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Rooting Pattern and Biomass Potential of Henna (*Lawsonia inermis* L.) in Legume Based Intercropping Systems Under Rainfed Condition of Hot Semi-Arid Region of Rajasthan, India

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Abstract: The knowledge of rooting pattern and structural development of roots are prerequisite to improve and optimize the productivity of any agroforestry systems. The present study was conducted to observe the rooting pattern and distribution of henna (*Lawsonia inermis*) roots in leguminous based intercropping combinations in relation to leaf production under hot semi-arid region Rajasthan, India. The experiment plot was laid out in a Randomized Block Design with three replications. Different combination of cluster bean and henna were taken and Sole henna was taken as control. The mean of horizontal root length increased from 76.66cm (H: CB 1:1) to 111.6 cm (Alley cropping (6m)) while vertical root length varied from 62.33 cm (H: CB 1:2) to 99.66 cm (Sole henna (C)). The maximum root spread was recorded in Alley cropping (6m) (98.88 cm) and minimum root spread was in H: CB 1:1 (61.22 cm) followed by Sole henna (C). The maximum above ground biomass was recorded in alley cropping (6m) while minimum in Alley cropping (3m). Maximum below ground biomass was recorded in H: CB (1:2) followed by strip cropping and sole henna (C) and minimum was in H: CB (1:1). Since considering economical parameters, alley cropping with cluster bean (6m) is the best intercropping system among the other systems in hot semi arid region of Rajasthan under rainfed condition.

Keywords: Henna, Hot arid and semi-arid zone, Cluster bean based intercropping systems, Rooting pattern and distribution

The hot semi-arid regions are highly dynamic, sensitive, fragile and are adaptable to human induced changes in climate as well as land use transitions. The large amount of food production cannot be achieved with agricultural enterprises alone with this uncertain climatic and edaphic condition in arid and semi-arid region. Moreover, water is often the most limiting resources and competition for water can impair the effectiveness of agroforestry systems in semi-arid region (Smith et al 1998). So that the integration of trees/ shrubs with the agricultural crops may serve the purpose of achieving the basic needs of farmer in terms of food, fodder and fuelwood in drought prone area. But the soil moisture and nutrient deficit and chances of crop failure may occur due to the adverse climatic factors in arid and semi-arid region when the new trees/shrubs are introduced along with the agricultural crops (Cai et al 2009).

The root depth of trees/ shrubs determines the competition between crops and trees/ shrubs for nutrients and soil moisture in a particular agroforestry system. The deep-rooted plants may be drawn the moisture and nutrients from the deeper layer of soil, which makes less competition with crops while the shallow rooted plants can compete with associated crops through their root system which may leads to yield depressions and may contribute the economic failure of the particular land use systems (Schroth 1995, Chauhan et al 2019).

Lawsonia inermis L. belongs to the family Lythraceae commonly called as Henna or Mehndi has been commercially cultivated 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.

Cluster bean is an important leguminous crop and mostly cultivated mostly on marginal and sub marginal lands of arid and semi-arid regions. Overall, India produces around 80% of global cluster bean production. It is cultivated on more than 4 m ha in India, Rajasthan alone accounts for around 80% of the area and production. It has gaining its importance for its gum named as guar gum which is used in multiple commercial applications (Bhatt et al 2017).

However, there was no study was undertaken to evaluate the integration of henna with agricultural crops. And also, integration of henna with leguminous crop may ensure the income and productivity of farmers in henna growing areas of India. Deep rooted trees/ shrubs are widely recommended to achieve the complementary in use of below ground soil resources in agroforestry systems (van Noordwijk et al 1996). In view of growing needs and for the better understanding of the rooting pattern, biomass and yield potential of henna in cluster bean based different intercropping systems under rainfed condition, the present study was conducted with different combinations of henna with leguminous crop and sole henna under hot semi-arid region Rajasthan, India.

MATERIAL AND METHODS

The study was conducted in henna intercropping experimental field, at ICAR-Central Arid Zone Research Institute (CAZRI), Regional Research Station (Pali-Marwar, Rajasthan) in hot semi-arid region of India during 2019-20. The experimental site of henna is located between 25°47′-25°49′N and 73°17′-73°18′E at 217-220 m msl and receives 460 mm annual average rainfall with annual maximum mean temperature of 42°C and minimum 7°C. 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).

Experimental design and site management: The henna plants were planted at 60X 30 cm in seven cluster bean based different intercropping systems during 2003 and leguminous crop cluster bean was taken as inter crop during kharif season in second year onwards under rainfed condition at ICAR-Central Arid Zone Research Institute, Regional Research Station, Pali in Rajasthan, India. The experiment plot was laid out in a Randomized Block Design with three replications. Sole henna was taken as control. The treatment details were given in Table 1.

Demarcation and enumeration of plants: Uniform and healthy plants were selected randomly in each system from middle portion of the plantations. Since the root excavation is a very laborious process, three representative plants of henna from each system were selected for destructive sampling. Growth variables for *viz.*, plant height, basal diameter and number of branches (primary and secondary) were measured before cutting the plants of henna.

Excavation of roots of henna: Plants were harvested during the month of September, 2019 at the experimental site of henna. After recording the above ground parameters of henna, the plants were harvested into 10cm above ground level which is usually followed by farmers. The roots of henna under different systems were excavated and complete recovery of roots were done from the base of plant. All categories of roots were carefully picked from soil during the excavation and rearranged. The below ground variables viz., root depth, root spread and horizontal root length were measured. Shoot and roots of henna were separated from uprooted plants and dry biomass for above ground and below ground were recorded for each component. All biomass estimates were based on oven dry weight. These measurements were recorded as per established procedure.

Data analysis and interpretation: Analysis of variance (ANOVA) followed by Duncan multiple range tests (DMRT) was performed at 95% confidence level for comparing means of above and below ground growth parameters and biomass among the different systems of henna plantations.

Table 1. Treatment details of henna under different intercroppings

Treatment code	Abbreviations	Remarks
H: CB 1:1	Henna: Cluster bean (1:1)	One row of henna was alternated with one row of legume and each crop component was spaced at 60 cm from each other.
H: CB 1:2	Henna: Cluster bean (1:2)	One row of henna was alternated with two rows of legumes at 40 cm distance
H: CB 1:3	Henna: Cluster bean (1:3)	One row of henna was alternated with three rows of legumes
H: CB 1:5	Henna: Cluster bean (1:5)	One row of henna and five rows of legumes. Each row whether of henna or legume are spaced at 60cm from the other one.
Strip cropping	2.4m Strip cropping	A 2.4m wide strip of henna was alternated with 2.4m wide strip of legumes. In this system proportion is 50:50.
Alley (3m)	Alley cropping (3m wide)	Two rows of henna were planted in 60 cm rows at 3m distance. Four rows of legume were arranged in the open strip. Henna would be maintained in the form of hedge from third year onwards after the plantation.
Alley (6m)	Alley cropping (6m wide)	Paired rows of henna at 60cm are planted at 6m distance. Ten rows of legumes were maintained between the 6m space. Henna would be maintained in the form of hedge from third year onwards after the plantation.
Sole henna (C)	Sole henna (Control)	The only henna is planted with standard spacing with in the experiment.

RESULTS AND DISCUSSION

Above ground morphometric traits of henna under different intercropping systems: Among the different systems, the significant variation was observed in above ground and below ground morphometric parameters. The maximum plant height was observed in H: CB 1:2 followed by Alley cropping (6m) while minimum was in H: CB 1:5. The highest collar diameter was registered in H: CB 1:2 system and minimum in Sole henna (C). The primary branches were more in strip cropping followed by H: CB 1:1 while less in H: CB 1:2 and Alley cropping (3m). The maximum secondary branches were recorded in Alley cropping (6m) followed by H: CB 1:5 and minimum was recorded in H: CB 1:1 and Sole henna (C). The results indicated that maximum growth was attained with increased spacing (Table 2). Songyos et al., 2013 and Noor et al., 2018 also reported that the stems and branches are relatively more with increased spacing due to the higher availability of soil moisture, nutrients and light resources. And also, these results are supported with the findings of Hafeez and Hafeezullah (1993); Misra et al. (1996); Nissen et al. (2001).

Root distribution of Henna under different intercropping systems: Rooting depth determines to which extent the plants can use sub soil nutrients and water. The higher root depth of plants may use sub soil resources viz., water, nutrients, etc., by nutrient pumping and hydraulic lifting and made less competition for the resources with associated agricultural crops which produces the shallow root system in the top layer of the soil (Emerman and Dawson 1996).

Root length is one of the best parameters relating to the uptake of water and nutrients. The length and spread of henna roots were showed a wide range of variation among the systems (Table 2). The mean of horizontal root length increased from 76.66cm (H: CB 1:1) to 111.6 cm in Alley cropping (6m) while vertical root length varied from 62.33 cm (H: CB 1:2) to 99.66 cm (Sole henna (C)). There was no significant difference were observed in root spread among the systems. But the maximum root spread was recorded in Alley cropping (6m) (98.88 cm) followed by strip cropping (94.66 cm) and minimum root spread was in H: CB 1:1 (61.22 cm) followed by Sole henna (C) (Table 2).

Deeper zone of soil has less number of lateral roots when compared with upper zones. The accumulation of more root biomass in the upper layers of soil gives access to more moisture and nutrients available in the top soil. Similar observations on the root distribution of five multipurpose tree

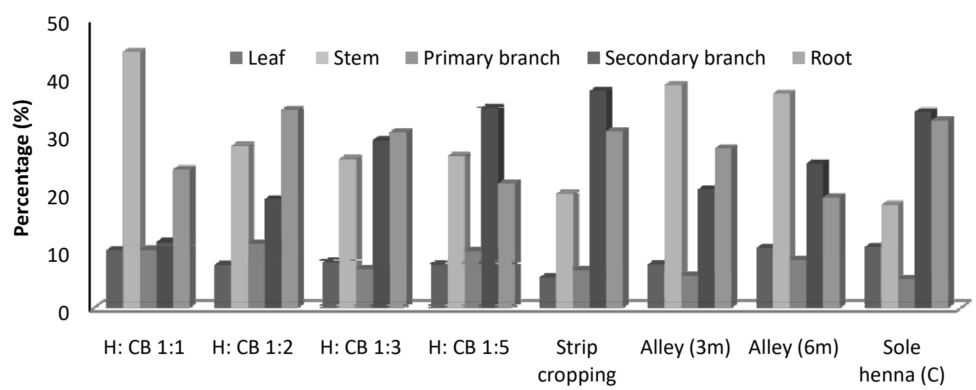

Fig. 1. Percentage distribution of biomass in henna under different intercropping systems

Table 2. Above ground and below ground morphometric characteristics of henna under different intercropping systems

Treatment	Plant height (cm)	Collar diameter (cm)	Primary branches	Secondary branches	Vertical root length (cm)	Horizontal root length (cm)	Root spread (cm)
H: CB 1:1	129.0[abc]	0.395[a]	5.33[ab]	10.00[a]	77.33[abc]	76.66[a]	61.22[a]
H: CB 1:2	156.0[c]	1.000[d]	3.00[a]	19.00[cd]	62.33[a]	108.6[a]	75.44[a]
H: CB 1:3	133.6[abc]	0.466[ab]	4.33[ab]	17.33[bcd]	63.66[ab]	107.3[a]	76.11[a]
H: CB 1:5	105.6[a]	0.682[bc]	5.00[ab]	21.00[d]	87.00[abc]	98.66[a]	73.00[a]
Strip cropping	112.6[ab]	0.948[cd]	6.00[b]	18.00[bcd]	67.66[ab]	109.6[a]	94.66[a]
Alley (3m)	114.6[ab]	0.519[ab]	3.00[a]	11.66[ab]	95.00[bc]	92.00[a]	75.22[a]
Alley (6m)	141.6[bc]	0.904[cd]	4.33[ab]	23.66[d]	78.00[abc]	111.6[a]	98.88[a]
Sole henna (C)	121.6[abc]	0.321[a]	4.00[ab]	10.00[a]	99.66[c]	88.66[a]	69.00[a]

*Mean value followed by same alphabet (superscript) in a column are insignificantly different (according to DMRT at P = 0.05)

Table 3. Above ground and Below ground biomass of Henna under different intercropping systems

Treatment	Leaf wt. (kg plant^{-1} year^{-1})	Stem wt. (kg plant^{-1} year^{-1})	Primary branch wt. (kg plant^{-1} year^{-1})	Secondary branch wt (kg plant^{-1} year^{-1})	Root wt. (kg plant^{-1} year^{-1})
H: CB 1:1	0.093^{a}	0.413^{a}	0.094^{a}	0.106^{a}	0.223^{a}
H: CB 1:2	0.095^{a}	0.358^{a}	0.142^{a}	0.240^{abcd}	0.437^{c}
H: CB 1:3	0.093^{a}	0.302^{a}	0.078^{a}	0.340^{bcd}	0.356^{bc}
H: CB 1:5	0.088^{a}	0.309^{a}	0.115^{a}	0.407^{de}	0.253^{ab}
Strip cropping	0.074^{a}	0.277^{a}	0.092^{a}	0.527^{e}	0.429^{c}
Alley (3m)	0.064^{a}	0.327^{a}	0.047^{a}	0.174^{ab}	0.234^{a}
Alley (6m)	0.128^{b}	0.458^{a}	0.102^{a}	0.309^{bcd}	0.236^{a}
Sole henna (C)	0.116^{a}	0.196^{a}	0.055^{a}	0.373^{cde}	0.356^{bc}

*Mean value followed by same alphabet (superscript) in a column are insignificantly different (according to DMRT at P = 0.05)

species were recorded by Dhyani et al (1990). Similarly, the plants exhibited spreading root parallel to the soil surface was exploited water and nutrients and increased below ground completion in *C. mopane* and *Cordia myxa* based agri horti silvi system (Bilas Singh et al 2013) and same trend was observed in other studies also (Dhyani et al 1990, Toky and Bisht 1992, Akinnifest et al 2004).

The present study indicated that the more root depth might be resulted in sole henna due to unavailability of nutrients in top layer of soil and which might be drawn from the sub soil in the system. And also, the alley cropping (6m) and other systems produced more horizontal roots and less vertical roots indicated that availability of nutrients and water from top layer of soil due to less competition among the plants.

Biomass potential of henna under different intercropping systems: The results on above and below ground biomass of henna showed the significant difference among the systems. But the differences were non-significant among the different intercropping systems for stem weight and number of primary branches (Table 3). The percentage distribution of biomass in henna under different intercropping systems also given in Figure 1. The maximum dry leaf (0.128 kg) and stem biomass (0.458 kg) was produced in Alley cropping (6m) while minimum in Alley cropping (3m) (0.64 kg) for dry leaf and sole henna (C) (0.196 kg) for stem weight respectively (Table 3). Since the economic part of the henna is ultimately dry leaf yield, Alley cropping (6m) followed by sole henna produced more dry leaf yield per plant. But the Alley cropping (6m) was having more sub surface root spread and less root depth than sole henna which may lead to competition between the agriculture crops for soil moisture and nutrients. It may reduce the yield of agriculture crop. The other researchers also suggested the similar results that the deep primary roots and moderate secondary root length of plants are less competitive with the companion crops (Das and Chaturvedi 2008; Makhumba et al. 2009; Chauhan et al. 2012).

The significant differences were observed among the systems for root weight. Maximum root weight was recorded in H: CB (1:2) followed by strip cropping and sole henna (C) and minimum in H: CB (1:1) (Table 3 and 4). Generally, trees allocate more biomass to root system with increased spacing due to less competition for uptake of nutrients, soil moisture and resources. In the present study, more root biomass was observed in henna with cluster bean-based system under H: CB (1:2) followed by strip cropping but there was less root biomass in sole henna which was planted closely with standard spacing. The similar results are observed by Swamy et al. (2003). Wani et al (2014) also reported that trees produce large root system that needed for uptake of soil resources which resulting in higher values in higher diameter. The same trend was observed in H: CB1:2 and strip cropping which resulted the more root biomass produced higher collar diameter and less in sole henna. Several other workers also support this finding (Yadava 2010, Uma et al 2011) who reported that root biomass is more in higher diameter class as compared to lower diameter class.

The lower nutrient availability from the deeper zone may affect the growth and biomass production in the sole plant

Table 4. Biomass potential of henna under different intercropping systems

Treatments	Above ground biomass (Kg/ Plant/Year)	Below ground biomass (Kg/ Plant/Year)	Total biomass (Kg/ Plant/Year)
H: CB 1:1	0.707	0.223	0.930
H: CB 1:2	0.837	0.437	1.275
H: CB 1:3	0.814	0.356	1.170
H: CB 1:5	0.920	0.253	1.174
Strip cropping	0.971	0.429	1.401
Alley (3m)	0.613	0.234	0.847
Alley (6m)	0.998	0.236	1.234
Sole henna (C)	0.741	0.356	1.098

and relatively greater availability of soil resources from the sub surface soil in alley cropping system facilitated more growth and biomass production. But wider spread of root in Alley cropping system may be the reason for competing the resources with agricultural intercrops.

CONCLUSION

The present study suggested that the increased availability of space facilitated the development of henna roots to confine mostly in upper layer of soil which may compete with agriculture crops for nutrient and soil moisture. Since the dry leaf yield is economical part in henna, alley cropping (6m) produced more dry leaf yield per plant followed by sole henna. So, the study suggests that alley cropping (6m) with cluster bean was best intercropping system considering other comparative factors. Further, the study may extend with evaluation of crops with different intercropping combination in henna may leads to select the potential combination of henna intercropping system for hot arid and semi-arid zone of Rajasthan, India and this study will serve as a base for future henna-based agroforestry studies.

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