methylation, of which eight showing differential expression were also reported (Bhat et al 2020).

DNA methylation changes between DER and VL 1; DNA methylation was also compared between the parent (DER) and the mutant (VL 1) in the second set. The number of methylation sites increased in the mutant VL 1

Table 1. Methylation sites and methylated sites among the parents and their mutants in groundnut

Genotypes	Total number of methylation sites	Total number of methylated sites	Frequency of methylated sites	Rate of increase in methylation sites of mutants over its parents (%)	Rate of increase in methylated sites of mutants over its parents (%)
TMV 2	219,013,323	68,893,302	0.31		
TMV 2-NLM	254,452,659	78,856,993	0.31	16.18	14.46
DER	261,792,657	77,745,065	0.30		
VL 1	275,442,003	79,831,117	0.29	5.21	2.68

Table 2. Methylated sites in the A and B genomes of the parents and their mutants in groundnut

Genotypes	Total number of methylated sites		Rate of increase in methylated sites of mutants over its parents (%)	
	A genome	B genome	A genome	B genome
TMV 2	27,365,742	41,527,560		
TMV 2-NLM	31,097,925	47,759,068	14.00	15.01
DER	30,970,192	46,774,873		
VL 1	31,709,436	48,121,681	2.39	2.88
TMV 2	27,365,742	41,527,560		
TMV 2-NLM	31,097,925	47,759,068	14.00	15.01
DER	30,970,192	46,774,873		
VL 1	31,709,436	48,121,681	2.39	2.88

Table 3. Methylated sites among the contexts of parents and their mutants in groundnut

Genotypes	CPG	CHG	CHH	Rate of increase in CPG of mutants over its parents (%)	Rate of increase in CHG of mutants over its parents (%)	Rate of increase in CHH of mutants over its parents (%)
TMV 2	26,820,849	27,768,275	14,304,178			
TMV 2-NLM	30,608,417	30,706,545	17,542,031	14.12	10.58	22.68
DER	30,760,532	31,247,081	15,737,452			
VL 1	32,340,030	31,728,796	15,762,291	5.13	1.54	0.16

Table 4. Methylated sites in exonic and intronic regions among the parents and their mutants in groundnut

Genotypes	Exonic	Intronic	Rate of increase in exonic region of mutants over its parents (%)	Rate of increase in intronic region of mutants over its parents (%)	Genes with methylation
TMV 2	853,885	1,407,484			51,866
TMV 2-NLM	1,018,559	1,687,698	19.29	19.91	54,463
DER	964,170	1,618,932			53,555
VL 1	1,045,365	1,723,338	8.42	6.45	54,876

(27,54,42,003) when compared to its parent DER (26,17,92,657) when 100% reads showing methylation were considered. Similarly, the number of methylated sites increased in the mutant VL 1 (79,831,117) compared to its parent DER (77,745,065) (Table 1). This increase in the methylated sites was more pronounced in the B genome than in the A genome (Table 2). In this set, CPG context showed the highest increase in DNA methylation in the mutant (Table 3). Both genic and non-genic regions showed increased DNA methylation. In genic region, exonic regions (1,045,365 in VL 1) showed a higher rate of increase in DNA methylation than intronic regions (1,723,338 in VL 1). Overall, the number of genes showing DNA methylation increased in the mutant VL 1 (54,876) over the parent (53,555) (Table 4).

DNA methylation changes between TMV 2 versus TMV 2-NLM and DER versus VL 1: Changes in DNA methylation between the parent and the mutant were compared across the two sets. The rate of increase in the total number of methylation sites and the methylated sites in the mutant (over the parent) was more in the first set (~0.31) than in the second set (~0.29) (Table 1). The rate of accumulation of DNA methylated sites in the B genome over the A genome of the mutant was also more in the first set as compared to the second set (Table 2). The rate of increase was highest in CHH context in the first set (Table 3). In contrast, the rate of increase was highest in CPG context in the second set, indicating that the methylation in the contexts (CPG, CHH and CHG) was genotype-specific. Though the genic and non-genic regions showed higher methylated sites in the mutant over the parent in both the sets, intronic regions exhibited a higher rate of increase in methylated sites in the first set, while the exonic regions showed a higher rate of increase in the second set (Table 4). These results are in the line with the results indicating the higher methylated sites at intronic region (Rigal et al 2012) and exonic region (Wang et al 2014) among Arabidopsis mutants.

CONCLUSIONS

The genome-wide DNA methylation analysis among the parents and their EMS-derived mutants revealed that the induced mutagenesis increases the DNA methylation in groundnut. This might contribute to the overall phenotypic variability which can be employed for groundnut improvement.

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Effect of Elevated CO_2 on Growth and Yield Parameters of Groundnut Genotypes (*Arachis hypozeae* L.)

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Abstract: Elevated carbon dioxide is known to impact crop growth and productivity. Groundnut is a very important edible oilseed crop raised mostly under rainfed situations worldwide. in the present study, five cultivars of groundnut (*Arachis hypogaea* L.) viz., TG 86, TG 84, TG 82, Mallika and Gangapuri were raised in three circular open top chambers at different elevated CO_2 levels as ambient condition (450 & 500ppm) and open atmospheric condition during *Kharif* 2019 at the research farm, College of Agriculture, Gwalior. to investigate the effect of elevated CO_2 on growth and yield parameters of groundnut *Arachis hypozeae* L. Groundnut grown in eCO_2 (500 ppm) exhibited significantly higher plant height with maximum number of branches/plants, number of nodules, 50% flowering & 50% maturity. the yield parameters also increased with increasing CO_2 concentration. minimum was recorded in open atmospheric condition. The experiment revealed that among different groundnut genotypes, TG 86 performed best and recorded the maximum yield of kernel, pod and haulm/plant which was statistically at par with TG 84.

Keywords: Elevated, CO_2, OTC, Groundnut, Genotypes

The future climate change is projected to have increased concentration of CO_2 in the atmosphere. The concentration of tropospheric CO_2 has progressively increased from about 280 to 411 µmol/mol from the pre-industrial revolution to present and which is likely to reach 450-600 µmol/mol between 2030 and 2052, if it continues to increase at the current rate. in the recent years, the changing climate has declined the production of oilseeds by 13.7% and recorded negative growth rate of 14% over the corresponding season in the previous year. As it is well known that CO_2 is an important plant nutrient which could enhance crop growth and productivity (Erda et al 2005), however, its increasing levels could affect the majority of crop plants. The plants with C_3 photosynthetic pathway are highly sensitive to atmospheric CO_2 concentration thus it could limit ttheir performance to a great extent affecting crop productivity. Since legume crops can fix atmospheric nitrogen, they respond relatively more to a rise in CO_2 concentration. This ongoing global increase of atmospheric CO_2 could affect plant growth, yield, photosynthesis and below ground biomass. At present, understanding their effects on crops, and soil is crucial for predicting future plants response to maintain higher crop productivity of major crops like groundnut. Groundnut is C_3 legume crop, hence it is expected to be affected by the elevated CO_2 in the atmosphere in terms of its growth, physiological and yield parameters.

Results from Open top chambers (OTC), experiments indicated that elevated CO_2 concentrations resulted in higher biomass production in wheat, groundnut, sunflower, onion, tomato, coconut, cocoa, castor, sweet potato and arecanut. Significant yield response to elevated CO_2 has been reported in crops like rice (Shimono et al 2009), wheat (Ziska et al 2004), blackgram (Jyothilakshmi et al 2013), cowpea (Ahmed et al 1993), soybean (Ziska et al 2001), common bean (Bunce 2008) and also in several non-crop species (Ward and Kelly 2004). More than two decades of study on the effects of CO_2 enrichment have greatly improved our understanding on the above ground plant processes (Drake et al 1996; Baker 2004, Ainsworth 2008).

The genotypes of cultivated crops vary in their response to increased CO_2 concentrations. Thus, understanding their variability of the responses could help us to select specific cultivars with optimal performance (Vaidya et al 2014). Therefore, it becomes imperative to conduct studies which would improve our understanding on the impacts of elevated CO_2 on crop growth & yield, parameters under near-field conditions. The overall goal of the present investigation was to improve our knowledge of groundnut performance under high levels of CO_2.

MATERIAL AND METHODS

For the present experiment, three open top chambers were selected having the diameter of 7.4 m^2 with transparent PVC (polyvinyl chloride) sheet having 90% transmittance of light. To find out the effect of elevated CO_2 on growth and yield parameters of groundnut *Arachis hypozeae* L. Five groundnut genotypes - TG 86, TG 84, TG 82, Mallika and Gangapuri were evaluated under open atmosphere condition, ambient CO_2 and elevated CO_2 concentration of (450 & 500 ppm) in selected open top chamber (OTCs). At the research farm, College of Agriculture, Gwalior during *kharif* 2019. The crop was grown inside the chambers as well as under the natural conditions. First open top chamber was maintained with elevated level of CO_2 at 450 ppm, second chamber with 500 ppm CO_2 and the third chamber without any external CO_2 supply served as an ambient chamber which was the control treatment for the present study.

RESULTS AND DISCUSSION

The growth and yield parameters of selected five groundnut genotypes showed positive response to elevated CO_2 (500 ppm) at different growth stages. The ANOVA and mean performance for growth and yield parameters were presented in Tables 1-2. Correlation between yield and yield attributes was presented in Figure 1-2.

Groundnut grown in eCO_2 (500 ppm) exhibited significantly higher plant height ((51.5 cm) with maximum number of branches (7.2) & number of nodules/plants (79.4, respectively) at 90 DAS. it was followed by eCO_2 concentration of 450 ppm. and the corresponding values were significantly lower plant height (47.7) number of branches (5.8) nodules/plant (75.0 respectively) was recorded in the open atmosphere condition at all growth stages. However, the genotypes TG 84 and TG 86 were found statistically at par with each other in term of plant height. The genotype Gangapuri (14.9cm) recorded comparatively shorter plant height at 30 DAS.

Significantly maximum number of branches & number of nodules /plants was recorded in TG 86 (6.9, 77.5), which was at par with TG 84 (6.8, 77.5), However, the genotype Gangapuri recorded the minimum number of branches/plant & number of nodules (5.7, 75.0 respectively) at 90 DAS. (Bhattacharya et al2000) reported a significant increase in plant height, leaf expansion in sweet potato and cowpea under eCO_2. Similar results were also reported by Vanaja et al (2007) and Srivastav et al (2001). carbon dioxide has direct fertilizing effect on plant growth. Groundnut, being a C_3 leguminous plant has found to show increased growth rates in eCO_2 (500 ppm) conditions. Crop respond positively to eCO_2 showed increase in photosynthetic rate, biomass (Stanciel et al 2002) increased plant height, root length, shoot length, stem length, leaf area and total biomass compared to the aCO_2 condition (Sreenivasulu et al 2015) Similarly, in some other crops like soyabean (Dongxiao et al 2013) and legume (Jennifer 2013) more plant height, leaf area, photosynthesis and total dry matter was noticed under eCO_2condition (Table 1).

Yield attributes: The yield parameters also increased with increasing CO_2 concentration.Significantly, maximum number of pods /plant (34.8), pod weight/plant (19.7 gm), shelling (%) of groundnut (66.4%), 100-kernel weight (26.0 g) and SMK % (86.2%) were recorded with 500 ppm CO_2, the results indicated that increasing CO_2 concentrations up to 500 ppm recorded 16, 20.8, 16, 6.8 and 7.1% higher number of pods /plants, pod weight/plant, 100 kernel weight, shelling

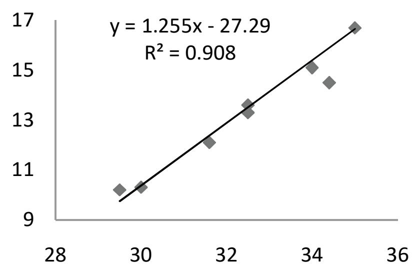
Table 1. The effect of elevated CO_2 on growth parameters of groundnut genotypes (*Arachis hypozeae* L)

Factor A (CO_2 levels)	Plant height (cm)			No. of branches /plant			No. of nodules /plant			50 % flowering	50 % maturity
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	45 DAS	60 DAS	90 DAS		
Open atmosphere	15.6	37.7	47.7	3.6	5.2	5.8	48.6	78.6	75.0	25.8	108
Ambient CO_2	15.9	38.0	48.0	4.1	5.5	6.2	50.2	80.6	76.2	25.3	108
CO_2 Concentration 450 ppm	16.5	40.2	50.1	4.2	5.8	6.6	51.6	81.6	77.2	24.4	106
CO_2 Concentration 500 ppm	17.3	41.7	51.5	4.4	6.3	7.2	54.2	84.2	79.4	24.3	105
SEm±	0.11	0.45	0.48	0.11	0.13	0.16	0.28	0.37	0.59	0.17	0.46
CD (0.05)	0.35	1.38	1.48	0.33	0.42	0.50	0.86	1.15	1.81	0.53	1.41
Factor B (genotypes)											
TG 86	17.3	39.3	49.3	4.4	5.3	6.9	51.5	81.8	77.5	25.0	107
TG 84	17.5	39.8	49.6	4.4	6.3	6.8	51.3	81.3	77.5	24.8	106
TG 82	16.1	38.0	47.7	3.8	5.7	6.5	50.8	81.3	77.0	24.7	106
Mallika	15.9	41.5	51.5	4.0	5.7	6.4	51.3	80.8	77.8	25.0	107
Gangapuri	14.9	38.4	48.7	3.7	5.6	5.7	51.0	81.3	75.0	25.4	108
SEm±	0.13	0.50	0.54	0.12	0.15	0.18	0.31	0.42	0.66	0.19	0.51
CD (p=0.05)	0.40	1.55	1.66	0.37	0.46	0.56	0.96	1.29	2.02	0.59	1.58

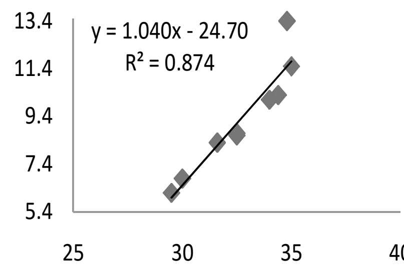
% and SMK%, respectively, over open atmosphere condition. However, the treatments of 500 ppm and 450 ppm CO_2 concentration were statistically similar for all these recorded parameters.

As for different genotypes, TG 86 recorded the maximum number of pods /plants, (35.0), pod weight/plant (18.8g), 100-kernel weight (27.3 g), Shelling (%) (68.2) and SMK (%) (87.8) of groundnut. However, it was found statistically similar with TG 84 and the minimum values for these observations were observed in Gangapuri.

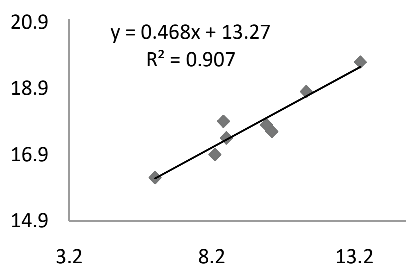
Yield: The pod, kernel, haulm yields were significantly influenced with increasing eCO_2 concentrations among different genotypes of groundnut. The treatment with 500 ppm eCO_2 concentrations resulted in significantly highest kernel yield/plant (13.41 g), haulm yield (54.3 g), pod yield/plant (18.1 g) However, the yield values remained



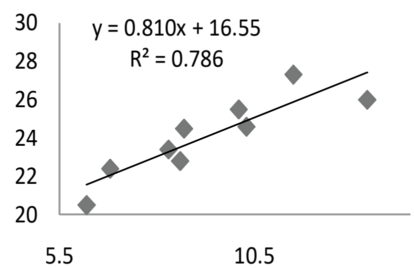
No. of pod/plant vs pod yield /plant



No. of pod/plant vs kernel yield/plant



Kernel yield/plant vs pod weight /plant



Kernel yield/plant vs 100 -kernel weight

Table 2. The effect of elevated CO_2 on yield & yield attributes of groundnut genotypes (*Arachis hypozeae* L)

Factor A (CO_2 levels)	Yield attributes					Haulm yield/plant (gm)	Pod yield/plant (gm)
	No. of pods / plant	Pod weight / plant (gm)	100-kernel weight (gm)	Shelling (%)	Sound mature kernel (%)		
Open atmosphere	30.0	16.3	22.4	62.2	80.5	34.6	10.3
Ambient CO_2	31.6	16.9	23.4	64.6	82.8	37.0	12.1
CO_2 Concentration 450 ppm	34.4	17.6	24.6	65.2	84.0	42.5	14.5
CO_2 Concentration 500 ppm	34.8	19.7	26.0	66.4	86.2	54.3	18.1
SEm±	0.48	0.35	0.27	0.88	0.45	1.71	0.58
CD (p=0.05)	1.49	1.08	0.82	2.72	1.38	5.27	1.80
Factor B (genotypes)							
TG 86	35.0	18.8	27.3	68.2	87.8	50.8	16.7
TG 84	34.0	17.8	25.5	66.5	86.1	46.7	15.1
TG 82	32.5	17.4	24.5	63.8	84.1	42.5	13.6
Mallika	32.5	17.9	22.8	63.8	84.4	40.4	13.3
Gangapuri	29.5	16.2	20.5	60.9	74.5	30.2	10.2
SEm±	0.54	0.39	0.30	0.99	0.50	1.91	0.65
CD (p=0.05)	1.66	1.21	0.92	3.04	1.54	5.89	2.01

statistically similar with the value recorded with elevated CO_2 concentrations of 450 ppm. The percentage increase in yield values was 98.3, 56.4 and 75.7 higher as compared to open atmosphere condition. Higher yield attributes with different CO_2 levels are responsible for increased yields which could also be explained by positive correlation between yield attributes with yield of groundnut (Fig. 1, 2). Similarly, the genotype TG 86 recorded 85, 68.2, 63.8 higher kernel, haulm, pod and respectively, in comparison to gangapuri. Significantly, highest kernel yield (11.46 g), pod yield (16.7 gm), haulm yield (50.8 g) was obtained in TG 86 which was followed by TG 84 (Table 2).

The eCO_2 levels of 500 ppm had highest above-ground biomass production which suggests greater availability of metabolites for growth and development of reproductive structures (sink), which ultimately led to realization of higher yield/plant The elevated CO_2 concentration levels resulted in the highest yield attributes of groundnut genotypee as reflected by the highest values of pod/plant, pod weight/plant, test weight and pod yield. The yield attributes and pod and haulm yield had shown linear increment along with CO_2 enrichmentt. The better yield attributes and increased pod yield obtained in this study agrees with the findings of Chen and Sung (1990) and Hardy and Havelka (1977). Ackerson et al (1984) attributed the high seed yields obtained for soybeans under CO_2 enrichment to more pods and seeds per plant.

CONCLUSION

It was concluded that, the elevated CO_2 concentration 500 ppm improved all the growth and yield parameters in the selected genotype (TG 86) of groundnut. This is due to improved photosynthesis as groundnut being a C_3 crop responded positively to enhanced CO_2 levels. However, a variability of response among these genotypes was noticed for different traits which could be used in selection or development of varieties to fit into future climatic conditions. Thus, it is evident that the mechanism of enhanced CO_2 action varies for different potentials of genotype.

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Diatom Communities in Himalayan River (Lower Stretch of Alaknanda, Srinagar): Periodic Variations in Relative Abundance

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Abstract: The mountain rivers are under anthropogenic stress, especially from habitations along the banks, exemplified by Srinagar Garhwal (Uttarakhand) situated on the banks of lower stretch of Alaknanda. The relative abundance patterns characterise a community and hence the ecosystem. In view of this, a study was designed to assess short and long-term response of benthic diatoms at 5-year and 30-year intervals. For this study we made species count by examining the diatom mounts of 1st, 2ndand 3rd period (1991-92, 1995-96 and 2021-22). The 1st and 2nd periods were characterised by consistently high relative abundance of *A. pyrenaicum* and *A. minutissimum.* In contrast, 3rd period is characterised by high relative abundance of *A. pyrenaicum* in January only and that of *A. minutissimum* and *C. excisa* from February to April. The relative abundance varies significantly (p=0.0043) in long-term interval. Flora varies conspicuously in these periods as some of the taxa exhibited restricted distribution; 5 of 54, 6 of 53 and 33 of 92 species in respective periods. Species diversity increases from 1st to 3rd periods and varies significantly for long-term interval. The variations in long-term interval reflect lack of stability in the ecosystem, possibly due to the flow modification (flooding and desiccation) caused by the power house. The temporal patterns of relative abundance and hence community structure over a period of time would be a suitable bench-mark for ecosystem integrity, and hence restoration.

Keywords: Mountain rivers, Alaknanda, Diatom communities, Relative abundance, Temporal

The rivers in Himalaya are under stress, the magnitude of which is proportionate to the human habitations along its course, well reflected by changing land use from forests, grasslands, marshes, agriculture to built-up area. The mountain rivers that appear to be serene are severely stressed due to tourist and pilgrim activities besides general development in urbanized pockets along its course. The benthic community structure has been studied at different scales, such as spatial and temporal (Nautiyal and Nautiyal 2002, Potopova and Charles 2003, Nautiyal et al 2004, Nautiyal 2009 and Mirzahasanlou et al 2020), but scarcely examined for a short and long-term intervals of 2-5 years (Stevenson and Hasim 1989) and >5years to decade (Strayer et al 2014, Stonik 2021 and Gonzalez-paz et al 2021). Connell and Sousa (1983) suggested that examination of long-term data can be useful for assessing community stability.

Different organisms respond variously in short and long-term intervals; year-to-year variation in aquatic macroinvertebrate fauna from 1980-87 in the Big Sulphur Creek stream, California affected by Mediterranean climate (McElravy et al 1989); long term changes in benthic diatom composition and density under conditions of high (1977 to 1980) and low (1987 to 1993) organic waste input during 1977 to 1993 in the intertidal brackish mudflat in the Ems-Dollard estuary, Netherland/Germany (Peletier 1996); changes in diatom community structure due hydro-morphological changes on a decadal basis from 1991 to 2009 and 2019 in the Danube river, Hungary (Ács et al 2020); long term (1974 to 2008) shift in fish assemblages, body size and functional feeding group in the Wabas river U.S due to increasing anthropogenic activities (Broadway et al 2015).

This study records a short and long-term periodic response of the diatom communities to anthropogenic stressors for 5-year (1991-92 and 1995-96) and 30-year interval (1991-92 and 2021-22) in the river Alaknanda at Srinagar, the largest human habitation along its course from source to confluence with the Bhagirathi at Devprayag. Owing to its holy nature, it is of high religious value (one of the ecosystem services) and is the major source of water for domestic use. Presently, the hydroelectric project and other anthropogenic stressors have severely affected the river ecosystem (Bartwal and Nautiyal 2023).

MATERIAL AND METHODS

Study area: The ~200 km long Alaknanda is one of the two major source tributaries of the river Ganga. The upper ~100 km has a steep gradient, compared to its lower half. The river forms five confluences (prayag) known for their religious value, of which Vishnuprayag lies in the upper half while

Nandprayag, Karanprayag, Rudraprayag and Devprayag in the lower half. Owing to the religious Kedarnath and Badrinath shrines ~70 and 50 km upstream of Rudraprayag and Vishnuprayag, respectively, there is an immense pilgrim and tourist inflow. The size of human habitations have gradually increased around these 'prayags' and pilgrim destinations. Srinagar is the largest habitation in the lowermost part of the Alaknanda. This study has been carried out at Srinagar, an important station along the pilgrim route that has gradually grown in dimension, horizontally and vertically due to development (Government and private infrastructure). Subsistence agriculture in the Srinagar-Chauras valley facilitated by a wide terrace before the year 1980 was gradually replaced by an increase in the built-up area. The Srinagar hydroelectric project became functional in 2014 that modified hydrology of the river.

Numerous studies have been conducted on the Alaknanda by virtue of its proximity to our University. It was sampled for the diatom community structure in past years (1991-92, 1995-96) at Srinagar around Alkeshwar temple on left bank of the river. This location cannot be sampled now due to construction of Alkeshwar Mahadev Ghat under National Mission for Cleaning Ganga (NMCG) and Rishikesh-Karanprayag railway project. Hence sampling was carried out opposite to powerhouse which is ca~200 meter upstream of the past location. Availability of Naphrax diatom mounts for stated periods provided the opportunity to examine changes in the diatom community over a period of time.

Since the diatom mounts are prepared according to Brun's method (Sarode and Kamat 1984) in Pleurax/Naphrax (mountant of high refractive index) they could be stored in the lab. These diatom mounts were prepared for studies related to Ph. D. or research project work from time-to-time. The possibility of using these diatom samples for deciphering the changing riverscape over a period of time was explored in this study. The present samples collected during 2021-22 were subjected to acid treatment and the permanent diatom mounts were prepared in Naphrax. Identification was carried out using OLYMPUS CX41 Trinocular research microscope. Examination of the past mounts was also required to incorporate changes in the taxonomy and current nomenclature, particularly around "minutissimum" and "pyrenaicum" complex of *Achnanthidium* derived from *Achnanthes* s.l. (a species-rich genera, Nautiyal et al 2004) that usually occur in high abundance (Nautiyal and Nautiyal 2002). The species count data was generated from diatom mounts for recording relative abundance in these periods.

Data analysis: The samples of 1991-92, 1995-96 and 2021-22 respectively represent the 1st, 2nd and 3rd period in the following text. One-way ANOSIM and SIMPER dissimilarity matrix (Bray Curtis measure) were performed for determining significant differences and average dissimilarity in the taxa attaining >10% relative abundance of diatom communities between these periods. Kruskal-Wallis test was used to determine significant differences in the species diversity between periods. All statistical analyses and Shannon species diversity were computed using PAST software ver 4.11 (Hammer et al 2001).

RESULTS AND DISCUSSION

Structure of Diatom Communities: Periodic Variations in Relative Abundance

Short-term interval: The 1st period is characterized by higher relative abundance of *Achnanthidium pyrenaicum* (Hustedt) Kobayasi (27.5 to 52.6%) followed by *Achnanthidium minutissimum* (Kutzing) Czarnecki (14.4 to 27.7%) across all months except April when *Nitzschia palea* (Kutzing) W. Smith attains high abundance (37.6%) and that of *A. pyrenaicum* declines (Fig. 1). Similar patterns occurred for 2nd period also (33.1 to 61% *A. pyrenaicum;* 16-33.5% *A. minutissimum*) during most of the months, but in alternating inconsistent fashion from November to March as *A. minutissimum* and *Diatoma moniliformis* Kutzing attain higher abundance in December and February, respectively Additionally, consistent abundance was shown by *Achnanthidium crassum* (Hustedt) Potapova and Ponader, extending from January to April during the 2nd period. *Synedra inaequalis* var. *jumlensis* Jüttner & Cox and *S. inaequalis* Kobayasi attains >10% relative abundance during December only in both the periods (Fig. 1). SIMPER shows only 35.7% average dissimilarity. *A. pyreniacum* (9.9%), *A. minutimssimum* (6.4%), and *N. palea* (5.1%) are most contributing taxa to the average dissimilarity between the periods (Table 1). One-way ANOSIM does not reflect significant difference (p = 0.5581) in the relative abundance during 1st and 2nd period (short-term interval). ANOSIM statistic exhibits (R= -0.02037) low dissimilarity between the periods relative to within periods.

The 3rd period is in contrast characterised by high relative abundance of *A. pyrenaicum* (33.4%) and *Gomphonema olivaceum* (Hornemann) Brébisson (17.6%) in January only. *A. minutissimum* (20.04 to 33.3%) and *Cymbella excisa* Kützing (13.6 to 24.6%) consistently occur in high abundance from February to April (33.3%). *G. olivaceum* in November (23.05%) and *C. excisa* in December (21.01%) characterise the long-term interval (Fig.1). The presence of *Achnanthidium latecephalum* Kobayasi as a taxon with >10% too was notable. The average dissimilarity between 1st and 3rd periods is 60.2%. *A. pyreniacum* (21.9%), *C. excisa*

(8.2%) and *A. minutissimum* (7.7%) are the most contributing taxa (Table 1). There is a significant (p=0.0043) difference in taxa attaining >10% relative abundance for long-term interval and ANOSIM statistic (R=0.5222) shows a high dissimilarity between the periods compared to within periods. Consequently, the patterns appear to be visibly different during long-term for all species with >10% abundance (Fig. 1). Box plot of ANOSIM analysis shows larger variation in 3rd period compared to 1st and 2nd (Fig. 2).

Species richness and diversity: Besides relative abundance the community features like species richness and diversity were useful in understanding the response of the community. Of 114 species recorded from the periods under observation; 54 taxa in the 1st, 53 taxa in 2nd and 92 taxa occurred in the 3rd period. Restricted distribution was observed in these periods; 5 and 7 taxa to 1st and 2nd period respectively, while 33 taxa to 3rd period only (Table 2). Some of these taxa have preferences for higher trophic (19 taxa, meso-eutrophic to eutrophic) and saprobic (7 taxa, α-mesosaprobe to α-meso - >polysaprobe taxa) category (van Dam et al 1994) in 3rd period compared to 4 taxa in 1st and 5 taxa (only eutrophic) in 2nd period. Like-wise species diversity (H) and Evenness (E) were observed to be relatively low (2.388, 0.7885) during 1st period compared to 2.536, 0.8367 in the 2nd period and 3.28, 0.9233 in the 3rd period (Fig. 3). Kruskal-Wallis test indicates no significant difference in species diversity in short-term interval (p= 0.02497), in contrast to significant difference during long-term interval.

The mountain river ecosystems are highly varied but stressed by urban development. They provide a variety of habitats and hence support exemplary biodiversity considering the meager share of freshwater on the Earth. This study aimed to record short and long-term responses vis-a-vis temporal variability in diatom taxa exhibiting > 10 % of the relative abundance in the Alaknanda at Srinagar. The relative abundance of *A. pyrenaicum* and *A. minutissimum* was persistently high, as observed in other glacier-fed rivers (Nautiyal and Nautiyal 2002, Nautiyal and Mishra 2013, Nautiyal et al 2015). In south-eastern Alps the taxa belonging to *Achnanthidium* including those related to *A. pyrenaicum* were also abundant in clean, fast flowing streams with stony substratum (Cantonati and Spitale 2009). Consistently high

Table 1. Dissimilarity and % contributing taxa between the periods of short and long-term intervals

Short-term interval	1st and 2nd period		
Average dissimilarity	35.79 %		
Taxon	Average dissimilarity	Contribution (%)	Cumulative (%)
A. pyrenaicum	9.966	27.85	27.85
A. minutissimum	6.466	18.07	45.92
N. palea	5.153	14.4	60.32
A. crassum	4.329	12.1	72.42
D. moniliformis	3.19	8.915	81.33
*S. i.*var.*jumlensis*	2.481	6.932	88.26
T. inaequalis	1.752	4.897	93.16
C. excisa	1.541	4.306	97.47
G. olivaceum	0.5452	1.524	98.99
Long-term interval		1st and 3rd period	
Average dissimilarity		60.2%	
A. pyrenaicum	21.9	36.38	36.38
C. excisa	8.283	13.76	50.14
A. minutissimum	7.731	12.84	62.98
G. olivaceum	6.093	10.12	73.11
N. palea	5.619	9.334	82.44
A. latecephalum	3.975	6.603	89.04
A. crassum	2.562	4.256	93.3
S. inaequalis var.*jumlensis*	1.828	3.037	96.34
D. moniliformis	1.496	2.485	98.82

Table 2. Characteristics taxa present in each period

Taxa	P1	P2	P3
Achnanthes brevipes Agardh	+		
Fragilaria capitellata (Grunow in Van Heurck) J.B. Petersen	+		
Nitzschia communis Rabenhorst	+		
Nitzschia minuta Bleisch`	+		
Cymbella turgidula var.*bengalensis* Krammer	+		
Fragilaria brevistriata Grunow in Van Heurck		+	
Navicula erifuga Lange-Bertalot in Krammer & Lange-Bertalot		+	
Navicula schroeteri Meister		+	
Surirella sp.		+	
Cymbella cistula (Hemprich in Hemprich et Ehrenberg) Kirchner		+	
Cymbella exigua Krammer		+	
Sellaphora bacillum (Ehrenberg) D.G.Mann		+	
Psammothidium pseudoswazi (Carter) Bukhtiyarova et Round			+
Halamphora montana (Krasske) Levkov			+
Amphora veneta Kützing var. *veneta*			+
Cyclotella pseudostelligera Hustedt			+
Cymbella novazeelandiana Krammer			+
Cymbella tropica Krammer			+
Craticula ambigua (Ehrenberg) Mann			+
Craticula dissociata (Reichardt) Reichardt			+
Cyclotella atomus Hustedt			+
Cyclotella sp.			+
Cymbella excisa var. *subcapitata* Krammer			+
Cymbella parva (W.Sm.) Kirchner in Cohn			+
Cymbella pervarians Krammer			+
Encyonema silesiacum (Bleisch in Rabh.) D.G. Mann			+
Encyonopsis cf *microcephala* (Grunow) Krammer var. *microcephala*			+
Eunotia sp.			+
Fragilaria capucina var. *perminuta* (Grunow) Lange-Bertalot			+
Gomphoneis olivaceoides (Hustedt) Carter & Bailey-Watts ex. Tuji			+
Nitzschia acicularis Kützing) W.M.Smith			+
Navicula caterva Hohn & Hellerman			+
Nitzschia draveillensis Coste & Ricard			+
Nitzschia frustulum (Kützing) Grunow var. frustulum			+
Navicula symmetrica Patrick			+
Navicula amoena Manguin ex Kociolek & Reviers			+
Navicula exilis Kützing			+
Nitzschia inconspicua Grunow			+
Nitzschia intermedia Hantzsch ex Cleve & Grunow			+
Diatoma tenue Agardh var. *tenue*			+
Pinnularia sp.			+
Synedra acus Kützing			+
Surirella linearis W.M.Smith in Schmidt et al.			+
Synedra dorsiventralis O.Müller			+
Sellaphora stroemii (Hustedt) Kobayasi in Mayama Idei Osada & Nagumo			+

(Acronyms: P1- 1st period, P2- 2nd period, P3- 3rd period)

Table 2 (Continued). Taxa common to any two periods

Taxa	P1	P2	P3
Achnanthidium minutissimum complex	+	+	
Cymbopleura korana Krammer	+	+	
Navicula radiosafallax Lange-Bertalot	+	+	
Nitzschia sinuata var. *delognei* (Grunow in Van Heurck) Lange-Bertalot	+	+	
Cymbella laevis Naegeli ex Kützing	+	+	
Synedra ulna var. *oxyrhynchus* (Kützing) O'Meara		+	+
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	+	+	
Diatoma mesodon (Ehrenberg) Kützing	+	+	
Melosira varians Agardh		+	+
Cyclotella meneghiniana Kützing		+	+
Nitzschia dissipata (Kützing) Grunow		+	+
Diatoma vulgaris Bory		+	+
Platessa conspicua (A.Mayer) Lange-Bertalot		+	+
Gomphonema lagenula Kützing		+	+
Gomphonema olivaceum (Hornemann) Brébisson		+	+
Gomphonema pumilum var. *rigidum* Reichardt & Lange-Bertalot	+		+
Gomphonema parvulum (Kützing) Kützing	+		+
Cocconeis pediculus Ehrenberg	+		+
Fragilaria capucina Desmazieres	+		+
Cymbella excisa var.*angusta* Krammer	+		+
Nitzschia amphibia f. amphibia Grunow var. amphibia	+		+
Achnanthidium microcephalum Kützing	+		+
Achnanthidium cf. *subatomus* (Hustedt) Lange-Bertalot	+		+
Planothidium lanceolatum (Brébisson) Round et Bukhtiyarova	+		+
Navicula caterva Hohn & Hellerman	+		+
Nitzschia linearis (Agardh)	+		+

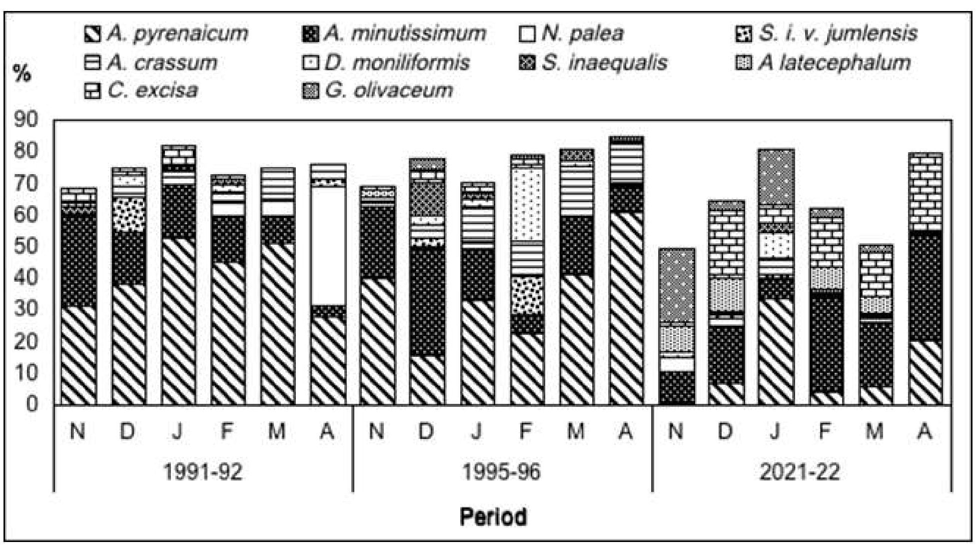

Fig. 1. Temporal patterns of diatom species figuring >10% relative abundance in the community during 1st, 2nd and 3rd periods. The relative abundance of *A. pyrenaicum* and *A. minutissimum* is continuously high for 5-months in the 1st period, while it increases or decreases intermittently in the 2nd period. *A. minutissimum* and *C. excisa* attain higher relative abundance in the 3rd period

abundance of a species in tune with seasonal hydrology is a feature of undisturbed ecosystem as observed in the 1st period. This is attributable to the natural unhindered flow of the river responsible for the supply of nutrients as the river is in semi-natural state and not severely impacted by human activities. This accounts for consistent abundance of *A. pyrenaicum* in this period. Long-term interval clearly reveal the symptoms of disturbances and severe anthropogenic stressors. The relative abundance pattern in the 3rd period differ significantly from the 1st period characterised by increase in relative abundance of *A. minutissimum*, *C. excisa* and *G. olivaceum* attributed to water abstraction and modified hydrology for the peaking requirements (hold and release during generation) of Srinagar hydro-project. The impact of such flow modification has been studied for the macroinvertebrate community in the serially impounded Bhagirathi R. (Kumar and Nautiyal 2019 a, b).

In short-term interval the community reflects only increase or decrease in relative abundance as compared to shift during long-term interval due to replacement of taxa attaining high abundance (Fig. 1). Stevenson and Hasim (1989) studied diatoms in two streams during two summers (1983, 1984) and observed little change between the years (average similarity between the years was 72%) when compared to the same stream and habitat. Gonzalez-paz et al (2021) found no significant difference in the composition of diatom assemblages between the periods (2003-2008 and 2016-2020) attributed to no remarkable change in land use, although agriculture seems to have declined over the last decades in this well-preserved protected area (Picos de Europa National Park, Spain). Stonik (2021) examined long term (1992 to 2015) variation in the composition of bloom forming genus *Pseudonitzschia* and with no significant difference between them. Significant increase in sspecies diversity during long-term interval was attributed to moderate levels of disturbance due to hydroelectric project at Srinagar. The mega developmental activities in recent times are responsible for increased species diversity (Bartwal and Nautiyal 2023) and cannot be used to explain impacts of habitation, organic and/or nutrient load in particular. Gonzalez-paz et al (2021) found a decrease in diversity and evenness over the two periods in which forest area had increased while agriculture had declined. Though inferences from the species diversity explain impacts of hydropower only, the increase in the number of taxa showing restricted distribution and preferences of various taxa with low relative abundance in the 3rd period provide an insight into the ecological health of the Alaknanda. The prevalence of mesotrophic and ß-mesosaprobic taxa, implies lack of pristine conditions. Thus

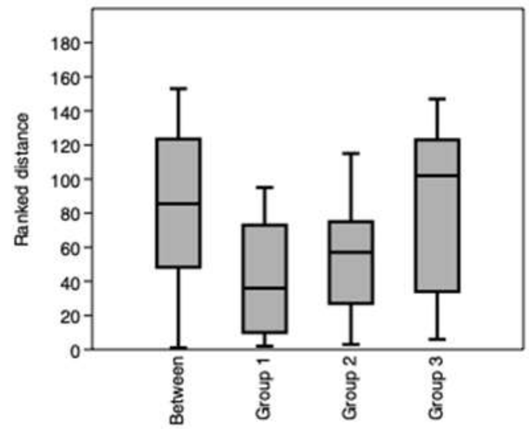

Fig. 2. Box Plot of ANOSIM analysis shows dispersion of data among and between group 1 (1991-92), group 2 (1995-96) and group 3 (2021-22). The horizontal line in the middle indicates median (Q2). The edges of the plot represent lower quartile (Q1) and upper quartile Q3. The vertical lines (whiskers) from the edges of box represent the minimum and maximum value

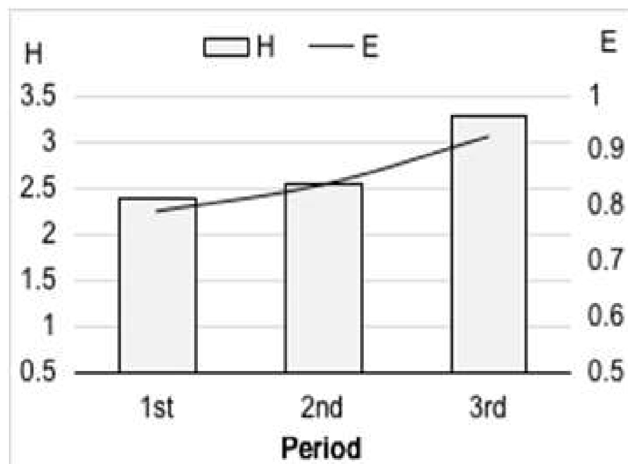

Fig. 3. Shannon species diversity (H) and Evenness (E) between 1st, 2nd and 3rd periods

mild nutrient load and hence mild impact prevails in the river for the short-term interval. The presence of taxa those known for mesotrophic to eutrophic and ß-mesosaprobic to α-meso ->polysaprobe (OMNIDIA ver 6.0.8 Lecointe et al 1993) in the long-term interval indicates the presence of nutrient and organic load, mainly from the habitation at Srinagar.

CONCLUSIONS

The examined community features show a significant shift for long-term interval only. These shifts could be investigated at decadal interval and could be used as a criterion for monitoring human-impacted rivers.

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Elucidation of Growth Status and Condition Factor of Indian Major Carp (*Catla catla*, Hamilton 1822) Reared in Extensive Culture System

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Abstract: The Indian major carp (*Catla catla*, Hamilton 1822) important cultivable fish in Indian subcontinents and aim of the present research is to determine the growth status and condition of fish reared in small village pond or extensive culture system. This study is based on length weight relationship and condition factor so length and weight of the selected species were measured during January to March 2021. The total length ranged between 19.100 - 52.500 (38.675) cm and body weight from 92.000 - 2607.000 (887.259) gm. The length frequency distribution shows that length group C was contributing 64.67% followed by length group B, D and A contributing 20.0, 10.0 and 5.33%, respectively. The correlation coefficient (r^2) 0.963, intercept (a) -2.667 and observed regression coefficient or growth constant (b) was 3.50 which showed the linear and positive relationship between the length weight variables and growth of the fish was found positive allometric. The mean value of condition factor (K) was 1.151 (A), 1.131 (B), 1.428 (C), 1.507 (D)for different length groups and 1.362 for the pooled population which showed better dwelling and good condition of fish in the culture system. These finding clearly indicated that the growth status of catla was good in village pond and aquatic environment of village pond .

Keywords: *Catla catla*, Length-weight relationship, Growth, Condition factor, Extensive culture system

The inland fisheries contributed about 70% of total fisheries production of India and there is further scope to increase the production by sustainable exploitation of the resources through advanced aquaculture practices. Indian major carps forms a dominating group among cultured fish species in inland water resources of the country (DOF 2021) and among these carps catla is the fastest growing fish species and has high economic value in Indian aquaculture sector. The appropriate information about the fish biology can assist for better culture practices and conservation strategies. The length weight relationship (LWR) and condition factor are the important tools of fish biology which provide the basic information to expedite the fish growth and production. The LWR expresses the length increment to weight gained while condition factor is an indicator of the appropriateness of water environment for fish growth and represents the flashiness of fish (Froese 2006, Mensah 2015). Further, it facilitates the comparative growth studies (Moutopoulos and Stergiou 2002), life history of fishes (Shah et al 2013), stock assessment and various components of population dynamics (Adeyemi et al 2009) and assessment of growth rate in the fishes (Johal et al 2005). Recent studies on length-weight relationships for various fish species have been carried out across India (Panda et al 2016, Borah et al 2017, Karna et al 2017, Baitha et al 2017, Nallathambi et al 2020). The length weight relationship and condition factor for *Catla catla* (Hamilton 1822) has been carried out in Indian waters by many authors (Patgiri et al 2001, Prashant et al 2008, Ujjania et al 2012, Das et al 2015, Sharma et al 2016). The present study aimed to carry out length weight relationship and condition factor to determine the growth status and well being of Indian major carp *Catla catla* in Village-pond of Atgam, Valsad (Gujarat).

MATERIAL AND METHODS

The morphometric measurements like total length and weight were recorded from 300 randomly collected catla fish specimens form the landing center of village pond during January, 2021 to March, 2021 from village pond of Atgam, Valsad district, Gujarat (India) which is situated at 20º39ˈ05″ N and 73º00ˈ27″ E. -The total length of (TL) fish specimen was measured from tip of snout to the posterior end of caudal fin with the help of a measuring tape while body weight of individual fish was measured with the help of digital single pan balance. These collected data were categorized into different length groups *viz*., A (15-25 cm), B (25-35 cm), C (35-45 cm) and D (45-55 cm) with 10.00 cm length intervals to assess the length frequency distribution. The length weight relationship based on parabolic equation and the variables relationship from log transformed data of length and weight were evaluated by equations $W = aL^b$ (Biswas 1993) and Log W = Log a + b Log L (Froese 2006), respectively. The correlation coefficient (r) of the variables (total length and total weight) were calculated following the standard statistical procedure of Snedecor and Cochran (1967). Condition factor (K) which shows the well-being of the fish in water body was calculated by equation K = (W/L^3) x 100 (Fulton 1904). Where, 'W' is Weight (g) of fish, 'L' is total length (cm) of fish, 'a' is the Correlation coefficient (or Intercept) and 'b' is the slope (weight at unit length). For statistical analysis and graphical representation of data MS excel 2013 software was used.

RESULTS AND DISCUSSION

The length weight relationship of morphometric variables including total length (TL) and body weight (WT) was determined from logarithmic transformed data of Indian major carp catla from village pond. The total length varied from 19.100 to 52.500 cm with average length 38.675 cm while body weight ranged from 92.000 to 2607.000 gm with average of 887.259 gm (Table 1). The length data was divided into different length groups and it was observed that length group C was contributing 64.67% and dominated,whereas the length group B, D and A contributing 20.00, 10.00 and 5.33%, respectively (Table 1 and Fig. 1). The larger fishes (length group C) maintained dominance during the study which indicates active growth of the fish and favourable aquatic environment of the studied village pond. The findings of the present study are in confirmity to the findings reported for different water bodies as the larger fishes dominated in Daya reservoir (48%) and Pichhola lake (64%) (Rajkumar 2005).

The length-weight relationship of variables (length and weight) were positive and strong relationships of the variables which revealed by correlation coefficient (r^2) 0.963 (Fig. 2). The intercept (a) -2.667 and regression coefficient or growth constant (b) of 3.50 was noted during in the studied area (Fig. 2). The regression coefficient or growth constant (b) was noted as > 3.0 which shows that fish weight increases at faster rate with respect to length indicating a positive allometric growth in the studied pond. The findings of present study were in accordance with the results of Singh and Lakhwinder (2015) and Khalid et al (2020) for catla from different water bodies. In catla, Singh and Lakhwinder (2015) documented b value of 3.20 from Harike wetland while Khalid et al (2020) observed b value of 3.23 in farmed catla thus indicating positive allometric pattern of growth. Ishtiaq and Naeem (2016) reported isometric growth while negative allometric growth in catla has been reported by Ujjania and Soni (2017). The variations in the findings could be attributed by fish size, length intervals, weather fluctuations, gonadal maturity (Macieira et al 2008), sex (Naeem et al 2010), season (Yeasmin et al 2015) and feed availability (Iqbal and Naeem 2018)

The condition factor (K) was 1.362 for pooled population

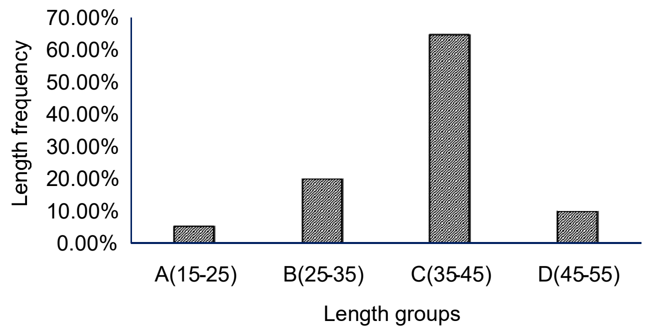

Fig. 1. Length frequency distribution of catla from Atgam village pond

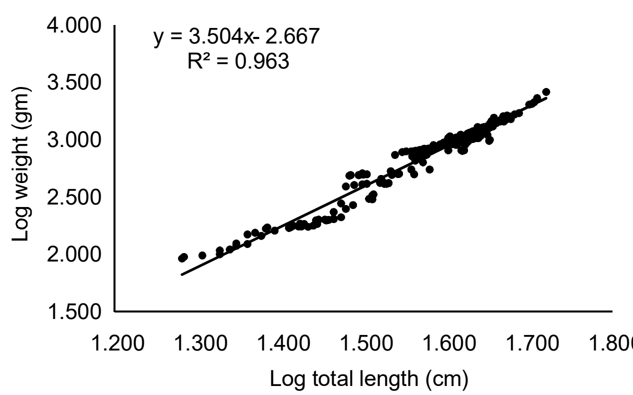

Fig. 2. Length weight relationship of pooled population of Catla from village pond

Table 1. Length weight parameters of catla in Atgam village pond

Length group	N	Total length (cm)		Weight (gm)	
		Range	Mean±SE	Range	Mean±SE
A (15-25)	16.0	19.10-24.70	22.21±0.43	92.00-171.00	127.19±6.72
B (25-35)	60.0	25.70-34.90	30.48±0.37	170.00-735.00	337.28±18.26
C (35-45)	194.0	35.20-45.00	41.24±0.19	500.00-1380.00	1009.23±13.06
D (45-55)	30.0	45.10-52.50	47.17±0.37	1301.00-2607.00	1599.80±57.58
Pooled	300.0	19.10-52.50	38.67±0.39	92.00-2607.00	887.26±24.95

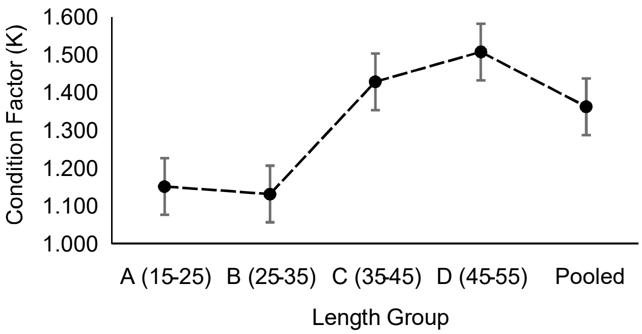

Fig. 3. Condition factor of different length groups and pooled population of Catla

while it was 1.151, 1.131, 1.428±0.009 and 1.507 for different length groups A, B, C and D, respectively (Fig. 3). The condition factor of larger fishes i.e. length group C and D was much higher that might be attributed to sexual maturity and gonadal development in the adult fishes. The overall value of K was >1.0 which indicates the good condition of fish as well as favourable aquatic environmental condition of pond for the fish. Ujjania (2003) observed the oscillated K values varyedg from 2.78 to 3.22 for catla and reported it as an indication of suitability of water body for growth of fish. Similar findings were also documented by Prasad et al (2012) for rohu, Singh et al (2015) for catla, Das et al (2019) for common carps and Khalid et al (2020) for catla.

CONCLUSION

The present study describes the length weight relationship of *Catla catla* (Hamilton 1822) which shows the significantly linear and positive relationship. Growth exponent was > 3.0 that indicates positive allometric growth of studied species. The high value of condition factor indicates better dwelling condition and optimum environmental condition of Atgam village pond for fish growth. Present study suggested to explore and manage the village pond potentially for enhancement and quality production of fishes. These findings may serve as baseline information on growth status and condition of fishes which would be useful for management and conservation practices.

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Assemblage Depended Distribution of Sponge Community in Rocky Intertidal Ecosystem

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Abstract: Population ecology and distribution pattern of common intertidal sponges were studied at Veraval coast of Gujarat state, India. The uneven substratum of the studied intertidal zone supports various macrofaunal assemblages like coral assemblage, zoanthid assemblage and *cerethium* assemblage which provides unique habitat for sponges. Sponges were identified using standard identification keys while the quadrate method and various statistical tools like ANOSIM, SIMPER and PCA were used to study the distribution pattern of common sponge species. Amongst the studied sponge species, *Cliona* sp. was distributed abundantly throughout the sampling sites in all vertical zones and assemblages, five sponge species observed in the coral assemblage and eight sponge species observed in both Zoanthid and *Cerethium* assemblages that indicates essential substrate preferability for the spatial distribution of sponges. Inferences shows that diversity, distribution and seasonal existence of sponges were depends on existing assemblages and substratum.

Keywords: Sponge diversity, Population ecology, Assemblages, Intertidal zone, Gujarat

The coastal environments, especially the rocky intertidal zones show higher degree of spatiotemporal variations in comparison to open sea that provides a unique place to study the diversity and distribution patterns of the organisms in particular ecosystem. Zonation patterns of intertidal rocky shores and its organisms have been intensively well studied in the tropical regions of the world (Denny and Wethey 2001, Chapman and Underwood 2016). Among the intertidal organisms, sponges are sessile and considered to be the first and simplest metazoans with great ecological importance as bioeroders (Hooper 2000), filter feeders (Allen 2000) and biofoulers (Periera et al 2002). Marine sponges inhabit from shallow intertidal areas to deep sea, attached to substratum such as rocks, coral, shells, and marine organisms. Physical characteristics of habitats i.e. vertical, inclined, horizontal and overhanging cliff surfaces are considered as prominent responsible factors for the morphology and shape of sponge species (Bell and Barnes 2000). History of spongology of the Indian Ocean is first given by Thomas in 1971and explained the distribution of sponges of Indian Ocean. Today, the phylum Porifera contributed 8517 valid sponge species all over the world according to World Porifera Database (https://www.marinespecies.org/porifera). In India, nearly 486 sponge species were reported by Dendy (1916), Thomas (1984, 1989), Pattanayak (2006), Vinod (2014), Immanuel (2015), Pawar (2017), Lakwall (2018), Pereira (2020) and George (2020). However, distribution patterns of sponges in context of faunal assemblages and habitats have been meagrely studied particularly in west coast of India. Among the states of India, Gujarat has the longest coastline of 1600 km. Various ecological studies carried out from Gujarat coast (Misra and Kundu 2005, Vaghela et al 2010, Gohil et al 2011, Bhadja et al 2014, Poriya and Kundu 2014, Poriya et al 2014, Raval et al 2015, Vakani et al 2016, Chaudhari et al 2016, Beleem et al 2017, Baroliya and Kundu 2022, Jethva et al 2022). These includes intertidal fauna like molluscs, crabs, worms, echinoderms but the ecology of intertidal sponges of is less explored. The studied coast has rich diversity of sponges but few species are dominated and found throughout seasons. The present study aimed to through insight into the distribution patterns of twelve common intertidal sponges based on existing faunal assemblages.

MATERIAL AND METHODS

Study area: The present study was carried out at a rocky intertidal belt of Veraval (20° 53' N, 70° 26' E), west coast of Gujarat, India (Fig. 1). Site was chosen on the basis of their strategic locations, different types of substratum, assemblages and coast characteristics. The intertidal belt has variety of topographical features such like tide-pools of various sizes, puddles, crevices, small channels and flat rocky surface that provides variety of microhabitats. The upper zone ends up with broad elevation and deep crevices formed by heavy wave action of splash zone.

Quadrate monitoring: Distribution and population of sponges were determined with random quadrate method during the lowest tides of every month. For this, quadrats of

50 x 50 cm were laid at approximately regular intervals in a criss-cross direction on the open area of intertidal belt following a transverse direction covering the maximum area.

Percent cover: Visual methods was used to estimate the percent covers of sponge in permanent 50 x 50 cm quadrats on a wave exposed rocky shore at the Veraval coast. Visual estimates were made with the aid of 25 small squares (10 X 10 cm each) marked off within the quadrat frame. Each small square 'filled' by a species was counted as 4 % cover; often this technique required mentally 'grouping' organisms smaller than one full square and then counting the numbers of squares filled (Fig. 2). This method eliminates the need for decision rules such as 'any square >half-filled is counted as filled instead, a square 3/4 filled is simply 3 % cover. Organisms filling < 1/4 square (<l %) were noted as 'rare', and given an arbitrary rating of 0.5-0.7% (Fig. 2). Among the ecological attributes, monthly variation in percent cover of sponges calculated by following formula:

$$\text{Percent-cover} = \frac{\text{Total cover of benthos from all quadrates}}{\text{Total number of quadrate studied}}$$

Data analysis: ANOSIM, SIMPER analysis and PCA analyses were used to test different ecological attributes. Jaccard Similarity Index used to measure similarity between three assemblages and SHE analysis used to determine the relationship between S (species richness), H (Shannon-Wiener diversity index) and E (evenness as measured using Pielou J) in the samples. It is therefore an approach to look at the contribution of species number and equitability to changes in diversity. Data were transformed using the SQRT transformation to normalize a Poisson distribution. All data was calculated with the help of Microsoft Office Excel. For other ecological data PAST 3 (https://past.en.lo4d.com/windows) software used.

RESULTS AND DISCUSSION

Each organism has different types of adaptations strategies to survive in the particular zone and substratum types that creates dominancy of that organisms in particular area and make its own assemblage. Results of the present study depicted that diversity and distribution of sponge species in studied coastline merely depends on existing assemblages and substratum types. Different ecological aspects like diversity of common sponges, its seasonal existence and percent cover, distribution in different assemblages and substratum were analysed and described here to establish distribution pattern of sponges.

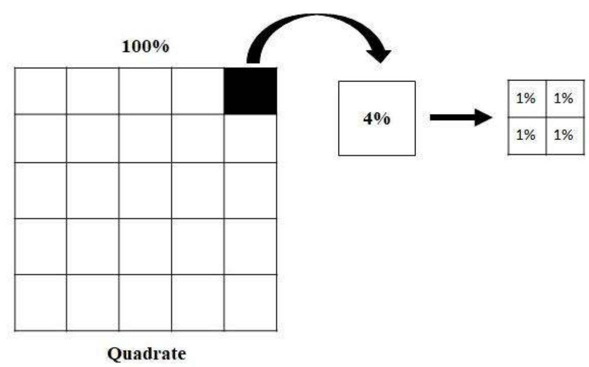

Fig. 2. Schematic diagram showing percent cover analysis of sponge in intertidal zones

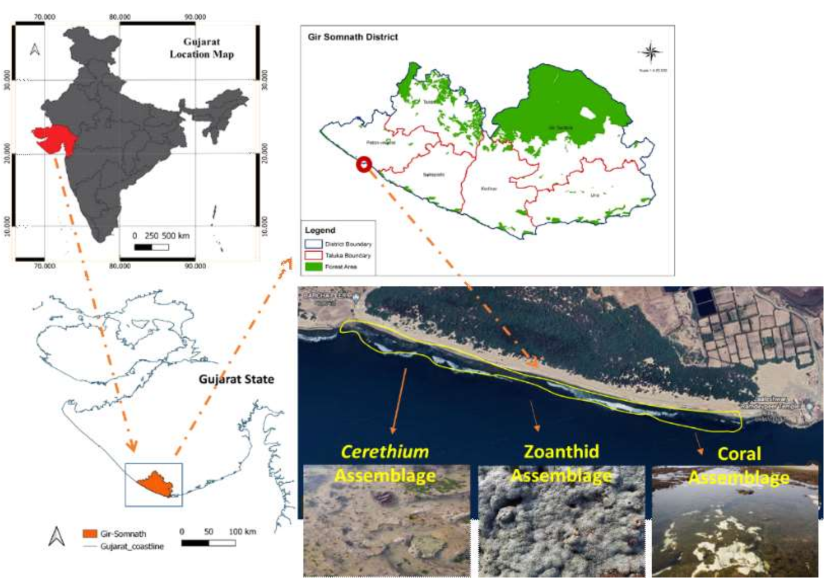

Fig. 1. Study area and assemblages

Faunal assemblages: The entire intertidal zone having different substratum structures and abiotic factors, according to this substratum coral, zoanthid and *cerethium* assemblage were observed during study period where sponge population was present. A total of 12 species of sponges were studied from the selected sites. Sponges were in particular zone (Table 1).

Coral assemblage: The coral assemblage is about 700 m long and has tidal exposure of 60 m, having bare rocky substratum with fewer sharp edges and has a gradient slope. This area identified as coral assemblage as the major biotic portion structured by small to medium sized colonies of different coral species like *Goniopora* Sp., *Porites lutea* and *Porite stephansoni*. Sponges are considered to be important space competitors for corals and other sedentary organisms. There were five sponge species observed in Coral assemblage. Coexistence of sponge and corals in these small to big submerge tidepools indicates benefits for both community for shelter and food, but sometime creates space competition. The upper intertidal zone of this area has big shallow rock pool that expanded up to middle intertidal zones with some algal population of chlorophyceae like *Ulva* sp. By living between the seaweed, sponges get benefited by not getting desiccated.

Zoanthid assemblage: This assemblage is about 700 m long with tidal exposure of about 85 m, having flat substratum with many crevices, few small pools and puddle. The entire intertidal area has large number of small to big, growing and established zoantharian colonies. Total eight sponge species observed in this assemblage. Amongst *Callyspongia (Cladochalina) diffusa* distributed most in this assemblage between the colonies of zoanthids. Good numbers of small pools and puddles, crevices provide variety of microhabitats in this area which nourishing population of sponges. The entire intertidal area of this assemblage has small vertical crevices with sharp edge that makes a good substratum for species like *Haliclona (Reniera) tubifera*, Thus, a different type of habitat then coral assemblage provides more change of settlement to the species like *Callyspongia (Cladochalina) diffusa* and *Haliclona (Reniera) tubifera*.

***Cerethium* assemblage**: This one is one of the large assemblages of about 1200 m long with tidal exposure of about 85 m, with few small pools and puddles and many crevices. The area named as *Cerithium* assemblage due to dominant population of gastropods *Cerithium collumna and Cerithium caeruleum*. All the eight studied sponge species observed in this assemblage. However, *Cinachyrella hirsuta* sponge were most common one in this assemblage. Encrusting sponges found growing on the shells of gastropods due to fewest pools and puddles compare to other assemblages. Thus, it indicates that distribution of different sponge species merely depends on substratum or other substratum forming species.

Spatio-temporal distribution pattern of sponges in different intertidal assemblages: The overall percentage distribution of sponges identified from the study area showed highest cover (46.58%) of *Cliona* sp. followed by *Cinachyrella hirsuta* (Fig. 3).

Cliona sp. was the dominant species of studied coast with cover of 46.58% in sponge community Species distributed randomly in all three assemblages and all vertical zones however it mostly recorded in middle zone of all three assemblages. *Cinachyrella hirsuta* contributed 13.18% cover in sponge community of the coast. Species observed in

Table 1. Distribution of the intertidal sponges recorded between the different vertical zones of different assemblages

Species name	Coral assemblage			Zoanthids assemblage			*Cerethium* assemblage		
	U	M	L	U	M	L	U	M	L
Cliona sp.	++	+++	++	++	+++	++	++	++	+++
Cinachyrella hirsuta (Dendy 1889)	+	++	-	+	++	-	+++	++	-
Callyspongia (Cladochalina) diffusa (Ridley 1884)	-	-	-	-	+	++	-	+	++
Halichondria (Halichondria) panicea (Pallas 1766)	-	++	-	-	-	-	-	-	++
Haliclona (Reniera) cinerea (Grant 1826)	-	-	-	-	++	+	-	-	+
Haliclona (Reniera) tubifera (George & Wilson 1919)	-	+	-	-	+	-	-	-	-
Tetilla dactyloidea (Carter 1869)	-	+	-	-	-	-	-	-	-
Plakortis simplex Schulze 1880	-	-	-	-	-	+	-	-	+
Dysidea sp.	-	-	-	-	+	-	-	-	-
Mycale (Zygomycale) parishii (Bowerbank 1875)	-	-	-	-	-	-	-	+	-
Raspailia (Clathriodendron) arbuscula (Lendenfeld 1888)	-	-	-	-	-	+	-	-	-
Clathria (Microciona) sp.	-	-	-	-	-	-	-	-	+

Signs denote: + Rare, ++ Moderate, +++ Abundant, U- Upper littoral zone, M- Middle littoral zone, L-Lower littoral zone)

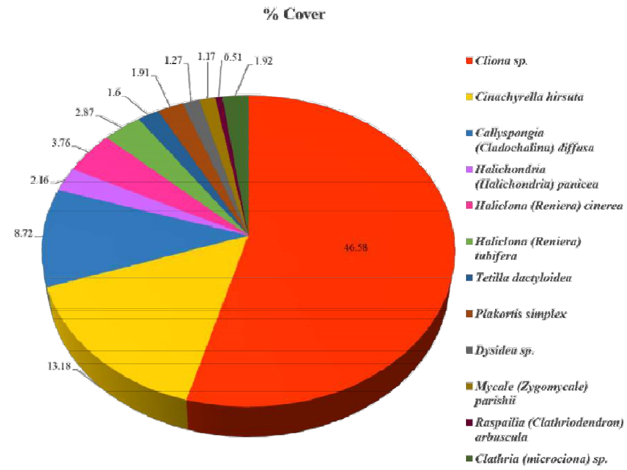

Fig. 3. Percent cover of each species in sponge community of studied coast

all three assemblages in upper and middle vertical zones. Highest abundance of species was in February (17.65% cover) and was abundant in upper zone of *Cerethium* assemblage (Fig. 6). *Callyspongia (Cladochalina) diffusa* distributed in middle and lower littoral zones of zoanthid assemblage and *Cerethium* assemblage while absent in coral assemblage. This was third dominant species of sponge community with highest cover of 10.82% in January in zoanthid assemblage. Abundance of species was increased from September to January (Fig. 5).

Halichondria (Halichondria) panicea typically observed in the middle littoral zone of coral assemblage (Fig. 4) and lower littoral zone of *cerethium* assemblage while absent in zoanthid assemblage. *Haliclona (Reniera) cinerea* distributed mostly in middle to lower littoral zone of the zoanthid assemblage and scarcely scattered in *cerethium*

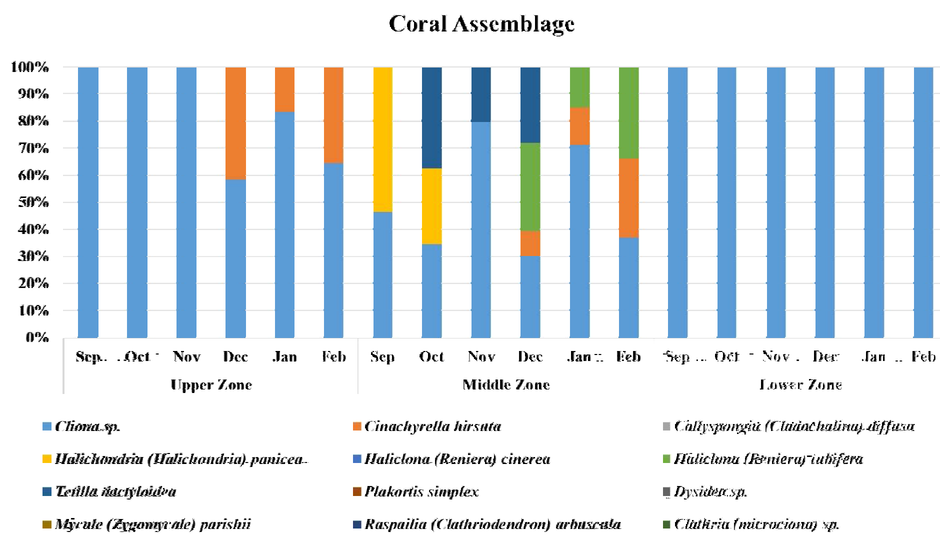

Fig. 4. Distribution of sponge species in coral assemblage

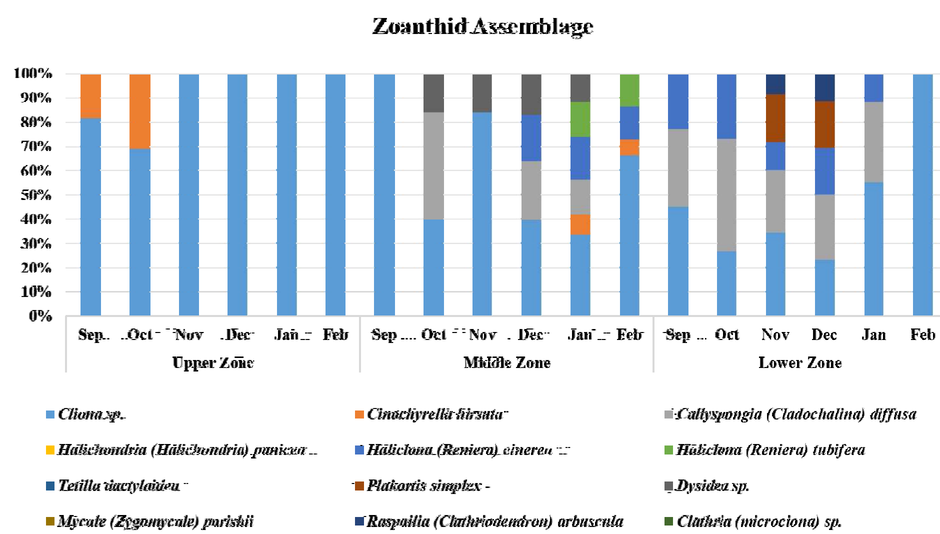

Fig. 5. Distribution of Sponge species in Zoanthid assemblage

assemblage. Increasing trend in abundance of species reported from September to January month. *Haliclona (Reniera) tubifera* was only reported from coral and zoanthid assemblages in the February with 6.30% cover. *Tetilla dactyloidea* was observed only in the coral assemblage with increasing abundance from post monsoon to winter months. *Plakortis simplex,* a boring sponge, was observed only during winter months with highest cover of 4.82% from the lower zone of zoanthid and *cerethium* assemblages. *Dysidea* sp. was observed only in the middle littoral zone of zoanthid assemblage from October to January .*Mycale (Zygomycale) parishii* was observed only in the middle littoral zone of *cerethium* assemblage from October to January month with highest cover of 2.19% in the month of December. *Raspailia (Clathriodendron) arbuscula* was observed only in the lower zone of zoanthid assemblage with the cover of only 0.51% during winter months. *Clathria (microciona)* sp. was observed in the lower zone of *cerethium* assemblage during the winter months with the highest cover of 4.47% in January month.

The percent cover of most sponge species exhibited significant spatial variation in the population attributes. However, no significant variation observed in temporal variation of sponge distribution that may due to the uneven patterns for distribution and growth and preference of different types of microhabitat in different assemblages of studied coast where these species exist.

Relative Distribution of Sponges in Faunal Assemblages

Jaccard similarity index: The Jaccard similarity index varied from 0.14 to 0.30 (Fig. 7). Assemblage wise similarity index indicates that all three assemblages were similar up to some extant in sponge community structure. Highest

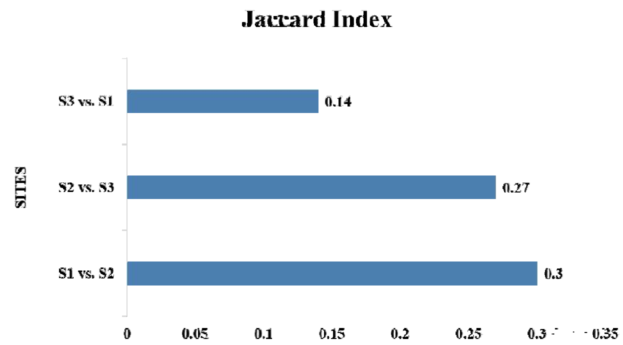

Fig. 7. Comparison of similarity between assemblages for sponge species. (S1- Coral Assemblage, S2- Zoanthid Assemblage, S3-*Cerethium* Assemblage)

Table 2. Temporal and spatial variations of observed sponge species between three micro sites of Veraval

Species of sponge	Temporal	Spatial
Cliona sp.	3.421*	0.539
Cinachyrella hirsuta	0.147	66.157*
Callyspongia (Cladochalina) diffusa	0.503	4.232*
Halichondria (Halichondria) panicea	0.414	1.277
Haliclona (Reniera) cinerea	0.250	14.272*
Haliclona (Reniera) tubifera	1.300	2.016
Tetilla dactyloidea	0.685	3.759*
Plakortis simplex	0.992	1.225
Dysidea sp.	0.488	7.284*
Mycale (Zygomycale) parishii	0.430	8.948*
Raspailia (Clathriodendron) arbuscula	0.802	2.473
Clathria (microciona) sp.	0.620	4.666*

The f-critical value is 3.105875 for temporal variation and 3.68232 for spatial variation and *denotes significance at P < 5 %

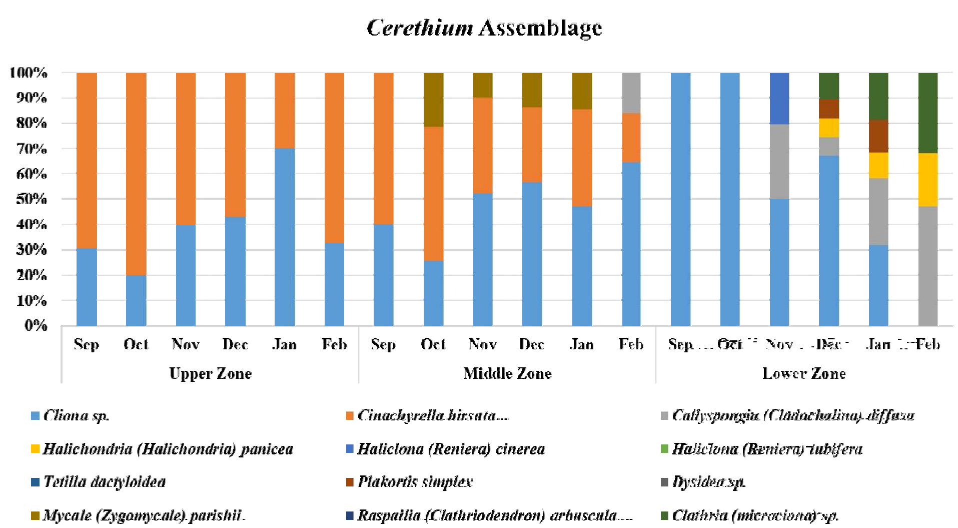

Fig. 6. Distribution of sponge species in *Cerethium* assemblage

similarity was 30% between Coral and Zoanthid assemblages while 27% between Zoanthid and *Cerethium* assemblages, 14% between *Cerethium* assemblage and Coral assemblage. Coral and Zoanthid assemblages were quite similar while lowest similarity was 14% between *Cerethium* and Coral assemblages.

SHE analysis: SHE analysis examines the relationship between species richness, diversity and evenness in the samples (Fig. 8). In the Coral assemblage, analysis showed that, the two diversity indices, the richness (S) and Shannon index (H) have the same increasing gradient while the evenness index (E) has downward gradient. In the Zoanthid assemblage, the richness and Shannon indices have also same pattern as coral assemblage. However, head of both lines starts from 1.3 (ln S) and 0.7 (H) which shows that the range of both indices were greater than Coral assemblage. The minimum evenness was observed in *Cerethium* assemblage. So, it can be determined that the Zoanthid assemblage is the most diverse and favourable for sponges..

SIMPER analysis: ANOSIM analysis showed occurrence of dissimilarity in contribution of sponge species in studied assemblages. It is evaluated by SIMPER analysis that calculates the contribution of each species (%) to the dissimilarity between each two groups. It is calculated from Bray-Curtiss dissimilarity matrix. *Cliona* sp. contributed highest 26.3% dissimilarity between Coral and Zoanthid assemblages, where the overall average dissimilarity is 44.39%. In case of Zoanthid and *Cerethium* assemblages, the overall average dissimilarity is 50.09%, where *Cinachyrella hirsuta* contributed highest 31.89% and lowest contribution 0% is of *Tetilla* dactyloidea. The overall average dissimilarity between *Cerethium* and Coral assemblage is 48.69% where, *Cinachyrella hirsuta* contributed 37.31% while *Raspailia (Clathriodendron) arbuscula and Dysidea* sp. contributed 0% contribution (Table 3).

Principal component analysis (PCA): The 7 principal components (PCs) were contributed to explain 100% of variance among the sites (Fig. 9). The eigen-values associated with each PC. These are often presented as raw values and as proportions of the total variance (which is the sum of all eigen-values). Examining the proportion of variance explained attributed to each PC is useful in determining how much variation that PC is able to 'explain'. Of these, PC 1 (Eigenvalue 5.18) and PC 2 (Eigenvalue 3.71), which together explained 76.91% of the variance. Analysis showed sites and different zones are indicated. This indicates habitat preference of sponge species is also depends on existing assemblage. As few species prefer unique microhabitat in specific assemblage.

The present study reports the distribution and contribution of sponges in the existing intertidal faunal community. Population of sponges significantly not varied

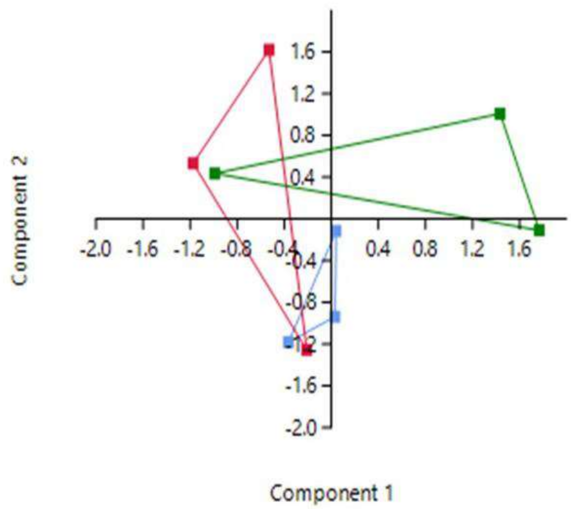

Fig. 9. Principal component analysis (PCA) for species abundance variables. Blue colour indicates the Coral assemblage, red colour indicates the Zoanthid assemblage and green colour indicate the *Cerethium* assemblage. Three point of each site indicates for vertical zonation. Overlapping shows the similarity of sites and distance between two triangle shows dissimilarities between them

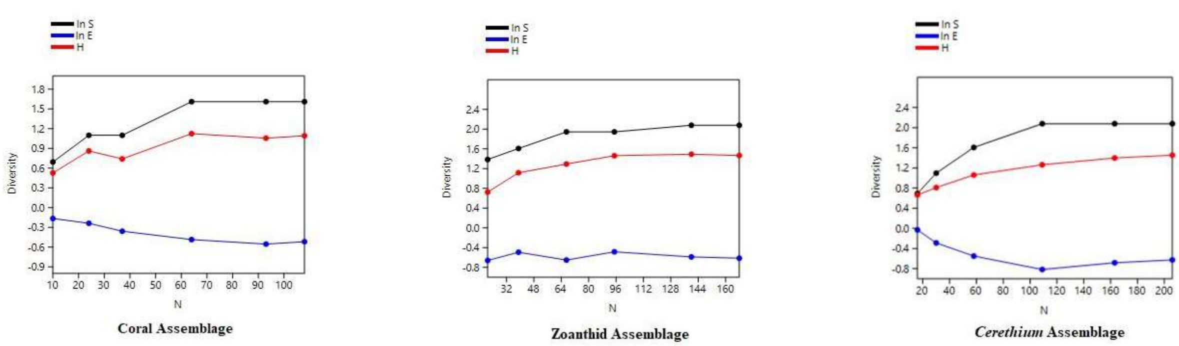

Fig. 8. SHE analysis shows the relationship between species richness, diversity and evenness in the samples

Table 3. Results of SIMPER Analysis between assemblages

Taxon	Average dissimilarity	Contribution (%)	Cumulative (%)	Mean abundance 1	Mean abundance 2
Coral and Zoanthid assemblage					
Cliona sp.	11.67	26.3	26.3	4.29	5.5
Callyspongia (Cladochalina) diffusa	9.552	21.52	47.81	0	1.79
Haliclona (Reniera) cinerea	6.147	13.85	61.66	0	1.18
Cinachyrella hirsuta	3.933	8.861	70.52	0.696	0.325
Haliclona (Reniera) tubifera	3.851	8.675	79.2	0.608	0.35
Tetilla dactyloidea	2.691	6.063	85.26	0.535	0
Dysidea sp.	2.069	4.662	89.92	0	0.424
Plakortis simplex	1.94	4.37	94.29	0	0.35
Halichondria (Halichondria) panicea	1.581	3.562	97.86	0.314	0
Raspailia (Clathriodendron) arbuscula	0.9519	2.144	100	0	0.172
Clathria (microciona) sp.	0	0	100	0	0
Mycale (Zygomycale) parishii	0	0	100	0	0
Zoanthid and *Cerethium* assemblage					
Cinachyrella hirsuta	15.97	31.89	31.89	0.325	3.37
Cliona sp.	9.745	19.46	51.35	5.5	5.73
Callyspongia (Cladochalina) diffusa	7.507	14.99	66.34	1.79	1.12
Haliclona (Reniera) cinerea	4.637	9.257	75.6	1.18	0.0786
Clathria (microciona) sp.	2.969	5.927	81.52	0	0.641
Plakortis simplex	2.008	4.01	85.53	0.35	0.287
Halichondria (Halichondria) panicea	1.872	3.737	89.27	0	0.404
Mycale (Zygomycale) parishii	1.736	3.467	92.74	0	0.39
Dysidea sp.	1.604	3.201	95.94	0.424	0
Haliclona (Reniera) tubifera	1.321	2.637	98.57	0.35	0
Raspailia (Clathriodendron) arbuscula	0.714	1.425	100	0.172	0
Tetilla dactyloidea	0	0	100	0	0
Cerethium and Coral assemblage					
Cinachyrella hirsuta	18.16	37.31	37.31	3.37	0.696
Cliona sp.	9.444	19.4	56.71	5.73	4.29
Callyspongia (Cladochalina) diffusa	5.981	12.29	68.99	1.12	0
Clathria (microciona) sp.	3.458	7.103	76.1	0.641	0
Halichondria (Halichondria) panicea	2.664	5.472	81.57	0.404	0.314
Haliclona (Reniera) tubifera	2.656	5.455	87.02	0	0.608
Tetilla dactyloidea	2.335	4.797	91.82	0	0.535
Mycale (Zygomycale) parishii	2.013	4.134	95.95	0.39	0
Dysidea sp.	1.547	3.177	99.13	0.287	0
Plakortis simplex	0.4237	0.8702	100	0.0786	0
Haliclona (Reniera) cinerea	0	0	100	0	0
Raspailia (Clathriodendron) arbuscula	0	0	100	0	0

between seasons (temporal). Taxonomic similarity-dissimilarity among the different phyla and assemblage structure were studied previously by Poriya and Kundu (2015). The relationship between sponge distribution and assemblages herein demonstrated by various statistical tools that also indicates importance of sponge morphology in assemblage selection (Wulff 2006) and habitat preference that allows the competitive coexistence of species (Montenegro-González and Acosta 2010). Distribution can also be predicted by description or correlations between organisms and habitat components (Kearney 2006).

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CONCLUSION

Sponge communities at studied coast are diverse and this study shows how variation in the sponge distributions dependent on other faunal assemblages. Sponges mostly prefers rock pools, zoanthids bed, underneath of rock, shallow pool, coralline bed, caves-crevices, algal bed. The majority of observed sponges were of encrusting in nature occurring in the cryptic habitats of caves and under surfaces of boulders. Under-surfaces of rocks and caves provides protection from temperature, water current, other extremes and trapping pools helps to reduce evaporation, thus reducing desiccation and salinity ingression. Changes in communities or structure of assemblages can alter the distribution of sponge community, thus sponges can be indicator of coastal ecological studies.

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Population Dynamics and Stock Assessment of Stripped Murrel *Channa striata* from River Sutlej, Punjab

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Abstract: Present study is conducted to assess population dynamics and stock assessment of *C. striata* first time from Sutlej River stretches in Punjab, India to evaluate its present status and outlining the future policies. Length frequency data of *C. striata* around 500 fish samples was collected at monthly intervals from selected three sites (November 2020 to October 2021) and analyzed using the FiSAT II (FAO-ICLARM). Asymptotic length (L_∞), growth coefficient (K) and age at zero length (t_o) to be calculated as 63 cm, 0.77 yr^{-1} and 0.02 yr, respectively. The growth performance indices (Ø) and longevity (t_{max}) value was 3.488 and 3.92 yr. Total mortality (Z), fishing mortality (F) and natural mortality (M) were 2.51, 1.27 and 1.24 yr^{-1}, respectively. The exploitation ratio was 0.51 and the exploitation rate (U) to be 0.39 yr^{-1} indicating overexploited condition. The $E_{cur} < E_{0.1}$ denotes there is little scope to increase further fishing efforts for this species to reach the target reference point (TRP). Existing fishing pressure should be reduced substantially for sustainable development of *C. striata* species in River Sutlej.

Keywords: Sutlej River, *Channa striata*, Growth parameters, Exploitation ratio, Overexploitation

Fisheries are a key source of employment and revenue for the country development and if they are used in a planned manner, fish populations are subjected to natural management process and are a renewable resource (Rizvi et al 2010). Knowledge of population dynamics is an important fundamental part of fish biology for establishing the status of fish stocks and management of targeted fisheries (Dwivedi and Nautiyal 2012). *Channa striata* commonly known as stripped Murrel/snakehead (locally known as Shol fish) is an important member of Channidae family that can be found in a variety of habitats including rivers, marshes, pond, canals, lakes and rice fields. It is a freshwater fish that is native to Asia and tropical Africa. It can withstand harsh environmental condition in water with low dissolved oxygen content and can even survive for long time in land with the help of its accessory respiratory organ. Dua and Kumar (2006), Khan and Khan (2009) and Khan et al (2012) worked on population dynamics of *Channa* species such as *C. marulius* and *C. punctata* but the literature with respect to population dynamics and stock assessment of *C. striata* from India is in scanty. Fahmi et al (2013) and Sofarini et al (2018) studied population dynamics and stock assessment of *C. striata* from Indonesian waters. *C. striata* also has a very good demand as a potential candidate species in ornamental fish markets. The species is mostly harvested from natural water bodies, road side's ditches, derelict water bodies, and is placed under least concerned category in IUCN Red list.

This is the first study to look into population dynamics and stock assessment of C. *striata* from Sutlej River, India. The latest modelling approach is employed in this study to compute growth, recruitment, mortality, yield/ recruit and virtual population analysis (VPA) using FAO's fishery software FiSAT II and developing management plans for the conservation of this valuable aquatic resource.

MATERIAL AND METHODS

Study sites and experimental design: Length-frequency data of a *C. striata* has been collected on weekly interval basis from the three different sampling sites of Sutlej river i.e. Rupnagar (30°59′ 52.9404″N, 76°32′ 00.636″E), Rail/road Bridge at Phillaur, Ludhiana (30°59′ 35.2608″N, 75°47′ 28.2516″E) and Harike (31°08′ 32.334″N, 74°56′ 55.0032″E). The basin shapefile was obtained from the NRSC/INDIA-Water Resource Information System, and the sampling map was created using the ArcMap 10.8.1 platform (Fig. 1). Population dynamics and stock assessment of one of the commercially important *C. striata* has been evaluated from November, 2020-October, 2021 using FiSAT II (FAO-ICLARM Stock Assessment Tools) computer software package. A total of 500 numbers of *C. striata* was considered for population dynamics study. Total length was measured to a nearest 0.1 cm from tip of snout to the posterior end of caudal fin in measuring board and fish weight was noted to nearest gram with the help of a precision balance (Mettler

Toledo, Switzerland). Multistage stratified random sampling method described by Srinath et al (2005) of CMFRI, Cochin was followed during sampling.

Growth parameter: The growth pattern of fish has been expressed using Von Bertalanffy growth equation (Von Bertalanffy 1938):

$L_t = L_\infty(1-e^{-K(t-to)})$

Where: L_t is the mean length at age t, L_∞ is the asymptotic length, K is the growth coefficient and t_o is the age at zero length (initial condition parameter). During the present study estimation of growth parameter was performed by employing computer based FiSAT program developed by Gayanilo et al (1996).

Age at Zero Length (t_o): Pauly's empirical equation (Pauly 1979) was used to determine the age at zero length (t_o)

$\log(-t_0) = -0.392 - 0.275 \log L_\infty - 1.0381 K$

Where, t_0 = age at zero length, L_∞ = asymptotic length, K = growth coefficient

Growth Performance Index (Ø): The final estimations of asymptotic length (L_∞) and growth coefficient (K) (Pauly and Munro 1984) were used to calculate the growth performance index:

Phi (Ø) = $\log K + 2 \log L_\infty$

Where, Phi (Ø) = growth performance index, L_∞ = asymptotic length, K= growth coefficient.

Longevity (t_{max}): The equation presented by Pauly (1983) was used to calculate the longevity.

$t_{max} = 3/K + t_o$

Mortality parameters: The mortality parameters are those key parameters which are used to describe the rate of death. A cohort is the batch of fish with approximately the same age and belonging to the same stock. The total mortality rate of the cohort Z is the sum of the instantaneous rate of fishing mortality F, which is caused by the fishing operation and the instantaneous rate of natural mortality M, which includes deaths caused by all other factors other than fishing like predation, starvation, disease, competition and senility. Length converted catch curve was used to calculate total mortality (Z). Pauly's empirical formula was used to determine natural mortality (M) by taking the mean water surface temperature of River Sutlej as 28.7°C (Pauly 1980).

$\ln(M) = -0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T)$

Where, L_∞= Asymptotic length, K= Growth coefficient, T= Surface water temperature

Total mortality (Z) was calculated from the length converted catch curve using FiSAT software (Pauly 1983). Fishing mortality (F) was estimated by Pauly (1980).

$F = Z - M$

Where, F= Fishing mortality, Z= Total mortality, M= Natural mortality

Length structured virtual population analysis (VPA) of FiSAT was used to calculate fishing mortality of each length class. Exploitation ratio (E) and exploitation rate (U) were estimated from the equations given below (Narasimham 1994):

$E = F/Z$

$U = (F/Z)*(1-e^{-z})$

Where, F= Fishing mortality, Z = Total mortality, E = Exploitation ratio

Relative yield and Biomass per recruit: The original yield per recruit model of Beverton and Holt (1957) has modified by Beverton and Holt (1966) to estimate relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R). The L_c can be taken from knife-edge selection method suggested by Beverton and Holt (1957).

Relative yield per recruit (Y'/R):

$Y/R' = E*U\ M/K*[1-\{3U/(1+m)\}+\{3U^2/(1+2m)\}-\{U^3/1+3m\}]$

Where,

$U = 1-(L_C/L_\infty)$

$m = (1-E)/(M/K) = (K/Z)$

$E = F/Z$

Relative biomass per recruit (B'/R) was estimated from the following relationship

$B'/R = (Y'/R)/F$, while E_{max}, $E_{0.1}$ and $E_{0.5}$ were assessed by using the first derivative of this function. In FiSAT package 'E_{max}' represents the exploitation rate which produces maximum yield. The Y'/R and B'/R were calculated at different exploitation ratios by keeping the L_{c50} as constant. The yield isopleth diagram is a three dimensional figure giving exploitation ratio (E) on the X-axis and different sizes at first capture by using L_c/L_∞ ratios on Y-axis the iso-values of Y'/R were plotted to generate the yield isopleth diagram. The output of this process are plots of Y'/R vs. E = (F/Z) and of B'/R vs. E, from which E_{max} (is the exploitation rate which produces maximum yield), $E_{0.1}$ (is the exploitation rate at which the marginal increase in relative yield per recruitment is 1/10th of its value at E=0) and $E_{0.5}$ (value of E which denote 50% deduction of its unexploited biomass) are also estimated. Data was analysed using the FiSAT II (FAO-ICLARM) computer software package.

RESULTS AND DISCUSSION

Growth parameters: The mean length of *C. striata* was higher in April (46.45 cm) followed by October and March but lower in December to August (Table 1). Using the ELEFAN I algorithm, the asymptotic length (L_∞) and growth coefficient (K) was calculated as 63 cm and 0.77 year^{-1} in *C. striata*, respectively (Fig 2).The t_o was estimated 0.02 year in *C. striata*. The growth equation of von Bertalanffy was estimated as $Lt=63[1-e^{-0.77(t-0.02)}]$

Fahmi et al (2013) reported L_∞ and K of the *C. striata* as 72.98 cm and 0.36 year^{-1} and t_o be estimated -0.52 year at Lubuk Lampam flood plains, South Sumetra. Sofarini et al (2018) at Danau Panggang swamp (South Kalimantan) reported L_∞ and K value as 63.4 cm and 0.15 year^{-1}, respectively and calculated t_o value as -0.52 year. The t_o value is considered as an indicator of juvenile development. If t_o be positive, it implies that juvenile growth is slow, while a negative value suggests that juvenile growth is quick as compared to adult fish (King 2013). In present study, the estimated value was 0.02 year indicating slow initial growth of juvenile fish in River Sutlej. The growth performance indices (ø) and longevity (t_{max}) was recorded 3.488 and 3.92 year which is considered good. Length-weight relationship in *C. striata* established as Log W = -1.12 + 2.15 log L with co-efficient 'b' value 2.15 (Fig.3). The co-efficient of determination (r^2) values explains the proper fit of the model for growth. Value of r^2 in *C. striata* was calculated as 0.85 indicating more than 85% variability by the model and good fitness (Table 2). Negative allometric growth was observed in *C. striata*; thus species became slender as it increased in length. The fish normally does not retain the same shape or body outline throughout their lifespan and specific gravity of tissue may not remain constant, the actual relationship may depart significantly from the cube law (Datta et al 2013).

Table 1. Length range and mean length of *C. striata* at Sutlej River

Month	Length range (cm)	Mean length (cm)
December-2020	27-46	36.5
January-2021	24.5-51.9	38.2
February-2021	23-55.8	39.4
March-2021	27.5-55.4	41.45
April-2021	36.9-56	46.45
August-2021	26-49	37.5
September-2021	25.2-53	39.1
October-2021	32.6-53.6	43.1

Mortality rate and exploitation ratio: Natural mortality rate calculation is important to understand the rate of stock decay. Calculation of 'M' is difficult for exploited resources. Natural mortality (M), fishing mortality (F) and total mortality (Z) was 1.24 year^{-1}, 1.27 year^{-1} and 2.51 year^{-1} for *C. striata*, respectively. Fishing mortality rate was to be higher than the natural mortality which implies existing fishing pressure in River Sutlej is high. The natural mortality generally casused due to disease, environmantal transition, predation, hazards, pollution and senility(Guilin et at 2019). Estimation of Z from Length converted catch curve method with extrapolated data points in *C. striata* from River Sutlej are depicted in Figure 4. Exploitation ratio (E) and explotation rate were 0.51 and 0.39, respectively which clearly indicates that the stock is over

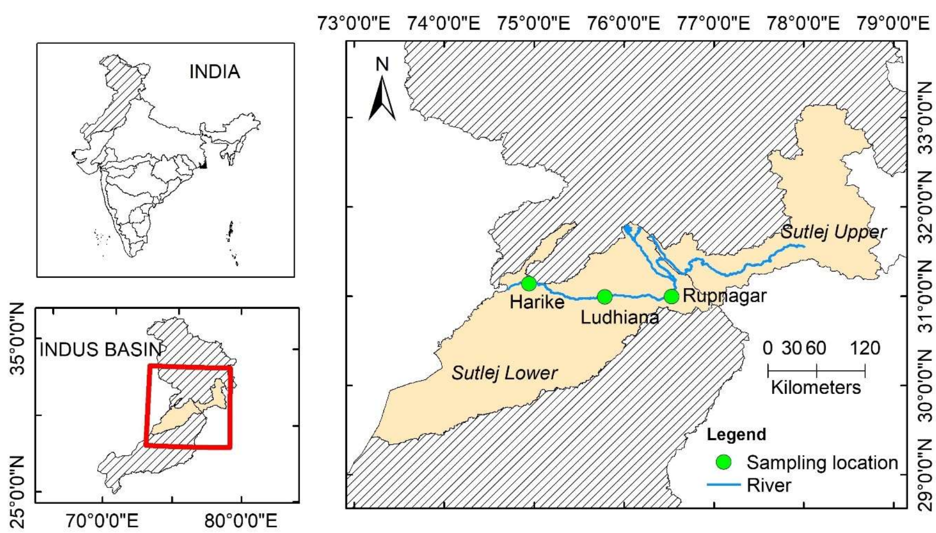

Fig. 1. Map view of the selected sampling site of Sutlej River

Table 2. Length-Weight relationships of *C. striata* collected from Sutlej River

Fish species	Logarithmic equation (Log W = Log a + b Log L)	Mean length (cm)	Mean weight (gm)	Growth coefficient 'b'	Correlation coefficient 'r'	Coefficient of determination 'r^2'	Growth type
Channa striata	Log W= -1.12+2.15 log L	41.00±1.64	570.58±53.72	2.15	0.92	0.85	Negatively allometric

exploted in River Sutlej. A stock is considered ideally exploted when F= M and or E= 0.50 when E value exceeds 0.5 the stock is considered over exploted (Guilin et at 2019). Fishing mortality should be reduced to be $E_{0.5}$ to achieve maximum sustainable yield for *C. striata*. Fahmi et al (2013) observed the average total, natural and fishing mortalities in *C. striata* in the Lubuk Lampam flood plains were 1.72, 0.73, and 0.58 per year, respectively. Fishing and total mortality were used to compute the exploitation rate (E), was 0.58, indicating overexploitation (E > 0.5). Sofarini et al (2018) observed average total, natural and fishing mortalities of *C. striata* at Danau Panggang swamp as 1.12, 0.43, and 0.69 per year, respectively. Natural mortality was predicted to be lower, which could be attributed to its extremely predatory nature.

Recruitment pattern: The recruitment pattern was investigated from recruitment curves using final estimated values of L_∞, K and t_o using FiSAT II program. In present study for the *C. striata*, recruitment was continuous throughout the year. However, higher recruitment peaks was detected during June (15.14%) and July (16.66%) (Fig. 5). The length at recruitment (L_r) of *C. striata* was 25 cm ry. Fahmi et al (2013) in *C. striata* at Lubuk Lampam flood plains, South Sumatera indicated average recruitment percentage as 8.3.

Virtual population analysis (VPA): Based on the VPA analysis it can be stated that the fish upto 25 cm are mainly subjected to natural mortality (Fig. 6). After this size, fish become more vulnerable to fishing gear, resulting in an increasing fishing related mortality. Total length ranging from 35 to 45 cm was vulnerable to fishing mortality.

Probability of capture: The probability of capture denoted the critical length of fish vulnerable to gear. In *C. striata* L_{25}, L_{50} and L_{75} were calculated 23.53 cm 27.28 cm and 31.08 cm, respectively. The L_C/L_∞ and M/K value was found to be 0.433 and 1.61, respectively (Fig. 6). The evaluated M/K score was 1.61, indicating good condition. M/K ratio determines the reliability within the range of 1.0-2.5 in most of the fishes.

Relative yield per recruit (Y/R) and biomass per Recruit (B/R): L_C/L_∞ = 0.433 and M/K = 1.61 was used as input data to calculate Y/R and B/R. *C. striata* was exploited by selective as well as semi selective gears; thus 'knife edge selection' is hardly met in real situation. The present study revealed maximum Y/R could be achieved at an exploitation ratio (E_{max}) of 0.647 in *C. striata*. However the exploitation level of a stock at E_{max} level can decrease the biomass in a drastic level thus it should not be used as a target reference point (TRP). As a part of precautionary measures the exploitation level should be reduced to a point where marginal increase in Y/R reaches 1/10th of the marginal increase calculated at a very low value of E ($E_{0.1}$) which was 0.55 in *C. striata* and this may be used as relatively safe reference TRP (Fig. 8). E_{cur} value (0.51) is less than $E_{0.1}$ (0.55) which indicates that there is little

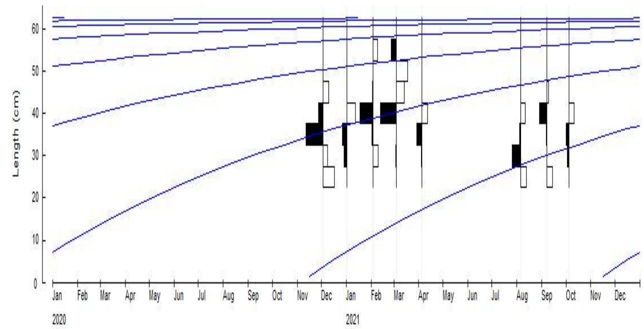

Fig. 2. von Bertalanffy growth curve of *C. striata* superimposed on the restricted length frequency histogram with normal length-frequency histograms (L_∞ = 63 cm, K = 0.77 yr^{-1}, t_o= 0.02 yr, C = 0 and WP = 0). Lines superimposed on the histograms link successive peaks of growing cohorts as extrapolated by the model

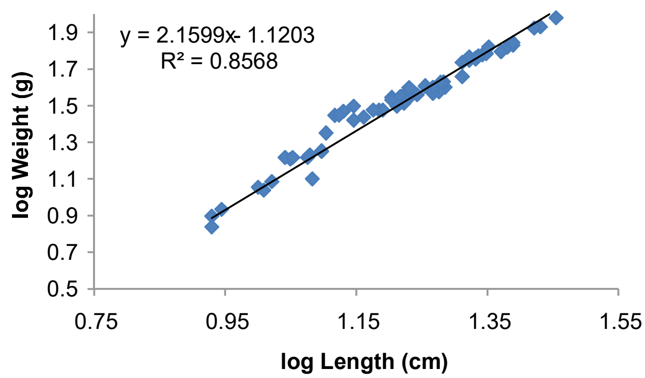

Fig 3. Length-weight relationship of *C. striata* collected from Sutlej River

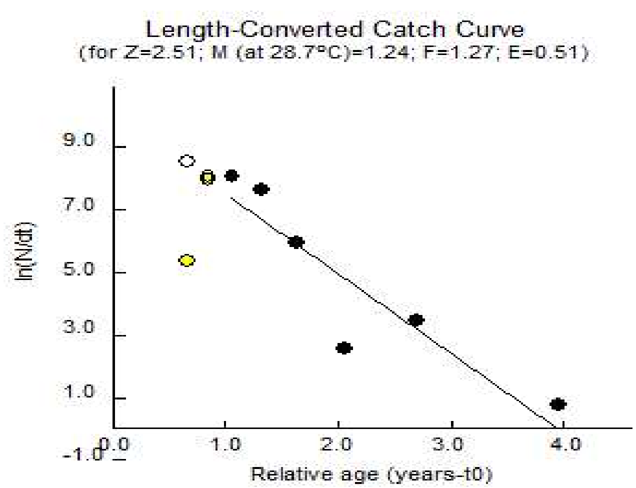

Fig. 4. Estimation of Z from length converted catch curve method with extrapolated data points in *C. striata* from River Sutlej

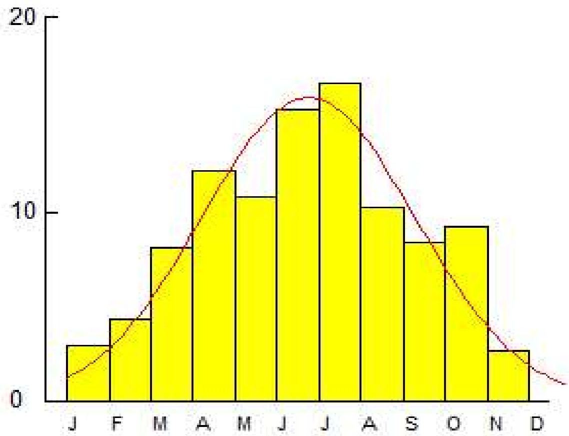

Fig. 5. Recruitment pattern of *C. striata* from River Sutlej during the study period

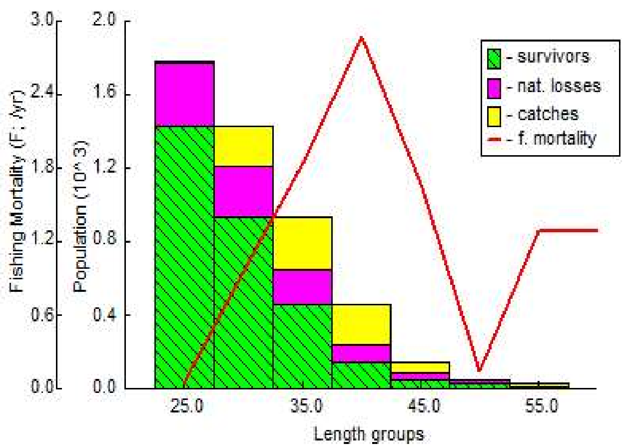

Fig. 6. Length structured virtual population analysis (VPA) of *C. striata* at River Sutlej

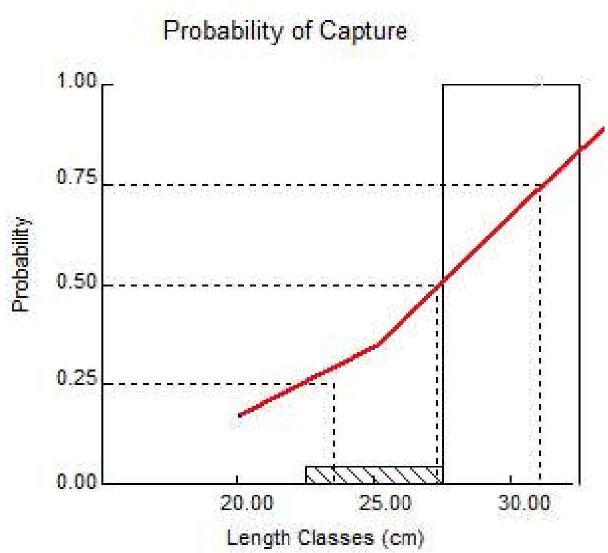

Fig. 7. Probability of capture of *C. striata* from River Sutlej during the study period (L∞ = 63 cm, K= 0.77 $year^{-1}$ and t_o=0.02 year)

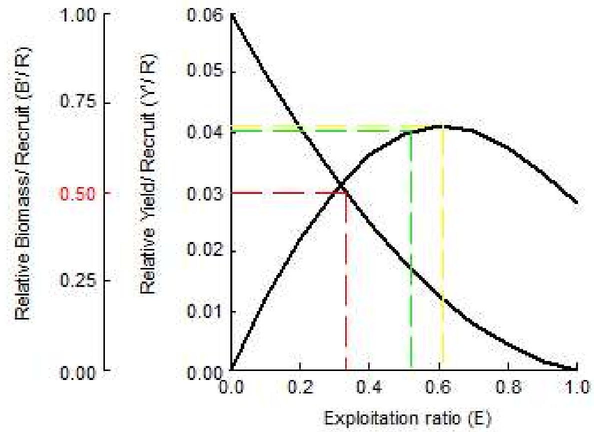

Fig. 8. *C. striata* stock structure with the use of Beverton and Holt's Relative yield per recruit and biomass per model from River Sutlej

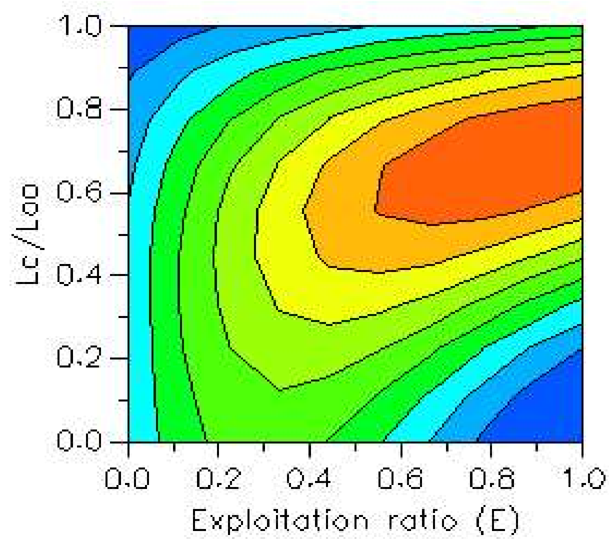

Fig. 9. Yield isopleth diagram of *C. striata* from River Sutlej

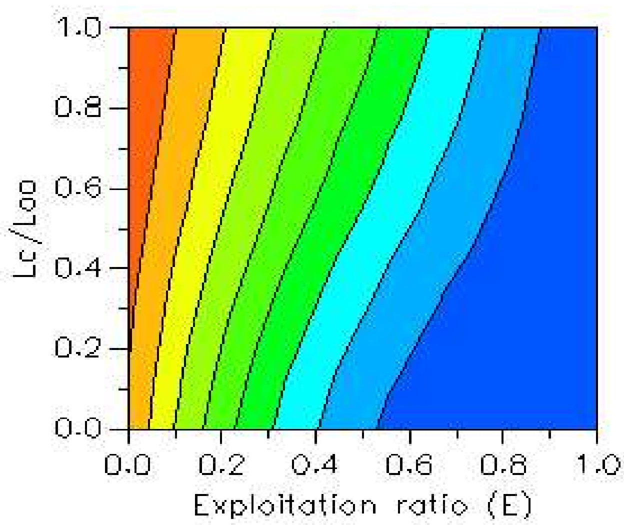

Fig. 10. Biomass isopleth diagram of *C. striata* from River Sutlej

scope to increase further fishing efforts for this species to reach the TRP. Fahmi et al. (2013) reported E_{max} (0.52) value less than exponential ratio (E= 0.58) in case of *C. striata* at Lubuk Lampam flood plains, South Sumatera. The yield isopleths diagram (Fig. 9 and 10) denoted that the relative yield per recruit may be obtained at L_C/L_∞ of 0.55 and an E of 0.5.

CONCLUSIONS

C. striata established negative allometric growth; thus species became slender as it increased in length. Length frequency distribution suggested that juvenile and adult stages of *C. striata* are equally vulnerable to fishing pressure. The highest recruitment peaks were detected during June and July in *C. striata* indicating monsoon is the breeding season for *Channa* species in Punjab waters. Fishing mortality was higher than natural mortality (thus the stock is subjected to heavy fishing pressure. E_{cur} value is less than $E_{0.1}$ which denotes there is little scope to increase further fishing efforts for this species to reach the target reference point The fishing pressure can be decreased until $E_{0.5}$ to get maximum sustainable yield for *C. striata* in river Sutlej. Population dynamics of *C. striata* revealed that existing fishing pressure should be reduced substantially for sustainable development of species in River Sutlej. Findings pertaining to present study may be useful as valuable time series data w.r.t. future study and policy making of fisheries in River Sutlej.

AUTHORS CONTRIBUTION

Shikha conducted sampling and analysed the data and wrote the manuscript. Surjya Narayan Datta conceptualized the theme, helped in sampling, interpreted the results and wrote the manuscript. Prabjeet Singh and Grishma Tewari helped in sampling.

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Phenotypic Differences in Pacific Whiteleg Shrimp (*Litopenaeus vannamei,* Boone 1931) Reared in Different Types of Culture Ponds-Statical Approach

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***Abstract*:** The aquafarming of shrimp is booming with updated innovations to produce successful and profitable crop of whiteleg shrimp *L. vannamei* which is major stocking species in aquaculture and also in highly demanded among seafoods. Present study was conducted to assess the phenotypic differences or morphometric variations of shrimp. The shrimps (*Litopenaeus vannamei*) were randomly collected during summer crop (2021) from earthen and polyethylene culture ponds located at Bhimpore, Surat (Gujarat-India). The morphometric parameters (16) were measured from 500 shrimp specimens from each pond to describe the morphological variations among the shrimp population of different culture ponds. The actual total length and partial total length of shrimp in earthen pond and polyethylene lined pond are positively and significantly correlated to each other. PCA shows that shrimp (*L.vannamei*) population variability is denoted by the three groups of variables in earthen pond (EP) while in polyethylene lined pond (PELP) it was donated by only one group of morphometric variables. The graphical presentation of PCs were depicted that separate cluster of shrimp population from earthen ponds and polyethylene lined pond which subsequently confirm and conclude that morphological structure of shrimp (*L. vannamei*) population of EP and PELP were entirely different from each other.

***Keywords*:** Shrimp (*L. vannamei*), Different culture pond, Morphometric parameter, Correlation matrix, PCA, Cluster plot

The whiteleg shrimp, *Litopenaeus vannamei* (Boone 1931) is native of eastern Pacific Ocean from Mexican state of northern Peru and belongs to the phylum Arthropoda which having joined appendages and hard exoskeleton or cuticle (Bailey-Brock and Moss 1992). The post larvae of this shrimp is easy to available, specific pathogen free, specific pathogen resistance, fast growth rate, high export rate so far culture of whiteleg shrimp is globally disseminated and production increased in many folds from 0.01 MMT (1970) to 4.5 MMT since 2021 that contributing about 80% of the cultured shrimp in global aquaculture (FAO 2021P, Prajapati and Ujjania 2021). Indian scenario shows that it contributing about 0.81 MMT in cultured shrimp production (https://mpeda.gov.in). Hence, shrimp aquaculture vibrantly took a part to produce nutrient rich aquatic food as well as increase significantly in economy of India. Improvements in innovations of culture methods like spreading polyethylene liners on earthen pond come around to enhance the production and meet the global market demand. The phenotypic or morphometric a tool are used in multidisciplinary approaches for stock identification, separating various species and population, determine sexual dimorphism and relate population, classify the evolutionary connections among fish fauna and to identify biogeography and phenotypic plasticity (Deesri et al 2009, Hopkins and Thurman 2010, Silva et al 2010, Hirsch et al 2013). Furthermore, use of geometric morphometrics are principally apt due to the accurate identification of homologous landmarks on the hard exoskeleton (Rufino et al 2006). Gujarat is one of the dominant state in shrimp production and limited reviews are available on this aspects, so the current study was taken up to discriminate the shrimp (*L. vannamei*) cultured in two different types of culture ponds (earthen and polyethylene) which would be helpful for farmers and researchers to assess the growth and health status of shrimp.

MATERIAL AND METHODS

The 500 specimens of *L. vannamei* was randomly collected during summer crop of 2021 from each earthen and polyethylene lined culture ponds at Bhimpore, Surat (Gujarat). Morphometric variables of *L. vannamei* including 14 morphometric lengths and 2 circumferences (Fig. 1) were measured (Lester, 1983) with the help of digital vernier caliper (accuracy ±0.02 mm). The morphometric versions of the shrimp were described based on statistical tools i.e., principal components analysis (PCA), principal components (PCs), Eigen value, cumulative percentage, components matrix and rotated component matrix by SPSS (v26).

RESULTS AND DISCUSSION

Correlation coefficient (r): The correlation coefficient (r) shows that significance of inter-relationship of two different variables and in present study the range of correlation coefficient (r) was directly propose net between actual total length (ATL) and different morphological parameters and it was maximum (0.938) in between ATL and PTL, minimum (0.198) in between PAC and FoSL morphometric variables of shrimp population in earthen pond. Similarly, the range of “r” was directly proposing net between ATL and different morphological parameters of shrimp population in polyethylene lined pond and maximum (0.938) in between ATL and PTL and minimum (0.222) in between PAC and TSL variables of shrimp (Table 1 and Fig. 1). The observed correlation coefficient values shows that actual total length (ATL) and partial total length (PTL) of shrimp in earthen pond and polyethylene lined pond are strongly, positively, and significantly correlated to each other while morphometric variables PAC v/s FoSL and PAC v/s TSL of shrimp in earthen pond and polyethylene lined pond are positively and weakly correlated to each other. Vincent et al (2014) reported maximum correlation coefficient value (0.960) between PCL and TLW morphometric measurements of the shrimp (*P. monodon*) and concluded positive and strong correlation of

Table 1. Correlation matrix of *L. vannamei* morphological parameters

		ATL	PTL	CW	PCL	CD	FSL	SSL	TSL	FoSL	FiSL	SiSL	SSD	EnUL	EUL	PAC	AAC
ATL	EP	1.000															
	PELP	1.000															
PTL	EP	0.938	1.000														
	PELP	0.938	1.000														
CW	EP	0.431	0.449	1.000													
	PELP	0.740	0.690	1.000													
PCL	EP	0.755	0.729	0.476	1.000												
	PELP	0.893	0.872	0.684	1.000												
CD	EP	0.580	0.569	0.853	0.655	1.000	.										
	PELP	0.764	0.709	0.937	0.738	1.000											
FSL	EP	0.659	0.668	0.470	0.604	0.633	1.000										
	PELP	0.722	0.703	0.639	0.723	0.751	1.000										
SSL	EP	0.591	0.592	0.363	0.526	0.480	0.718	1.000									
	PELP	0.715	0.690	0.638	0.693	0.744	0.834	1.000									
TSL	EP	0.615	0.617	0.317	0.492	0.379	0.604	0.635	1.000								
	PELP	0.270	0.433	0.221	0.313	0.240	0.383	0.400	1.000								
FoSL	EP	0.452	0.444	0.287	0.225	0.259	0.343	0.408	0.647	1.000							
	PELP	0.748	0.742	0.653	0.756	0.769	0.758	0.784	0.429	1.000							
FiSL	EP	0.509	0.481	0.268	0.328	0.281	0.488	0.442	0.592	0.791	1.000						
	PELP	0.509	0.481	0.268	0.328	0.281	0.488	0.442	0.592	0.791	1.000						
SiSL	EP	0.665	0.654	0.327	0.536	0.404	0.638	0.576	0.712	0.509	0.671	1.000					
	PELP	0.750	0.761	0.559	0.725	0.659	0.679	0.701	0.338	0.734	0.752	1.000					
SSD	EP	0.679	0.696	0.331	0.618	0.517	0.685	0.619	0.499	0.249	0.368	0.639	1.000				
	PELP	0.737	0.700	0.534	0.726	0.636	0.688	0.724	0.303	0.735	0.738	0.729	1.000				
EnUL	EP	0.627	0.649	0.341	0.568	0.413	0.594	0.456	0.540	0.436	0.430	0.550	0.628	1.000			
	PELP	0.765	0.711	0.576	0.699	0.662	0.653	0.679	0.343	0.682	0.709	0.664	0.622	1.000			
EUL	EP	0.647	0.655	0.465	0.572	0.526	0.570	0.502	0.492	0.477	0.444	0.527	0.580	0.771	1.000		
	PELP	0.813	0.749	0.617	0.784	0.718	0.745	0.713	0.260	0.724	0.727	0.725	0.706	0.843	1.000		
PAC	EP	0.625	0.570	0.172	0.480	0.428	0.495	0.403	0.273	0.198	0.338	0.399	0.477	0.296	0.327	1.000	
	PELP	0.693	0.672	0.531	0.614	0.576	0.666	0.635	0.222	0.651	0.607	0.679	0.578	0.527	0.667	1.000	
AAC	EP	0.616	0.613	0.201	0.545	0.367	0.465	0.365	0.442	0.316	0.375	0.456	0.432	0.394	0.375	0.519	1.000
	PELP	0.732	0.722	0.623	0.668	0.655	0.633	0.689	0.284	0.713	0.638	0.629	0.580	0.607	0.670	0.584	1.000

*Correlation is significant at the 0.01 level. EP for Earthen Pond and PELP for Polyethylene Pond the variables. Rafael et al (2022) reported maximum correlation coefficient value (0.94) between 6SL and WAE morphometric measurements of the shrimp (*Penaeus schmitti*) and concluded positive and strong correlation of the variables.

Principal component analysis (PCA): PCA was conducted and range of eigenvalues 0.05-8.72 and 0.03-11.02, variance (%) 0.33-54.54 and 0.18-68.89 were observed in EP and PELP respectively (Table 2, Fig. 1). The component matrix (CM) shows 3 groups of principal components with cumulative variance 71.90% and eigenvalue 8.72, 1.56, 1.20 were in EP while only 1 group with cumulative variance 68.89% and eigenvalue 11.02 were in PELP (Table 2 and Fig. 2). Furthermore, rotated component matrix (RCM) denoted the major components of first group (PAC, ATL, PTL, AAC, SSD, PCL, FSL, SSL), second group (FoSL, FiSL, TSL, SiSL, EnUL) and third group (CW, CD, EUL) containing factor loading 4.65, 3.78, 3.06 and cumulative variance 29.10, 52.74, 71.90 % , respectively in shrimp population of EP whereas all morphometric variables (ATL, PTL, FoSL, PCL, FiSL, EUL, SSL, CD, FSL, SiSL, SSD, EnUL, AAC, CW, PAC, TSL) containing factor loading 11.02 and cumulative variance 68.89% were observed in shrimp population of PELP (Table 2, 3, Fig. 1). These finding shows that shrimp (*L. vannamei*) population variability is contributed by the three groups of variables while in PELP it was contributed by only one group of morphometric variables. Geometrically, the principal component (PC-1) explains most of variables in data set and assumed to lie parallel with the largest axis in the

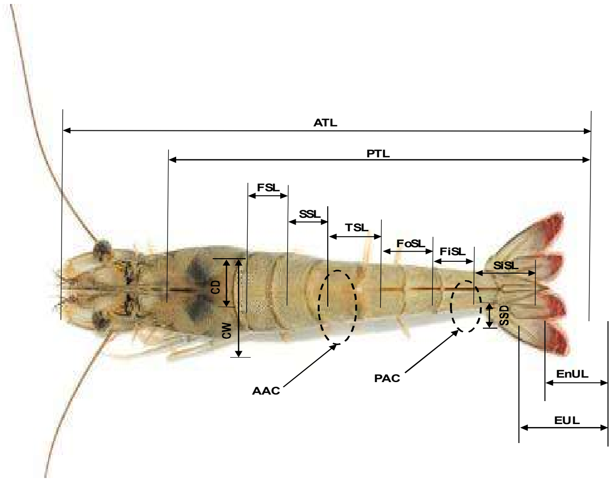

Fig. 1. Morphometric parameters [Actual total length (ATL), Partial total length (PTL), Carapace width (CW), Partial carapace length (PCL), Carapace depth (CD), First segment length (FSL), Second segment length (SSL), Third segment length (TSL), Forth segment length (FoSL), Fifth segment length (FiSL), Sixth segment length (SiSL), Sixth segment depth (SSD), Endopod of uropod length (EnUL), Exopod of uropod length (EUL), Posterior abdomen circumference (PAC) and Anterior abdomen circumference (AAC)] of shrimp (*L. vannamei*)

Table 2. Principal components analysis for Eigenvalue, loadings and percentage (Variance and cumulative) of various components for shrimp (*L. vannamei*)

CP	Eigenvalues		Variance (%)		Loadings		Variance (%)		Cumulative (%)	
	EP	PELP	EP	PELP	EP	PELP	EP	PELP	EP	PELP
1	8.72	11.02	54.54	68.89	4.65	11.02	29.10	68.89	29.10	68.89
2	1.56	0.97	9.80	6.09	3.78		23.64		52.74	
3	1.20	0.69	7.55	4.36	3.06		19.15		71.90	
4	0.87	0.57	5.48	3.57						
5	0.77	0.51	4.81	3.19						
6	0.54	0.44	3.42	2.78						
7	0.43	0.40	2.71	2.52						
8	0.40	0.34	2.49	2.16						
9	0.29	0.27	1.82	1.69						
10	0.28	0.22	1.76	1.38						
11	0.24	0.17	1.51	1.06						
12	0.23	0.12	1.49	0.77						
13	0.16	0.08	1.05	0.55						
14	0.10	0.08	0.67	0.50						
15	0.07	0.03	0.48	0.23						
16	0.05	0.03	0.33	0.18						

CP for Component, EP for Earthen Pond and PELP for Polyethylene lined Pond

Table 3. Principal component analysis and major components of *L. vannamei*

Component Matrix						Rotated Component Matrix			
Morphological variable		Component				Morphological characters	Component*		
EP	PELP	EP*			PELP**	EP	1	2	3
		1	2	3	1				
ATL	ATL	0.894			0.919	PAC	0.791		
PTL	PTL	0.889			0.898	ATL	0.761		
FSL	FoSL	0.826			0.894	PTL	0.739		
SiSL	PCL	0.794			0.890	AAC	0.728		
PCL	FiSL	0.784			0.876	SSD	0.683		
SSD	EUL	0.780			0.875	PCL	0.679		
EUL	SSL	0.764			0.863	FSL	0.574		
TSL	CD	0.756			0.862	SSL	0.479		
EnUL	FSL	0.748			0.857	FoSL		0.900	
SSL	SiSL	0.744			0.843	FiSL		0.853	
CD	SSD	0.704			0.818	TSL		0.743	
FiSL	EnUL	0.653			0.817	SiSL		0.651	
AAC	AAC	0.634			0.793	EnUL		0.474	
PAC	CW	0.593			0.782	CW			0.922
FoSL	PAC		0.649		0.753	CD			0.865
CW	TSL			0.648	0.414	EUL			0.509

*Three components extracted, ** one components extracted, EP for earthen pond and PELP for polyethylene lined pond

hyperdimensional cloud of data though, principal component (PC-2) is independent of PC-1 and its lies perpendicular to the axis of PC-1 and explains the second largest component of variation in the data set. Each PC is linear combination of the variables and defined by vector (an eigen vector) of coefficients and eigenvalue (Vincent et al 2014). The distance dimensions were further subjected to sheared PCA and the PCs were plotted on a graph with PC-1 and PC-2 on X and Y axes respectively. The shrimp population of earthen ponds formed separate cluster from shrimp population of polyethylene lined pond which shows that the morphological

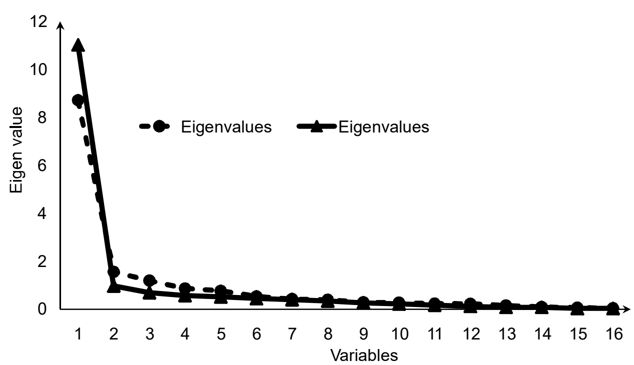

Fig. 2. Eigen value plot of morphometric parameters for different cultured ponds populations of shrimp (*L. vannamei*)

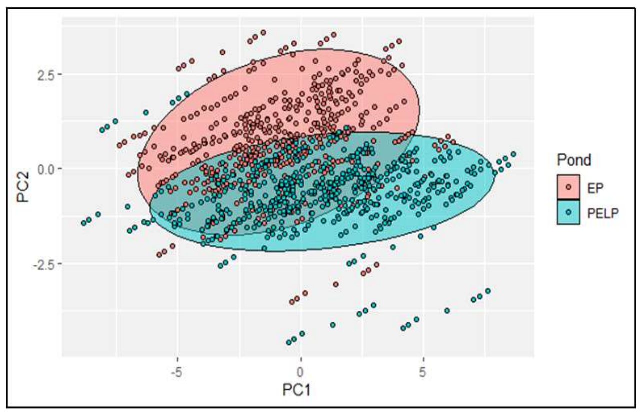

Fig. 3. Scatter plot with sheared PC scores of morphometric parameters for different cultured ponds populations of shrimp (*L. vannamei*)

outlines of studied shrimp (*L. vannamei*) population of EP and PELP were entirely different from each other (Fig. 3). Ujjania and Kohli (2011) observed intra species variability in major carp during their study while in contrast Vincent et al (2014) reported no significantly different in *P. monodon* population.

CONCLUSION

The present study was elucidated the morpho geographical structure of the shrimp which help to determine the shape, size and structure of the shrimp's body. The findings help to conclude that all phenotypic variables are positively corelated in both the water body. It is also concluded that sharing PCs scores were successfully applied in discriminating the stocks of *L. vannamei* of earthen and polyethylene lined ponds. Eventually, the population of EP and PELP were not similar from each other. This simple technique provide a greater number of segregate characters.

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Comparative Study of Avifauna in Junagadh, Gujarat, India

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Abstract: The present study was conducted at two freshwater reservoirs of Junagadh Baliyavad Dam and Vadla Lake from July 2021 to February 2022. A total 183 species of birds were recorded belonging to 18 orders and 65 families during the study period. Family Accipitridae and Ardeidae represents the significant number of species (11 and 12 species). As per IUCN Status, one is vulnerable, two are critically endangered and five are near threatened. Out of 10 feeding guilds, insectivores are prominently dominant in both study sites. The result provided the baseline information on avifauna of Vadla Lake and Baliyavad Dam which can provide a good preliminary database and should incorporate in conservation implications.

Keywords: Diversity, Avifauna, Baliyavad Dam, Vadla Lake

Birds are one of the vital components of biodiversity and population very sensitive indicator of pollution in both terrestrial and aquatic ecosystem (Datta 2016). Understanding on the distribution pattern and habitat preference of bird communities over heterogeneous environment is very much essential for conservation and management of avifauna in regional as well as in local environment (Kattan and Franco 2004). Freshwater wetlands support more than 40% of all bird species and 12% of all animal species on the planet (Thapa et al 2012). Migratory birds are a vital biotic element of the wetland environment as they occupy numerous trophic tiers within side the meals net of wetland (Malik and Joshi 2013). Now-a-days, avifaunal diversity has been decreasing due to the destruction of natural habitats and human disturbances. Random destruction of natural habitats by cutting nesting trees and foraging plants for commercial use of woods and lands are the main factor responsible for narrow down in avian foraging habitat and their nesting sites (Vala and Trivedi 2018). To understand the processes of habitat selection and preference by birds is dependent on an accurate representation of the patterns of habitat occupancy. Organisms threatened by urbanization are likely to be affected for other human impacts like agriculture, recreation, roads and so on (McKenny 2005), rapid decline of some common birds has been reported with a gap of proper documentations (Rajshekhar and Venkatesha 2008, Shaw et al 2008, Khera et al 2010). The water dependent avifauna and their habitats are affected by various factors like food availability, hunting and poaching threats, the size of the dams (Paracuellos 2006), and the abiotic changes in the dams (Jaksic 2004, Lagos et al 2008, Vishwakarma et al 2020). There are 1341 species (26 orders, 113 families and 489 genera) are recorded from India (Praveen et al 2021) from Gujarat 612 species are recorded (Ganpule 2021).

It is very difficult to prepare any conservation plan without any baseline data (Jamam et al 2011). Thus, this study presents a checklist of birds with updated systematic, family or order wise distribution, abundance status, and enlisted base line data of avifauna. Two different habitat Baliyavad Dam and Vadla Lake has been selected for the study of diversity of avifauna and its distribution on each site. Baliyavad Dam and Vadla lake are the important bird habitat and provides suitable breeding, staging, and wintering grounds for a wide array of migratory birds.

MATERIAL AND METHODS

Study area: Baliyavad Dam (21° 3541''N and 70° 34'00''E) is the one of the largest freshwater reservoirs in Junagadh, situated 18 km away from Junagadh city (Fig. 1). The dam is filled with rainwater only once in a year during the monsoon. This site has rich plant diversity and distinct with different types of vegetative landscapes viz open scrubland, open grass land, herbaceous land, dense scrubland and trees, as well as the peripheral agro-fields, including crop rotations all over the years viz; vegetable plants, commercially important flower plants, and different grain.. Vadla Talav (21°28'55''N 70o24'15''E) (Fig. 1) is located at Vadla village, Junagadh. Approximant temperature 27.1°C and humidity 15%. This lake is one of the fresh water reservoir lake and peripheral area is surrounded by forest area. This water is used for a variety of human purposes, including fishing, animal grazing, and bathing. Because this lake is a freshwater reservoir, many water birds rely on it. These birds are staying here for the purpose of feeding and breeding. This lake is home to Rohu, Katla, Mrigal, Silvercarp, Jadka, Dore, Mangur, and Kangsa. This lake also has zooplankton and many invertebrates, so aquatic fowl rely on it for food. Water Hyacinth's species are grow in this lake, which have completely covered the lake. As a result, this species has a greater impact on birds, as well as fish, invertebrates, and zooplanktons.

Sampling method: Study site was visited twice a week from July 2021 to February 2022. Surveys were conducted in the morning 8:00 to 1:00 pm and evening 4 pm to 6 pm. We collected data by using Point count, Line transects and Random transects method. The birds were observed from a safe distance to prevent the disturbance, and observations were made from the help of a Binocular Olympus (8x40), and a camera (Canon 1500d). Identification of species will be carried out with the help of standard identification key (Ali 2002, Grimmett *et. al.,* 2011, Kazmierczak 2000) and also by their calls/ songs. The birdcalls were confirmed using Xeno-Canto bird call database (Xeno- canto 2016). The threatened status of the birds given in the checklist is as per IUCN Red List 2021 of Threatened Species (Birdlife International 2001a, b). The threatened status of birds given in the checklist is as per IUCN red list into LC-Least Concern, VU-Vulnerable, NT- Near Threatened, LC-Least Concern. A Local abundance status was assigned into as per our observation R – Rare (1- 20 sighting) C – Common (> 80-100 sighting), UC – Uncommon (21-50 sighting), FC – Fairly common (51-80sighting).

Species richness: This was calculated as total number of bird species observed in the study area. The relative diversity (RDi) of bird families was calculated (Torre et al 2007):

$$RDi=\frac{\text{Number of bird species in a family}}{\text{Total number of species}}\times 100$$

RESULTS AND DISCUSSION

During the study period total of 183 species belonging to

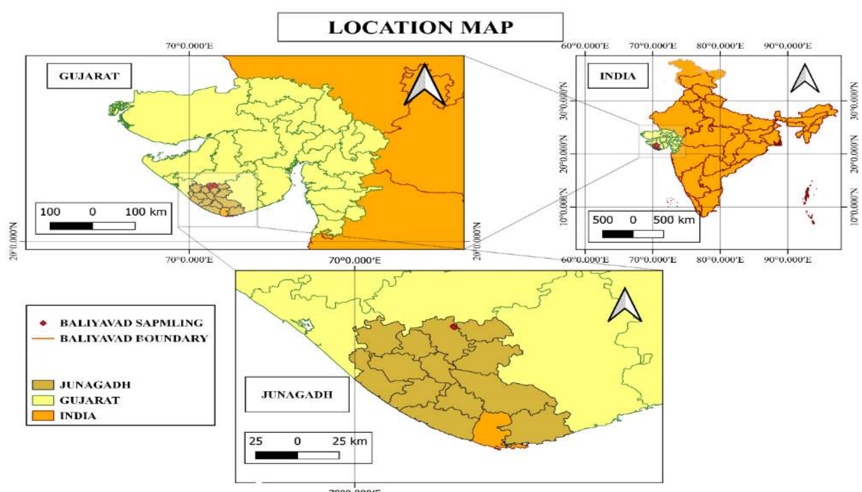

Fig. 1 A: Study area

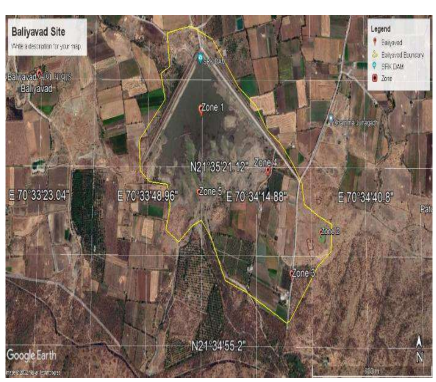

Fig. 1 B. Baliyavad Dam

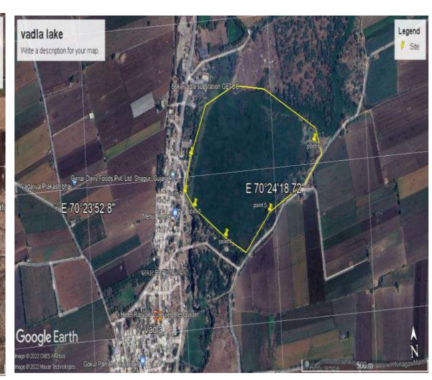

Fig. 1C. Vadla Lake

Fig. 1. Study area. A. location of Junagadh followed by Gujarat and India. B. site location of Baliyavad Dam and sampling location of survey. C. Site B location Vadla Lake. (Image sources: QGIS- Software 3.16, google earth pro)

Table 1. Bird checklist of Baliyavad Dam (Site 1) and Vadla Lake (Site 2)

Common name	Scientific name	Residential status	IUCN	Feeding guilds	Local status	WPA 1972	S1	S2
ANSERIFORMES: Anatidae								
Lesser Whistling Duck	*Dendrocygna javanica* (Horsfield 1821)	RM	LC	Omnivorous	FC	SCH IV	1	1
Ruddy Shelduck	*Tadorna ferruginea* (Pallas 1764)	WM	LC	Omnivorous	UC	SCH IV	1	0
Garganey	*Spatula querquedula* (Linnaeus 1758)	WM	LC	Omnivorous	UC	SCH IV	1	0
Northern Shoveler	*Spatula clypeata* (Linnaeus 1758)	WM	LC	Piscivorous	UC	SCH IV	1	0
Indian Spot-billed Duck	*Anas poecilorhyncha* (J. R. Forster 1781)	RM	LC	Omnivorous	UC	SCH IV	1	0
Common Teal	*Anas crecca*a Linnaeus 1758	WM	LC	Herbivorous	FC	SCH IV	1	1
knob-billed duck	*Sarkidiornis melanotos* (Pennant 1769)	RM	LC	Herbivorous	FC	SCH IV	1	1
Northern Pintail	*Anas acuta* innaeus 1758	WM	LC	Herbivorous	R	SCH IV	1	0
GALLIFORMES: Phasianidae								
Indian Peafowl	*Pavo cristatus* (Linnaeus 1758)	R	LC	Omnivorous	UC	SCH IV	1	1
Common Quail	*Coturnix coturnix* (Linnaeus 1758)	R	LC	Granivorous	FC	SCH IV	1	0
Rain Quail	*Coturnix coromandelica* (J.F. Gmelin 1789)	R	LC	Granivorous	FC	SCH IV	1	0
Painted Francolin	*Francolinus pictus* (Jardine & Selby 1828)	R	LC	Granivorous	R	SCH IV	1	1
Grey Francolin	*Francolinus pondicerianus* (Gmelin 1789)	R	LC	Granivorous	UC	SCH IV	1	1
PHOENICOPTERIFORMES Podicipedidae								
Little Grebe	*Tachybaptus ruficollis* (Pallas 1764)	R	LC	Carnivorous	UC	SCH IV	1	1
COLUMBIFORMES: Columbidae								
Rock Pigeon	*Columba livia* J.F. Gmelin 1789	R	LC	Granivorous	C	SCH IV	1	1
Eurasian Collared Dove	*Streptopelia decaocto* (Frivaldszky 1838)	R	LC	Granivorous	C	SCH IV	1	1
Spotted Dove	*Streptopelia chinensis* (Scopoli 1786)	R	LC	Granivorous	C	SCH IV	1	1
Laughing Dove	*Streptopelia senegalensis* (Linnaeus 1766)	R	LC	Granivorous	C	SCH IV	1	1
Yellow-legged Green Pigeon	*Treron phoenicopterus* (Scopoli 1786)	R	LC	Granivorous	FC	SCH IV	1	1
Oriental Turtle Dove	*Streptopelia orientalis* (Latham 1790)	WM	LC	Granivorous	UC	SCH IV	1	1
PTEROCLIFORMES: Pteroclidae								
Chestnut-bellied Sandgrouse	*Pterocles exustus* Temminck 1825	R	LC	Granivorous	C	SCH IV	1	0
CAPRIMULGIFORMES: Caprimulgidae								
Indian Nightjar	*Caprimulgus asiaticus* Latham 1790	RM	LC	Insectivorous	R	SCH IV	1	1
CAPRIMULGIFORMES: Apodidae								
Little Swift	*Apus affinis* (J.E. Gray 1830)	R	LC	Insectivorous	C	SCH IV	1	1
CUCULIFORMES: Cuculidae								
Greater Coucal	*Centropus sinensis* (Stephens 1815)	R	LC	Carnivorous	FC	SCH IV	1	1
Common Cuckoo	*Cuculus canorus* (Scopoli 1786)	RM	LC	Carnivorous	FC	SCH IV	0	1
Common Hawk Cuckoo	*Hierococcyx varius* (Vahl 1797)	RM	LC	Insectivorous	UC	SCH IV	0	1
Asian Koel	*Eudynamys scolopaceus* (Linnaeus 1758)	R	LC	Omnivorous	FC	SCH IV	1	1
GRUIFORMES: Rallidae								
White-breasted Waterhen	*Amaurornis phoenicurus* (Pennant 1769)	R	LC	Insectivorous	UC	SCH IV	1	1
Purple Swamphen	*Porphyrio porphyrio* (Latham 1801)	R	LC	Insectivorous	FC	SCH IV	0	1
Ruddy-breasted Crake	*Zapornia fusca* (Linnaeus 1766)	RM	LC	Insectivorous	R	SCH IV	0	1

Cont...

Table 1. Bird checklist of Baliyavad Dam (Site 1) and Vadla Lake (Site 2)

Common name	Scientific name	Residential status	IUCN	Feeding guilds	Local status	WPA 1972	S1	S2
Watercock	*Gallicrex cinerea* (J.F. Gmelin 1789)	MM	LC	Insectivorous	R	SCH IV	0	1
Baillon's Crake	*Zapornia pusilla* (Pallas 1776)	WM	LC	Insectivorous	R	SCH IV	0	1
Common Moorhen	*Gallinula chloropus* (Linnaeus 1758)	RM	LC	Omnivorous	R	SCH IV	1	1
Common Coot	*Fulica atra* Linnaeus 1758	WM	LC	Omnivorous	UC	SCH IV	1	1
GRUIFORMES: Gruidae								
Common Crane	*Grus grus* (Linnaeus 1758)	WM	LC	Omnivorous	UC	SCH IV	1	0
PELECANIFORMES:Ciconiidae								
Painted Stork	*Mycteria leucocephala* (Pennant 1769)	RM	NT	Carnivorous	C	SCH IV	1	1
Woolly-necked Stork	*Ciconia episcopus* (Boddaert 1783)	RM	VU	Carnivorous	R	SCH IV	1	1
Asian Openbill	*Anastomus oscitans* (Boddaert 1783)	RM	LC	Carnivorous	UC	SCH IV	0	1
PELECANIFORMES: Pelecanidae								
Great White Pelican	*Pelecanus onocrotalus* Linnaeus 1758	WM	LC	Piscivorous	R	SCH IV	1	1
Dalmatian Pelican	*Pelecanus crispus* Bruch 1832	WM	NT	Piscivorous	R	SCH IV	1	1
PELECANIFORMES: Ardeidae								
Grey Heron	*Ardea cinerea* Linnaeus 1758	RM	LC	Piscivorous	UC	SCH IV	1	1
Yellow Bittern	*Ixobrychus sinensis* (GmelinJF 1789)	WM	LC	Piscivorous	R	SCH IV	0	1
Purple Heron	*Ardea purpurea* Linnaeus 1766	RM	LC	Piscivorous	UC	SCH IV	0	1
Indian Pond Heron	*Ardeola grayii* (Sykes 1832)	R	LC	Piscivorous	C	SCH IV	1	1
Cattle Egret	*Bubulcus ibis* (Linnaeus 1758)	R	LC	Insectivorous	C	SCH IV	1	1
Intermediate Egret	*Ardea intermedia* Wagler 1829	R	LC	Piscivorous	C	SCH IV	1	1
Great Egret	*Ardea alba* Linnaeus 1758	R	LC	Piscivorous	UC	SCH IV	1	1
Little Egret	*Egretta garzetta* (Linnaeus 1766)	R	LC	Piscivorous	C	SCH IV	1	1
Striated Heron	*Butorides striata* (Linnaeus 1758)	R	LC	Piscivorous	R	SCH IV	1	0
Black-crowned Night Heron	*Nycticorax nycticorax* (Linnaeus 1758)	RM	LC	Piscivorous	R	SCH IV	1	1
Western Reef Egret	*Egretta gularis* (Bosc 1792)	RM	LC	Piscivorous	R	SCH IV	1	0
PELECANIFORMES: Threskiornithidae								
Black-headed Ibis	*Threskiornis melanocephalus* (Latham 1790)	RM	NT	Omnivorous	UC	SCH IV	1	1
Red Naped Ibis	*Pseudibis papillosa* (Temminck 1824)	R	LC	Omnivorous	C	SCH IV	1	1
Glossy Ibis	*Plegadis falcinellus* (Linnaeus 1766)	R	LC	Molluscivorous	FC	SCH IV	1	1
Eurasian Spoonbill	*Platalea leucorodia* Linnaeus 1758	RM	LC	Piscivorous	C	SCH I	1	1
PELECANIFORMES: Phalacrocoracidae								
Little Cormorant	*Microcarbo niger* (Vieillot 1817)	RM	LC	Piscivorous	C	SCH IV	1	1
Great Cormorant	*Phalacrocorax carbo* (Linnaeus 1758)	RM	LC	Piscivorous	FC	SCH IV	1	1
PELECANIFORMES:Anhingidae								
Oriental Darter	*Anhinga melanogaster* Pennant 1769	RM	LC	Piscivorous	R	SCH IV	1	1
CHARADRIIFORMES:Burhinidae								
Great thick-knee	*Esacus recutvirostris* (Salvadori 1865)	RM	LC	Carnivorous	C	SCH IV	1	0
CHARADRIIFORMES:Recurvirostridae								
Black-winged Stilt	*Himantopus himantopus* (Linnaeus 1758)	R	LC	Carnivorous	C	SCH IV	1	1
CHARADRIIFORMES: Charadriidae								
Little Ringed Plover	*Charadrius dubius* Scopoli 1786	RM	LC	Insectivorous	R	SCH IV	1	1
Common ringed plover	*Charadrius hitacula* Linnaeus 1758	WM	LC	Small invertebrate	R	SCH IV	1	0

Cont...

Table 1. Bird checklist of Baliyavad Dam (Site 1) and Vadla Lake (Site 2)

Common name	Scientific name	Residential status	IUCN	Feeding guilds	Local status	WPA 1972	S1	S2
Red-wattled Lapwing	*Vanellus indicus* (Boddaert 1783)	R	LC	Insectivorous	C	SCH IV	1	1
Yellow-wattled Lapwing	*Vanellus malabaricus* (Boddaert 1783)	RM	LC	Insectivorous	R	SCH IV	1	0
CHARADRIIFORMES:Rostratulidae								
Greater Painted-snipe	*Rostratula benghalensis* (Linnaeus 1758)	R	LC	Insectivorous	R	SCH IV	1	0
CHARADRIIFORMES: Jacanidae								
Pheasant-tailed Jacana	*Hydrophasianus chirurgus* (Scopoli 1786)	RM	LC	Carnivorous	R	SCH IV	1	1
Bronze-winged Jacana	*Metopidius indicu* (Latham 1790)	RM	LC	Carnivorous	UC	SCH IV	0	1
CHARADRIIFORMES: Scolopacidae								
Little Stint	*Calidris minuta* (Leisler 1812)	RM	LC	Small invertebrate	UC	SCH IV	1	1
Common Snipe	*Gallinago gallinago* (Linnaeus 1758)	WM	LC	Piscivorous	R	SCH IV	1	1
Common Sandpiper	*Actitis hypoleucos* (Linnaeus 1758)	R	LC	Insectivorous	C	SCH IV	1	1
Wood Sandpiper	*Tringa glareola* (Linnaeus 1758)	WM	LC	Insectivorous	UC	SCH IV	1	1
Black-tailed Godwit	*Limosa limosa* (Linnaeus 1758)	WM	NT	Insectivorous	R	SCH IV	1	0
Common Redshank	*Tringa tetanus* (Linnaeus 1758)	WM	LC	Insectivorous	R	SCH IV	1	0
Green Sandpiper	*Tringa ochropus* Linnaeus 1758	WM	LC	Insectivorous	UC	SCH IV	1	1
Temminck's Stint	*Calidris temminckii* (Leisler 1812)	WM	LC	Small invertebrate	R	SCH IV	1	1
CHARADRIIFORMES: Turnicidae								
Barred Buttonquail	*Turnix suscitator* (J.F. Gmelin 1789)	R	LC	Granivorous	UC	SCH IV	1	0
Small Buttonquil	*Turnix sylvaticus* (Desfontaines 1789)	R	LC	Granivorous	UC	SCH IV	1	0
CHARADRIIFORMES:Glareolidae								
Indian Courser	*Cursorius coromandelicus* (J.F. Gmelin 1789)	RM	LC	Insectivorous	R	SCH IV	1	0
Little Pratincole	*Glareola lacteal* Temminck 1820	RM	LC	Insectivorous	R	SCH IV	1	0
CHARADRIIFORMES Laridae								
Whiskered Tern	*Chlidonias hybrida* (Pallas 1811)	WM	LC	Piscivorous	FC	SCH IV	1	1
River Tern	*Sterna aurantia* Gray 1831	R	NT	Piscivorous	C	SCH IV	1	1
ACCIPITRIFORMES:Pandionidae								
Osprey	*Pandion haliaetus* (Linnaeus 1758)	WM	LC	Carnivorous	R	SCH I	1	1
ACCIPITRIFORMES: Accipitridae								
Black-winged Kite	*Elanus caeruleus* (Desfontaines 1789)	R	LC	Carnivorous	R	SCH IV	1	1
Oriental Honey-buzzard	*Pernis ptilorhynchus* (Temminck 1821)	R	LC	Carnivorous	R	SCH IV	1	1
Booted Eagle	*Hieraaetus pennatus* (J.F. Gmelin 1788)	WM	LC	Carnivorous	R	SCH IV	1	1
Shikra	*Accipiter badius* (J.F. Gmelin 1788)	R	LC	Carnivorous	R	SCH IV	1	1
Black Kite	*Milvus migrans* Boddaert 1783)	R	LC	Carnivorous	UC	SCH IV	1	1
Short-toed Eagle	*Circaetus gallicus* (J.F. Gmelin 1788)	R	LC	Carnivorous	R	SCH IV	1	0
Western Marsh Harrier	*Circus aeruginosus* (Linnaeus 1758)	WM	LC	Carnivorous	R	SCH IV	0	1
Indian Vulture	*Gyps indicus* (Scopoli 1786)	RM	CR	Carnivorous	R	SCH I	1	0
Red headed vulture	*Sarcogyps calvus* (Scopoli 1786)	RM	CR	Carnivorous	R	SCH IV	1	0
White-eyed Buzzard	*Butastur teesa* (Franklin 1831)	R	LC	Carnivorous	UC	SCH IV	0	1
Eurasian Sparrowhawk	*Accipiter nisus* (Linnaeus 1758)	WM	LC	Carnivorous	R	SCH IV	0	1
Black Eagle	*Ictinaetus malaiensis* Temminck 1822	RM	LC	Carnivorous	R	SCH IV	1	0
BUCEROTIFORMES : Upupidae								
Common Hoopoe	*Upupa epops* Linnaeus 1758	R	LC	Insectivorous	R	SCH IV	1	1
CORACIIFORMES: Meropidae								
Green Bee-eater	*Merops orientalis* Latham 1801	R	LC	Insectivorous	C	SCH IV	1	1

Cont...

Table 1. Bird checklist of Baliyavad Dam (Site 1) and Vadla Lake (Site 2)

Common name	Scientific name	Residential status	IUCN	Feeding guilds	Local status	WPA 1972	S1	S2
CORACIIFORMES: Coraciidae								
European Roller	*Coracias garrulus* Linnaeus 1758	MM	LC	Insectivorous	R	SCH IV	1	0
Indian Roller	*Coracias benghalensis* (Linnaeus 1758)	RM	LC	Insectivorous	R	SCH IV	1	1
CORACIIFORMES: Alcedinidae								
Common Kingfisher	*Alcedo atthis* (Linnaeus 1758)	R	LC	Piscivorous	UC	SCH IV	1	1
Pied Kingfisher	*Ceryle rudis* (Linnaeus 1758)	R	LC	Piscivorous	UC	SCH IV	1	1
White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus 1758)	R	LC	Piscivorous	C	SCH IV	1	1
PSITTACIFORMES: Psittaculidae								
Rose-ringed Parakeet	*Psittacula krameria* (Scopoli 1769)	R	LC	Frugivorous	C	SCH IV	1	1
Plum-headed Parakeet	*Psittacula cyanocephala* (Linnaeus 1766)	RM	LC	Frugivorous	UC	SCH IV	0	1
PASSERIFORMES:Pittidae								
Indian Pitta	*Pitta brachyura* (Linnaeus 1766)	MM	LC	Insectivorous	R	SCH IV	1	0
PASSERIFORMES:Aegithinidae								
Common Iora	*Aegithina tiphia* (Linnaeus 1758)	R	LC	Insectivorous	UC	SCH IV	1	1
Marshall's Iora	*Aegithina nigrolutea* (G.F.L. Marshall 1876)	R	LC	Insectivorous	C	SCH IV	0	1
PASSERIFORMES: Dicruridae								
Black Drongo	*Dicrurus macrocercus* Vieillot 1817	R	LC	Insectivorous	FC	SCH IV	1	1
Ashy Drongo	*Dicrurus leucophaeus* Vieillot 1817	RM	LC	Insectivorous	UC	SCH IV	1	1
PASSERIFORMES: Rhipiduridae								
White-browed Fantail	*Rhipidura aureola* Lesson 1831	R	LC	Insectivorous	FC	SCH IV	1	0
White-spotted Fantail	*Rhipidura albicollis* (Vieillot 1818)	R	LC	Insectivorous	UC	SCH IV	1	1
PASSERIFORMES:Laniidae								
Bay-backed Shrike	*Lanius vittatus* (Valenciennes 1826)	R	LC	Insectivorous	UC	SCH IV	1	0
Brown Shrike	*Lanius cristatus* Linnaeus 1758	WM	LC	Insectivorous	R	SCH IV	1	0
Long-tailed Shrike	*Lanius schach* Linnaeus 1758	R	LC	Insectivorous	UC	SCH IV	1	1
PASSERIFORMES:Monarchidae								
Black-naped Monarch	*Hypothymis azurea* (Boddaert 1783)	WM	LC	Insectivorous	R	SCH IV	1	0
Indian Paradise-flycatcher	*Terpsiphone paradisi* (Linnaeus 1758)	RM	LC	Insectivorous	R	SCH IV	1	1
PASSERIFORMES: Campephagidae								
Small Minivet	*Pericrocotus cinnamomeus* (Linnaeus 1766)	RM	LC	Insectivorous	R	SCH IV	0	1
PASSERIFORMES:Nectariniidae								
Purple Sunbird	*Cinnyris asiaticus* (Latham 1790)	R	LC	Nectarvorous	C	SCH IV	1	1
PASSERIFORMES:Ploceidae								
Baya Weaver	*Ploceus philippinus* (Linnaeus 1766)	R	LC	Granivorous	C	SCH IV	1	1
PASSERIFORMES: Sturnidae								
Rosy Starling	*Pastor roseus* Linnaeus 1758	WM	LC	Insectivorous	C	SCH IV	1	1
Brahminy Starling	*Sturnia pagodarum* (Gmelin 1789)	R	LC	Omnivorous	UC	SCH IV	1	1
Common Myna	*Acridotheres tristis* (Linnaeus 1766)	R	LC	Omnivorous	C	SCH IV	1	1
Bank Myna	*Acridotheres ginginianus* (Latham 1790)	R	LC	Omnivorous	C	SCH IV	1	1
PASSERIFORMES: Muscicapidae								
Indian Robin	*Saxicoloides fulicatus* (Linnaeus 1766)	R	LC	Insectivorous	C	SCH IV	1	1
Oriental Magpie Robin	*Copsychus saularis* (Linnaeus 1758)	R	LC	Insectivorous	C	SCH IV	1	1
Common Stonechat	*Saxicola rubicola* (Linnaeus 1766)	WM	LC	Insectivorous	C	SCH IV	1	1

Cont...

Table 1. Bird checklist of Baliyavad Dam (Site 1) and Vadla Lake (Site 2)

Common name	Scientific name	Residential status	IUCN	Feeding guilds	Local status	WPA 1972	S1	S2
Black Redstart	*Phoenicurus ochruros* (Gmelin 1774)	WM	LC	Insectivorous	R	SCH IV	1	1
Spotted Flycatcher	*Muscicapa striata* (Pallas 1764)	WM	LC	Insectivorous	R	SCH IV	0	1
Asian Brown Flycatcher	*Muscicapa dauurica* Pallas 1811	WM	LC	Insectivorous	R	SCH IV	0	1
Bluethroat	*Luscinia svecica* (Linnaeus 1758)	WM	LC	Insectivorous	R	SCH IV	0	1
Blue-capped Rock Thrush	*Monticola cinclorhyncha* (Vigors 1831)	WM	LC	Insectivorous	R	SCH IV	0	1
Tickell's Blue Flycatcher	*Cyornis tickelliae* Blyth 1843	RM	LC	Insectivorous	R	SCH IV	1	1
Brown-breasted Flycatcher	*Muscicapa muttu* (E.L. Layard 1854)	WM	LC	Insectivorous	R	SCH IV	1	1
PASSERIFORMES: Acrocephalidae								
sykes's Warbler	*Iduna ram* (Sykes1832)	WM	LC	Insectivorous	R	SCH IV	1	1
Booted Warbler	*Duna caligat* (M.H.C. Lichtenstein 1823)	WM	LC	Insectivorous	R	SCH IV	0	1
Clamorous Reed Warbler	*Acrocephalus stentoreu* (Hemprich & Ehrenberg 1833)	WM	LC	Insectivorous	R	SCH IV	0	1
Blyth's Reed Warbler	*Acrocephalus dumetorum* Blyth 1849	WM	LC	Insectivorous	R	SCH IV	0	1
PASSERIFORMES: Dicaeidae								
Thick-billed Flowerpecker	*Dicaeum agile* (Tickell 1833)	R	LC	Nectarvorous	FC	SCH IV	0	1
PASSERIFORMES: Corvida								
Rufous Treepie	*Dendrocitta vagabunda* (Latham 1790)	RM	LC	Omnivorous	C	SCH IV	0	1
Large-billed Crow	*Corvus macrorhynchos* Wagler 1827	RM	LC	Omnivorous	FC	SCH IV	0	1
House Crow	*Corvus splenden* Vieillot 1817	R	LC	Omnivorous	C	SCH IV	0	1
PASSERIFORMES: Fringillidae								
Common Rosefinch	*Erythrina erythrina* (Pallas 1770)	WM	LC	Frugivorous	R	SCH IV	0	1
PASSERIFORMES: Paridae								
Cinereous Tit	*Parus cinereus* Vieillot 1818	RM	LC	Insectivorous	UC	SCH IV	0	1
PASSERIFORMES: Phylloscopidae								
Common Chiffchaff	*Phylloscopus collybita* (Vieillot 1817)	WM	LC	Insectivorous	UC	SCH IV	0	1
PASSERIFORMES: Zosteropida								
Oriental White-eye	*Zosterops palpebrosus* (Temminck 1824)	RM	LC	Insectivorous	FC	SCH IV	0	1
PASSERIFORMES: Timaliidae								
Tawny-bellied Babbler	*Dumetia hyperythra* (Franklin 1831)	RM	LC	Insectivorous	UC	SCH IV	0	1
PASSERIFORMES: Turdidae								
Orange-headed Thrush	*Geokichla citrina* (Latham 1790)	WM	LC	Insectivorous	R	SCH IV	0	1
PICIFORMES: Ramphastidae								
Coppersmith Barbet	*Psilopogon haemacephalus* (Statius Muller 1776)	R	LC	Frugivorous	UC	SCH IV	0	1
PICIFORMES: Picidae								
Northern Wryneck	*Jynx torquilla* Linnaeus 1758	WM	LC	Insectivorous	R	SCH IV	0	1
Yellow-crowned Woodpecker	*Dendrocopos mahrattensis* (Latham 1801)	R	LC	Insectivorous	FC	SCH IV	0	1
STRIGIFORMES: Strigidae								
Jungle Owlet	*Glaucidium radiatum* (Temminck 1821)	R	LC	Insectivorous	FC	SCH IV	0	1
FALCONIFORMES: Falconidae								
Peregrine Falcon	*Falco peregrinus* Tunstall 1771	WM	LC	Insectivorous	R	SCH IV	0	1

Table 2. Relative diversity index (RDi) of recorded avifauna families in Baliyavad

No	Families	Number of species recorded	RDi
A1	Podicipedidae, Pteroclidae, Caprimulgidae, Apodidae, Gruidae, Anhingidae, Burhinidae, Recurvirostridae, Rostratulidae, Pandionidae, Upupidae, Meropidae, Pittidae, Aegithinidae, Nectariniidae, Ploceidae, Estrildidae, Emberizidae, Pycnonotidae, Campephagida, Dicaeidae, Fringillidae, Paridae, Phylloscopidae, Zosteropida, Timaliidae, Ramphastidae, Strigidae, Falconidae, Turdidae,	1	0.54
A2	Cuculidae, Ciconiidae, Pelecanidae, Phalacrocoracidae, Laridae, Coraciidae, Psittaculidae, Dicruridae, Rhipiduridae, Monarchidae, Passeridae, Turnicidae, Glareolidae, Jacanidae, Picida	2	1.09
A3	Leiothrichidae, Laniidae, Alcedinidae, Ciconiidae, Corvida	3	1.64
A4	Threskiornithidae, Charadriidae, Acrocephalidae, Sturnidae, Cuculidae, Hirundinidae	4	2.19
A5	Motacillidae, Phasianidae, Cisticolidae	5	2.73
A6	Columbidae, Alaudidae	6	3.28
A7	Rallidae, Monarchidae	7	3.83
A8	Anatidae	8	4.37
A9	Muscicapidae	10	5.46
A10	Ardeidae	11	6.01
A11	Accipitridae	12	6.56

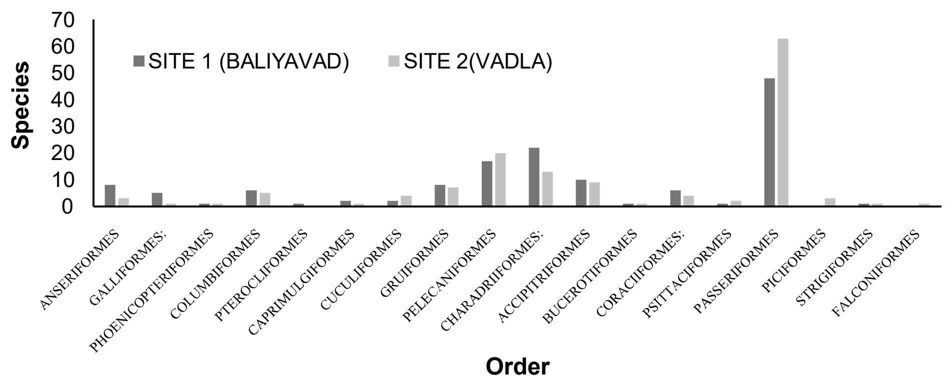

Fig. 2. Comparative account of species at site 1 and site 2. Comparative species level representation of Avifauna at Site 1 and Site 2

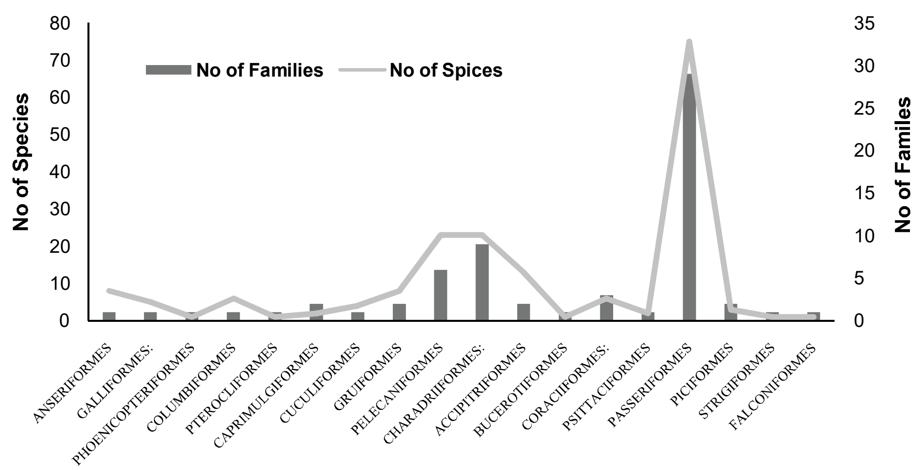

Fig. 3. Order and family representation of avifauna from the Site 1 and Site 2

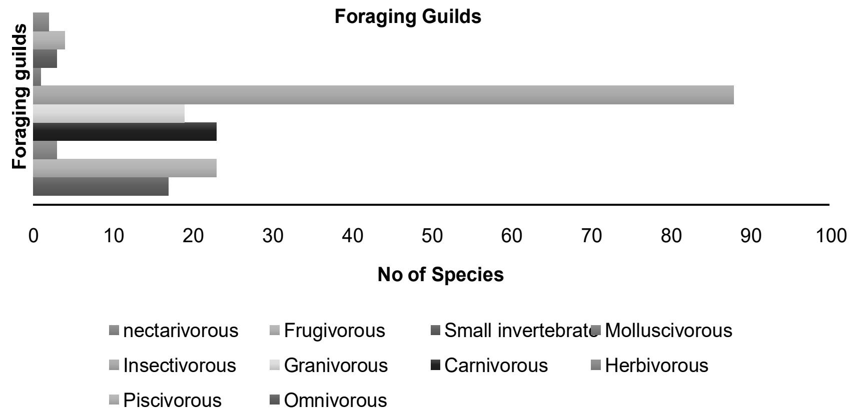

Fig. 4. Representation of Foraging Guilds of avifauna from the study Site 1 and Site 2

65 families, 18orders has been recorded. Total 16347 individuals were recorded in the study area during the study period. Passeriformes (48 species) has highest number of species followed by Phoenicopteriformes, Pterocliformes, Bucerotiformes, Strigiformes and Falconiformes (1 species each). The family Accipitridae and Ardeidae was most diverse among all the 65 families, with a species richness of 12-11 species, the second largest family was Anatidae. Moreover, there were 30 families which were represented with single species (Table 1, Fig. 1 to 4).

The foraging guilds was divided into 10 guilds, out of 10 feeding guilds 88 were insectivorous, 23 Piscivorous, 23 carnivorous, 19 Granivorous, 2 Nectarivorous,17 was omnivorous, 3 were small invertebrates eaters, 2 Frugivorous, 2 were and 1 were Molluscivorous. Eight species are fall under the IUCN categories. One is Vulnerable, two are Critically Endangered and five are Near Threatened178. Out of the total 183 recorded avian species, 55.22% were Resident, 21.64% were Resident Migrants, 3(1.49%) were Monsoon Migrants & 48 (21.64%) were Winter MigrantsIn the present study, a local status to each recorded bird species according to their encounter in the field revealed that 51 species were common, 20 species were fairly common, 45 species were uncommon, and 67 species were rare. Accipitridae and Ardeidae was the most diverse bird family in the study area (12 species, RDi =6.55) followed by Ardeidae) Anatidae and Rallidae, Monarchidae, Columbidae, Alaudidae (6 species, RDi =3.27), Motacillidae, Phasianidae, Cisticolidae (5 species, RDi =2.73), Threskiornithidae, Charadriidae, Acrocephalidae, Sturnidae, Cuculidae, Hirundinidae (4 species, RDi =2.18), Leiothrichidae, Laniidae, Alcedinidae, Ciconiidae, Corvida (3 species, RDi =1.63), Cuculidae, Ciconiidae, Pelecanidae, Phalacrocoracidae, Laridae, Coraciidae, Psittaculidae, Dicruridae, Rhipiduridae, Monarchidae, Passeridae, Turnicidae, Glareolidae, Jacanidae, Picida (2 species, RDi =1.09), while 30 families were poorly represented in the study area with a single species in each (RDi =0.54; Table 2). Baliyavad Dam and Vadla lake are quite rich in bird diversity including a good number of winter visitors. No systematic checklists are available for the Junagadh. This data will give detailed account of avifaunal diversity which will help in management of anthropogenic activities at the study areas.

CONCLUSION

During the entire study period recorded to 138 species of birds belonging to 14 orders and 51 families during the study period. Both habitats are suitable for the avifauna. This happened due to heterogeneity and rich amount of shelter and food available to migratory birds. Good number of migrant species in December and January. Since no significant records of diversity are available on the both the sites, this data will be useful for the further conservation plans of avifauna at Baliyavad Dam and and Vadla lake.

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Increase in Sarus Crane *Grus antigone* (Linnaeus 1758) Population in and Around Alwara Lake of District Kaushambi, India

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***Abstract*:** The Sarus crane (*Grus antigone*) is a flagship species of marshland and wetlands. This is the only resident and non-migratory breeding crane of the Indian subcontinent. Its population is gradually decreasing and now globally threatened due to the shrinkage of wetlands, reduction in safe mating sites and enhanced anthropogenic activities. On the contrary, a remarkable increase of around 78% in the population of Sarus cranes was observed during a survey conducted from March 2020 to February 2021 in and around the Alwara Lake of district Kaushambi (Uttar Pradesh), India, as compared to 2013 population. This systematic survey was done to estimate an increase in the number of Sarus cranes during 2020-2021 when compared to their available population records between 2013 and 2019 from the same study area. This might be due to recent climatic, environmental and ecological progression along with continuous awareness campaigns started since 2012.

***Keywords*:** Alwara Lake, Flagship species, Pandemic, Sarus crane, Vulnerable, Wetland

The Sarus crane (SC), *Grus antigone* (Linnaeus 1758) is world's largest flying bird acts as flagship and wetland indicator species (FWI 2013, Katuwal 2016, WWF 2021). This monogamous and graceful water bird is well known as an eternal symbol of unconditional love, devotion with high degree of marital fidelity as they pair for lifelong and absolutely devoted for each other (Ashok 2016, Prakash and Verma 2016a, Verma 2018a).The Sarus cranes are spectacularly impressive and reach up to the height of six feet with a wing span of about eight feet. The three subspecies of Sarus cranes are: Indian Sarus crane (ISC) *Grus antigone antigone*, Eastern Sarus crane (ESC) *Grus antigone sharpii* and Australian Sarus crane (ASC) *Grus antigone gillae*. Due to its declining number across the globe, the SC has been listed as vulnerable avian species (IUCN 2021). The SC prefers to reside close to human habitation and open habitats like marsh areas, abundantly irrigated paddy fields, grass land and river banks as these areas suit them for foraging, roosting and nesting (Yav et al 2015, Verma and Prakash 2016a, Prakash and Verma 2016b). They show a strong correlation with agriculture especially paddy ecosystems and their occurrence represent a healthy wetland ecosystem (Verma 2018b). Sarus cranes are social creatures, mostly in pairs or in small groups (Verma and Prakash 2021). The compressive review of literature was given by Sundar and Chaudhary (2003) where as Archibald et al (2003) gave the comparative review of three subspecies. A number of researchers did their works related with habit, habitat, population dynamics and conservation status of Sarus crane in India and Nepal (Vyas 2002, Aryal 2004, Aryal et al 2009, Tripathi 2014, Ghosh et al 2016, Tomar 2017, Kumar and Kanaujia 2017, Sengar 2018, Dashahre et al 2020, Malek et al 2020) but study of Sarus crane from population dynamics and conservation point of view, in and around the Alwara Lake is done only by few researchers (Verma et al 2015, Verma and Prakash 2018b, 2019, Prakash and Verma 2019).

In the present exploration, a systematic survey was done to estimate an increase in the number of Sarus cranes during 2020-2021 in order to know the degree of success of awareness campaign started by the authors since 2012, impact of Corona pandemic as well as lockdown and current scenario of their conservation status in and around the Alwara Lake of district Kaushambi (Uttar Pradesh), India.

MATERIAL AND METHODS

Study area: The Alwara Lake is a natural lake and a part of perennial marshy wetland and is situated between the latitude 25^{0}24'05.84”S-25^{0}25'10.63”N and longitude 81^{0}11'39.49”E-81^{0}12'57.95”W with altitude MSL 81.08 meter (Fig. 1). It is surrounded by agricultural fields and covers more than 1750 hectares. The lake is skirted by villages like; Ranipur, Dundi, Hatwa and Bhawansuri in the east, Paur Kashi Rampur, Alwara and Gaura in the north, Shahpur, Umrawan in the south and Mawai, Tikra and Dalelaganj in the west. The study area was divided into three major transects based on its vastness, diversity and nature of habitat. These transects were: (i) Paur Kashi Rampur, (ii) Tikara and (iii) Shahpur. The lake is connected to the river Yamuna towards transect III and terminal part of Kishanpur lift canal towards transect I.

Data collection: The binocular, camera, motorbike and chappu boat (Oar boat) etc. were used for the survey regularly but the counting of cranes was accomplished on a single day from 6 am to 7 pm in order to avoid the possible double counting due to local movements of the birds to nearby locations. The most of the parts of the lake both during the breeding and non-breeding seasons and counted the cranes by direct observations in all potential habitats of the study area were surveyed. Crane count was made in all the three different transects of the study area and the census route was decided in such a manner to ensure maximum coverage of each transect travelling a minimum distance of 2-3 km. The census was avoided during rainy days. Besides actual sightings, opinions and views from local people were also collected to ensure the existing population and their perceptions about the existence of the crane after the authors' awareness campaign and Corona pandemic as well as lockdown. Since SC was a huge bird and visible from a distance by naked eyes hence counting was done through a simple method of watching. Many local people cooperated well to count the SC. Identification, counting methods and other demographic parameters were aided by using standard guides such as Ali (1941), Wetland Research Methodology (1999), methods adopted by Ali and Ripley (1980) and Aryal et al (2009).

RESULTS AND DISCUSSION

The Sarus crane normally seen in pair (Fig. 2) or in pair with one or two juveniles (Fig. 3) or in flock (Fig. 4) and rarely solo. During non-breeding season, cranes are seen in flocks making a congregation mostly in evening for mate finding or pair formation activities. Authors noticed this aquatic bird in maximum number during first fortnight of June as they remain confined around the wetlands in search of water. In the present study, a sum of 755 cranes was observed in 2020 that reflects around 78 percent increase since 2013 (Table 1).

The Sarus crane is listed as vulnerable because it is suspected to have suffered a rapid population decline globally, which is projected to continue, as a result of widespread reductions in the extent and quality of its wetland habitats, exploitation and the effects of pollutants, unsustainable agriculture, unplanned irrigation (IUCN 2021). Water diversions and unsustainable conversion of wetlands, habitat loss, poisoning, increased anthropogenic activities, collisions with power lines, invasive species and changes in agricultural practices and ignorance of wild life rules and regulations are the major threats of this graceful bird

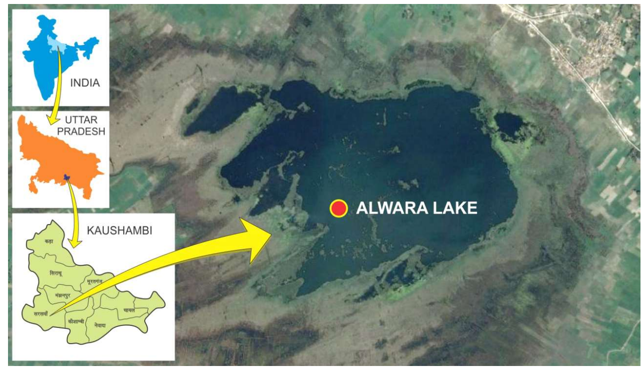

Fig. 1. Study area in Kaushambi district (U.P.), India

Fig. 2. Sarus crane pair in the bank of Alwara Lake

Fig. 3. Sarus crane pair with two juveniles in study area

Fig. 4. Flock of Sarus cranes in Alwara Lake

Table 1. Year wise number of sarus crane recorded from 2013 to 2020

Year	No. of cranes	Increase in crane population (approx.)	Citation reference
2013	425	--	Verma and Prakash (2016b)
2014	510	20%	Verma and Prakash (2016c)
2015	537	26%	Verma and Prakash (2017)
2016	575	35%	Verma and Prakash (2018a)
2017	605	42%	Verma and Prakash (2018b)
2018	625	47%	Verma and Prakash (2019)
2019	650	52%	Prakash and Verma (2019)
2020	755	78%	Current finding

(International Crane Foundation 2021, Prakash and Verma 2022). Contrary to global scenario, the area studied, normal increasing trend of Sarus crane number was seen from 2013 to 2019 (Table 1). Before awareness campaign, number of cranes was not much significant. During this current survey in and around Alwara Lake, presence of abundant paddy fields, land under irrigation, vegetation at the edge of the crop fields, type of crops grown, marshy wetland and the openness of habitat are the major factors for flourishing the cranes. The lockdown resulted into increased transparency of environment, abundance of food and other nutrients, availability of natural habitat for reproduction, decreased human activities and pollution level (Roy and Chaube 2021). In villages adjoining to Alwara Lake, a number of times especially on first Sunday of every month since 2012, contacted the people and told as well as convinced them spiritually not to kill or hunt these cranes, their eggs and juveniles. They were aware about the legal aspect, protection, conservation, and maintenance of its natural habitat (Prakash and Verma 2016c). The authors strongly recommend the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India for continuous population census of this flagship, vulnerable bird (State Bird of Uttar Pradesh) and declaration of the entire Alwara Lake as *Sarus Sanctuary* to make it safe zone for their conservation.

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Village Ponds as Unexplored Habitation Sites for Resident Migratory and Migratory Bird Species in Punjab State, India

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Abstract: Village ponds are recognized as integral constituents of agricultural landscape throughout the world. Objective of the present study was to assess the abundance, diversity and composition of avian fauna inhabiting village ponds in winter season. Line/ point transect methods were followed to record bird data at three selected locations in Punjab State from November 2019 to February 2020. Overall, 59 species of birds including 45 resident, 11 resident migratory and 3 migratory species belonging to 15 orders and 30 families were recorded. Order Passeriformes was most represented in both abundance and species richness. Study revealed six feeding guilds of birds; out of these carnivores (20 species) were most abundant followed by omnivores (19 species) and insectivores (13 species). Three species of winter migratory namely *Motacilla cinerea*, *Calidris minuta* and *Spatula clypeata* were recorded foraging in mixed species flocks. The six resident migratory species were water dependent in nature with three species each of omnivores and carnivores guilds. At present, significance of avian diversity of village ponds is often overlooked therefore, their potential as bird habitats of both resident and migratory must be documented, protected, and restored in Punjab State.

Keywords: Village ponds, Resident migratory, Migratory bird

Ponds being small lentic water bodies (<2 ha in size) can hold water for at least a quarter of the year (Williams et al 2010) are present throughout the world and includes both anthropogenic and naturally formed ponds (Biggs et al 2005). Ponds aid in enhancing biodiversity of aquatic and terrestrial species that are dependent directly or indirectly on these freshwater ecosystems (Céréghino et al 2014). There are several studies of interactions at the aquatic-terrestrial interface. Ponds are known to be a prominent habitat for waterfowl populations (Rajakumar 2012). Many birds seem to associate with ponds due to its various attributes in providing rich nutrition and adequate breeding sites etc. In India, 1340 species of birds have been reported; 330 out of these species are dependent on water bodies (Ali 2002, Kumar and Gupta 2009, Kler and Kumar 2015). Kler (2009) in Punjab State recorded 14 species of water birds out of a total of 51 species belonging to 25 families in 13 orders inhabiting along the banks of Sirhind canal. Different orders of water bird species include Anseriformes, Charadriiformes, Ciconiiformes, Gruiformes, Gaviformes, Pelecaniformes and Procellariformes (Paracuellos 2006). Bird diversity assessment study at village ponds in Sangrur district of Punjab State had shown a total of 36 species belonging to 24 families and 13 orders (Kaur et al 2018).

Birds play a vital role in increasing the biodiversity of ponds. Thus, their population characteristics i.e. size and composition act as bio indicators to pond health as they are largely sensitive to habitat disturbances. Ponds having vast ecological and economic value typically due to their high productivity enhances the avian diversity around them. Unfortunately, freshwater bodies like ponds in general are being exposed to huge scale anthropogenic stress (Prasad et al 2002) which has detrimental effects on the bird community characteristics (Verma et al 2004). Current study was planned with an objective to get insight into relevance of water bodies both natural ponds in villages and manmade ponds in district Ludhiana, Punjab State for providing niches to bird populations and also to propose readily implementable local level conservation measures. Present communication has highlighted the village pond habitats as significant sites for particularly for bird diversity and specifically for supporting the resident migratory and migratory bird species.

MATERIAL AND METHODS

The present investigations on avian diversity and abundance were carried out at three selected ponds in district Ludhiana; two of these selected ponds were natural and situated in villages Jhamat (30°54'15.0"N 75°44'43.0"E) and Malakpur (30°55'44.7"N 75°44'09.4"E) and third pond was selected in Punjab Agricultural University campus (30° 54' 22.3"N 75°48'36.1"E), Ludhiana from November 2019 to February 2020. These ponds have been referred as Pond A, B and C respectively in result details. Habitat features of selected ponds were different from each other's, pond A of area 1.01 ha was surrounded by residential houses; pond B of 1.21 ha was bordered by crop fields on three sides and residential area on one side. Pond C was manmade (1.61 ha area), surrounded by crop fields and having treated water from sewage plant.

Bird surveys were conducted following Line/Point count transect methods at the selected ponds. Data was recorded on bird species inhabiting or foraging in the specified transects (Verner 1985, Buckland et al 2015). Observations were made between 8am to 10am in said months on weekly basis. The population number of bird species encountered was recorded within the selected transects. Bushnell binoculars (7X50) were used for noting morphological features of birds; identification was made as per reference of Ali (2002). Camera Nikon D3300 was used for bird photography. Birds were grouped in different feeding guilds and trophic levels as given by Kler and Kumar (2015). The checklist of bird species was prepared according to Manakadan and Pittie (2001). Vegetation structure (trees, shrubs and weeds) of catchment area around selected ponds was also recorded. Reference books like Trees of Delhi: A field guide (Krishen 2006) and The Book of Indian Trees (Sahni 1998) were consulted for vegetation identification. Bird community structure characteristics like relative abundance, species richness, species evenness and species diversity (Shanon- Weiner Index) were evaluated using standard methods given by Krebs (1985). Two-way Anova and Correlation analysis was applied on values of statistical parameters to find out any significant variance or association in bird species at the selected ponds. Analyses were performed with SPSS v 16.0. Sorensen's similarity coefficient was calculated as given by Southwood (1966).

RESULTS AND DISCUSSION

Present investigation revealed fifty nine species of birds falling under 15 orders and 30 families at selected ponds. Order Passeriformes was the most abundant and consisted of 11 families with 24 bird species (Fig. 1). Order Charadriiformes was second with 4 families; it consisted of 5 species. Passeriformes constituted 40.67 % of total species richness. Species belonging to order Charadriiformes formed 8.47% of total species richness followed by Order Gruiformes with 6.77%. Four orders namely Accipitriformes, Anseriformes, Columbiformes and Pelecaniformes followed with 5% each. There were 13 insectivores, 20 carnivores (soil invertebrate and small invertebrate feeders), 19 omnivores, 3 granivores and 2 frugivores cum grainivores and one species of nectarivore at selected ponds. Out of total 59 observed bird species, recorded 32, 37 and 40 species of birds at ponds A, B and C respectively. There were 26 species of resident birds (82.01%), 25 species (72.41%) and 31 species (85.24%) at ponds A, B and C in winter months respectively (Fig. 2). The 11 species of resident migratory species; out of these 5 species, 9 and 8 species were noted at ponds A, B and C respectively. Combined relative abundance (%) of resident migratory species was 17.54, 24.45 and 14.46 at ponds A, B and C respectively. Data analysis showed there were 3 migratory bird species visiting and inhabiting studies ponds; out of these one species each was found at ponds A and C and 3 species were at pond B. Species of migratory birds constituted combined relative abundance 0.45, 3.14 and 0.30 percent at ponds A, B and C respectively. Six species of resident migratory and two species of migratory birds were water dependent in nature. There were significant difference between resident, resident migratory and migratory bird species. Species richness was highest (42) at pond C and lowest at pond A (33). Species diversity value and species evenness was highest at pond C followed by pond B and pond A (Table 2). Sorensen's coefficient of similarity index showed more similarity in bird fauna between ponds A and C as compared to other ponds (Table 3).

At pond A, the highest relative abundance 25.44% was of Rock Pigeon followed by Common Myna, Common Moorhen and House Crow and Indian Spot-billed Duck. Migratory species Little Stint was observed foraging with Black-winged Stilt in shallow waters near banks of pond A. The most abundant species at pond B was Rock Pigeon (20.28%) followed by Common Moorhen, Common Myna, House Crow and Common Swallow. Large flocks of Common Swallow (20 to 30) were observed flying over pond waters during aerial foraging endeavors. Mixed flocks of Indian Spot-billed Duck, Lesser Whistling Duck and Northern Shoveler were recorded foraging and hiding in pond vegetation. Pheasant-tailed Jacana was observed only at Pond B. The five most abundant species at pond C were Black-winged Stilt (11.60%) followed by Black Kite, Red-wattled Lapwing, House Crow and Common Moorhen. Composite groups of Black-winged Stilt, Northern Shoveler and Common Sandpiper were noted swimming and involved in foraging activities. Black Kites were noticed flying overhead in circles and congregations were also noted near pond banks in evenings at pond C. There were significant difference between relative abundance of different species observed at the studied ponds A, B and C and non-significant difference in overall abundance of different ponds. In Punjab State, net area sown is 4119 thousand hectares out of total geographical area of 5033 thousand hectares (Anonymous 2022). Out of total cultivated area of 4119 thousand hectares in Punjab State, combined area under studied ponds comes

Table 1. Bird species present at selected ponds

Bird species	Scientific name	Pond A	Pond B	Pond C	Trophic groups	Resident status
Order: Passeriformes, Family: Sturnidae						
Common Myna	*Acridotheres tristis*	11.80	8.57	5.51	I, F	R
Asian Pied Starling	*Sturnus contra*	1.39	0.00	0.00	I, F	R
Bank Myna	*Acridotheres ginginianus*	0.00	0.44	2.11	I, F	R
Brahminy Starling	*Sturnia pagodarum*	4.42	0.62	1.05	I, F	R
Family: Hirundinidae						
Common Swallow	*Hirundo rustica*	2.30	6.39	0.00	I	R
Wire-tailed Swallow	*Hirundo smithii*	0.00	2.55	0.00	I	R
Family: Pycnonotidae						
Red-vented Bulbul	*Pycnonotus cafer*	1.85	0.99	0.75	I, P, F	R
Family: Muscicapidae						
Indian Robin	*Saxicoloides fulicatus*	0.00	1.20	0.00	I	R
Brown Rock Chat	*Cercomela fusca*	0.00	0.28	0.59	I	R
Black Redstart	*Phoenicurus ochruros*	0.00	0.00	0.49	I	RM
Oriental Magpie Robin	*Copsychus saularis*	0.00	0.14	0.00	I	R
Family: Motacillidae						
White Wagtail	*Motacilla alba*	0.15	0.00	0.00	I, SI	RM
White-browed Wagtail	*Motacilla maderaspatensis*	0.30	0.38	0.29	I, SI	R
Grey Wagtail	*Motacilla cinerea*	0.00	2.01	0.00	SI	M
Paddy Field Pipit	*Anthus rufulus*	0.00	0.00	1.37	I	R
Family: Estrildidae						
Scaly-breasted munia	*Lonchura puctulata*	3.43	0.00	0.39	I, G	R
Indian Silverbill	*Euodice malabarica*	0.00	1.71	0.00	G	R
Family: Dicruridae						
Black Drongo	*Dicrurus adsimilis*	0.72	0.55	0.85	I	R
Family: Corvidae						
House Crow	*Corvus splendens*	7.27	7.76	8.31	O	R
Rufous Treepie	*Dendrocitta vagabunda*	1.91	0.00	0.81	I, SV	R
Family: Cisticolidae						
Common Tailorbird	*Orthotomus sutorius*	1.58	0.00	0.49	I	R
Plain Prinia	*Prinia inornata*	0.70	0.00	3.18	I	R
Family: Leiothrichidae						
Jungle Babbler	*Turdoides striatus*	1.24	2.00	4.98	I, F	R
Family: Nectariniidae						
Purple Sunbird	*Cinnyris asiaticus*	0.96	0.00	0.00	P	R
Order: Gruiformes, Family: Rallidae						
White-breasted Waterhen	*Amaurornis phoenicurus*	0.00	3.41	0.00	I, SI, G, P	R
Common Moorhen	*Gallinnula chloropus*	8.90	12.64	6.82	I, SI, G, P	RM
Purple Swamphen	*Porphyrio porphyrio*	0.00	0.76	0.00	SI, P, I	RM
Common Coot	*Fulica atra*	0.00	0.53	0.44	P, I, SI	RM
Order: Charadriiformes, Family: Recurvirostridae						
Black-winged Stilt	*Himantopus himantopus*	4.36	0.59	11.60	I	R
Family: Jacanidae						
Pheasent-tailed Jacana	*Hydrophasianus chirurgus*	0.00	0.11	0.00	I,SI	R

Cont...

Table 1. Bird species present at selected ponds

Bird species	Scientific name	Pond A	Pond B	Pond C	Trophic groups	Resident status
Family: Charadriidae						
Red-wattled Lapwing	*Vanellus indicus*	0.30	4.40	8.80	I, SI	R
Family: Scolopacidae						
Common Sandpiper	*Actitis hypoleucos*	0.35	0.91	1.78	I, SI	RM
Little Stint	*Calidris minuta*	0.45	0.28	0.00	SI	M
Order: Anseriformes, Family: Anatidae						
Indian Spot-billed Duck	*Anas poecilorhyncha*	6.78	5.26	2.98	SV, P	RM
Lesser Whistling Duck	*Dendrocygna javanica*	0.00	1.72	3.24	SI, SV	R
Northern Shoveler	*Spatula clypeata*	0.00	0.85	0.30	P, SI	M
Order: Columbiformes, Family: Columbidae						
Rock Pigeon	*Columba livia*	25.44	20.28	1.09	G	R
Eurasian Collared Dove	*Streptopelia decaocto*	2.67	3.65	1.49	G	R
Laughing Dove	*Streptopelia senegalensis*	0.78	0.00	0.00	P, G, I	R
Order: Psittaciformes, Family: Psittacidae						
Rose-ringed Parakeet	*Psittacula krameri*	4.14	0.32	3.73	F, P, G	R
Alexandrine Parakeet	*Psittacula eupatria*	0.00	0.00	0.30	F, P	R
Order: Pelecaniformes, Family: Ardeidae						
Cattle Egret	*Bubulcus ibis*	0.50	1.19	2.30	I, SI	R
Indian Pond Heron	*Ardeola grayii*	0.91	0.88	1.43	I, SI, SV	R
Purple Heron	*Ardea purpurea*	0.00	0.11	0.00	I, SI, SV	RM
Family: Threskiornithidae						
Indian Black Ibis	*Pseudibis papillosa*	0.00	0.00	1.63	I, G	R
Order: Podicipediformes, Family: Podicipedidae						
Little Grebe	*Tachybaptus ruficollis*	0.86	4.86	1.51	I, SI, SV	R
Order: Cuculiformes, Family: Cuculidae						
Asian Koel	*Eudynamys scolopaceus*	0.57	0.00	0.00	I, F	R
Greater Coucal	*Centropus sinensis*	0.91	0.52	0.93	I, SI, SV	RM
Order: Bucerotiformes, Family: Bucerotidae						
Indian Grey Hornbill	*Ocyceros birostris*	1.55	0.00	0.57	F, I	R
Family: Upupidae						
Common Hoopoe	*Upupa epops*	0.00	0.29	0.28	I	RM
Order: Piciformes, Family: Picidae						
Common Golden-backed Woodpecker	*Dinopium javanense*	0.00	0.00	0.28	I	R
White-breasted Kingfisher	*Halcyon smyrnensis*	0.21	0.56	0.00	I, SV	R
Order: Galliformes, Family: Phasianidae						
Indian Peafowl	*Pavo cristatus*	0.00	0.00	5.76	G, P, I, SV	R
Grey Francolin	*Ortygornis pondicerianus*	0.00	0.00	0.44	I, G	R
Order: Accipitriformes, Family: Accipitridae						
Black Kite	*Milvus migrans*	0.00	0.00	9.81	SV	R
Shikra	*Accipiter badius*	0.00	0.00	0.64	I, SI, SV	R
Black-winged Kite	*Elanus caeruleus*	0.00	0.00	0.24	I, SI, SV	R
Order: Suliformes, Family: Phalacrocoracidae						
Little Cormorant	*Microcarbo niger*	0.00	0.29	0.44	SV	RM
Order: Strigiformes, Family: Strigidae						
Spotted Owlet	*Athene brama*	0.30	0.00	0.00	I, SV	R

Trophic groups
I-Insects, SI- Small Invertebrates, SV- Small Vertebrates, F- Fruits, P- Plants, G- Grains

out to be 3.83 ha which is a fraction of area inhabited by 59 species of birds including 45 resident species, 11 resident migratory and 3 migratory bird species. Present observations pointed out these ponds as significant habitats for accommodating and supporting diversity of terrestrial and water dependent avian fauna.

Vegetation features of studied ponds comprised of 22 tree species, 11 weed species and 4 other (cereal, fodder and vegetable) crops There were recorded 10 tress species at pond C followed by 9 ponds at A and 2 at B. Dhek /Bakayan (*Melia azedarach*), Peepal (*Ficus religiosa*) and Sarin (*Albizia lebbeck*) were found at banks at ponds A and C. Wheat and paddy were the cultivated crops in the vicinity of pond B and C. Alfred et al (2001) reported that birds of Family Anatidae consisting of ducks and geese formed the most abundant group of winter migrants to the Indian subcontinent. Different studies have emphasized the vital role of freshwater bodies like wetlands in harboring migratory and residential bird species (Vijayan 2004, Rathod et al 2016 and Krishnamoorthi et al 2020). Céréghino et al (2014) pointed out about large lacuna in biodiversity related basic knowledge associated with pond ecosystems. Location specific or proper guidelines are lacking to restore or preserve ponds locally and at global level (Chen et al 2019).

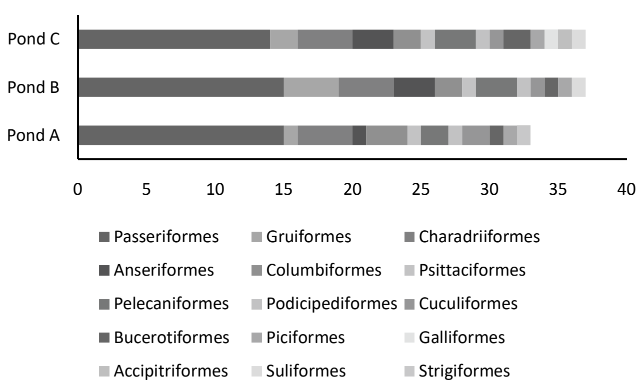

Fig 1. Comparative representation of different bird orders at selected ponds

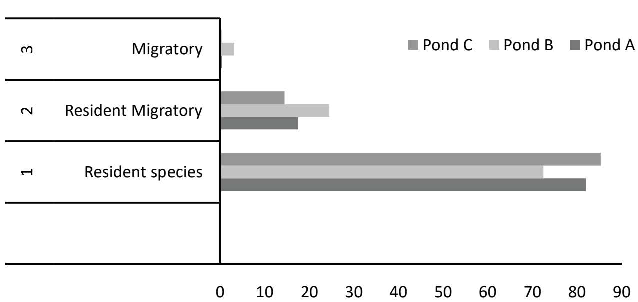

Fig. 2. Relative abundance (%) of bird species according to their resident status in studied ponds

Table 2. Bird community characteristics at studied ponds

Community characteristics	Pond A	Pond B	Pond C
Species richness	33	38	42
Species diversity	2.738386	2.877752	3.157504
Species evenness	0.783177	0.791116	0.844779

Table 3. Sorenson's coefficient of similarity of bird species at studied ponds

	Pond A	Pond B	Pond C
Pond A	1	0.627	0.657
Pond B	0.627	1	0.649
Pond C	0.657	0.649	1

National and international treaties are almost non-existent to protect water bodies in agricultural areas which has accelerated losses in their number, area and state in last 50 years (Bridgewater and Kim 2021, Goyal et al 2021). The present study bring out undeniable significance of rural ponds as an abode of avian diversity in comparison to well recognized and well documented Ramsar wetland habitats. Therefore, timely and urgent interventions are needed for location specific and situation specific habitat improvement measures to sustain avian fauna of diverse residential status and foraging guilds.

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Effect of Risk on Irrigation Adoption by Coconut Farmers in Kerala

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***Abstract*:** Many technologies and better management practices are found to be facing issue of low adoption rates and hence not able to give remarkable results. It is important to know the reasons behind low adoption. Present paper tried to study the effect of risk on adoption of irrigation by coconut farmers of Kerala. The study is based on primary data collected from 275 farmers selected from Calicut and Malappuram districts of Kerala. Risk measures of each farmer were assessed using sample moments and they were later incorporated into a probit model to assess the effect of risk on adoption. Results showed that risk factors do affect irrigation adoption decision by farmers. Probability to get higher profit and the variance of profit were found to have positive effect on irrigation adoption decision, whereas chances of downside risk and extreme events were found affecting irrigation adoption decision negatively.

***Keywords*:** Adoption, Coconut, Irrigation

Coconut has high economic importance in India. Kerala is the largest coconut producing state in India, with a contribution of 35.31 percent of total area and 36.50 percent of production of coconut in the country. Low productivity of coconut in major producing states like Kerala is a cause for concern (Chowdappa et al 2015, Thamban et al 2016, Kappil et al 2021). Kerala leads in area and production of coconut in the country, but its productivity is much low compared to many other states. Coconut productivity in Kerala in 2019 was 10232 nuts/ha, whereas it was 14136 nuts/ha in Andhra Pradesh, 12487 nuts/ ha in West Bengal, 12,296 nuts/ ha in Tamil Nadu (Coconut Development Board 2021). Prevalence of old and senile palms, pests and diseases, soil related constraints and lack of adoption of better management practices are the major factors causing low yield of coconut in Kerala (Chowdappa et al 2015). Irrigation is an important management practice crucial for ensuring better yield from coconut. Though Kerala is a state that receive good monsoon showers, there is a dry summer and it causes yield reduction in this perennial crop (Dhanapal et al 2003, Maheswarappa and Krishnakumar 2019). Irrigation increases production of more female flowers and helps in avoiding premature nut fall (Carr 2011). Unlike other crops, coconut produces flower primordia throughout the year and hence adequate moisture should be available in the soil throughout the year (Dhanapal et al 2002). Water stress leads to long-term negative impacts in the growth and nut yield in coconut. Summer season extending upto six months lead to soil moisture stress and is an important limiting factor for higher crop productivity in Kerala, where crops like coconut are mostly cultivated as rainfed crops. Water deficit for coconut in the state during the summer season is estimated to range from 259 mm to 546 mm (Chandran and Joseph 2015). Coconut is cultivated mostly as a rainfed crop in Kerala and by providing adequate irrigation, yield can be increased significantly (Thamban et al 2004, Kumar and Bai 2009, Thamban et al 2016). Only around 21 percent of the total area under coconut in the state is irrigated. Remaining 79 percent of coconut area is maintained as rainfed crop only (FIB 2021). Though irrigation is much important to fetch better yield, many farmers are still not irrigating their coconut palms. Among many reasons, risk may be one factor influencing farmers' decision to adopt or not to adopt irrigation.

Poor adoption of improved technologies and better management practices by farmers is an important issue. Lot of innovations have happened in scientific agriculture; but still a large section of farmers could not reap benefits out of it because of the poor adoption rates. There are several studies which tried to find out the important factors responsible for this poor adoption rates. Most of these studies concentrated on individual and farm level characteristics or the role of social factors. Apart from these, risk involved is an important aspect which influences farmers' decisions. But very little work has been done on the role of risk in adoption of technologies or better management practices (Marra et al 2002, Ghadim et al 2005) – especially in the Indian context and little attention has been given in the context of plantation crops like coconut. In this background, the present study aims to assess whether risk factors affect irrigation adoption decision by coconut farmers in Kerala.

MATERIAL AND METHODS

The study is based on primary data extracted from a broader data set prepared for a study supported by Indian Council of Social Science Research. Sample for the present study consists of 275 coconut farmers from two districts of Kerala: Calicut and Malappuram, during 2017-18. Respondents were selected randomly from a cluster of villages from each district, after satisfying multiple criteria like irrigation status, producer company membership, etc. Primary data were collected by personal interview method, using structured, pre-tested interview schedule. In order to study the effect of risk on irrigation adoption decision, a two-step approach was used. In the first step, risk measures for each farmer were estimated by computing the first four sample moments (mean, variance, skewness, and kurtosis) of the profit distribution. In the next step, these risk measures along with other relevant variables were incorporated into a discrete choice probit model to study their influence on adoption of irrigation. This methodology was first used in Koundouri et al (2006) and later used with slight modifications by Juma et al (2009) and Salazar & Rand (2016)

The model used in the first step was:

$$PROF = \beta_0+\beta_1 PCM+\beta_2 NT+\beta_3 MEXP+\beta_4 FEXP+\beta_5 IREXP+\beta_6 LEXP+\beta_7 HHS+\beta_8 IG+\beta_9 AGE+\beta_{10} EDU+\beta_{11} FQEXT+\beta_{12} MMEXP+U$$

Where, PROF = Profit/palm/year (Rs), PCM = Producer Company membership status (1 for member, 0 otherwise), NT = Number of trees, MEXP = Manure expenditure (Rs/palm/year), FEXP = Fertilizer expenditure (Rs/palm/year), IREXP = Irrigation expenditure (Rs/palm/year), LEXP = Labour expenditure (Rs/palm/year), HHS = Household size (Number), IG = Income group (I for APL, 0 for BPL), AGE = Age of farmer in years, EDU = Education of farmer in years, FQEXT = Frequency of extension contact in score for frequency of visit, MMEXP = Mass media exposure in score for frequency of exposure, U = Error term

The estimated errors from the mean effect regression are the estimates of first moment of profit distribution. They were then raised to the powers of 2nd, 3rd and 4th and regressed on the same set of explanatory variables to get the second, third and fourth moments of profit distribution. OLS method was used for regression. The four moments (risk measures), along with other relevant variables, were then incorporated into a discrete choice model (probit)

$$IRGN = \beta 0 + \beta 1\ M1 + \beta 2\ M2 + \beta 3\ M3 + \beta 4\ M4 + \beta 5\ NT + \beta 6\ HHS + \beta 7\ AGE + \beta 8\ EDU + \beta 9\ FQEX$$

Where, IRGN = Irrigation status (1 for irrigating, 0 otherwise), M1, M2, M3 & M4 = First four moments, NT = Number of trees, HHS = Household size, AGE = Age of

Table 1. Summary statistics of variables used

Variable	Irrigating		Non-irrigating		Combined	
	Mean	S.D	Mean	S.D	Mean	S.D
Profit/palm (Rs/year)	270.22	67.34	198.67	74.77	226.25	79.89
Number of trees	52.18	37.87	48.15	39.62	49.71	38.93
Irrigation status (1= yes; 0 = no)	1	0	0	0	0.39	0.49
PC membership (1= yes; 0 = no)	0.60	0.49	0.38	0.49	0.47	0.50
Manure expenditure/ tree (Rs/year)	60.36	30.67	41.38	30.97	48.70	32.16
Fertilizer expenditure/ tree (Rs/year)	17.84	18.95	11.88	17.55	14.17	18.30
Irrigation expenditure/ tree (Rs/year)	4.66	3.56	0	0	1.80	3.16
Labour expenditure/tree (Rs/year)	320.36	71.05	316.29	79.32	317.86	76.13
Family size	4.71	1.07	4.25	1.19	4.43	1.16
Income group	0.79	0.41	0.58	0.50	0.66	0.47
Age of farmer (Years)	56.08	9.56	57.48	8.83	56.94	9.19
Education (Years)	9.61	2.22	7.95	2.34	8.60	2.43
Frequency of extension contact	6.76	2.70	5.40	2.63	5.93	2.73
Mass media exposure	4.0	1.30	3.67	1.52	3.8	1.45
Number of respondents	106		169		275	

farmer in years, EDU = Education of farmer in years, FQEX = Frequency score of extension contact.

RESULTS AND DISCUSSION

Among the 275 respondents, 106 farmers were irrigating and 169 farmers were not irrigating their coconut palms, among the respondents 129 farmers were members and 146 farmers were non-members of coconut producer company. On an average, farmers were having 50 palms, and the average profit/palm was Rs.226.25/year. Respondent farmers were having 8 years of education, and the average age was 59.6 years. Farmers were not applying adequate quantity of manures or fertilizers, and thus the average amount spent on these were low. Earlier government reports (GoK 2016) also had commented on the low rate of fertilizer and manure application by coconut farmers in Kerala, owing to less profit realized from the crop.

In the first step of the analysis, profit/palm was regressed on different farm and farmer related variables like number of trees, manure expenditure/tree, fertilizer expenditure/tree, irrigation expenditure/tree, labour expenditure/tree, family size, income group, age, education, frequency of extension contacts and mass media contact. Results of profit function estimation are presented in Table 2. Among the different variables included in the model, being a member of producer company have positive effect on the profit obtained by the farmer. Producer Companies are farmer collectives for the benefit of its member farmers. This structure of farmer collective is expected to enable small producers to pool their resources and establish successful business models, which would improve their income and reduce risks (Govil 2020). In the study area they were helping member farmers through bulk purchase and distribution of inputs, trainings and dissemination of technical knowhow, procurement of products, value addition and marketing, etc. These activities in a collective manner ensure opportunities to the member farmers to fetch better profit.

Table 2. Profit function estimates of coconut

Variable	Coefficient	Standard error
Constant	-1.845	49.790
PC membership status	15.130**	7.334
Number of trees	0.017	0.101
Manure expenditure	0.702***	0.130
Fertilizer expenditure	0.079	0.1993
Irrigation expenditure	3.946***	1.122
Labour expenditure	-0.284***	0.050
Family size	-0.644	2.986
Income group	-1.827	7.273
Age	2.626***	0.514
Education	12.062***	2.049
Frequency of extension contact	3.452**	1.449
Mass media exposure	0.041	2.437
R^2: 56.23, Adj. R^2: 54.23		

Note: ***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels respectively

Similarly, irrigation expenditure and expenditure on organic manure affect profit positively. Though Kerala gets ample rainfall, summer season is affecting coconut yield drastically, and many studies have shown that irrigation will help to achieve higher yield (Thamban et al 2004, Kumar and Bai 2009, Thamban et al 2016). Same result were observed in present study also. Proper soil moisture throughout the growing and production period might have helped in enhancing the nut yield and quality. Basin opening and applying organic manure prior to monsoon season is a common practice being adopted by coconut farmers in Kerala and the regression results showed application of these organic manures contributed positively to profit by means of improved quality and quantity of nuts. Fertilizer expenditure was found to have no significant effect on the profit and might be because many of the farmers in the study area were not applying fertilizers to coconut palms, and even if they apply, it was meagre. Inadequate fertilizer application in coconut plantations in the state was already reported in official reports (GoK 2016). Labour expenditure was found to affect negatively; it may be because of the high wage rate. Labour shortage and high wage rate were the major issues that all the farmers in the area were complaining about. This seems to be a common concern of coconut farmers in the state (Thamban et al 2016).

Age, education and frequency of extension contact- the variables which are expected to enhance farmer's knowledge and expertise, were found to have positive influence on the profit obtained. As the farmer become more knowledgeable and experienced, it will be helping him/ her for better utilization of resources and better marketing, thus increasing the profit. Farmers were found to get extension support from Krishi Bhavans in the locality and Kisan Call Centres.

The influence of risk on farmers' adoption behaviour was well reflected in the probit regression (Table 3). All the four moments were significant-mean and variance positively and skewness & kurtosis negatively. The higher the expected profit, the greater the probability that a farmer will be adopting irrigation. Farmers are driven by profit maximization and would be motivated to adopt irrigation if it is guaranteeing a higher profit. Similarly in the case of increasing variance, the probability of adopting irrigation also increased significantly. When there was higher probability of getting large profit values- as indicated by higher variance, willingness for adoption of irrigation was also found increasing. Third and fourth moments were negatively significant. A higher probability of downside risk, represented by skewness of profit, decreases the chance of farmers' adopting irrigation. Along with the third moment (skewness), fourth moment (kurtosis) also was negatively significant. It showed that as a result of extreme events farmers adoption decreases significantly. These results confirmed that farmers are not risk neutral, or risk factors have significant influence on adoption of better management practices like irrigation. Thus, addressing the risks involved is much crucial for encouraging farmers to make further efforts and investments for development of coconut plantations. The lack of better management practices is a major reason for low yield of coconut in the state, overlooking such critical factors like influence of risk on farmers' irrigation decisions will have long lasting negative impacts.

Apart from the risk variables, most of the other farm and farmer related factors also showed significant positive/ negative influence on adoption of irrigation. It was observed that as the number of trees increases, adoption decision goes low. It may be because of the larger efforts/ arrangements needed for irrigating huge area. Chances of occurrence of losses also may be deterring farmers with large number of trees to spend higher amount of money or efforts on management practices like irrigation. There are a number of issues like high cost of inputs, shortage of labourers, stagnating yield, price volatility etc. which the coconut farmers are facing and this creates hurdles in getting a reasonable profit in a stable manner. These might be making them cautious while diverting further resources for coconut farming. Thus farmers with more number of coconut palms might be trying to minimize the expenditure incurred and this would have negatively affected decision to adopt irrigation.

Family size was found to have positive effect which may be because of the increase in availability of family labour. As more number of people become available, it may be easier to adopt better management practices as there will be people available to look after the various activities required. This might have positively influenced decision to adopt irrigation. Information providing factors of farmer - such as education and frequency of extension contact were also found to have positive influence on adoption of irrigation. Both these factors might have helped the farmer to have a clear picture on possible incremental return if they irrigate the farm, and also might have provided with information regarding various schemes, techniques and necessary details so that they might have got encouraged to adopt irrigation.

Table 3. Probit regression to study effect of risk on adoption of irrigation

Variable	Coefficient	Standard error
Constant	-23.72***	3.992
First moment (Mean)	0.010***	0.003
Second moment (Variance)	0.006***	0.001
Third moment (Skewness)	-2.72e-04***	4.21e-06
Fourth moment (Kurtosis)	-1.89e-07***	3.53e-08
Number of trees	-0.022***	0.006
Family size	0.521**	0.196
Age	0.046	0.035
Education	0.427***	0.122
Frequency of extension contact	0.878***	0.150
Log likelihood: -31.15, Prob>Chi^2: 0.000		

Note: ***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels respectively

Table 4. Marginal effects of the explanatory variables

Variable	Coefficient	Standard error
First moment (Mean)	0.003***	0.0011
Second moment (Variance)	0.002***	0.0003
Third moment (Skewness)	-8.39e-06***	1.55e-06
Fourth moment (Kurtosis)	-5.82e-08***	1.23e-08
Number of trees	-0.007***	0.0020
Family size	0.161**	0.0594
Age	0.014	0.0108
Education	0.132***	0.0366
Frequency of extension contact	0.271***	0.0516
Log likelihood: -31.15, Prob>Chi^2: 0.000		

Note: ***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels respectively

CONCLUSION

It is concluded that risk do have significant influence on coconut farmers' irrigation adoption decision in the study area. Probability to get a higher profit, and also variance of profit were found to have positive effect on irrigation adoption decision. Whereas a higher probability of downside risk and chances of occurrence of extreme events were found to affect irrigation adoption negatively. There is immense need for efficient risk management mechanisms which can avoid chances of huge losses. In the absence of such risk management mechanisms, management practices like irrigation may not get adopted by the farmers and thus they won't be able to get adequate economic returns from farming activities. Prospect of an assured and decent income from coconut palms will further encourage farmers to make investments in order to improve yield. This will help the farmers to get better returns over time. Being a perennial crop, care / negligence shown on management of coconut palms will definitely have long term impacts. Hence providing efficient risk management mechanisms to coconut farmers is much crucial for long term profitability and feasibility of plantations.

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System Productivity and Economics of Seasonal Sugarcane Based Intercropping Systems under different Farming Practices

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***Abstract*:** A field experiment was carried out at Agricultural Research Station, Hukkeri (Dist. Belagavi) during 2019-20 to study the productivity and economics seasonal sugarcane based intercropping systems. The experiment was laid out in split-split plot design with three farming practices in main plot such as M_1: recommended package of practices (RPP), M_2: organic farming (OF) and M_3: natural farming (NF); in sub plots two spacings *viz*., S_1: 60-180-60 cm × 60 cm (paired row planting) and S_2: 240 cm × 60 cm (wide row planting) and in sub-sub plots three intercropping systems were taken *viz*., I_1: sugarcane + onion *fb* turmeric, I_2: sugarcane + onion + cowpea + coriander + green chilli and I_3: sole sugarcane. Results revealed that, RPP recorded a significantly higher NMC (73.04 thousand ha^{-1}), cane yield (93.8 t ha^{-1}) and net returns (₹ 244855 ha^{-1}) than organic farming and natural farming practices. Between two spacings, paired row planting recorded significantly higher NMC (83.77 thousand ha^{-1}), cane yield (100.9 t ha^{-1}) and net returns (₹ 214718 ha^{-1}) than wide row planting. Among the intercropping systems, sugarcane + onion *fb* turmeric recorded significantly higher sugarcane equivalent yield (170.3 t ha^{-1}) and net returns (₹ 277556 ha^{-1}) than other intercropping systems.

Keywords: Intercropping systems, Farming practices, Natural farming, Organic farming, Sugarcane

Sugarcane (*Saccharum* spp. hybrid complex) is an important commercial crop in tropical and subtropical regions of the world and is cultivated in more than 115 countries and grown over an area of 26.27 million hectares with a production of 1907.02 million tonnes and productivity of 72.59 t ha^{-1} (Anonymous 2020). Sugarcane plays a pivotal role in the national economy by sustaining the second-largest agro-industry in the country next to textile. To meet the growing demand for sugar and energy by 2050 India, need to produce around 630 million tonnes of sugarcane with a recovery of 11.5 per cent having average productivity of 105.0 t ha^{-1} (Anonymous 2015). In the wake of the green revolution, agriculture is heavily dependent on fertilizers and chemicals. Their imbalanced and indiscriminate usage is leading to increased soil, water, environmental pollution, and health hazards. Organic farming emerged as an alternative agricultural system in the 20th century and addresses self-reliance in food production, rural development, and conservation of natural ecosystems. The green revolution has bought about debt and despair among the farming community due to the increased cost of cultivation and with specified ingredients and processes, organic farming is also becoming difficult. To overcome the ill-effects of conventional agriculture and make technology feasible for adoption by economically poor and marginal farmers is by adopting natural farming (Palekar 2006). Natural farming (NF) is a grassroots peasant movement that is trying to improve India's capacity to produce its own food by farming with nature and ending farmers' reliance on purchased inputs and credit and is a holistic agricultural practice that reduces commercial expenditure and market dependency of farmers by avoiding the use of external inputs (Smith et al 2020). It is seen as a way of overcoming the inability of many poor farmers to access improved seed and manufactured agrochemicals (Palekar 2006). In India, presently farmers are adopting wide row spacing (120 to 180 cm) in sugarcane than the existing 90 cm row spacing which is being popularized. Sugarcane, being a long duration with initial slow growth nature much of the space between two rows remains unutilized for an initial period of 100-120 days. In addition, sugarcane generates income only once in a year due to its long crop duration. So, this situation provides ample opportunity for intercropping in sugarcane which increases the total production per unit area (Nadiger et al 2017). Increased crop yield often observed in intercrops compared to sole crops has been attributed to enhanced resource use (Szumigalski and Van 2008). Therefore, the inclusion of short duration, high value and midseason income-generating intercrops is the need of the hour to provide economic security and maximise farm productivity in sugarcane. Crop diversification increases resource use efficiency, reduces production costs and improves or maintains soil quality in intensive agriculture systems (Singh et al 2021). In this view, the study was undertaken to investigate the influence of natural, organic, and conventional farming practices (RPP) on the productivity and economics of sugarcane based intercropping systems.

MATERIAL AND METHODS

Experimental site: Field experiment was carried out at Agricultural Research Station, Hukkeri in Belagavi district of Karnataka which is situated in the Northern Transition Zone of Karnataka (Zone 8) lies 16° 13' 48.00'' North latitude, 74° 35' 59.99'' East longitude and at an altitude of 631 m above mean sea level (MSL). The monthly mean annual rainfall of the experimental site was 650.1 mm (2004-2018). During the crop growing season, the rainfall received was excess by 48.39 per cent during the year 2019 compared to the mean annual rainfall of the experimental site (630.0 mm). The total rainfall received during the entire crop growth period was 964.7 mm. Sufficient rainfall was received for sugarcane crop growth. The soil of the experimental site was medium black clay in texture having a slightly alkaline pH (8.20) with normal electrical conductivity (0.283 dSm^{-1}). The soil had medium in organic carbon content (0.68 %), low in available nitrogen (241.2 kg ha^{-1}), medium in available P_2O_5 (38.54 kg ha^{-1}) and high in available K_2O (433.6 kg ha^{-1}).

Experimental details: The experiment was laid out in split-split plot design with three farming practices in main plot namely M_1:Recommended package of practices, M_2:Organic and M_3: Natural farming; two planting methods in sub plots *viz*., S_1: paired row planting (PRP: 60-180-60 cm × 60 cm) and S_2: wide row planting (WRP: 240 cm × 60 cm) in which three intercropping systems were introduced *viz*., sugarcane + onion *fb* turmeric (I_1), sugarcane + onion + cowpea + coriander + green chilli (I_2) and sole sugarcane (I_3) in sub-sub plots. A total of eighteen treatment combinations were replicated thrice (Table 1).

Transplanting of settling and sowing of intercrops: Furrows were opened at 60 cm apart and settlings of ssugarcane cultivar Co 86032 of 25 days old were transplanted on 9th March 2019. Settlings were transplanted in furrows with paired row plating (S_1: 60-180-180 cm × 60 cm) and wider row planting (S_2: 240 cm × 60 cm). Intercrops were sown on both sides of furrows opened at 60 cm distance provided between sugarcane planted rows. Sowing of intercrops in the five-tier model (Fig. 1, 2). The onion was planted on both sides of sugarcane furrows, cowpea and green chilli were planted alternatively on the sides of furrows and coriander was sown in the middle of furrows. After harvesting onion in intercropping system I_1, the land was levelled with the help of small tractor (power tiller) and furrows were opened at 60 cm apart between the wide row, then turmeric rhizomes were dibbled on the sides of furrows at 20 cm apart.

Harvest of sugarcane, intercrops, and yield: Sugarcane was harvested on 23rd January 2019 to the ground level, detrashed, bundled and stacked before recording the plot yield. Intercrops were harvested from the net plot at physiological maturity and harvestable maturity yield were converted in kg ha^{-1}. Intercrop yields were computed as sugarcane equivalent yields. Sugarcane Equivalent Yield (SEY) is a simple expression in intercropping to compare the economics of intercrops by converting grain/seed/economic part *etc.* in terms of gross returns/net returns for valid comparison. The economics was worked out from prevailing market prices of inputs and outputs for different treatments.

Statistical analysis: The data recorded during the investigation were compiled and analysed for statistical significance by Microsoft excel as per the analysis of variance for the spilt-split plot design. Fisher's method of analysis of variance as described by Gomez and Gomez (1984) was adopted for the purpose. Standard error of mean and coefficient of variability have been worked out for a set of observations under each character at p=0.05 to interpret the significance.

RESULTS AND DISCUSSION

Sugarcane yield and yield parameters: Number of millable canes (NMC) and cane yield were significantly influenced by different farming practices, spacings, intercropping systems and their interactions (Table 2). RPP recorded significantly higher NMC (73.04 thousand ha^{-1}) and cane yield (93.8 t ha^{-1}) as compared to organic farming and natural farming. Higher yield under RPP was mainly due to the integrated use of different sources of the nutrients which comprises FYM @ 25 t ha^{-1}, 250:75:190 kg $N:P_2O_5:K_2O$ ha^{-1}, micronutrients *viz*., $FeSO_4$ and $ZnSO_4$ @ 25 kg ha^{-1} and biofertilizers *viz*., *Azospirillum* and PSB @ 10 kg ha^{-1}, which is a well-established system for meeting the sugarcane crop's nutrient demands. Higher single cane weight (1.45 kg) under RPP was due to higher millable cane height (240.3 cm), number of internodes (18.99), internodal length (12.39 cm) and cane diameter (3.13 cm) (Table 1). Increased cane yield was attributed to these entire yield attributing parameters in RPP. Similar results were reported by earlier scientist that among the nutrient management practices, RPP recorded significantly higher yield attributes are mainly due balanced nutrition in the form of chemical fertilizers along with FYM and biofertilizers (Kuri and Chandrashekara 2015, Shridevi et al 2016, Nooli et al 2019). Cane yields were lower with organic farming and natural farming due to a lack of readily available

Table 1. Yield parameters of sugarcane as influenced by different farming practices, spacings and intercropping systems

Treatments	Yield parameters of sugarcane															
	Millable cane height (cm)				Number of internodes cane^{-1}				Internodal length (cm)				Cane diameter (cm)			
	RPP	OF	NF	Mean S	RPP	OF	NF	Mean S	RPP	OF	NF	Mean S	RPP	OF	NF	Mean S
S: Row Spacings (cm)		M × S				M × S				M × S				M × S		
S_1: 60-180-60 cm × 60 cm (PRP)	238.9	222.4	208.2	223.2	18.57	17.97	17.60	18.04	12.38	12.08	11.61	12.02	3.12	3.03	2.84	3.00
S_2: 240 cm × 60 cm (WRP)	241.7	225.5	211.8	226.3	18.10	17.63	17.08	17.61	12.39	11.98	11.71	12.03	3.14	3.04	2.86	3.01
I: Intercropping systems		M × I		Mean I		M × I		Mean I		M × I		Mean I		M × I		Mean I
I_1: Sc + O - T	240.1	225.1	211.8	225.7	18.57	17.97	17.60	18.04	12.59	12.19	11.71	12.16	3.16	3.04	2.83	3.01
I_2: Sc + O + Cp + Co + GC	229.7	217.1	202.8	216.6	18.10	17.63	17.08	17.61	12.35	11.97	11.55	11.96	3.01	2.96	2.80	2.92
I_3: Sole sugarcane	251.0	229.7	215.3	232.0	20.30	18.77	18.13	19.07	12.22	11.92	11.71	11.95	3.23	3.11	2.91	3.08
		M × S × I		S × I		M × S × I		S × I		M × S × I		S × I		M × S × I		S × I
S_1: 60-180-60 cm × 60 cm (PRP) I_1	237.0	225.1	210.1	224.1	18.53	17.80	17.47	17.93	12.45	12.30	11.69	12.15	3.16	3.05	2.82	3.01
I_2	229.5	215.5	200.5	215.1	18.00	17.53	17.00	17.51	12.40	11.95	11.41	11.92	3.00	2.93	2.79	2.91
I_3	250.1	226.7	214.0	230.3	20.33	18.40	18.07	18.93	12.28	12.00	11.72	12.00	3.21	3.12	2.90	3.08
S_2: 240 cm × 60 cm (WRP) I_1	243.1	225.1	213.5	227.2	18.60	18.13	17.73	18.16	12.73	12.08	11.73	12.18	3.16	3.02	2.85	3.01
I_2	230.0	218.8	205.2	218.0	18.20	17.73	17.17	17.70	12.30	12.00	11.68	11.99	3.02	2.99	2.82	2.94
I_3	251.9	232.7	216.5	233.7	20.27	19.13	18.20	19.20	12.15	11.85	11.70	11.90	3.25	3.10	2.91	3.09
M: Farming practices	240.3	224.0	210.0		18.99	18.12	17.61		12.39	12.03	11.66		3.13	3.03	2.85	

Source of variations	C. D. (p=0.05)	C. D. (p=0.05)	C. D. (p=0.05)	C. D. (p=0.05)
M - Farming practices	12.14	0.98	0.51	0.161
S - Spacings	NS	NS	NS	NS
I - Intercropping systems	9.84	0.80	NS	NS
M × S	NS	NS	NS	NS
M × I	NS	NS	NS	NS
S × I	NS	NS	NS	NS
M × S × I	NS	NS	NS	NS

M: Main plot (Farming practices)

M_1: Recommended package of practices (RPP)

M_2: Organic farming (OF)

M_3: Natural Farming (NF)

S: Sub plot (Row spacings)

S_1: PRP - Paired row planting (60-180-60 cm × 60 cm)

S_2: WRP - Wide row planting (240 cm × 60 cm)

I: Sub sub plot (Intercropping systems)

I_1: Sugarcane + Onion – Turmeric (Sc + O - T)

I_2: Sugarcane + Onion + Cowpea + Coriander + Green Chilli (Sc + O + Cp + Co + GC)

I_3: Sole sugarcane

Table 2. Yield parameters, yield and sugarcane equivalent yield of seasonal sugarcane as influenced by different farming practices, spacings and intercropping systems

Treatments	Yield parameters of sugarcane															
	Number of milable canes (000' ha^{-1})				Single cane weight (kg $cane^{-1}$)				Cane yield (t ha^{-1})				Sugarcane equivalent yield (t ha^{-1})			
	RPP	OF	NF	Mean S	RPP	OF	NF	Mean S	RPP	OF	NF	Mean S	RPP	OF	NF	Mean S
S: Row Spacings (cm)		M × S				M × S				M × S				M × S		
S_1: 60-180-60 cm : 60 cm (PRP)	92.56	83.74	75.03	83.77	1.44	1.40	1.26	1.37	120.0	101.2	101.2	100.9	163.6	141.8	117.4	141.9
S_2: 240 cm × 60 cm (WRP)	53.53	47.82	40.13	47.16	1.45	1.42	1.27	1.38	67.6	57.2	57.2	56.3	128.0	110.6	91.7	110.1
I: Intercropping systems		M × I		Mean I		M × I		Mean I		M × I		Mean I		M × I		Mean I
I_1: Sc + O - T	76.14	70.18	58.82	68.38	1.46	1.41	1.28	1.38	98.4	85.7	85.7	83.7	194.9	172.8	143.1	170.3
I_2: Sc + O + Cp + Co + GC	61.69	52.84	48.74	54.42	1.40	1.37	1.24	1.33	77.0	59.6	59.6	62.3	136.9	113.4	99.3	116.4
I_3: Sole sugarcane	81.30	74.31	65.18	73.60	1.49	1.44	1.28	1.40	105.9	92.4	92.4	89.9	105.9	92.4	71.3	89.9
		M × S × I		S × I		M × S × I		S × I		M × S × I		S × I		M × S × I		S × I
S_1: 60-180-60 cm × 60 cm (PRP) I_1	96.49	90.69	76.41	87.86	1.46	1.40	1.27	1.38	127.1	113.1	86.4	108.9	206.3	187.5	151.6	181.8
I_2	79.00	66.89	62.89	69.59	1.39	1.36	1.23	1.33	97.3	73.7	66.2	79.1	149.1	121.0	108.5	126.2
I_3	102.2	93.64	85.78	93.87	1.48	1.43	1.28	1.40	135.5	116.9	92.3	114.9	135.5	116.9	92.3	114.9
S_2: 240 cm × 60 cm (WRP) I_1	55.79	49.68	41.23	48.90	1.46	1.43	1.28	1.39	69.7	58.4	47.7	58.6	183.6	158.1	134.7	158.8
I_2	44.38	38.80	34.60	39.26	1.40	1.37	1.24	1.34	56.7	45.4	34.5	45.5	124.1	105.9	90.0	106.7
I_3	60.42	54.98	44.57	53.32	1.50	1.45	1.29	1.41	76.3	67.8	50.3	64.8	76.3	67.8	50.3	64.8
M: Farming practices	73.04	65.78	57.58		1.45	1.41	1.27		93.8	79.2	62.9		145.8	126.2	104.6	
Source of variations				C. D. (p=0.05)				C. D. (p=0.05)				C. D. (p=0.05)				C. D. (p=0.05)
M - Farming practices				3.39				0.082				4.27				4.1
S - Spacings				2.42				NS				2.87				2.7
I - Intercropping systems				2.99				0.056				3.58				4.2
M × S				4.19				NS				4.97				4.7
M × I				5.04				NS				6.02				7.0
S × I				4.23				NS				5.06				5.9
M × S × I				7.33				NS				8.76				10.2

See Table 1 for details

nutrients from organic sources which takes time to mineralize and made available to the crop (Durai and Devaraj 2003).

The superiority of cane yield under organic farming over natural farming was attributed to the application of 100 per cent organics equivalent to RDN through FYM + VC + EPM 1/3[rd] each and biofertilizers like *Azosprillum* and PSB @ 10 kg ha^{-1} along with the foliar application of *panchagavvya* as well as soil application of *jeevamrutha* resulted in higher sugarcane yield. The increase in cane yield under organic farming was to the extent of 25.91 per cent over natural farming (Table 2). This might be due to the application of FYM, vermicompost as well as press mud which is a good source of nutrients *viz.*, organic carbon (34.19 %), nitrogen (2.0 %), phosphorus (1.55 %), potassium (2.85 %) and micronutrients (Fe, Zn, Cu and Mn) (Sinha et al 2014). In organic farming, the application of carbonic substrate through organic manures coupled with soil application of *jeevamrutha* which was congenial for microbial growth (Vinay et al 2020a) lead to better mineralization of organic matter and further increased the availability of essential nutrients coupled with foliar nutrition with *panchagavya* lead to better growth and yield attributes of sugarcane. The lower yield was observed in natural farming due to fact that external application of fertilizer as well as organic manures are avoided which led to insufficient nutrient supply from soil to sugarcane crop which is huge biomass producing as well as nutrient demanding crop throughout its growth stages. Hence, undernourished crops resulted in poor growth and yield attributes finally reducing cane yield. Significantly higher number of millable canes (83.77 thousand ha^{-1}) and cane yield (100.9 t ha^{-1}) were recorded under PRP (60-180-60 cm × 60 cm) compared to WRP (240 cm × 60 cm). The increase in the yield was to the extent of 79.21 per cent over wide row planting (WRP). Higher cane yield with PRP attributed to significantly higher number of millable canes than WRP (Table 2). Higher NMC's were the main reason for higher cane yield under the PRP of sugarcane. Sarala et al (2014) also observed that sugarcane planting with paired rows at 75/105 cm recorded better yield attributes like number of millable canes and cane yield compared to wider row planting.

The wide row spacings of sugarcane give ample opportunity for the intercrops which leads to crop intensification and increase the system productivity. The significantly higher number of millable canes (73.60 thousand ha^{-1}) were recorded under sole sugarcane as compared to

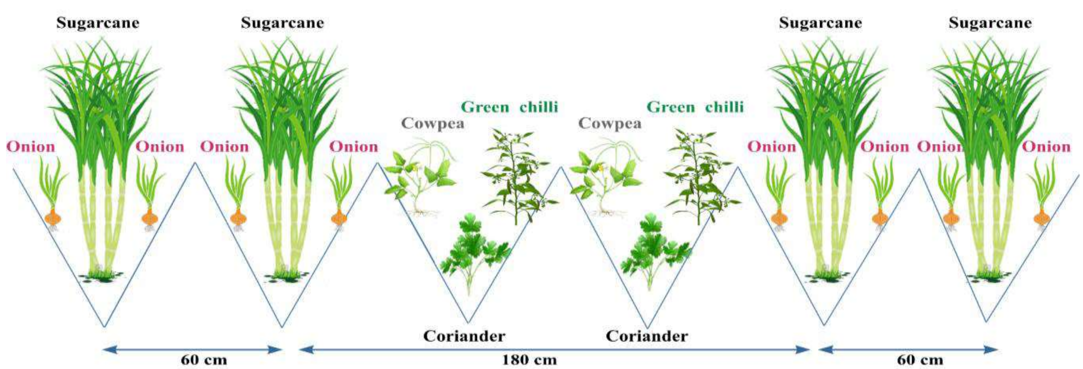

Fig. 1. Planting pattern in 60-180-60 cm × 60 cm paired row planting

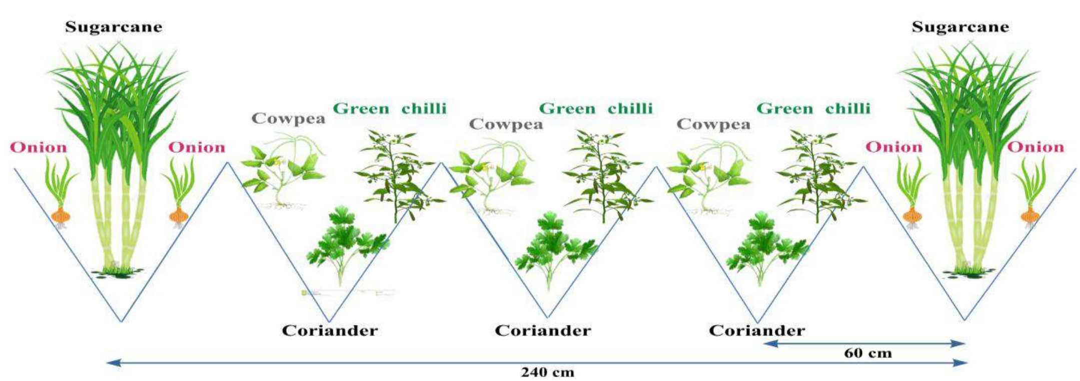

Fig. 2. Planting pattern in 240 cm × 60 cm wide row planting

sugarcane + onion *fb* turmeric (I_1) and sugarcane + onion + cowpea + coriander + green chilli (I_2). The extent of reduction in cane yield was least (7.40 %) in sugarcane + onion *fb* turmeric (I_1) and as compared to 44.30 per cent in sugarcane + onion + cowpea + coriander + green chilli (I_2) than sole sugarcane. Results are in line with El-Gergawi and Abdalla (2000) found that higher yield with sugarcane + sweet potato; and Mahadevaswamy (2001) in sugarcane + onion. Significantly superior cane yield under sole sugarcane was due to the absence or least of competition for natural resources as compared to intercropping involving component crops. However, cane yield recorded with intercropping of sugarcane + onion *fb* turmeric (I_1) was comparable to that of sole sugarcane due to the least competition by onion in the early growth stages of sugarcane. Among the interaction effects of farming practices with different spacings and intercropping, RPP + PRP + sole sugarcane ($M_1S_1I_3$) recorded significantly higher NMC (102.19 thousand ha^{-1}) and cane yield (135.5 t ha^{-1}) than other interactions. However, interaction of RPP with PRP of sugarcane + onion *fb* turmeric ($M_1S_1I_1$)was on par with RPP + PRP + sole sugarcane ($M_1S_1I_3$). The significantly lower NMC and sugarcane yield were recorded under natural farming with WRP of sugarcane + onion + cowpea + coriander + green chilli ($M_3S_2I_2$). Significantly higher NMC recorded with recommended package of practices with paired row planting of sole sugarcane might be due to higher cane population coupled with better nutrient management as per RPP lead to reduced tiller mortality over other treatment combinations. It was due to the better availability of growth resources like water, nutrients, air, better cultural practices in wider plant geometry with no intercrop competition might have helped the plants to exhibit their full potential and produced higher yields than other treatment combinations with intercrops (Nadige et al 2017).

Sugarcane equivalent yield (SEY) of sugarcane based intercropping systems: Sugarcane equivalent yield (SEY) differed significantly due to different farming practices, spacings, intercropping systems and their interactions (Table 2). Among the farming practices, recommended package of practices (RPP) resulted in significantly greater SEY (145.8 t ha^{-1}) compared to organic farming and natural farming practices. The greater SEY was mainly due to maximum sugarcane and intercrop yield under recommended package of practices than with organic farming and natural farming practices. It is also due to the higher price of intercrops with higher yield levels thereby higher sugarcane equivalent yield. The extent of increase in SEY under RPP over organic farming was 15.53 per cent and 39.38 per cent over natural farming. The lower sugarcane equivalent yield is attributed to natural farming mainly due to a drastic reduction in sugarcane and intercrop yield. Different spacings significantly influenced sugarcane equivalent yield (SEY). Significantly higher SEY was recorded with PRP of sugarcane (141.0 t ha^{-1}) compared to WRP. The higher SEY in PRP of sugarcane to the extent of 28.06 per cent over WRP. It was mainly due to higher sugarcane yield under PRP of sugarcane by higher NMC compared to WRP. Even though higher intercrop yields under wider space (240 cm) are unable to compensate for reduced yield under WRP in the form of sugarcane equivalent yield as compared to PRP of sugarcane. Among the intercropping systems tested, sugarcane + onion *fb* turmeric (I_1) recorded significantly higher SEY (170.3 t ha^{-1}) as compared to intercropping of sugarcane + onion + cowpea + coriander + green chilli (I_2) (116.4 t ha^{-1}) and sole sugarcane (I_3). The higher SEY under sugarcane + onion *fb* turmeric (I_1) to the extent of 46.30 per cent over sugarcane + onion + cowpea + coriander + green chilli (I_2) and 89.43 per cent over sole sugarcane (I_3). The higher SEY was mainly due to higher sugarcane and intercrop yield as well as the higher market price of the produce. Lower SEY under intercropping of sugarcane + onion + cowpea + coriander + green chilli (I_2) was mainly due to lower sugarcane and intercrop yields which were attributed to reduced NMC, cane diameter, single cane weight due to smothering effect by spreading nature of cowpea on sugarcane and other component crops. Similar observations reported by Khandagave (2010). The interaction of RPP with PRP of sugarcane + onion *fb* turmeric ($M_1S_1I_1$) recorded significantly higher SEY (206.3 t ha^{-1}) as compared to other treatment combinations. The higher sugarcane equivalent yield in RPP with PRP of sugarcane + onion *fb* turmeric ($M_1S_1I_1$) was mainly due to higher cane and intercrop yield as well as the higher market price of sugarcane, onion and turmeric crops. Kumar et al (2011) reported that higher sugarcane equivalent yield was recorded with the sugarcane + onion intercropping system.

Economics of sugarcane based intercropping system: The cost of cultivation (COC) of sugarcane was very high in organic farming (₹ 212896 ha^{-1}) and it was least in natural farming (₹ 119500 ha^{-1}) (Fig. 3). The reduction in the cost of cultivation in natural farming to the extent of 23.72 per cent over RPP and 43.86 per cent over organic farming. It was mainly due to lower input costs in natural farming. The higher cost of cultivation in organic farming was mainly due to the high cost involved in supplementation of nutrients through bulky organic manures (FYM, vermicompost and enriched press mud) equivalent to nitrogen (250 kg N ha^{-1}) requirement of sugarcane. Among the farming practices, RPP resulted in significantly higher gross returns (₹ 401529 ha^{-1}), net returns (₹ 244855 ha^{-1}) and B:C ratio (2.51) than organic and natural

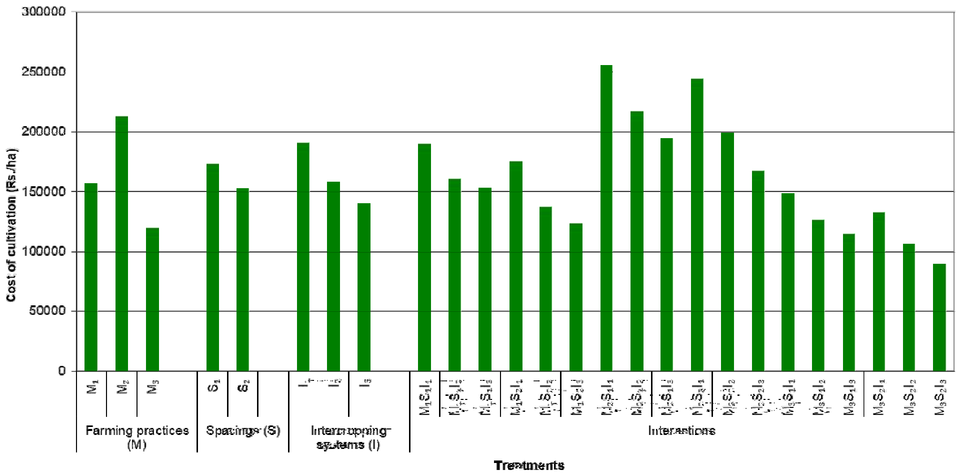

Fig. 3. Cost of cultivation of seasonal sugarcane based cropping systems as influenced by different farming practices, spacings and intecropping systems

Table 3. Economics of seasonal sugarcane based cropping systems as influenced by different farming practices, spacings and intecropping systems

Treatments		Economics of seasonal sugarcane											
		Gross returns (₹ ha^{-1})				Net returns (₹ ha^{-1})				B:C ratio			
		RPP	OF	NF	Mean S	RPP	OF	NF	Mean S	RPP	OF	NF	Mean S
S: Row spacings (cm)			M × S				M × S				M × S		
S_1: 60-180-60 cm × 60 cm		450403	390336	323326	388022	282491	168116	193547	214718	2.66	1.74	2.46	2.29
S_2: 240 cm × 60 cm		352655	304759	252715	303377	207219	101188	143495	150634	2.36	1.46	2.23	2.02
I: Intercropping systems			M × I		Mean I		M × I		Mean I		M × I		Mean I
I_1: Sc + O - T		536032	475244	393619	468299	353610	225611	253446	277556	2.94	1.90	2.81	2.55
I_2: Sc + O + Cp + Co + GC		377274	313356	274418	321683	228089	105211	158285	163862	2.53	1.50	2.36	2.13
I_3: Sole sugarcane		291279	254042	196025	247115	152866	73134	93832	106611	2.07	1.38	1.88	1.78
			M × S × I		S × I		M × S × I		S × I		M × S × I		S × I
S_1: PRP	I_1	567245	515659	416874	499926	377805	260420	268770	302331	2.99	2.02	2.81	2.61
	I_2	411275	333793	299408	348159	250140	116762	172956	179953	2.55	1.54	2.37	2.15
	I_3	372687	321556	253697	315980	219529	127165	138917	161870	2.43	1.65	2.21	2.10
S_2: WRP	I_1	504820	434830	370365	436671	329415	190802	238122	252780	2.88	1.78	2.80	2.49
	I_2	343274	292920	249429	295207	206039	93659	143615	147771	2.50	1.47	2.36	2.11
	I_3	209871	186529	138353	178251	86204	19102	48748	51351	1.70	1.11	1.54	1.45
M: Farming practices		401529	347548	288021		244855	134652	168521		2.51	1.60	2.35	

Source of variations	Gross returns C. D. (p=0.05)	Net returns C. D. (p=0.05)	B:C ratio C. D. (p=0.05)
M - Farming practices	11403	11403	0.05
S - Spacings	7421	7421	0.05
I - Intercropping systems	11435	11435	0.07
M × S	12853	12853	0.09
M × I	19248	19248	0.12
S × I	16172	16172	0.10
M × S × I	28011	28011	0.17

See Table 1 for details

farming practices (Table 3) and were mainly attributed to higher sugarcane equivalent yield. Tyagi *et al*. (2011), Shridevi *et al*. (2016) and Kuri and Chandrashekar (2015) also observed that RPP recorded maximum gross and net returns. The, PRP (60-180-60 cm × 60 cm) recorded significantly higher gross returns (₹ 388022 ha^{-1}), net returns (₹ 214718 ha^{-1}) and B:C ratio (2.29) than WRP (240 cm × 60 cm). The additional net returns with PRP to an extent of 42.54 per cent over WRP could be due to the higher yield under PRP (Table 3). Among the intercropping systems, significantly higher gross returns (₹ 468299 ha^{-1}), net returns (₹ 277556 ha^{-1}) and B:C ratio (2.25) were recorded with sugarcane + onion *fb* turmeric (I_1) as compared I_2 and I_3. This could be due to significantly higher sugarcane equivalent yield (170.3 t ha^{-1}) under intercropping of sugarcane + onion *fb* turmeric (I_1) than other intercropping systems. The extent of increase in SEY in I_1 over I_2 was 46.30 per cent and 89.43 per cent over sole sugarcane (I_3). It was attributed to the higher market price for onion and turmeric crops and the higher yield of sugarcane in these intercropping systems. The reduction in SEY in intercropping of sugarcane + onion + cowpea + coriander + green chilli (I_2) was mainly due to a lower yield of sugarcane and intercrops due to the smothering effect of cowpea. In the present investigation interaction of recommended package of practices with PRP of sugarcane + onion *fb* turmeric resulted in significantly higher gross returns (₹ 567245 ha^{-1}), net returns (₹ 377805 ha^{-1}) and B:C ratio (2.99) than other interactions (Table 3). It could be due to higher cane and intercrop yield and higher market prices for onion and turmeric crops.

CONCLUSIONS

Finally, it can be concluded that paired row planting of sugarcane + onion *fb* turmeric under RPP resulted in higher sugarcane equivalent yield, gross returns, net returns and B:C ratio. However, cost of cultivation of sugarcane can be reduced by adopting natural farming to the extent of 23.72 per cent over RPP and 43.86 per cent over organic farming. Natural farming with intercropping of sugarcane + onion *fb* turmeric under paired row planting resulted in higher sugarcane equivalent yield and net returns than sole sugarcane under recommended package of practices.

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Tradeoff Between the Coastal Wetland and Interlinked Ecosystem Services: A Case of Kazhuveli Coastal Wetland, India

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Abstract: Wetlands in India are an interconnected environment, complex, and a significant contributor to biodiversity and other living beings. Understanding the dynamics of spatial planning, preservation and conservation is becoming challenging for the authorities due to the overlap of their functions and services. Set against this backdrop, the present study was carried out to map the component-wise outputs of ecosystem services and their interlinkages of the Kazhuveli wetland, located near Puducherry using SWOT (Strength Weakness Opportunity Threat) Analysis and Causal Loop Diagram (CLD). The data was generated from 12 community-based focused group discussions and 10 key informant interviews among community groups living around the wetland. The results show that no synchronization occurs amongst the key service users (farmers, salt pan owners, fishermen, shrimp farm owners, and local communities), leading to an extra burden on the wetland. Furthermore, the primary stakeholders highlighted that the presence of shrimp farms leads to groundwater depletion and deterioration of surface water quality, resulting in depressed salt production, decreased fish production, and scaled-down agricultural practices.

Keywords: Coastal Wetland Ecosystem, SWOT analysis, Ecosystem Services, Causal Loop Diagram (CLD)

Coastal wetlands and their interlinked ecosystems like saltmarsh and mangroves that sustain biodiversity, fish production, sand dunes, and aquaculture activities are under tremendous pressure due to over-exploitation of resources and encroachment (Nordlund et al 2016, Carrasquilla-Henao and Juanes 2017, Sievers et al 2019, Silliman et al 2019). Due to anthropogenic pressure and impact of climate change, coastal wetland ecosystems are being lost or are undergoing depletion (Davidson 2014, Hamilton and Casey 2016). Hence, the biodiversity and the goods and services provided by them face a huge stress (IPBES Secretariat, 2019). Policy makers and the general public consider wetlands as “wasteland”, which leads to tremendous pressure on these wetlands (Rao et al 2019). Coastal wetlands continue to be one of the most threatened ecosystems, experiencing an annual physical loss of 0.7–1.2% (Davidson 2014), associated functions and services provided to local communities (Mulatu 2021). Wetlands provide livelihood support to local communities (Chuma et al 2012, Hardy et al 2013), alleviate poverty (Verma et al 2012), and provide stability for communities associated with them (Maund et al 2019). Globally, the aerial extent of the wetland ecosystem is estimated at 917 million hectares (Lehner and Doll 2004), generating an economic value of about US$15 trillion a year (MEA 2005), yet face threats (Zhou et al 2020). In recent decades, wetlands have undergone dramatic changes due to rapid urbanization, population explosion, dumping of solid and liquid wastes, encroachment, and degraded water quality, reducing their productivity, resulting in a reduction of water supply and quality, levels of soil nutrients, habitat fragmentation, vegetation and biodiversity loss, increased water pollution, and loss of provisioning services like medicinal plants (Saunders et al 2012), affecting livelihoods, and well-being of communities (Van Dam et al 2013, Morrison et al 2013). The urgency for immediate actions to prevent wetland degradation due to development and anthropogenic pressures with the active participation of communities and stakeholders needs no further elaboration (Gosling et al 2017). An enhanced understanding of the tradeoff between wetlands and other uses would aid policymakers and local authorities in making rational decisions that hinge on sustainability.

Ecosystem services provided by wetlands depend on the type of wetland, its association with different ecosystems, and the communities that depend on those services; hence, tradeoffs require customization of the content. The present study investigates the Kazhuveli wetland using strength, weakness, opportunities, and threats (SWOT) framework and applies the system thinking framework to generate information that could aid in narrowing down key issues and describing expressing them in generic terms (Kangas et al

2003) and help map ecosystem linkages, their interrelationships, and tradeoffs.

MATERIAL AND METHODS

Study location: The Kazhuveli Wetland is located in the eastern part of Villupuram district, Tamil Nadu, India, and lies between latitude 11.9576° N and 79.2902° E longitude. The wetland covers 13,200 hectares with a catchment area of 740 sq. km (Ramanujam 2005). Kazhuveli backwater is 12.5 km long and 370 meters broad. It is one of the most extensive brackish and semi-permanent wetlands in South India. Biophysically, the wetland consists of three parts: the Kazhuveli flood plain, Uppukali creek, and Yedayanthittu estuary. In 2021, the Government of Tamil Nadu (GoTN) declared Kazhuveli Wetland as Kazhuveli Bird Sanctuary under sub section (1) of section 18 of the Wild Life (Protection) Act, 1972 (Central Act 53 of 1972) (GoTN 2021). The wetland is considered a coastal wetland of international importance by the International Union for the Conservation of Nature and Natural Resources (IUCN). The wetland is hedged with naturally formed sand dunes that protect people from natural disasters like cyclones, storm surges, and tsunamis. This wetland offers multiple benefits to local communities in terms of grazing for livestock, timber for roof thatch, and fishing. Additionally, 18 revenue villages utilize direct benefits from the wetland, like grazing cattle, fishing, collecting reeds, fuelwood, minor forest produce and soil, paddy cultivation and aquaculture, and more than 150 villages benefit directly and indirectly from fishing, farming, pottery, shrimp farming, and salt farms (Fig. 1).

Methodology: The present study adopts a qualitative approach to comprehend the relationship between local communities and the Kazhuveli Wetland, in terms of livelihoods, linkage to different ecosystems and their services. Following an extensive literature review, field visits were made to the study area during November and December 2020. Communities living around the wetland pursue four types of livelihoods related to -shrimp farming, salt pan, fishing, and agriculture. A separate questionnaire was developed and deployed for each group of respondents. Shrimp farms are primarily located in the Kazhuveli flood plain and Uppukalli creek. During the initial field visit, a total of 10 villages were identified, four which were involved in shrimp farming, two in fishing and four in agriculture. Separate interviews were carried out with shrimp farm owners, workers, and technicians. In each village, four shrimp farmworkers, four owners, and two technicians were interviewed. Focused group discussions (FGDs) and interviews were conducted on-site, while shrimp farm culture operations were on. In the salt pans, two key informants, two salt pan owners, and one FGD was conducted among the women workers. An FGD was conducted in a fishing village adjoining the wetland, followed by an in-depth interview with an 80-year-old fisherman. With regard to agriculture, FGD were conducted in agricultural villages adjoining the wetland located within a radius of two kms. Care was taken to identify key informant interviews among farmers who had experience of more than 40 years to capture the present and past trends in agriculture. One mediator and reporter were deployed for carrying out the FGD, and the conversation recorded with prior permission from the respondents. All FGDs and key informant interviews (KIIs) reports were decoded, cleaned, and analyzed. Individual SWOT analysis results were produced for shrimp farm owners and workers, salt pan

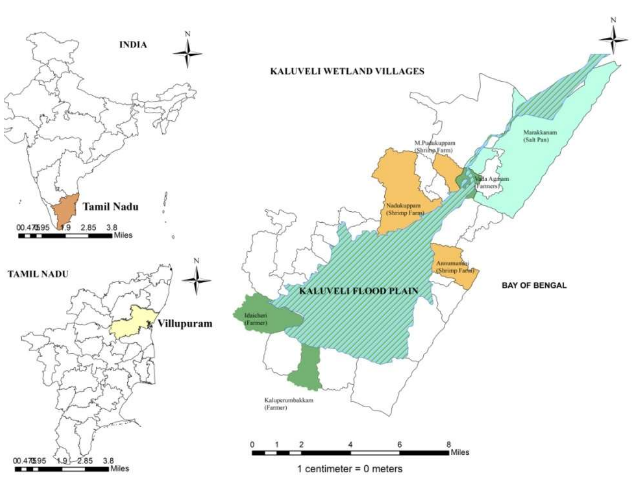

Fig. 1. Study location

Fig. 2. Process flow of the study

owners and workers, fishermen, farmers, and agricultural laborers, who contributed to the overall SWOT concerning the wetland and its tradeoff between different services and in the construction of a CLD capturing key variables.

Selection of respondents: A total of 18 villages were selected to assess the dependence of local communities on the Kazhuveli Wetland. Objectives for the qualitative exercises were formulated based on a review of literature and stakeholder mapping. Respondents for individual interviews were identified and selected randomly based on the initial explorative visits. Respondents for FGD were identified based on suggestions provided by researchers well-versed with the local wetland characteristics and livelihoods associated with them. Before engaging communities in FGD and qualitative exercises, a five-step strategy was adopted (Fig. 2). Stakeholders were invited to the FGD at their workplace and at a time convenient to them. In-depth interviews were conducted in villages by engaging respondents having more than 20 years of experience and those stakeholders contact details duly recorded for future clarifications and engagements.

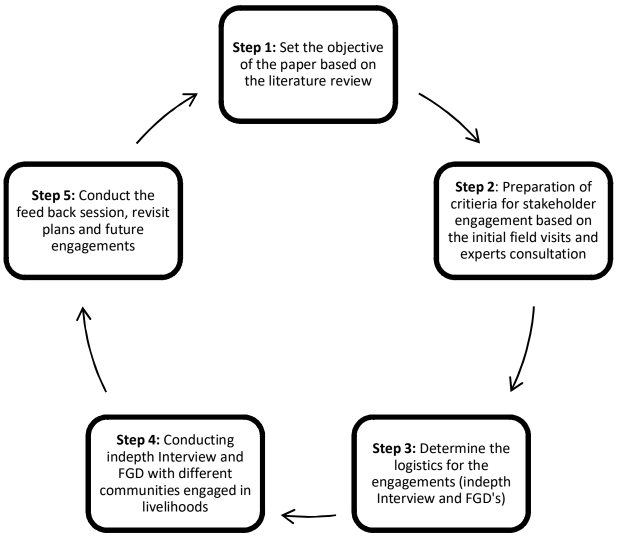

Fig. 3. Five-step strategy for community engagement for In-depth interview and FGD

Changes in Kazhuveli and associated ecosystem: In the recent decade, the Kazhuveli Wetland and associated ecosystems have undergone major changes due to anthropogenic activities. The range of activities that have impacted the wetland include encroachments, illegal poaching, construction of mega power industry, hydrocarbon extraction hotspot, construction of a harbor, over exploration of flora and fauna, transport of sediments and nutrients by surface drainage. Traditionally, the Kazhuveli Wetland is linked to a network of irrigation tanks that supplies surplus freshwater. Since the wetland is interrelated, there are different communities and villagers directly involved in utilizing the benefits from Kazhuveli Wetland.

RESULTS AND DISCUSSION

This section comprises two different sub-sections 1. Ecosystem tradeoff between Kazhuveli Wetland and

Table 1. Stakeholders in Kazhuveli wetland

Nature	Stakeholders	
	Primary	Secondary
National	Ministry of Environment, Forest, and Climate Change (MoEF&CC), National Wetland Authority.	National Biodiversity Authority (NBA)
State	State Wetland Authority (SWA)	Tamil Nadu Forest Department, State Biodiversity Board (SBB), Public Works Department (Water Resources).
District	Communities who directly utilize the services, namely, (i) Farmers (ii) Shrimp farmers (iii) Salt pan (iv) Fisherman (v) Potters etc. (vi) Associations (salt pan)	(I) District wetland authority (consists of all the department representation), (ii) Village panchayat heads, (iii) Village administrative officers, (iv) Non-governmental Organizations (NGO), (v) Research Institutes, (vi) Academicians
Definition of Key stakeholders covered in the present paper (Three FGD's were conducted in each category.		
Shrimp farmers	o Shrimp farm owners do business in aquaculture (marine or freshwater environment), producing shrimp or prawns for human consumption. o Shrimp farmworkers are those who work on daily or monthly wages in a shrimp farm.	
Salt Pan	o Salt pan owners own the salt pan or lease out land for the extraction of salt. o Salt pan workers are daily wagers	
Fishermen	o Fishermen, who harvest fish, prawns, and crabs from the Kazhuveli wetland	
Farmers	o Farmers involved in farming activities around the Kazhuveli wetland	

Source: Author's compilation based on discussion with Experts, 2020 associated wetlands using the CLD 2. Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis for shrimp farms, salt pan, fisheries and agriculture. The SWOT analysis and (CLD) are presented in Figure 2 and provide insights into the Kazhuveli Wetland, its associated ecosystems, and the interrelationships among the ecosystem services it provides for communities and highlight the complex tradeoffs in the light of its management as per the Wetland Conservation and Management Rules 2017. The District Wetland Conservation Committee is responsible for conservation, management, protection, and implementation of interventions in wetlands at the district level to ensure efficient and effective ecosystem services. The current work is likely to assist the district wetland authority by gaining an understanding of the current interrelationships and tradeoffs between the significant ecosystems and communities living around the Kazhuveli Wetland.

Causal loop diagram (CLD): The Kazhuveli Wetland consists of fresh water from the hinterlands and saltwater from the sea joining in Uppukalli creek. It plays a significant role in groundwater recharge, and is the primary source of groundwater recharge, an essential resource for irrigation and drinking water. The fact that nearly 60% of irrigation land in India primarily utilizes groundwater as source (Chindarkar et al 2019) needs to be taken into consideration. Farmers adjacent to the Kazhuveli are directly dependent on groundwater for irrigation for cultivation both during *Kharif* and *Rabi*. An increase in the number of borewell/tube wells leads to a reduction in the ground and surface water storage around the wetland (Figure 2 Agriculture loop B4), resulting in water scarcity. The affordability of modern irrigation systems by farmers is critical, and the pollution of surface water is a significant issue due to shrimp farms located in the northern part of the wetland. Water scarcity has forced farmers to seek alternative mechanism by changing cropping patterns, shift from water consuming crop to water-sensitive crops, restricting cultivation only for one of the two seasons (Agriculture loop B3). The shrimp farms in the Kazhuveli Wetland are categorized into two groups, licensed and non-licensed farms. License is provided by the Central Aquaculture Authority (CBA) based on the individual application by shrimp farmers. In the shrimp farm loop, the critical input is large quantities of surface and groundwater.

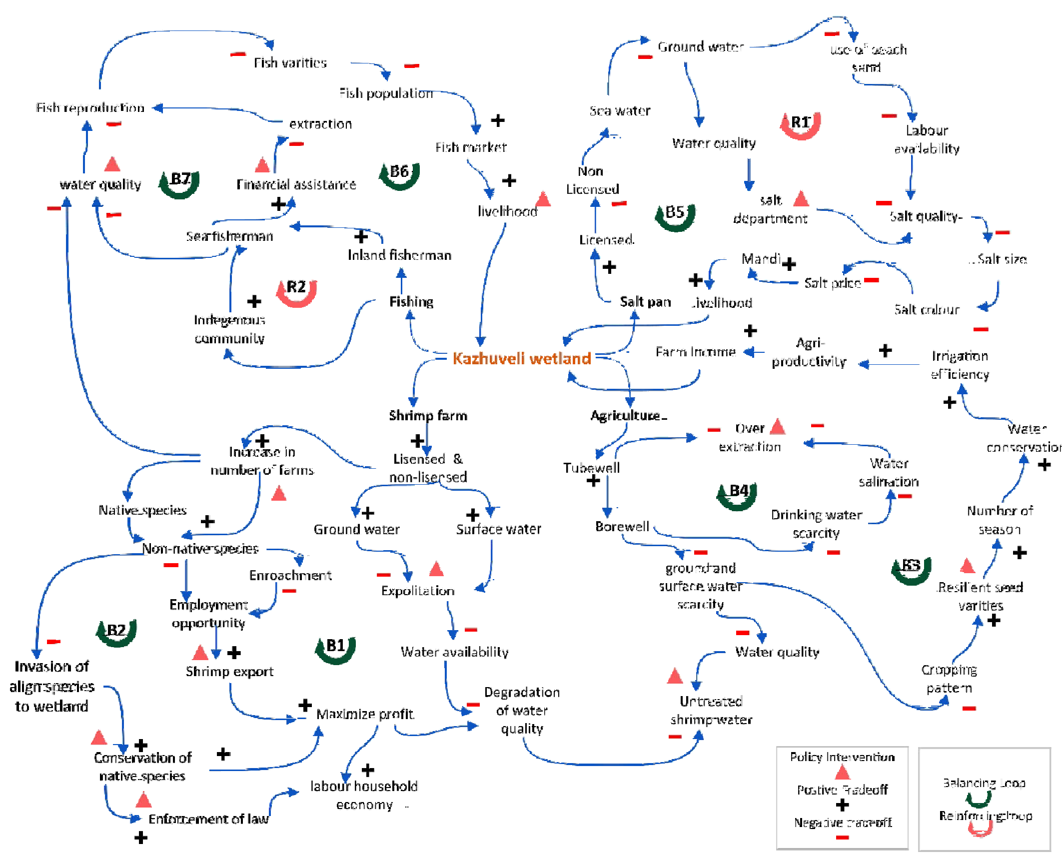

Fig. 4. Kazhuveli wetland and associated ecosystem services Causal Loop Diagram

Table 2. SWOT analysis results for Shrimp Farms in Kazhuveli

	Favorable	Unfavorable
Internal	Strength (S)	Weakness (W)
	• Pond culture and prior business experience • The vast area available near the coastal belt • Availability of groundwater as well as Kazhuveli water • Substantial business and employment opportunities for the local community • International export agencies collect the shrimp near the pond. • 80% of the ponds area is more than 1/2 acres (50 cents) • 90% of water extracted from the ground is reused for other cultures. • Shrimp farm farmers indicated that there is a strong desire to go back doing the shrimp culture business. • The wage for labor is high and less stressful compared to other work.	• Deficient business, whereas Operational capital, is more. • Less educated and lack of proper technical training • Access to aid from agencies like National Aquaculture Regulatory Authority or GoI. • Repeated business failures have made the farmers of Kazhuveli wetland abstain from the intensive shrimp seed stocking. • 80% of the farmers have completed their elementary education. • Culture facilities, such as a pond, dyke, water inlet, guardhouse, and others, were found to be well maintained. • Seasonal employment opportunity
	Opportunities (O)	Threats (T)
External	• Continuous market demand for shrimps • Shrimp price is relatively stable and tends to be better. • Transportation facilities are getting better. • Decreased cultured shrimp production at the regional level and closure of 3300 shrimp farm units in the Kazhuveli area.	• Environmental carrying capacity gets degraded due to high mining activities around the Kazhuveli wetland. • The procurement program of cultivation production facilities from the government is minimal. • Low availability of shrimp seeds • Increasing environmental pressures because of a decrease in plantation activity and other economic activity • Rapid economic activities in the area have reduced the mangrove area and water catchment, resulting in diminished aquatic environmental quality for aquaculture. • No government procurement system. • Low migration rate increases due to the closure of shrimp farms.

Preparation of field before for the year 2020

Preparation of field and canal connects to Kaluveli wetland for the year 2020

Storage of salt after the cultivation in 2020

Salt cultivation in the field ready to be shifted for storage

Before the forest department handled Kazhuveli Wetland, shrimp farmers were letting out untreated water into Kazhuveli, which eventually causing eutrophication and water pollution. Most of the unlicensed shrimp farmers have encroached on the government land (*Poramboke* land) (Figure 2: shrimp farm loop (B1)). Since the year 2017, due to the severe conservative measures of the forest department, the licensed shrimps are located around the Kazhuveli wetland is permitted to do culture but the non-licensed holders are forced to close the culture in between the culture. The shrimps were directly exported to China, Japan, and other countries. Most of the shrimp farmers use exotic species. Hence, the district forest officials have taken preventive measures to safeguard the native species by enforcing preventive measures among shrimp farmers adjacent to Kazhuveli (Figure 2 Shrimp Farm Loop (B2)).

Table 3. SWOT analysis for Salt Pan

	Favorable	Unfavorable
Internal	Strength (S)	Weakness (W)
	• One of the largest producers of salt in south India • Natural cultivated salt • Leased in land for salt cultivation. • Excessive labor availability • The salt production process is different from other sites in Tamil Nadu (Vedaranyam, Thoothukudi). • Traders collect the salt from the field itself.	• The leased land is a weakness for the cultivators as it may be taken back at any time by the owner with no prior notification. • There is no legal document for lease. It is only based on goodwill. • Lack of operation cost critical for salt cultivation. • Changing climatic variabilities.
	Opportunities (O)	Threats (T)
External	• Salt cooperative society fixes the cost of the salt bag (*Barthi*) • A merchant from Andhra Pradesh, Odisha, Karnataka used to come and purchase the salt.	• The quality of water from Kazhuveli getting worse after expansion of shrimp farming. • Unusual rain during the off-season. • District administration has banned collection of soft sand from dunes located near the sea for field preparation. • The majority of the people are moving away from this livelihood. • The rate of return is based on the climate, labor availability, price-fixing by the market. • If the check dam and the fishing harbor are built, this will lead to the non-availability of quality salt.

Table 4. SWOT analysis for fishermen

	SWOT Analysis for fisherman	
	Favorable	Unfavorable
Internal	Strength (S)	Weakness (W)
	• Availability of brackish water swamp and estuary fish • Competition is less for fishing. • Day to day income • Own boat use gives less stress to fisherman. • Family members are also involved in fishing. • Nearly 270 households are involved in the fishing activities either in Kaluveli and Yedayanthittu estuary. • The fish catch happens between 4 to 6 km in the Kaluveli wetland.	• Small size fishes exist. • Fish catch reduced in recent years due to the degradation of water quality. • Access to the fish market is less since it is wetland fish, crab, and prawn. • Mangrove patches also not developing much faster, and is not helping fish reproduction. • Due to forest department restrictions, fishers cannot go beyond the Vada Agaram village (in the Kazhuveli flood plain).
	Opportunities (O)	Threats (T)
External	• Since the family members (son) are part of fishing, they can also take forward fishing in the future. • Women used to sell fish in villages around the Kazhuveli wetland. • Youth has done advanced fish breeding in Uppukalli creek to increase the fish stock. • Apart from the fisherman, the people from other villages also catch the fish for their self-consumption in different parts of the Kazhuveli wetland.	• Increased shrimp farms reduce the water quality and fish stock in the Edaiyanthittu estuary and Uppukali creek. • There is a threat to fish stock if harbor construction is completed due to the inflow of big fiber boats from neighboring fisherman villages. • There is a threat to direct impact on livelihood activities due to development activities. • There is a conflict of interest between Kanthadu village and fisherman villages for fishing in the Kazhuveli wetland. • Invasion of alien fish variety, crab, and prawn can mix in the Kazhuveli wetland due to the unprotected shrimp/ fish culture. • Crab farming people ~~sell~~ market crab, reducing the importance of purchasing crab from fisherman.

Table 5. SWOT analysis for Agriculture

	SWOT Analysis for farmers	
	Favorable	Unfavorable
Internal	Strength (S)	Weakness (W)
	• Availability of both surface and groundwater. • Traditional system tanks are located in the upper reaches of the wetland that recharges the groundwater. • The fertility of agricultural land is high. • The availability of seeds is sufficient for farmers. • The availability of agriculture labor is sufficient. • Limited bore well availability in the farm located near a wetland.	• Surface contamination is more due to shrimp farms. • The migration of youth is more from the wetland area. • Cultivation only during *Kharif* season. • Farmers living in the adjacent villages are migrating to Puducherry/ Chennai as daily wage laborers. • The availability of subsidies for the farmers is minimal. • Farmers are primarily practicing mono-cropping method.
	Opportunities (O)	Threats (T)
External	• The possibility of rainwater penetration into the ground is high due to a check dam in the Kazhuveli Wetland area.	• Due to the high migration of youth, shift in farming to non-farm occupation. • Due to the construction of a check dam, waterlogging has intensified in agricultural land. • Due to the increase in the use of fertilizers, the eutrophication at Kazhuveli Wetland water would be more disturbing to the wetland species.

Salt production is an important and crucial livelihood activity for salt farmers located in Marakannam revenue village. Nearly 80% of the salt farmers use land leased from the landowners residing in Marakkanam town. This salt production in Marakkanam is a traditional method of brine evaporation (water with a high concentration of water) filled in the salt pans (Cherian et al 2019). Farmers use freshwater from Kazhuveli and groundwater and seawater from the Yedayanthittu estuary, respectively. Based on the qualitative interview, due to the poor quality of surface water, the color of the salt changes to a light shade. Hence, the per kilogram rate for the salt decreases in the market (Figure 1 Salt pan Loop (B5). One of the critical inputs to reduce the cost of labor was the use of coastal sand available at the Marakkanam dunes, which helps the laborers complete the salt pan preparatory work in 5-8 days. Recently, the Villupuram district administration has restricted sand excavation from the dunes and beaches that have high silica, gypsum, sodium sulfate, and carbonate content that are present around Kazhuveli Wetland (District Survey Report of Silica Sand 2019). Hence, salt farmers require more days to work on the preparation of the salt pan. Recently, farmers used ordinary sand from other places for land preparation, eventually increasing the number of workdays of laborers and sand. Once the salt is cultivated, the *mandi* located in Marakannam town, fix the price per *barthi* (140 kgs of the salt bag). The price of the salt depends on the color and size of the crystals during the year/ season. The *mandi* facilitates by providing human resources to the salt farmers to pack salt in *barthi* and fetch salt from the pan (Figure 2 shrimp farm loop R1). Based on the field visits and discussion, nearly 200 fishing households were engaged in fishing activities in the Kazhuveli Wetland every day, and they substantially depend on it for their livelihood. Fishermen are divided into inland and sea fishermen (Figure 2 Fishing Loop R2). Inland fishers limit their activities to Kazhuveli Wetland due to the impact of the eutrophication from the shrimp farm, water quality has deteriorated significantly over the years. Several fish varieties have become endangered in Kazhuveli compared to 10 years ago. Ecosystem around the Kazhuveli Wetland is under severe threat due to multiple disturbances, and hence, the livelihoods of numerous communities (farmer, fisherman, shrimp farm, and salt pan) depending on these ecosystems are at risk (Figure 2 Farm Income Loop).

SWOT for shrimp farms: Based on the multiple interactions with different levels of stakeholders, the SWOT analysis was performed among the major activities around the Kazhuveli Wetland which are shrimp farm, salt pans, fishing, and agriculture. The SWOT analysis for shrimp farms in Kazhuveli is presented in Table 2.

SWOT for salt pan: The salt pans in Marakannam are an important livelihood opportunity for the communities located nearly eight villages (Marakkanam Town, Karipalayam, Konamkuppam, Thazankadu, Narvakkam, Kaipanikuppam, Pallampakam and Kolathur) adjacent to the salt pans. These people are either workers or are leased for the salt pans. The detailed SWOT analysis is presented in Table 3 the pictures of the salt pans during the field survey are presented below.

CONCLUSION

The current study investigates the tradeoff between the wetland ecosystem services and communities living in the vicinity of the Kazhuveli Wetland. Recently, environmental awareness among the communities has increased because of the decline in livelihood opportunities. Based on the rigorous qualitative exercise, we found that community engagement plays a significant role in conservation. Communities engaged in livelihood activities predominantly use ground and surface water as critical raw material for their actions. The preservation of such resources and their efficient use would help them sustain their livelihood activities. The intervention by the Tamil Nadu Forest Department in restricting shrimp farms can help further in the restoration of other ecosystems. During the initial stage of the field visit, availability of primary data about the villagers and communities dependent on the nationally important wetland was deficient. Hence, the preparation of village-level data for those directly depending on the wetland and its associated ecosystem is critical. Such information would help policymakers and wetland managers understand problems in-depth and frame an effective implementation mechanism at the district level. Finally, government intervention towards the conservation of Kazhuveli Wetland should be aimed at improving groundwater and treating surface water to enable local communities sustain their livelihoods. Further, the involvement of stakeholders and identification of their preference on the conservation of Kazhuveli Wetland plays a critical role for the district administration for planning for the sustainable use of resources of the wetland.

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Resource Use Efficiency Optimization of Major Farming Systems in Hills of Himachal Pradesh

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Abstract: Using primary data of 240 farmers, this study examines the resource use efficiency of predominant farming systems in the hills of Himachal Pradesh and optimizes the existing resource use using linear programming technique. Six predominant farming systems were identified in the study area and dairy was an important component in each farming system which indicates the importance of livestock in the study area. The study reveals the under-utilization of inputs in all farming systems. The optimization results indicate that there is a substantial scope for increasing per farm net income through an optimal use of the existing resources. The increase in the availability of binding resources can enhance the per farm net income of the farmers indicating the need to make scarce resources available to the hill farmers for increasing their income and improving livelihood security.

Keywords: Agriculture, Farming system, Linear programming, Optimization, Optimal resource use

United Nations estimated that world population would increase from 7.7 billion in 2019 to more than 9.5 billion by 2050 and 10.9 billion in 2100 (UN 2019). So, to improve the world food security and meet out the increasing food demand, food production needs to rise by 50 per cent up to the year 2030 (UN 2008) and 70 per cent up to the year 2050 (FAO 2009, King et al 2017). Indian population is also expected to reach 1.6 billion by the year 2050 (Lehane 2014) and country would require about 349 million tonnes of food grains, 342.2 million tonnes of vegetables, and 305.3 million tonnes of fruits by 2050 (Singh 2019). However, the average size of land holdings in the country is very small and has declined to 1.08 ha in 2015-16 from 2.28 ha in 1970-71 (Agriculture Census 2015-16). If this trend continues, the average size of holding in India would further get reduced to 0.32 ha in 2030 (Khan et al 2015) and would be increasingly difficult to produce enough food for meeting the requirements of the growing population. Hence, the emphasis must be on increasing productivity levels besides diversification towards high-value crops (Economic Survey of India 2020-21). Since there is no further scope for horizontal expansion of land for cultivation of farm enterprises, the emphasis should be on vertical expansion by using the available resources optimally, increasing the yield per unit area, and choosing the best enterprise mix for improving the income level of the farmers (Sharma et al 2015, Kumar et al 2018a, Rao et al 2019). The farmers need to be assured of regular income for living at least above the poverty line because unless farmers' income increases significantly, distress cannot be tackled (Chand 2016). In this context, the farming system approach is one of the important solutions to achieve better growth in agriculture, ensuring food security, nutritional security, reduction in global poverty, improvement in living standards, and overall sustainable development of the society (National Commission on Farmers 2006). It is a holistic approach that boosts crop productivity, profitability and can meet the future demand for food without impairing the environmental and ecological balance (Sarvankumar et al 2020). Kumar et al (2022) revealed that providing short term trainings and field demonstrations related to different farming systems along with input subsidies to the farmers could enhance their income and standard of living. In this context, estimated the resource use efficiency of predominant farming systems practiced by the farmers in the hills of Himachal Pradesh which is one of the most progressive and popular hilly States of India. In present study, also optimized the existing resource use to work out the maximum attainable net returns to farmers from existing farming systems.

MATERIAL AND METHODS

This study makes use of primary data collected during the agricultural year 2018-19 using stratified multistage random sampling technique. The entire State of Himachal Pradesh has been divided into four agro-climatic zones whose elevation ranges from less than 650 to more than 2200 m amsl (GoHP 2013). The study area was stratified into four strata as per these four agro-climatic zones of the state. Thereafter, one district with maximum cultivated area from each stratum, namely, Una district from Zone-I, Mandi district from Zone-II, Shimla district from Zone-III, and Kinnaur district from Zone-IV was selected. At the next stage, two blocks based on maximum cultivated area were selected from each selected district. Further, 3 gram panchayats from each block and 10 farmers from each gram panchayat were randomly selected. Thus, data were collected from 60 farmers from each district i.e., a total of 240 farmers using well designed pre-tested schedule.

Resource use efficiency: Cobb-Douglas production function was used to analyze the resource productivities of different farming systems in the study area.

$$Y = b_0 X_1^{b1} X_2^{b2} X_3^{b3} X_4^{b4} X_5^{b5} X_6^{b6} X_7^{b7} u_i$$

Where, Y is gross farm income (Rs./farm), b_0 is the intercept, X_1 is the expenditure on human labour (Rs./farm), X_2 is the expenditure on machine labour (Rs/farm), X_3 is the expenditure on seeds/ planting material (Rs/farm), X_4 is the expenditure on manure & fertilizers (Rs /farm), X_5 is the expenditure on plant protection chemicals (Rs/farm), X_6 is the expenditure on feed and fodder (Rs /farm), b_is are the regression coefficients (production elasticity) with i= 1,2,……,6 and u_i is the random term. Other researchers also use similar methodologies to assess the resource use efficiency (Mesike et al 2009, Kumar et al 2018b, Kumar et al 2018c, Singh et al 2018, Sharma and Kumar 2019).

Returns to scale: The response on output (gross farm income) due to a proportionate change in inputs was estimated directly by the summation of regression coefficients (b_i). If the value of summation of 'b_i' is greater, equal, and less than unity, then there are increasing, constant and diminishing returns to scale, respectively (Gujarati et al 2012). The returns to scale were statistically tested using F-test (Rauf 2009).

$$F = \frac{\Sigma(b_i - 1)^2}{\frac{\text{Var } \Sigma b_i}{N-k}} \sim F(k-1),(N-k)df$$

Where, N is the number of sample observations, k is the total number of parameters estimated and Σb_i is the summation of elasticity coefficients.

Optimization of farming systems: Farming is a business activity in which the farm enterprises/components bear a complementary relationship with one another. In the present study, the optimum enterprises' combination of various crops and livestock under existing farming situations was estimated using the deterministic linear programming technique, developed by George B. Dantzig in 1947 (Dantzig and Thapa 1997). The present model bears a close resemblance to one used by Majeke and Majeke (2010), Mohamad and Said (2011), Andreea and Adrian (2012) and Patel et al (2015) for determining the optimal farm resources allocation and maximizing the total returns on the farm. The specification of the model is

$$\text{Maximize } Z = \sum_{j=1}^{n} C_j X_j$$

Subject to

$$\sum_{j=1}^{n} a_{ij} X_j \le b_i \qquad \text{(Resource constraints)} \qquad (i = 1\text{………} m)$$

$X_j \ge 0$ (Non-negativity restriction) (j = 1……… n)

Where, Z is net returns from all crop and allied activities included in the model (Rs.), X_j is the level of the j^{th} activity in the model, C_j is the net returns per unit of j^{th} activity (Rs.), b_i is the total availability of i^{th} resource on the farm, a_{ij} is the total quantity/amount of i^{th} resource required per unit of j^{th} activity and n is the number of activities considered in the model. We maximized the annual net returns to owned resources subjected to various resource constraints, land, family labour, hired labour, farmyard manure (FYM), fertilizer requirements and working capital. Firstly, the optimization was done by fixing the availability of these resources equal to their existing use; and then by increasing the use of binding (scarce) resources by 20 per cent, except family labour. The binding resources are those which are fully consumed in a production process. In study fixed the on-farm requirement of farmers as, at least one standard animal unit (SAU) and 0.1 hectares of land under crops cultivation.

RESULTS AND DISCUSSION

The predominant farming systems were identified based on the number of farmers doing similar farming activities (Noorain 2010). The various components of farming systems included crops (cereals, pulses, and fodder crops), vegetables, fruits and dairy. Overall, six major farming systems were identified in the study area (Table 1), Crops + Vegetables + Fruits + Dairy (45% of the farmers), Crops + Fruits + Dairy (20%), Crops + Vegetables + Dairy (15%), Vegetables + Fruits + Dairy (10%), Crops + Dairy (8%) and Fruits + Dairy (2%), respectively. All farming systems have a dairy component which indicates the importance of livestock in the study area. In all the districts, the farmers practice Crops + Vegetables + Fruits + Dairy (C+V+F+D) and Crops + Fruits + Dairy (C+F+D) farming systems, although, C+V+F+D is predominant in Una (40%), Mandi (53%) and Shimla (45%) districts, and C+F+D is predominant in Kinnaur district. Vegetables + Fruits + Dairy (V+F+D) and Fruits + Dairy (F+D) farming systems were practiced by the farmers of Shimla (40%) and Kinnaur (8%) districts only.

Resource use efficiency of existing farming systems: The resource use efficiency was estimated by the Cobb-Douglas production function analysis at the overall level (Table 2) except for the F+D farming system, the reason being a few observations in this system. The significant F-value under all the farming systems indicates the better fit of the model. The model showed the positive and significant impact of human labour in C+V+F+D and C+V+D farming systems, manure and fertilizers in C+V+F+D, C+F+D and C+D farming systems, plant protection chemicals in V+F+D farming systems and feed and fodder in all the farming systems, indicating the sub-optimal use of these inputs, meaning that additional use of these inputs would increase the gross returns in the respective farming system. The overall significance suggests the need for additional application of labour, fertilizer management, judicial use of plant protection chemicals and additional feed and fodder to achieve higher gross returns. Mutoko et al (2013), Kumar et al (2018b) and Singh et al (2018) have also reported that farm revenue increases with additional application of fertilizers and labour use. The returns to scale in C+V+F+D (1.05), C+F+D (1.13) and C+D (1.15) farming systems indicate the need for increasing the input use in these farming systems to get more output, while in case of C+V+D (0.98) and V+F+D (0.88) farming systems, the farmers will lose efficiency if they increase the scale of production. These results are in correspondence with the findings of Mesike et al (2009) and Kasiime et al (2018).

Table 1. Existing farming systems in the study area

Farming systems	Proportion of farmers				
	Una (Zone-I)	Mandi (Zone-II)	Shimla (Zone-III)	Kinnaur (Zone-IV)	Overall
C+V+F+D	40 (24)	53 (32)	45 (27)	40 (24)	45 (108)
C+F+D	18 (11)	3 (2)	7 (4)	52 (31)	20 (48)
C+V+D	18 (11)	35 (21)	8 (5)	-	15 (36)
V+F+D	-	-	40 (24)	-	10 (24)
C+D	24 (14)	9 (5)	-	-	8 (19)
F+D	-	-	-	8 (5)	2 (5)
Total	100 (60)	100 (60)	100 (60)	100 (60)	100 (240)

C= Crops (Cereals, Pulses &Fodder crops), V= Vegetables, F= Fruits, D= Dairy
Figures in parentheses are the number of farmers practicing respective farming system

Table 2. Production function estimates for different farming systems in the study area

Independent variables	Regression coefficients				
	FS-I (C+V+F+D)	FS-II (C+F+D)	FS-III (C+V+D)	FS-IV (V+F+D)	FS-V (C+D)
Constant	0.747** (4.333)	0.363 (1.050)	0.839* (2.611)	4.308** (3.118)	0.367 (0.207)
Human labour	0.265** (5.075)	0.215 (1.939)	0.305* (2.358)	0.049 (0.132)	-0.075 (-0.160)
Machine labour	0.001 (0.264)	0.007 (0.782)	0.020 (1.734)	0.015 (1.027)	0.028 (0.898)
Seeds/ Planting material	0.039 (1.965)	0.016 (0.732)	0.104 (1.607)	-0.023 (-0.282)	0.013 (0.037)
Manure and fertilizers	0.396** (7.650)	0.348** (4..753)	-0.109 (-1.038)	-0.579 (-1.780)	0.488* (2.380)
Plant protection chemicals	0.013 (0.812)	0.020 (0.760)	0.113 (1.568)	0.782* (2.629)	-0.047 (-0.307)
Feed and fodder	0.337** (8.920)	0.519** (6.440)	0.551** (6.402)	0.636* (2.125)	0.739* (2.251)
Adjusted R^2	0.96	0.92	0.74	0.70	0.68
F-value	385.41**	91.92**	18.19**	9.95**	7.32**
Returns to scale	1.05**	1.13**	0.98**	0.88**	1.15**

Figures in the parentheses are t-values of respective variables
*, ** represent significance at 5% and 1% level of significance, respectively

Optimization of existing farming systems: The farmers in hilly regions of the country possess very limited resources particularly land, labour and capital. Therefore, the existing resource use under predominant farming systems have been optimized to maximize net farm income of the farmers (Table 3 to 7).

Optimization of Crops + Vegetables + Fruits + Dairy (C+V+F+D) farming system: The higher area allocation under vegetables (1.14 ha) followed by fruits (0.32 ha) and crops (0.10 ha), and rearing of 1.88 standard animal dairy units, would not only increase the farm income by 16.29 per cent compared to existing farm plan (Rs. 1,02,149), but also, decrease the use of hired labour, fertilizers and working capital by 56.12, 39.86 and 19.87 per cent, respectively (Table 3). There is scarcity of farmyard manure in the study area as it was fully used under the optimum farm plan. Therefore, if the availability of this scarce resource is increased by 20 per cent, then not only the farmers' income would increase by 30.17 per cent but the use of hired labour, fertilizers and working capital would also reduce compared to the existing farm plan.

Optimization of Crops + Fruits + Dairy (C+F+D) farming system: The farmers receive per farm annual net income of Rs. 88,137 under exiting C+F+D farming system (Table 4). If the existing resource use is optimized, the farmers would receive an increase of Rs. 687 by allocating more area under fruits (0.60 ha) as compared to area under crops (0.10 ha) and rearing 3.73 standard animal units, simultaneously. There would be reduction in the use of family labour from 284.84 to 265.92 man days, farmyard manure from 126.05 to 121.38 quintal and fertilizer from Rs.5863 to Rs. 5682. The results show the scarcity of hired labour and working capital in C+F+D farming system. The increased availability of these resources has the potential to increase the farmers' income by 5.79 per cent compared to income under the existing plan by allocating 0.75 hectare area under fruits, 0.10 hectare area under crops and rearing of 3.72 standard animal units on a farm.

Table 3. Optimum farm plan for C+V+F+D farming system in the study area

Particulars		Existing farm plan	Optimum farm plans with	
			Existing resource use	20% Increased resource use
Area (ha)	Crops	0.82	0.10	0.10
	Vegetables	0.13	1.14	0.80
	Fruits	0.61	0.32	0.66
Dairy (SAU)		3.42	1.88	2.24
Family labour (MD)		339.18	339.18	339.18
Hired labour (MD)		107.81	47.13	87.47
Farmyard manure (Qtl)		143.88	143.88	172.66
Fertilizers (Rs)		7325	4405	6922
Working capital (Rs)		99508	79735	85686
Income (Rs)		102149	118791	132967

Table 4. Optimum farm plan for C+F+D farming system in the study area

Particulars		Existing farm plan	Optimum farm plans with	
			Existing resource use	20% Increased resource use
Area (ha)	Crops	0.29	0.10	0.10
	Fruits	0.58	0.60	0.75
Dairy (SAU)		3.66	3.73	3.72
Family labour (MD)		284.84	265.92	284.84
Hired labour (MD)		75.06	75.06	78.44
Farmyard manure (Qtl)		126.05	121.38	125.24
Fertilizers (Rs)		5863	5682	5863
Working capital (Rs)		94104	94104	101776
Income (Rs)		88137	88824	93237

Optimization of Crops + Vegetables + Dairy (C+V+D) farming system: The optimization of existing resource use in C+V+D farming system (Table 5) results in an increase of Rs 11,056 in per farm net income (Rs 41546) compared to existing farm plan (Rs 30,490). Also, there is reduction in the use of family labour, hired labour and expenditure on fertilizer after allocating more area under vegetables (0.33 ha) compared to crops (0.10). There is scarcity of farmyard manure and working capital in C+V+D farming system and increased in availability of these resources has a potential to not only increase the per farm annual net income by 57.64 per cent but also reduce the use of hired labour and fertilizers as compared to the existing farm plan. This would require an allocation of 0.40 hectare under vegetables, 0.10 hectare area under crops and rearing of 3.15 standard animal units on a farm, simultaneously.

Optimization of Vegetables + Fruits + Dairy (V+F+D) farming system: Optimization of V+F+D farming system reveals that all the available resources are optimally used by the farmers as income in existing farm plan and optimum farm plan under existing resource use is same (Rs 8,491) (Table 6). All the resources are scarce under this system and increase in their availability would increase the farmers' income by 6 per cent after allocating more area under fruits (0.48 ha) as compared to vegetables (0.17 ha) and rearing 3.56 standard animal units on a farm, simultaneously.

Optimization of Crops + Dairy (C+D) farming system: The farmers under C+D farming system were also using the available resources optimally (Table 7). The optimization under increased resource availability indicates an increase of 10.44 per cent in per farm net income and less use of hired labour, farmyard manure and expenditure on fertilizers as compared to the existing farm plan. The results related to optimization of farming systems revealed that reallocation of available resources not only increased the income of the farmers but also reduced the use of some of the inputs. These results are consistent with the results of Noorain (2010), Kumar et al (2018a) and Nientao et al (2019).

Table 5. Optimum farm plan for C+V+D farming system in the study area

Particulars		Existing farm plan	Optimum farm plans with	
			Existing resource use	20% Increased resource use
Area (ha)	Crops	0.60	0.10	0.10
	Vegetables	0.09	0.33	0.40
Dairy (SAU)		3.20	2.99	3.15
Family labour (MD)		275.39	250.44	275.39
Hired labour (MD)		9.89	1.65	1.65
Farmyard manure (Qtl)		38.18	38.18	45.82
Fertilizers (Rs)		1350	310	330
Working capital (Rs)		80050	80050	86844
Income (Rs)		30490	41546	48064

Table 6. Optimum farm plan for V+F+D farming system in the study area

Particulars		Existing farm plan	Optimum farm plans with	
			Existing resource use	20% Increased resource use
Area (ha)	Vegetables	0.26	0.26	0.17
	Fruits	0.39	0.39	0.48
Dairy (SAU)		3.57	3.57	3.56
Family labour (MD)		289.41	289.41	289.41
Hired labour (MD)		40.42	40.42	47.94
Farmyard manure (Qtl)		95.38	95.38	110.48
Fertilizers (Rs)		4239	4239	5086
Working capital (Rs)		90050	90050	90465
Income (Rs)		85491	85491	90621

Table 7. Optimum farm plan for C+D farming system in the study area

Particulars	Existing farm plan	Optimum farm plans with	
		Existing resource use	20% Increased resource use
Area (ha)/ Crops	0.40	0.40	0.10
Dairy (SAU)	3.34	3.34	4.11
Family labour (MD)	258.34	258.34	258.34
Hired labour (MD)	2.11	2.11	0.53
Farmyard manure (Qtl)	23.00	23.00	5.75
Fertilizers (Rs)	971	971	243
Working capital (Rs)	79757	79757	93165
Income (Rs)	29121	29121	32162

CONCLUSIONS

Due to wide range of agro-climatic conditions, the farmers living in the hills of Himachal Pradesh practice six predominant farming systems for their food and nutritional security, namely, Crops + Vegetables + Fruits + Dairy (C+V+F+D), Crops + Fruits + Dairy (C+F+D), Crops + Vegetables + Dairy (C+V+D), Vegetables + Fruits + Dairy (V+F+D), Crops + Dairy (C+D) and Fruits + Dairy (F+D). The study indicates the under-utilization of inputs under all farming systems, meaning that opportunities still exists to increase the gross farm income by additional use of these inputs. The optimum farm plans developed for different systems reveal the possibilities to increase farm profitability by utilizing available resources optimally and following optimum-mix of different farm components. The farmers would get higher returns if they allocate more area under fruits and vegetables as compared to crops. Although, dairy is an important component of all farming systems, but there is resource scarcity of farmyard manure in the study area. Therefore, in addition to the State government's innovative schemes to provide subsidy for the purchase of '*desi*' cows, the government needs to extensively promote the use of vermiculture, forest leaf litter, farm waste, bio fertilizers and green manure in the fields which would help to improve the soil fertility and land productivity. The study clearly reveals the possibility of increasing the farm income if the availability of scarce resources is increased under all the existing farming systems. Further, the capital deficiency in the study area indicates the need to provide more capital to the hill farmers, so that they can increase the input use on their farms for generating more income and improving their living standards.

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Ergonomic Evaluation of Spading Machine for Tillage Operation Chandrashekar and Bini Sam

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Abstract: Spading is an important field operation, and a spading machine has been developed based on the principle of a four-bar mechanism. The ergonomic evaluation of the spading machine was conducted using physiological measurement techniques to assess the heart rate, oxygen consumption, and energy expenditure of the subjects. The average heart rate of the subjects during spading operation was 127 beats per minute. The estimated oxygen consumption rate was 0.798 litters per minute, which is 38% of the subject's aerobic capacity (VO_2 max). This value above the acceptable limit of 35% of VO_2 max, indicating that the subjects are working at a high level of exertion. The spading machine has field capacity of 0.096 hectares per hour and a field efficiency of 80% at a forward speed of 2 km/h.

Keywords: Heart rate, Oxygen consumption, Field capacity, Work load, Discomfort

The exterior triangle of efficiency, comfort, and health is commonly referred to as ergonomics. Ergonomic research encompasses all areas of anthropometry, workload assessment, working environment, safety features, and methods for optimizing the human-machine environment system. By adapting to the skills and limitations of human operators, this helps to increase working productivity while reducing drudgery. Ergonomics research improves worker efficiency, productivity, and safety while also reducing tiredness. Any machine's performance, particularly those are controlled by manually can be significantly enhanced if ergonomic considerations are considered. The evaluation of the energy consumption of the power tiller powered spading machine is vital from a safety standpoint because when a person's physical capacity is surpassed, it is sure to create significant weariness and a significant drop in attentiveness, making the operation dangerous. As a result, research into the ergonomics of a power tiller-operated spading machine can give a reasonable basis for technique recommendations and improvements in equipment design for increased production and safety (Sam 2014).

MATERIAL AND METHODS

Selection of subjects: In order to perform ergonomic research, it is critical to choose the right subjects. To engage in the studies, the subject must be medically fit. They should also be a true representation of the user community using the chosen implementations. The subjects must not be pregnant, breastfeeding, or disabled. Subjects were chosen based on the age, anthropometric data and medical fitness. Three males between the ages of 25 and 35 will be selected for the study, with anthropometric measurements that meet statistical standards. In the lab, all the subjects were calibrated to determine the link between heart rate and oxygen uptake. During the experiment, the subject's heart rates was monitored using a polar heart rate monitor. A 10-point psychophysical rating scale (0-no pain, 10-extreme discomfort) will be utilized to measure the overall discomfort rating (ODR), and a body map approach will be used to examine the body component discomfort score (BPDS).

Heart rate: Polar pacer heart rate monitor was used to assess the heart rate (Fig. 1). It is a small, portable device that keeps track of your heart rate. This may be utilized in the field without the need for a telemetry system. The three essential components are chest belt transmitter, elastic strap and receiver. Three males between the ages of 25 and 35 will be selected for the study, with anthropometric measurements that meet statistical standards. In the lab, all the subjects were calibrated to determine the link between heart rate and oxygen uptake. During the experiment, the subject's heart rates was monitored using a polar heart rate monitor. A 10-point psychophysical rating scale (0-no pain, 10-extreme discomfort) will be utilized to measure the overall discomfort rating (ODR), and a body map approach will be used to examine the body component discomfort score (BPDS).

The mean oxygen consumption was above the acceptable limit of 35% VO_2 max indicating that the spading machine could not be operated continuously for 8 hours without rest.

Oxygen consumption: The oxygen intake of the individual subjects were assessed using the Bendict-roth equipment for the determination of basal metabolic rate and while cycling on a bicycle ergometer (Fig. 2). A 6-litre spirometer with a speed strip chart recorder makes up the device. A chain suspends the spirometer bell, which is counter-weighted over a pulley. The light perspex ink writing pen is carried by the counter weight. With levelling screws, the primary base is constructed of aluminium casting. It contains the kymograph gear box, as well as three stop cocks, one for water and the other two for oxygen. The stopcock is connected to the two outlets on the left side of the base. One of the outlets has a rubber exit valve, while the other has a thermometer slot. Through corrugated rubber tubing, a two-way stopcock (breathing valve) is carried by an adjustable arm and equipped with a rubber mouthpiece. The inner diameter of all air hoses is 25 mm. The spirometer's speed is set to 20 minutes per revolution using the speed selector.

Energy cost operation: The physiological responses of the individual subject's were calculated using the resting heart rate and the 6^{th} to 15^{th} minute of operation (Tiwari and Gite 1998). The heart rate rises quickly at the start of a workout and then gradually decreases until it reaches a stable level by the sixth minute (Davis et al 1964). The mean value for the selected implement was calculated using the stabilized average heart rate measurement for each subject from the 6^{th} to 15^{th} minute of operation. The corresponding values of oxygen consumption rate (VO_2) of the subject's for all the selected subjects were estimated from the calibration chart of the subject's based on the values of heart rate (HR) recorded during the trials. For all of the subjects, the energy cost of operation of the selected spading machine was calculated by multiplying the oxygen utilized by the subject throughout the trial time by the calorific value of oxygen, which was 20.88 kJ lit^{-1} (Nag and Dutt 1980).

Overall discomfort rating (ODR): The subjects were anchored to a 10-point overall discomfort rating (ODR) scale prior to undertaking the trials with all of the specified devices (Borg scale). The trials for determining the level of pain for spading operations were conducted. A 10-point psychophysical rating scale (Fig. 3) (0-no discomfort, 10-intense discomfort) was employed to quantify overall discomfort. A scale of 70 cm in length was made with 0 to 10

Maximum heart rate (beatsmin^{-1}) = 200 - 0.65 x Age in years

Fig. 1. Polar pacer heart rate monitor

Fig. 2. Bendict-Roth apparatus

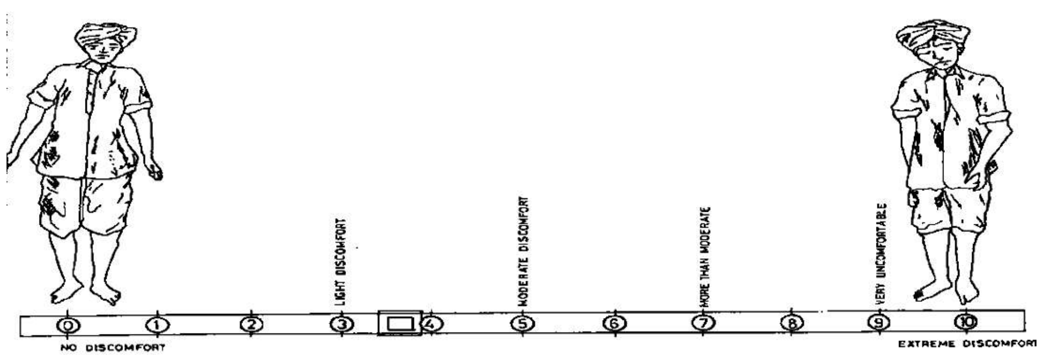
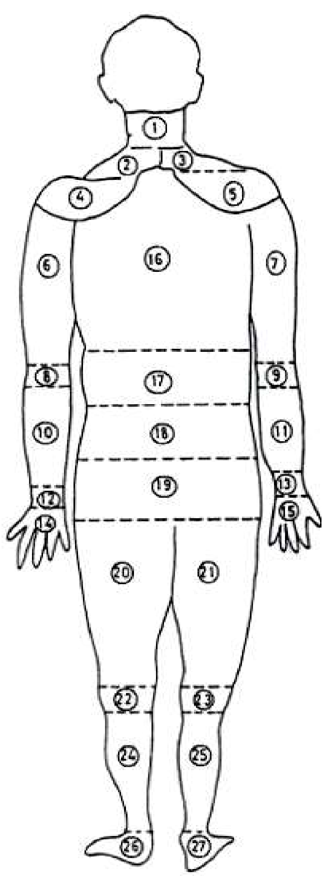


Fig. 3. Visual analogue discomfort scale for assessment of overall body discomfort

digits evenly spaced on it. The rating was indicated by a movable pointer. Subjects were asked to rate their overall pain on a scale at the end of each experiment. The mean rating was calculated by adding and averaging the overall discomfort ratings given by each of the 3 subjects. The results were tallied. All of the tests followed the same technique.

Body part discomfort score: The Corlett and Bishop (1976) approach were used to assess localized pain. The body of the subject was separated into 27 areas using this procedure (Fig. 4). To avoid a subject marking on only one body region, each body region was given a distinct number. The individual was asked to list all body parts that were bothering them, starting with the most painful and progressing down the list until no more locations were mentioned. The number of various groupings of body areas that were recognized, ranging from great suffering to no discomfort, indicated the operator's pain intensity levels. It is necessary to categorize the maximum number of pain severity levels encountered during the trial. As detailed below, the ratings were given to these categories in mathematical order.

Field layout experiments: The experimental method for evaluating machine performance as a function of soil, machine, and operational characteristics is given. The machine was developed using Pro-e software and empirical design. The development work was completed at the Department of FMPE's research workshop in KCAET, Tavanur, and the field trials were done in KCAET, Tavanur.



Body part regions
1. Neck
2. Clavicle Left
3. Clavicle Right
4. Left Shoulder
5. Right Shoulder
6. Left Arm
7. Right Arm
8. Left Elbow
9. Right Elbow
10. Left Forearm
11. Right Forearm
12. Left Wrist
13. Right Wrist
14. Left Palm
15. Right Palm
16. Upper Back
17. Mid Back
18. Lower Back
19. Buttocks
20. Left Thigh
21. Right Thigh
22. Left Knee
23. Right Knee
24. Left Leg
25. Right Leg
26. Left Foot
27. Right Foot

Fig. 4. Regions for evaluating body part discomfort score

RESULTS AND DISCUSSION

There was linear relation in heart rate and oxygen consumption rate for all selected subjects. The average working heart rate, oxygen consumption and energy expenditure of the spading machine operator were 127 beats min^{-1}, 1.20 l min^{-1} and 25.05 kJ min^{-1}, respectively. According to energy expenditure of the operator, the operation was graded as "heavy". In spading operation, the operator was continuously walking behind the machine. More pain occurs at both arms of the operator while operating the machine. It may be suggest that, there is need to attach the seat for operator in order reduce the strain. The field capacity and field efficiency of spading machine were 0.096 ha h^{-1} and 80% respectively with forward speed 2 km h^{-1}. The maximum oxygen consumption is the subject's maximal oxygen consumption at which an increase in effort does not result in an increase in oxygen intake.

Table 1. Physiological characteristics of subjects

Variables	Subjects		
	1	2	3
Age (years)	25	25	26
Body weight (kg)	58	57	63
Height (m)	1.6	1.7	1.7
Resting heart rate (Beats min^{-1})	60	60	60
ECG	Normal	Normal	Normal
Blood pressure, mm of Hg	120/80	120/80	120/80
Body mass index (kg m^{-2})	21.05	19.5	21.5

Table 2. Classification of strains (ICMR) in different types of jobs

Grading	Physiological response		
	Heart rate (beats min^{-1})	Oxygen uptake (lit min^{-1})	Energy expenditure (kcal min^{-1})
Very light	< 75	<0.35	<1.75
Light	75-100	0.35-0.70	1.75-3.5
Moderately heavy	100-125	0.70-1.05	3.5-5.25
Heavy	125-150	1.05-1.40	5.25-7.00
Very heavy	150-175	1.40-1.75	7.00-8.75
Extremely heavy	>175	>1.75	>8.75

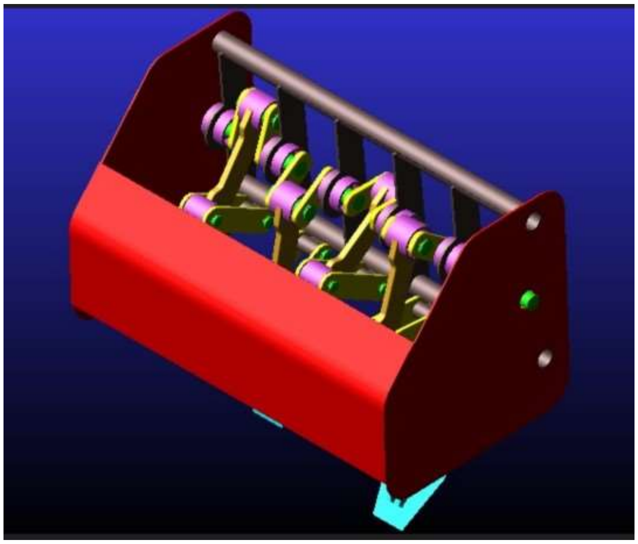


Fig. 5. Spading machine

Overall Discomfort Rating (ODR): The average overall discomfort rating was 7.0 and it scaled as "more than moderate discomfort" during spading operation.

Body part discomfort score (BPDS): The majority of discomfort was experienced in the right hand, left hand, right shoulder, left shoulder, right palm, left palm, right knee, left knee, right wrist, left wrist and mid back region of the all the selected subjects during spading operation. The average overall body part discomfort score of subjects while operating spading machine was 38.

CONCLUSIONS

An ergonomic evaluation of spading machine is carried out at research farm KCAET, Tavanur. The average working heart of operator was 127 beats min^{-1}. The operation work was grade as "heavy" the heart of the operator in spading operation is more than the limit. The mean oxygen consumption in terms of maximum aerobic capacity was calculated and it was above the acceptable limit of 35% VO_2 max indicating that the spading machine could not be operated continuously for 8 hours without rest. There is need to more than two operators for spading operation in shift for a day long work. The field capacity and field efficiency of spading machine were 0.096 ha h^{-1} and 80% respectively with forward speed 2 km h^{-1}. The average overall discomfort rating was 7.0 and it scaled as "more than moderate discomfort" during spading operation. The majority of discomfort was experienced in the right hand, left hand, right shoulder, left shoulder, right palm, left palm, right knee, left knee, right wrist, left wrist and mid back region of the all the selected subjects during spading operation.

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CONTENTS

CONTENTS

Indian Journal of Ecology (2023) 50(3)

Indian Journal of Ecology

CONTENTS

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