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TRANSFORMING AGRI-FOOD SYSTEMS IN THE FACE OF CLIMATE CHANGES AND ENERGY TRANSITIONS



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TRANSFORMING AGRIFOOD SYSTEMS IN THE FACE OF CLIMATE CHANGES AND ENERGY TRANSITIONS



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IESIC-2024
12-15 November, 2024



Title: Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions

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Sh Bhagwant Maan
Chief Minister, Punjab



ਮੁੱਖ ਮੰਤਰੀ, ਪੰਜਾਬ
Chief Minister, Punjab

Message

It is heartening to learn that The Indian Ecological Society, in collaboration with the Punjab Agricultural University Ludhiana, is holding a four day international conference on "Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions" from November 12-15, 2024.

The world is today grappling with the dual challenges of climate change and energy transitions and in this scenario, our mission to secure food and nutritional stability for a rapidly growing global population, without further straining our precious natural resources, is more critical than ever. I am hopeful that the theme of the conference will address crucial aspects of agricultural progress and see the inclusion of a farmer-industry-scientist interface, which is essential for translating research into practice and ensuring that innovations reach those who need them most.

I extend my best wishes to the organizers for the huge success of this conference.

Bhagwant Maan



PAU, Ludhiana



The Indian Ecological Society



IESIC-2024

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Dr Himanshu Pathak
Secretary (DARE) &
Director General (ICAR)



भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद्
कृषि एवं किसान कल्याण मंत्रालय,
कृषि भवन, नई दिल्ली-110 001

GOVERNMENT OF INDIA
DEPARTMENT OF AGRICULTURAL
RESEARCH AND EDUCATION (DARE)
AND INDIAN COUNCIL OF AGRICULTURAL
RESEARCH (ICAR) MINISTRY OF AGRICULTURE
AND FARMERS WELFARE
Krishi Bhavan, New Delhi 110 001

Message

I am happy to know that the Indian Ecological Society, in collaboration with Punjab Agricultural University, Ludhiana, is hosting an international conference during November 12-15, 2024, at PAU, Ludhiana. The conference, themed 'Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions,' promises to be a beacon of hope. I eagerly anticipate that the conference's recommendations will provide valuable insights and actionable strategies for all stakeholders, including farmers and policymakers, paving the way for a more sustainable future.

India's journey through the post-Green Revolution era has been marked by remarkable progress in agriculture. The relentless overuse of vital resources-soil, water, air, and biodiversity-has led to troubling degradation of these precious assets. As we face the challenge of feeding a burgeoning population with diminishing water supplies, shrinking arable land, and declining productivity, the impact of climate change further complicates water resource availability and distribution.

The crux of the issue lies in preserving the delicate ecological equilibrium between land, water, and biological resources while maintaining their productivity for sustainable agri-food systems. Additionally, we must ensure that climate change does not destabilize the biosphere's ecological components, thereby threatening sustainable development itself. This pivotal transition demands a shift from fossil fuels to renewable energy sources. By embracing solar, wind, and bioenergy, we can significantly reduce the carbon footprint associated with food production and distribution. This approach not only mitigates the environmental impact but also ensures the long-term sustainability of agricultural practices, thereby securing food security for future generations.

I wish the International conference a grand success

Himanshu Pathak



PAU, Ludhiana



The Indian Ecological Society



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Dr Satbir Singh Gosal
Vice Chancellor



ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ
ਲੁਧਿਆਣਾ-141 004

PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA - 141 004 (INDIA)

Message

I am delighted to know that the Indian Ecological Society, in partnership with Punjab Agricultural University, Ludhiana, Punjab, India, is hosting an international conference from November 12-15, 2024. The conference's theme, 'Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions,' is both timely and crucial.

Amidst the pressing global challenges of climate change and energy transitions, the theme of the upcoming conference is incredibly timely. Over the years, intensive agricultural practices have inflicted considerable damage on the environment, resulting in soil erosion, groundwater depletion, the emergence of new pests, and pollution. While enhancing productivity to meet the needs of a burgeoning population is crucial, climate change threatens to undermine the progress of the agricultural revolution.

To navigate this complex landscape, we must adopt a comprehensive approach that prioritizes sustainability across the entire agrifood value chain. This involves promoting agroecological practices, fostering collaboration among stakeholders, and investing in research and development. Additionally, implementing supportive policies is essential for cultivating resilient and eco-friendly agrifood systems. The urgency to reverse current environmental degradation through scientifically grounded conservation technologies cannot be overstated. By addressing these issues holistically, we can ensure a future where agricultural productivity and environmental stewardship go hand in hand, creating a sustainable and prosperous world for generations to come.

I am certain that this conference will provide a dynamic platform for scientists and professionals from diverse fields worldwide to tackle the critical issues of pest management and environmental conservation. Together, they will craft strategic recommendations to protect our crops and preserve our planet. I believe the picturesque setting of Punjab Agricultural University, Ludhiana, will inspire delegates to renew their dedication to serving farmers and the nation.

I commend the organizers for their efforts in hosting an international conference on such a pivotal topic and wish them great success and good fortune in their endeavours..



PAU, Ludhiana



The Indian Ecological Society



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IESIC-2024

Vice Chancellor



Prof Rajeshwar Singh Chandel
Vice Chancellor



**Dr. Yashwant Singh Parmar University
of Horticulture & Forestry
Nauni-173 230, Himachal Pradesh**

Message

I am delighted to know that the Indian Ecological Society is organizing its 4th International Conference (IESIC-2024) on '*Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions*' in collaboration with Punjab Agricultural University, Ludhiana, Punjab, India, from November 12-15, 2024.

Ever increasing global population is severely affecting the world's resources in terms of environmental degradation, risk to health and food security. It would be difficult to meet the growing demands for food, energy, clothing, shelter, etc. as the basic necessities of life for the growing population even in the developed countries. Further, climate change has emerged as a real threat for humanity. The impact of changing climate on agriculture is the key factor influencing global food security in the years ahead. The situation is becoming further aggravated as indiscriminate application of chemical inputs is adversely affecting the agricultural ecosystems, human health and environment. There is a need to focus on efficient management of our natural resources and follow system-based approaches. Global commitments to achieving the Sustainable Development Goals make it essential to create platforms for scientific knowledge sharing and to raise awareness about the protection and management of natural resources.

Transforming agrifood systems is critical in the face of climate changes and the transitions to renewable energy sources. There is a need to adopt eco-friendly climate resilient soil and crop management practices, so as to make the farming systems sustainable and ensure growth of the agricultural sector. Natural farming (NF), which is based on principles of agroecology, has shown potential to improve soil health, climate resilience and sustain agrifood systems. Dr YS Parmar University of Horticulture and Forestry is leading the NF initiatives, has established models on different cropping systems for scientific validation of NF practices and is associated in further development of Farmer's self-declared certification mechanism (CETARA). University is also working on establishment of circular economy model through standardization of a Sustainable Food Systems Platform for Natural Farming (SuSPNF), involving establishment and handholding of NF based FPCs. In this endeavour, university has started a model outlet for selling the NF produce from its farms and that from the FPCs, and demonstrate the supply chain model from farm to fork. I believe that the discussions and results of this conference, enriched by the diverse perspectives of all stakeholders, will introduce new dimensions to ongoing efforts towards sustainable agrifood systems and promote agroecological initiatives. The insights and knowledge shared will play a crucial role in forging a path towards lasting sustainability, and I am optimistic about the positive impact this conference will have. I wish IESIC-2024 a resounding success!



IESIC-2024

(Prof Rajeshwar Singh Chandel)



Dr B.N. Tripathi
Vice Chancellor



**Sher-e-Kashmir University of Agricultural
Sciences & Technology of Jammu
Jammu, India**

Message

I am delighted to learn that the Indian Ecological Society is organizing its 4th International Conference (IESIC-2024) on *Transforming agrifood systems in the face of climate change and energy transitions* in collaboration with Punjab Agricultural University, Ludhiana, Punjab, India, from November 12-15, 2024.

This timely and internationally important conference addresses the challenges facing agrifood systems due to climate change. Climate change and its catastrophic impacts on agricultural lands are witnessed all over the globe in the form of droughts, cyclones, floods, heat waves etc, that are challenging the agriculture community by pressurizing sustainable agriculture ecosystems. The heavy use of fossil fuels and nitrogenous fertilizers in agriculture contribute significantly to the climate change we are now enduring. Fossil fuels produce two major greenhouse gases, carbon dioxide and methane and nitrogenous fertilizers which produce nitrous oxide emissions in agriculture production that are contributing to climate change. The conference addresses these important issues.

I am also pleased to know that the United States- National Science Foundation (NSF) supported Symposium -Workshop, in which speakers from Africa, India and the United States, scientists and student participants will address key issues facing agricultural scientists to generate new ideas for research and teaching. This shall help to build sustainable agrifood systems.

I congratulate the Indian Ecological Society for organizing the International Conference in its 50th year of establishment. I wish the conference great success in generating new ideas for agricultural research and teaching.

(B.N. Tripathi)



PAU, Ludhiana



The Indian Ecological Society



IESIC-2024

IESIC-2024



Prof. Nazir Ahmad Ganai
Vice Chancellor



**Sher-e-Kashmir University of Agricultural
Sciences & Technology of Kashmir
Shalimar, Srinagar**

Message

I am pleased to learn that the Indian Ecological Society, Ludhiana, in collaboration with Punjab Agricultural University, Ludhiana, Punjab, is organizing an International Conference on "Transforming Agri-Food Systems in the Face of Climate Change and Energy Transitions" from 12th to 15th November 2024 at PAU, Ludhiana.

Indian agriculture remains highly vulnerable to climate change, with rising temperatures, erratic monsoons, and extreme weather events impacting crop yields and food security. The sector is exceptionally resource-intensive, utilizing about 18% of the nation's electricity and over 85% of its freshwater, underscoring an urgent need for sustainable resource management practices. While significant strides have been made in reducing hunger, malnutrition, and food insecurity continue to challenge us, particularly in rural areas. Protecting and restoring terrestrial ecosystems is essential for a sustainable agri-food system; through agroforestry, soil conservation, and natural resource management, India can combat desertification, restore degraded lands, and promote biodiversity-friendly farming practices.

To address these challenges, a multi-faceted approach integrating innovative technologies, policy reforms, and grassroots mobilization is vital. Digital agriculture, precision farming, artificial intelligence, and machine learning are transforming agricultural practices, enabling farmers to make data-driven decisions and improve resource efficiency. Public-private partnerships will also be instrumental, driving investments in infrastructure, research, and market linkages to ensure that rural and smallholder farmers benefit from technological advancements.

Furthermore, fostering an inclusive environment for women and marginalized communities in agriculture is crucial to bridge socio-economic inequalities. Community-based initiatives that empower rural women, support small-scale farmers, and promote sustainable agricultural practices can lead to more equitable growth and a resilient food system for India's future.

I hope that the deliberations in this conference by Indian and international experts will pave the way for a future roadmap to establish sustainable food systems within India and beyond. I wish the conference great success.



PAU, Ludhiana



The Indian Ecological Society



IESIC-2024

IESIC-2024

(Nazir Ahmad Ganai)



Dr J.P.S. Gill
Vice Chancellor



ਗੁਰੂ ਅੰਗਦ ਦੇਵ ਵੈਟਨਰੀ ਅਤੇ ਐਨੀਮਲ ਸਾਇੰਸਿਜ਼
ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ-141 004

Guru Angad Dev University & Animal
Sciences University, Ludhiana-141 004

Message

I am delighted to learn that Indian Ecological Society, in collaboration with Punjab Agricultural University is organizing four days' international conference on "Transforming Agrifood Systems in Face of Climate Change and Energy Transitions" from 12-15 November, 2024 at Punjab Agricultural University, Ludhiana, India. I complement the Indian Ecological Society and PAU, Ludhiana for shouldering the responsibility of organizing this conference.

The organization of this international conference is very timely and it will have a greater impact at national and international level in view of our commitment to ensure **food** and nutritional security to the ever-increasing population without putting a strain on natural **resources**.

I am happy to note that the five themes of the conference, namely, climate changes and energy transitions, regenerative agriculture, united nation sustainable development goals: Transition to resilient, biodiversity and provision of ecosystem services across agricultural landscape, future forest management; towards climate resilience for sustainable development of agriculture and farmer industry scientists interface, cover the most pertinent issues in the context of overall agricultural development. I hope that the deliberations of the Conference will result in a road map in support of holistic development agenda, demand-driven research programme and their applications in the entire value chain with farmers and market occupying the central place.

I send my best wishes for the success of the conference.

(JPS Gill)



PAU, Ludhiana



The Indian Ecological Society



IESIC-2024

IESIC-2024



Dr. Z.P. Patel
Vice-Chancellor



Navsari Agricultural University
Navsari, Gujarat

Message

With an exciting pride and indulgence, I am writing this message for the international conference on the theme 'Transforming Agrifood Systems in Face of Climate Changes and Energy Transitions', being organized by Indian Ecological Society in collaboration with Punjab Agricultural University, Ludhiana, Punjab, India from November 12-15, 2024 at PAU, Ludhiana.

In the face of climate change, we are witnessing extreme weather events, including heat waves, cold waves, droughts, floods, landslides due to heavy rains, and cloudbursts. These phenomena threaten the sustainability of life on earth. To maintain ecosystem sustainability, productivity enhancement is often advocated. However, increased productivity can lead to more emissions, worsening climate change.

There is an urgent need for platforms where scientists, NGOs, researchers, and stakeholders can innovate and develop technologies for sustainable agro-ecosystems. This collaboration can influence policymakers to take decisive action. The Indian Ecological Society, in collaboration with PAU, Ludhiana, is holding a conference to address these issues. Topics like circular economy, zero input agriculture, digital tools for sustainable agri-food systems, climate-smart organic farming, UN sustainable development goals, biodiversity and ecosystem services etc., need technology interventions to be addressed earnestly.

I believe this conference will provide a platform for experts to make tactical recommendations to protect crops and preserve the environment while developing sustainable agro-ecosystems. I hope the conference at Punjab Agricultural University will inspire delegates to serve farmers and the nation.

I convey my greetings to the organizers for this important international conference and wish the event a grand success.

Z.P. Patel



The Indian Ecological Society



IESIC-2024



Dr Parvinder Kaushal
Vice Chancellor



**Veer Chandra Singh Garhwali University
of Horticulture and Forestry,
Bharsar, Uttarakhand**

Message

It is my pleasure to note that the international conference entitled “Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions”, being organized by Indian Ecological Society in collaboration with Punjab Agricultural University, Ludhiana, Punjab, India from November 12-15, 2024 at Punjab Agricultural University, Ludhiana India.

Climate change has now become talk round the corner as it is being witnessed more deceptively. Throughout the world, everyone would like imagine a world with farmlands providing nutritious and healthy food and rearing healthy livestock without deteriorating the environment and natural resources. Every village, town and city powered by clean energy. People ethically doing each and every daily activity with sense of sustainable utilization and conservation for the future generation. Although, world has been facing climate change crises and these vagaries are more discernible from last few decades. However, it is time to act with sense of responsibility to subside these and obviously world is within our reach, but only if we wisely meet the challenges we are facing today. To have done so, there is urgency to have better opportunities and fora where scientists, policy makers, NGOs, and other stakeholder galaxy, having deep expertise and youngers with fervour, to deliberate and act upon these ever-burning issue.

In this regard, it is extremely appreciated that Indian Ecological Society has pertinently decided to organize an international conference to deliberate on very important themes. In the present scenario of climate change, it is important to have deliberation on climate change mitigation, utilization of resources efficiently to save energy, efficient innovations for agro-ecosystems, circular economy, to use digital tools in agri-food-forest-fuel ecosystems, climate smart organic farming, biodiversity conservation and ecosystem provisioning along with forest management to achieve climate resiliency. The deliberations centered around these points would surely help to achieve United Nations Sustainable Development Goals (SDGs) wherein again all these themes are advocated for the sustainability of the world. I am sure that the international conference will definitely help in creating platform for scientists, budding researchers, academicians from across the world-renowned Institutions and policy makers, NGOs and other stakeholders from agriculture and forest-based industries would deliberate upon and come out with specific new technologies to achieve set objectives. I convey my best wishes to the organizers for the benchmark success of this international conference.



IESIC-2024

Parvinder Kaushal



Dr Naveen Kumar
Vice Chancellor



**Chaudhary Sarwan Kumar Himachal
Pradesh Agriculture University (HPAU)
Palampur**

Message

I am pleased to learn that the Indian Ecological Society in collaboration with Punjab Agricultural University, Ludhiana, Punjab, India is organizing 'Indian Ecological Society International Conference 2024' from November 12-15, 2024 with the theme 'Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions'.

Climate change caused by greenhouse gases is a major global concern and scientists are considering energy transition as an essential component for addressing the climate changes. In agriculture, climate changes is expected to negate the gains of agricultural revolution by lowering productivity and thus, might disturb the food security leading to increased hunger. It is, therefore, quite befitting to have such a theme for the conference. Of late, intensive agricultural systems have been followed to feed the ever increasing world populace wherein large amounts of fertilizers are being applied. The dilemma to further increase or sustain agricultural production while lowering the emission of greenhouse gases is forcing the scientific community to devise new strategies to achieve both the goals. To realise the objectives of energy transitions, lower green house gases emission and improve productivity, the focus must be on transformation of agrifood systems by employing a comprehensive approach that integrates sustainability principles across the entire food chain. To achieve the mammoth goal of achieving a resilient and environment friendly agrifood system, there is a need to promote agroecological practices, foster effective collaborations supported by adequate investments and develop conducive policies.

I firmly believe that the deliberations of the conference would provide a platform to the scientists and professionals from various fields across the world to deliberate on the important issues noted above and make strategic recommendations for saving our earth from the challenges of changing climate. I hope the conference will inspire the delegates to rededicate themselves to the service of the farmers and the nation. I appreciate the efforts of the organizers for holding an International conference on such a vital topic and wish them good luck and grand success.



PAU, Ludhiana



The Indian Ecological Society



IESIC-2024

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Naveen Kumar



Dr Suresh Kumar Chaudhari
Deputy Director General
(Natural Resource Management)



INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Room No. 101, Krishi Anusandhan Bhawan-II,
Pusa, New Delhi-110012, India

भारतीय कृषि अनुसंधान परिषद्
कक्ष क. 101, कृषि अनुसंधान भवन-II,
नई दिल्ली-110012, भारत

Message

It is with immense joy that the Indian Ecological Society, in collaboration with Punjab Agricultural University, Ludhiana, is hosting an esteemed international conference titled "Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions." This significant event will take place from November 12-15, 2024, on the dynamic campus of PAU, Ludhiana.

Climate change presents the greatest threat to sustainable agriculture. To achieve sustainability, we must not only slow but ultimately halt anthropogenic climate change. This daunting task is intricately linked to our success in transitioning from fossil fuels to renewable energy sources. Without swift and effective energy transitions, climate change will continue and potentially worsen.

In our current climate, enhancing food availability is of utmost urgency. This requires not only increased production but also strengthened defenses against pests. Developing resilient production and protection technologies in response to climate shifts is essential. I am optimistic that this conference will provide a platform for comprehensive dialogue on cost-effective and environmentally friendly management strategies to tackle pest challenges amid our evolving climate and energy landscape. The insights and recommendations from this gathering are poised to significantly benefit the agricultural community.

I commend the organizers for assembling a distinguished group of international and national scientists to address this critical issue. May the conference achieve its goals and pave the way for transformative advancements in agriculture!

S.K. Chaudhari



IESIC-2024



Dr Ajmer Singh Dhatt
Director of Research



ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ
ਲੁਧਿਆਣਾ-141 004

PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA - 141 004 (INDIA)

Message

It is a matter of great pleasure that the Indian Ecological Society, in collaboration with Punjab Agricultural University, Ludhiana, India, the pioneer of ushering in the Green Revolution in India, is organizing an international conference with the important theme area of 'Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions' from November 12-15, 2024 at Punjab Agricultural University, Ludhiana.

The conference will highlight the various issues pertaining to climate change and energy transitions, biodiversity and ecosystem services role in agrifood systems, climate change adaptation and mitigation, energy and water efficient innovations for agrifood systems, breeding adaptation and tolerance systems, sustainable climate smart agricultural practices, novel approaches in pest management, and digital tools for sustainable agri-food systems.

The conference will provide a platform for an impressive diversity of knowledge, disciplines, and viewpoints to design a more holistic approach to reverse the climate crisis in line with the United Nations sustainable development goals. The deliberations will focus on regenerating and transitioning to resilient agri-food systems. Ecologists across the world have to play a significant role in providing safe, effective, and sustainable crop production and protection technologies to save the environment. There is an urgent need to transform agrifood systems through efficient management of natural resources. The participation of professionals from pesticide and seed industry will pave the way to strengthen public-private partnership in research for the betterment of the society.

I wish a great success for the conference and congratulate the organizers for publishing abstracts and the souvenir.

Ajmer Singh Dhatt



PAU, Ludhiana



The Indian Ecological Society



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Dr AK Dhwan
President
Indian Ecological Society



**PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA - 141 004 (INDIA)**

Message

The Indian Ecological Society (IES), established in 1974 at Punjab Agriculture University Ludhiana (PAU), is one of the pioneering organizations of India. The Society is engaged in advances in ecological sciences and environmental protection. It has organized nine national and three international conferences/ symposia in the last three decades. In its 50th year, the Society in collaboration with PAU, Ludhiana, is organising the 4th International Conference on **“Transforming Agrifood Systems in the face of Climate Changes and Energy Transitions”** (IESIC 2024) from November 12-15, 2024 at PAU, Ludhiana.

The conference will highlight the various issues pertaining to climate change and energy transitions, digital tools for sustainable agri-food systems, climate-smart organic farming, role of ecosystem services in agrifood systems, energy and water efficient innovations for agrifood systems, breeding adaptation and tolerance systems, novel approaches in pest management. Energy transitions that replace fossil fuels with renewable energy sources can mitigate climate change and must also occur in agrifood systems.

This International Conference will provide a platform to design a more holistic approach on transforming agrifood system in light of climate change and population growth. Delegates will have the opportunity to interact with experts and exchange their ideas, experiences, and feedback aimed at building strategies on **Transforming Agrifood Systems**, eventually reduce human-caused climate changes. In addition, a parallel symposium on “Agriculture, Climate Changes, and Energy Transitions: Building Capacity to Maintain Yields of Innovative Agrifood Systems” is also be organised and is supported by the **National Science Foundation** (NSF), USA for young scientist.

I, on behalf of IES, extend a hearty welcome to all the delegates from both India and abroad (Hong Kong, USA, Switzerland, Columbia, France, Nigeria, Nepal) including ICAR institutes, SAUs, traditional universities and colleges, and private sector, to this conference. I am sure, the deliberations in various sessions will lead to recommendations, to meet the challenges of food security and productivity, in a sustainable manner, maintaining environment quality.

I wish you all a very comfortable stay and joyful memories.

Akhwan
AK Dhawan



IESIC-2024



Dr Vijay Kumar
Organizing Secretary, IESIC- 2024



ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ
ਲੁਧਿਆਣਾ-141 004

PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA - 141 004 (INDIA)

Message

Food security and climate change are the major global concerns today, and it is quite befitting to have such a theme for the conference. Agrifood systems transformation is now being recognized as a significant part of the solution to the climate crisis and biodiversity loss. Biodiversity is the key to making agriculture and forestry systems productive, sustainable, and resilient, and that today's agrifood systems are greatest driver of biodiversity losses. Halting deforestation and forest degradation is critical for agrifood systems transformation and combating climate change. There is a need for global shift from fossil fuel based energy systems to low carbon and renewable energy sources and to reduce the negative impacts of agriculture practices on biodiversity while conserving, and restoring biodiversity. There is a need to reshape the food systems to reduce their impact on climate change and making food system less dependent on fossil fuels.

The efforts to revolutionize agrifood systems demand a collaborative approach involving various stakeholders, including governments, industry, corporate, farmers, public, and civil society. There are many encouraging innovations with potential to reshape these systems, encompassing climate resilient farming, regenerative agriculture practices, and the reduction of food shortage. There is a need to make strategic investments in research and to expedite the rate of innovation within agrifood systems

It is worth mentioning here that professional representatives from the pesticide and seeds industries will also be participating in the conference to interact on Private-Public Partnership during the four day deliberations. The conference will provide a platform for an impressive diversity of knowledge, disciplines, viewpoints to design a more holistic approach to reverse the climate crisis in line with the united nations sustainable development goals. The deliberations will focus on regenerating and transitioning to resilient agrifood systems. In view of these facts, The Indian Ecological Society, in collaboration with Punjab Agricultural University, Ludhiana, India, the pioneer of ushering Green Revolution in India, is organizing an International conference under the theme, "Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions" from November 12- 15, 2024 at Punjab Agricultural University, Ludhiana.

I extend a hearty welcome to all delegates from India and Abroad to this conference. I believe that thorough discussions and close interactions amongst the eminent scientists from various parts of the world during this 4-day long interaction conference will help in formulation of sound strategies for crop production and protection in future.

I wish you all a very comfortable stay at PAU, Ludhiana and good luck for future endeavours.



PAU, Ludhiana



The Indian Ecological Society



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Vijay Kumar
(Vijay Kumar)

Agroecology: Designing Sustainable Food Systems for Climate Change Adaptation

S. Sheraz Mahdi, B.N. Tripathi¹ and S.K. Gupta²

*Advanced Centre for Rainfed Agriculture, ¹Vice Chancellor Secretariat, ²Directorate of Research
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By the end of the 21st century, there is growing proof that, due to global climate change, temperatures may be as high as 1.8-5.0°C. This will result in extremely hot climates, floods, droughts and hurricanes and the gradual decline of glaciers in Himalayas in the next 20-50 years, which will lead to greater instability in food security, stability and production. Of the entire annual crop losses in agriculture, much of it is due to the precarious climate and the effects of climate change such as droughts, floods, storms, hail, heat and cold waves. It is anticipated that crop production loss in India by 2100 AD could be 10-40% despite the beneficial results of high CO₂ on crop yield increase. The Dynamics of pests and diseases might be drastically altered. Agroecology, as a science and practice, provides a sustainable alternative by applying ecological principles to the design and management of food systems. This paper examines the potential of agroecological practices to address the twin crises of climate change and food insecurity. Through diversification, agro-forestry, soil health enhancement, water conservation, and biodiversity promotion, agroecology fosters resilient food systems capable of adapting to climate stressors. The paper concludes that agroecology not only represents a sustainable pathway for food production but also serves as a vital strategy for building climate-resilient agrifood systems, contributing to both adaptation and mitigation efforts in the face of global climate change.

Introduction

The global average temperature has risen by around 1.1°C since pre-industrial times (IPCC 2020). On account of GHG-induced warming, India's average temperature has also risen by around 0.9°C during 1901–2019 (IMD 2020). By the end of the twenty-first century, average temperature over India is projected to rise by approximately 4.4°C. The summer monsoon precipitation (June to September) over India has declined by around 6% from 1951 to 2015, with notable decreases over the Indo-Gangetic Plains and the Western Ghats. The Hindu Kush Himalayas (HKH) experienced a temperature rise of about 1.3°C during 1951–2014 (Krishnan et al 2019). Several areas of HKH have experienced a declining trend in snowfall and also retreat of glaciers in recent decades. In contrast, the high-elevation Karakoram Himalayas have experienced higher winter snowfall that has shielded the region from glacier shrinkage. By the end of the twenty-first century, the annual mean surface temperature over HKH is projected to increase by about 5.2°C under the RCP8.5 scenario. Various studies suggest that maximum glaciers within the Northern Himalayas along with Kashmir Himalayas (Kolahoi peak: 5425 m; Harmukh Peak: 5143 m) and Amarnath Peak: 5, 186m) have decreased in number and volume due to climate change (Romshoo et al 2015, Wester et al 2019). Furthermore, proper quantification of clear expertise of its reasons in hilly terrains is subject of additional studies.

UT-Jammu and Kashmir, which form an integral part of the Great Himalayan range, also see significant effects on climate change in the form of increasing temperatures, decreasing precipitations, catastrophic floods, reduction in winter duration (Mahdi et al 2022, Khan et al 2019, Murtaza et al 2017). Given the negative impact of climate change, Kashmir County already has a 40% food crisis, 30% in vegetable production, and 69% in oil seed production, which puts UT food security at great risk (Bhat 2019). In addition, the effects of climate change are likely to affect several other sectors such as irrigated agriculture, horticulture farming, and the state's hydropower capacity (Sharma 2015). This impact is further triggered owing to worrying trend over 78,000 hectares of agricultural land conversion to non-farm activities in Kashmir division in the last six years (DAC 2020).

Climate Change Trends in Jammu & Kashmir



Climate change has had significant impacts on Jammu and Kashmir (J&K), a region with fragile ecosystems and diverse climatic zones. The trends related to climate change in J&K include rising temperatures, changes in precipitation patterns, and increased frequency of extreme weather events. These changes have far-reaching effects on the region's glaciers, water resources, agriculture, and biodiversity.

Temperature Trends

Several studies have indicated an upward trend in the temperature across J&K. According to a study by Mahdi et al 2021, Mir et al 2020, average annual temperatures in the region have increased by approximately 0.03-1.2°C from 1901 to 2018, with the warming being more pronounced in the last few decades. The trend of increasing temperatures is more significant during the winter season, which could have serious implications for snow cover and glacier dynamics, especially in the upper reaches of the Himalayas. Ahmed et al (2019) also reported a significant increase in both minimum and maximum temperatures, particularly in the Kashmir Valley, which experiences faster warming compared to the Jammu region. Likewise, Romshoo et al (2018) found that the Kashmir Valley is warming at a faster rate than the Jammu region, which could have serious consequences for both the natural ecosystems and agricultural productivity.

Precipitation Trends

Precipitation patterns in J&K have become increasingly erratic, with reports of both increasing and decreasing trends depending on the location and season. Analysis of seasonal and annual precipitation data shows a decreasing trend at the rate of -4.50 mm/year in the Kashmir Valley (Mahdi et al 2021). Bhat et al (2021) noted a decline in winter precipitation, especially in the form of snowfall, which is crucial for maintaining the glaciers that feed rivers and support agriculture. On the other hand, Romshoo et al (2018) found a slight increase in summer precipitation, although it remains highly variable. This variability contributes to more frequent and intense extreme weather events such as flash floods and cloudbursts. Furthermore, Shah et al (2022) observed that the overall annual precipitation trend shows a decline in Jammu, while Kashmir's precipitation has become more unpredictable, with significant intra-seasonal shifts.

Cardinal and Extreme Temperature Thresholds for the Major Cereal Crops

All cereal crops have a basic requirement of temperature for completion of a given phenological phase, or the entire life cycle (Craufurd and Wheeler 2009). The daily maximum and minimum temperature play a significant role in determining the optimum sowing time or window and defining the seasonal duration; thus, both can affect the achievable yield, produce quality, and along with their sustained productivity (Hussain et al 2021). Normally, the longer the optimum growing season, then higher the duration for maximum grain production. Luo et al (2011), reviewed threshold temperature of different crops and stated that identification of threshold temperature is very important aspect of climate change risk assessment. Cardinal and extreme temperature thresholds for the major cereal crops were reviewed by Ramirez-Villegas et al (2013) and are shown in Table 1.

Impact of Climate Change on Major Cereal Crops in India

Cereal grains including wheat, maize, and paddy are considered staple foods to most of the population across the globe. By 2050, a 70-100% increase in cereal food supply is required to feed the predicted world population of 9.8 billion people (Godfray et al 2010). But current production rates are near to equal what is required to meet the targets (Ray et al 2013). The problem is further compounded due to change in climate affecting the yield of major crops. To this, impact of climate change on Indian agriculture was studied under National Innovations in Climate Resilient Agriculture (NICRA). Rainfed rice yields in India are projected to reduce marginally (<2.5%) in 2050 and 2080 and irrigated rice yields by 7% in 2050 and 10% in 2080 scenarios. Further, wheat yield projected to reduce by 6-25% in 2100 and maize yields by 18-23%. Future climates are likely to benefit chickpea with increase in productivity (23-54%).

Climate change and other stresses are contributing towards yield losses and its simple representation is given



Figure 1. Climate change impacts are now advocating the necessity of changing the crop calendar. This necessity for changing the crop calendar is mainly because of changes in the timing of plant phenological stages or events that respond to temperature. This change in cropping calendar might have positive or negative impacts on productivity, depending on type of crop and geographical locations.

Agro-ecological Practices for Sustainable Agri-food Production

Agro-ecological practices offer a sustainable approach to food production by integrating ecological principles into agricultural systems. These practices aim to enhance biodiversity, improve soil health, optimize resource use,

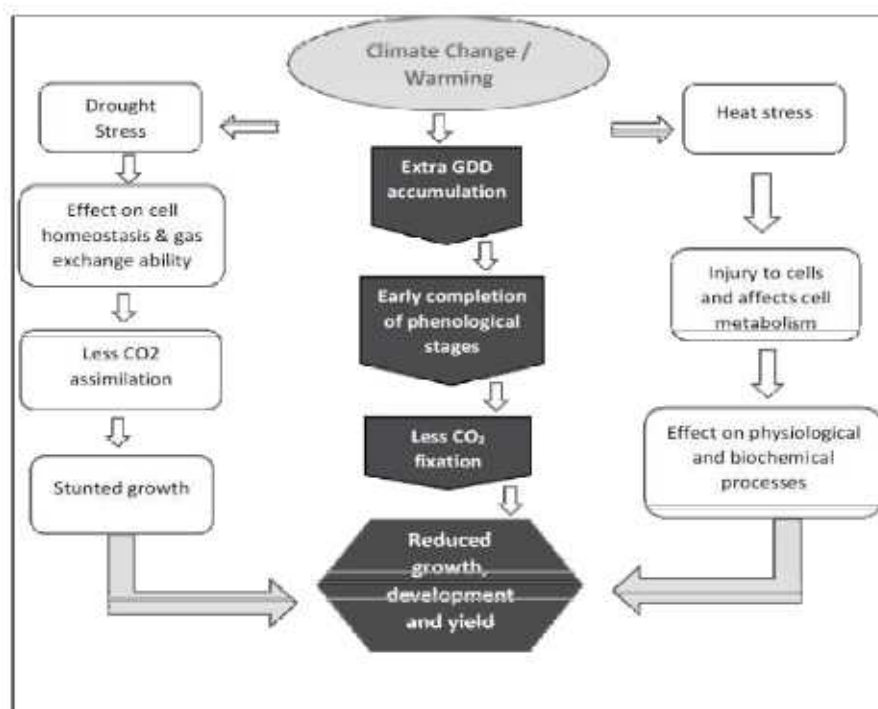


Fig. 1. Simple representation of climate change impacts on growth and development of crops

Table 1. Cardinal (Base (T_b), optimum (T_{opt}) and maximum (T_{max}) and extreme temperature thresholds (Ceiling vegetative temperature (T_{C1}) and Ceiling reproductive temperature (T_{C2}) for cereal crops

Crops	T_b (°C)	T_{opt} (°C)	T_{max} (°C)	T_{C1} (°C)	T_{C2} (°C)
Barley	0.0-5.0	25.0-31.0	50.0	30.0	40.0
Maize	8.0	30.0	38.0	33.0	44.0
Millet	10.0	34.0	40.0	30.0	40.0
Oats	0.0-5.0	25.0-31.0	31.0-37.0	-	-
Rice	20.0	28.0	35.0	22.0	30.0
Rye	0.0-5.0	25.0-31.0	31.0-37.0	-	-
Sorghum	8.0	34.0	40.0	32.0	44.0
Wheat	0.0	13.3	35.0	34.0	40.0

Source: Ramirez-Villegas et al 2013



and increase resilience to climate change. In the context of sustainable agri-food production, agro-ecological methods focus on long-term productivity, reducing dependency on chemical inputs, and promoting environmental stewardship.

Conservation Agriculture (CA)

CA procedure, taking into account the three main components, (i) Minimum soil disturbances (disturbed area should be less than 15 cm wide or 25% of the total area), (ii). Soil cover (soil cover should be more than 30%) and (iii) Sensible crop rotation (should include at least three different crop-plants) (Fig. 2). Globally, CA is produced at 157.8 M ha, countries adopting this technology are mainly USA (35.61 M ha), Brazil (31.81 M ha), Argentina (29.18 M ha), Canada (18.31 M ha) and Australia (17.69 M ha) (FAO, 2017). In India, the adoption of this technology is still in its early stages. Over the past few years, the adoption of zero cultivation and other technologies has expanded to cover approximately 1.5 million hectares (Jat et al 2012). The main agricultural-based technology adopted is the zero-grade cultivation of the rice wheat system in the Indo-Gangetic plains. By adopting CA, agricultural soils in the world are envisioned to have a capacity to sequester 0.4-0.8 Pg C per year (Lal 2004). Improved agricultural management practices such as conversion from conventional to no-till or reduced tillage, residue retention, conversion to permanent pasture, crop rotation and accurate fertilizer application have proven to boom soil C in diverse nations, including India (West and Marland 2002, Patle et al 2013).



Fig. 2. Depiction of three basic principles of CA

Plant Breeding and Genetic Modifications

Development of climate resilient varieties through the combination of molecular and conventional plant breeding and genetic methods, provide a dynamic mechanism for adaptation of cereal cropping systems to climate change. Some of the major cereal crop varieties with special traits such as climate resilience and nutrition rich content developed by ICAR Institutes / SAUs are given as under:

Crop	Variety	Special traits
Buckwheat	Him Phaphra	High protein (13.1%) with methionine and iron (6.6 mg/100g) content
Rice	CR Dhan 801 and CR Dhan 802	Average yield 6.5 t/ha under normal conditions, 4.3 t/ha under submergence and 2.3 t/ha under drought conditions (Area: Bihar, WB, Odisha)
	Swarna Sub-1 and Varsha Dhan	Late maturing (143-160 days), tolerant to complete submergence, productivity 5.5 t/ha, Coastal areas
	CR Dhan 200, CR Dhan 201, CR Dhan 202, CR Dhan 204	Suitable for aerobic rice cultivation, Average yield 3.8 t/ha, matures in 110-125 days. (Area: WB, Jharkhand, Bihar, Odisha)
Wheat	DBW 187, DBW 387	Heat resistant, average yield (80.0 q/ha)
	DBW 332	High yielding variety (78.3 q/ha) with high Zn content (44.4 ppm) in its grains
Maize	Shalimar maize composite-8	First drought tolerant variety for J&K, (Average yield 6 t/ha)
	Pusa Bio fortified Maize	Yield 84.33 q/ha rich in provitamin-A (6.7 ppm), lysine (3.47%) and tryptophan (0.78%)
	Hybrid-4 (APH4)	



Improved Crop Management Practices

Better and improved crop management practices can minimize negative impacts of temperature extremes. Apart from assurance of good quality and genetically pure seed to farmers, there are many helpful climate adaptation strategies related to crop husbandry reported by scientists, for example, changing sowing, planting geometry and harvesting date, crop rotation, irrigation techniques, supplement irrigation at critical stages, soil management practices, improvement of irrigation efficiency and variation in cropping patterns etc. (Hussain et al 2012, Jalota et al 2013).

Raised bed planting method using raised bed planter for maize is useful to obtain maximum attainable grain yield with 25-30% irrigation water savings (Fig 3). Water-saving interventions such as direct-seeded rice, a modified system of rice intensification and alternate wetting and drying (AWD) of rice were implemented in a cluster approach and resulted in enhanced water use efficiency (Alauddin et al 2020). Adaptation of integrated soil fertility management and precision nutrient management is helpful to minimize the negative influence of higher temperature. Laser land levelling (through enhancing water application efficiency, uniform distribution in fields and availability to crop plants; thus, increasing water use efficiency) can enhance cereal grain yield under warming climate.



Fig. 3. View of bed planter and maize under raised bed planting system

Agroforestry

Agroforestry integrates trees into agricultural landscapes, improving biodiversity and enhancing soil organic carbon and yield sustainability (Jose 2009). The practice has gained recognition in both tropical and temperate regions. In India, agroforestry has been promoted through the National Agroforestry Policy (NAP) of 2014, which aligns with the country's afforestation goals (GoI 2014).

In J&K, agroforestry can be particularly effective in hilly terrains where trees like poplar, willow, and fruit-bearing species can be integrated with crops like maize, saffron, and paddy. Example in this case is poplar-based agroforestry systems in the Jammu plains and temperate zones of Kashmir or else Punjab (Fig. 4) have shown potential for improving carbon stocks (Singh et al 2020).

Diversification in Crops

Crop diversification has tested to be one of the most popular farm degree responses to climate change, especially, in countries that are rich in rural economies and at high climate risks (Bradshaw et al 2004). In addition of protecting crop production from the effects of climate change and extreme adverse events, crop diversity improves resilience by producing greater capacity to suppress insect outbreaks and slow down the spread of pathogens, which may be worse in future climatic conditions, (Lin 2011). In India, a review of published reports suggested that few efforts have been



Fig. 4. Agro-forestry-sowing wheat under the canopy of poplar (widely practiced in Punjab, India) for sustainable use of soil-water resources and carbon sequestration in site specific situation

made to quantify the benefits of crop diversity in dealing with climate change and its risks. It is often studied to meet demand flexibility and to stabilize the farmer's income. Efforts are needed to identify low-impact planting systems and to incorporate those that improve carbon sequestration, such as maize-wheat and agroforestry systems with 65-88% more organic carbon stocks than the rice-wheat system (Benbi et al 2012). Results from a study by Saha (2013) have shown that crop diversification in India has occurred in the western and south-western provinces and crop specialization have occurred in provinces such as West Bengal, Assam, Manipur and Mizoram. Due to changes in rainfall patterns and depletion of water resources, the conventional planting methods have reduced production. Thus, crop consolidation, through mixed planting and integration of high value crops such as horticultural production, is gaining prominence as a strategy to adapt to climate change. Re-examination of cropping patterns and systems can provide high risk security.

Organic Farming

Organic farming is gaining prominence in India, particularly in states like Sikkim, which became the first fully organic state in 2016. Organic agriculture avoids the use of synthetic inputs, instead relying on organic manures, biofertilizers, and natural pest control methods. Studies show that organic farming improves soil fertility, enhances biodiversity, and increases farm resilience to climate variability (Sharma et al 2016). Additionally, organic farming systems have lower energy requirements and contribute to carbon sequestration (Lal 2019).

Integrated Pest Management (IPM)

The influence of **IPM** on India's agrifood systems has been transformative, contributing to environmental sustainability, economic benefits for farmers, and improved agricultural productivity. By integrating biological, cultural, and chemical control strategies, IPM has reduced the negative impacts of excessive pesticide use and enhanced agricultural resilience. A major influence of IPM in India has been the reduction in pesticide use, which traditionally has been excessive in crops like cotton, rice, and vegetables. According to a study by Shetty et al (2013), the adoption of IPM practices led to a 30-50% reduction in pesticide use in several crops, including cotton, rice, and vegetables in India, with improved crop yields and quality. IPM also contributes to the conservation of beneficial organisms such as pollinators and natural predators, which play a crucial role in sustainable agriculture (Sithanantham et al 2019).

Zero Budget Natural Farming (ZBNF)

ZBNF's emphasis on reducing external inputs and promoting local resource use makes it economically attractive for small and marginal farmers, who often struggle with high input costs and debts. A report by Andhra Pradesh State Government (2018) noted that farmers practicing ZBNF saw a reduction in input costs by 60-70% and increased net incomes. This shift is especially relevant for food security in India, as smallholder farmers are the backbone of the agrifood system. Research by Sivakumar et al (2019) shows that diversified farming under ZBNF not only improves food security but also helps improve the nutritional status of rural communities.

Conclusion

Climate change is threatening global food security and significantly impacting the yield of cereal crops by shortening various phenological stages, which reduces the time available for plants to assimilate CO₂, thereby decreasing overall yield. Agroecological practices offers a holistic and sustainable approach to food system design, integrating ecological principles with agricultural practices to enhance resilience to climate change. By fostering biodiversity, improving soil health, and promoting ecosystem services, agroecological systems are better equipped to adapt to the increasing challenges posed by changing climates. These systems not only improve food security but also support rural livelihoods and environmental sustainability. As climate change continues to threaten global and regional food production, adopting agroecological practices becomes essential for developing resilient, equitable, and sustainable food systems that can thrive under uncertain future conditions.



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Climate Change, Agriculture and Food Security-Implications and Way Forward

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Climate change refers to a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (UNFCCC). There are many external and internal causes of climate change. The external causes are all natural such as changes in solar activity / output, changes in earth's orbit or meteorites etc. The internal causes can be both natural and anthropogenic. The natural internal causes include volcanic eruptions and drifting continents etc. However, most of the climatic variations taking place now-a-days are occurring mainly due to anthropogenic causes such as urbanization, industrialization, burning of fossil fuels, deforestation and land use changes etc. Exponential increase in human population and vehicular pollution are increasing day-by-day.

All these human activities are leading to green house effect, global warming and resultant climatic variations. According to IPCC (2022), out of total net anthropogenic emissions by different sectors, 34% is contributed by energy supply sector, 24% by industrial processes, 22% by Agriculture, Forestry and Other Land Use changes (AFOLU), 15% by transportation fuels and 6% by building sector. CO₂ is mainly emitted by power stations (29.5%), industrial processes (20.6%), transportation fuels (19.2%) and residential, commercial and other sources (12.9%). Methane is mainly emitted from agricultural byproducts (40%), fossil fuel retrieval, processing and distribution (29.6%) and waste disposal and treatment (18.1%), whereas nitrous oxides are mainly contributed by agricultural byproducts (63%) and land use and biomass burning (26%).

As a result of anthropogenic activities, significant increase has been observed in the concentration of green house gases (Table 1). Historical measurements show that the current global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide are unprecedented compared with the past 800,000 years (EPA 2024).

Table 1. Major greenhouse gases and their characteristics

	CO ₂	CH ₄	N ₂ O	CFC's
Pre-industrial atmospheric concentration	280 ppmv	0.72 ppmv	280 ppbv	0
Current concentration	426ppmv	1.92ppmv	336ppbv	4.0 ppbv
Principal sources	Fossil fuel burning, Deforestation	Standing water in paddy fields, Dairy farming, Enteric fermentation	Biomass burning, Excessive use of fertilizers, Fossil fuel consumption	Refrigeration and air conditioning
Annual increase (%)	0.5 % (1.5 – 1.8 ppmv)	0.9 % (0.013 ppmv)	0.25 % (0.75 ppbv)	4 % (0.18 – 0.20 pptv)
Contribution to global warming	76%	16%	6%	2%
Global warming potential relative to CO ₂	1	24.5	320	4000
Atmospheric lifetime	100 years	12 years	114 years	100 years

Source: IPCC 2014, 2023



Carbon dioxide concentrations have increased substantially since the beginning of the industrial era, rising from an annual average of 280 ppm in the late 1700s to 426 ppmv recently. Almost all of this increase is due to human activities.

The concentration of methane in the atmosphere has more than doubled since pre-industrial times, reaching about 1.92 ppmv in recent years. This increase is predominantly due to agriculture and fossil fuel use (IPCC 2023). Over the past 800,000 years, concentrations of nitrous oxide in the atmosphere rarely exceeded 280 ppbv. However, its levels have risen since the 1920s, reaching a new high of 336 ppbv in 2022. This increase is primarily due to agriculture. Concentrations of many of the halogenated gases were essentially zero a few decades ago but have increased rapidly as they have been incorporated into industrial products and processes. Some of these chemicals have been or are currently being phased out of use because they are ozone-depleting substances, meaning they also cause harm to the Earth's protective ozone layer. As a result, concentrations of many major ozone-depleting gases have begun to stabilize or decline. Concentrations of other halogenated gases have continued to rise, however, especially where the gases have emerged as substitutes for ozone-depleting chemicals.

Overall, the total amount of ozone in the atmosphere decreased by about 4 percent between 1979 and 2020. All of the decrease happened in the stratosphere, with most of the decrease occurring between 1979 and 1994. Changes in stratospheric ozone reflect the effect of ozone-depleting substances. These chemicals have been released into the air for many years, but recently, international efforts have reduced emissions and phased out their use. Globally, the amount of ozone in the troposphere increased by about 12 percent between 1979 and 2020.

Green House Effect and Global Warming

According to IPCC (2022), global net anthropogenic GHG emissions have increased by 12% than 2010 and by 54% than 1990. All these gases are transparent to the short wave radiation received from the sun, but absorb the long wave radiation emitted by the earth. As a result, the heat energy emitted by the earth does not escape towards the upper atmosphere, but it is retained near the earth leading to global warming and hence, climate change. As a result, the Global mean temperatures have increased by more than 1°C during last 100 years and is likely to increase by 1.8-6.4°C by 2100 AD. Similarly, the annual maximum and minimum temperature in Punjab may increase by 2-3°C by 2050. The amount of GHGs in the atmosphere can influence global temperatures. Out of the total green house gas emissions, about 98% is contributed by CO₂ (76%), methane (16%) and nitrous oxides (6%) (Fig.1).

Carbon dioxide (CO₂) is an important heat-trapping gas, also known as a greenhouse gas, that comes from the extraction and burning of fossil fuels (such as coal, oil, and natural gas), from wildfires, and natural processes like volcanic eruptions. Methane (CH₄) is a powerful greenhouse gas, and is the second-largest contributor to climate warming after carbon dioxide (CO₂). A molecule of methane traps more heat than a molecule of CO₂, but methane has a relatively short lifespan of 7 to 12 years in the atmosphere, while CO₂ can persist for hundreds of years or more. Methane comes from both natural sources and human activities. An estimated 60% of today's

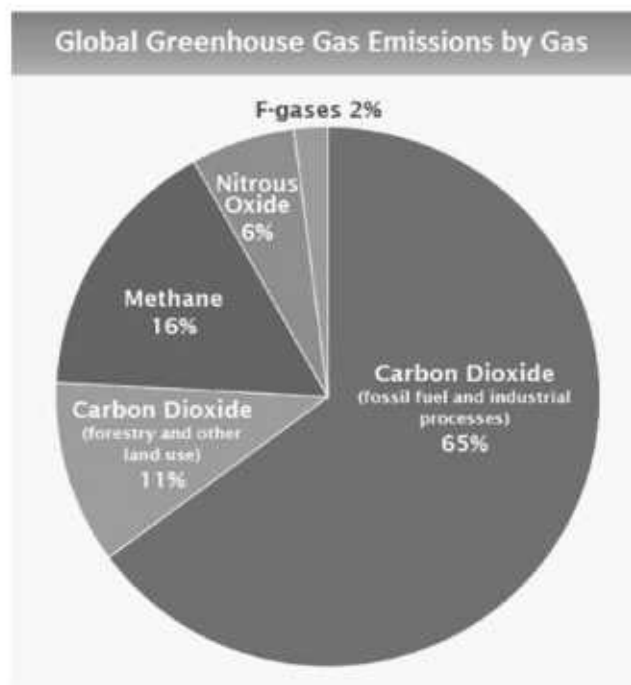


Fig. 1. Contribution to global warming by greenhouse gases from anthropogenic activities (IPCC 2014)



methane emissions are the result of human activities. The largest sources of methane are agriculture, fossil fuels, and decomposition of landfill waste. Natural processes account for 40% of methane emissions, with wetlands being the largest natural source. The concentration of methane in the atmosphere has more than doubled over the past 200 years. Scientists estimate that this increase is responsible for 20 to 30% of climate warming since the Industrial Revolution.

Global Climate Change

Global mean temperatures have increased by 1.17°C (2.11°F) since the pre-industrial levels. The oceans have absorbed much of this increased heat, with the top 700 meters of ocean showing warming of more than 0.4 °F since 1969. Glaciers are retreating almost everywhere around the world. Since 2002, Antarctic ice mass is shrinking @ 12.2% per decade (NASA 2024). Global sea level rose about 8 inches in the last century. Sea level rise during 1993-2024 has been observed to be 102 mm @ 3.3mm/yr. Frequency and intensity of extreme weather events has increased. Temperature is likely to increase by 1.8-6.4°C by 2100 AD (IPCC, 2014). The annual mean temperature over South Asia is projected to increase by 1.2°C, 2.1°C and 4.3°C under the low, medium and high emission scenarios by end century, relative to 1995-2014 climate (Almazroui et al 2020). Annual mean precipitation over South Asia is projected to increase by 8.7%, 11.6%, and 25.1%, under low, medium and high emission scenarios by end century. By the end of the twenty-first century, the annual mean temperature over India is projected to increase by 1.0-4.2 °C and precipitation by 9.3-27.3% under different emission scenarios. Frequency and intensity of extreme weather events is likely to increase. Sea level is projected to rise.

Climate Change in Punjab

The state of Punjab has also witnessed significant climatic variations during the recent decades. Rainfall patterns have become highly erratic and irregular. Since 2000, Punjab has witnessed only one year (2008) with above normal and nine years with below normal monsoon rains. Not only rain amount, but its distribution has also changed. There has been increase in intense rainfall events and decrease in the number of rainy days. Significant increase in minimum temperature (@ 0.05°C/year) has been observed in the state. Central Punjab has also witnessed significant increase in relative humidity (@ 1.3%) and decrease in wind speed (@ 0.67 km day⁻¹) and sunshine hours (0.03 hr day⁻¹). Decrease in sunshine hours especially during *kharif* season has been observed in all the agroclimatic regions along with decrease in number of frost days in the state. General circulation models are also predicting significant climatic variations in the region in future. The annual mean maximum temperature is projected to increase by 1.0-1.8°C and annual mean minimum temperature by 1.9-2.1°C by 2050, which may adversely affect the performance of crops. The annual average rainfall is projected to increase by 13.3-21.5 per cent by 2050 with more intense rainfall events.

Potential Impacts of Climate Change

Global warming and climate change are likely to impact all aspects of life including human beings, livestock and agriculture. Increasing intensity and frequency of extreme weather events can cause disasters, which may have severe implications on public health, agriculture and food security. It may also lead to increase in pest infestation, alterations in cropping patterns, water resources and forests. Increase in sea levels can adversely impact coastal areas. It can disturb natural habitats and may lead to extinction of species. It is also likely to impact energy sector and insurance industry. The crop yields in the tropical areas are specifically vulnerable to global warming, which is threatening food security in these regions (Fig. 2).



Fig. 2. Potential impacts of climate change

Increase in Extreme Weather Events

Global warming induced increase in the intensity and frequency of extreme weather events is highly detrimental to human beings, animals and crops. Global warming is likely to change the flow of ocean currents and the air circulation patterns resulting in changes in the weather patterns across the world. Due to this, the distribution of thermal energy may be altered causing unusual extreme weather conditions. As a result, a significant increase in extreme weather events such as floods, droughts, storms etc. has been observed. The frequency of cyclones, hurricanes, tornadoes etc. has also increased worldwide causing destruction over a large area. Similarly, the duration and frequency of severe heat and cold waves has also increased. The severe heat stress during March 2022 resulted in significant wheat yield losses in north-west India.

Public Health

Due to increase in the frequency and intensity of extreme weather events and disasters worldwide, the weather related mortality is likely to increase. As new viruses or even the older ones are re-emerging, it may also increase the incidence of infectious diseases. With travel becoming easier, the pace of virus transmission has also become rapid. So if any part of the world is affected by global warming, infections may spread faster without barrier. There have been several studies that link global warming and health conditions. According to WHO, climate change/global warming may cause additional 2,50,000 deaths per year worldwide. IPCC has reported that a rise in the global temperature by more than 2°C would have serious repercussions. Thus, if we continue without life style changes, then floods, droughts, storms and potable water shortages may all become more concentrated, more common and crop up in more places (Mahi and Kingra 2022).

Global warming may adversely affect public health. As it depends on factors such as sufficient food, safe drinking water, secure shelter as well as good social and environmental conditions, all these are severely affected under warm temperature conditions. Deteriorating air quality may lead to increase in respiratory illnesses. As a result, a large number of people might be exposed to deadly diseases. Due to rise in temperature and the distribution of insects, vectors that transmit diseases, various tropical diseases like dengue fever, malaria and yellow fever have been found spreading to higher altitudes and latitudes. Warm conditions are also favourable for increase in the concentration of ground ozone, which can cause irritation of the respiratory system and eyes. In addition to this, various vector borne diseases such as cardiovascular, respiratory diseases, malnutrition, diarrhoeal diseases and psychological disorders may erupt under global warming scenarios.

Pest Infestation

Large year to year rainfall fluctuations, warming scenarios and increase in extreme rainfall events are adversely affecting the incidence of insect-pests and hence crop productivity. These variations may affect the dynamics of insect-pest and disease in different crops such as more types and higher populations of insects, breakdown of resistance to certain insect-pests etc. Under warming scenarios, the conditions might become more favourable for the pests such as grasshoppers to complete a number of reproduction cycles. It may also lead to shifting of pests to new areas as pests can move to higher latitudes under rise in temperature. As a result, certain weeds, insects, bacteria and viruses may multiply rapidly and spread over more areas. This may also lead to transmission of diseases to the new areas adding to the risks of crop losses and creating havoc to the already stressed agricultural resources. For example, in North India, an increase in the overwintering range and population density of *Helicoverpa armigera* may increase damage to cotton resulting in significant economic losses. Similarly, the losses due to insect pests in wheat, which are at present minimal in North India, may increase as high as 15-20% in the new environment. The farmers in the south-western Punjab have also reported increase in the attack of thrips and mites in chilli.

Agriculture

Climate change has direct as well as indirect effects on agriculture. It directly affects crop yields due to variations in temperature, rainfall etc. and indirectly due to its effect on soil quality, pests and diseases etc. In



particular, yield of cereals is expected to decline in India, Africa and Middle East. Although under high levels of CO₂, the yield of major crops may increase, but associated increase in temperature is not favourable for plant growth. Although the adverse effect of rise in temperature up to 1°C may be neutralised by the higher concentration of CO₂, but warming beyond that has significant adverse impact on crop productivity. According to one of the estimates made by world bank, the temperature in India may rise by about 1.3°C during next 30 years. Under the warming conditions, the average land productivity may decline by about 17% across India. Higher yield losses are expected during *rabi* season. Studies also indicate that wheat production in India may experience a loss ranging from 4 to 5 million tones with each 1°C rise in temperature. High temperature conditions during reproductive period of wheat crop increases heat stress, disturbing the source and sink balance.

The monthly analysis of weather parameters in central Punjab has indicated highest increase in minimum temperature during the reproductive and maturity period of both *rabi* and *kharif* crops, which can lead to terminal heat stress and can have adverse effect on the productivity of these crops as observed during March 2022. Increase in temperature may lead to pollen sterility and forced maturity, thus declining yield quality and quantity. Maize is highly responsive to temperature and rainfall variations and high temperature cause reduction in its growing season, thus leading to yield reduction. Long-term data analysis has also indicated increase in rainfall during the month of September. It may be detrimental for cotton crop as it coincides with the maturity of cotton crop. Similarly, decrease in sunshine hours is likely to have adverse effect on photosynthetic activity and hence crop yield. Humid conditions are more conducive for insect and disease occurrence in the crops and hence may lead to reduction in crop yields.

Warming scenarios may also increase soil biological activity as well as physical and chemical processes, which may further lead to increase in fertilizer requirement of the crops due to its direct effect on nutrient availability and microbial activity. Climate change is also likely to affect the agricultural land. As snow cover is projected to shrink, hence arable land near the poles might increase. However, rise in sea level may result in losses in the agricultural land along with increase in submergence and salinity. Increase in intense precipitation may also result in flooding and erosion. Untimely rains may lead to lodging of the crop, thereby affecting the yield and quality. Increase in temperature and erratic rain patterns may also increase crop water requirements thus putting severe pressure on water resources. Climate change is likely to alter crop evapotranspiration and water use efficiency especially in the arid and semi-arid regions. Thus, climate change induced spatio-temporal changes in crop water requirements might affect irrigation scheduling, water resource planning and future decision making.

Cropping Pattern

Climate change is likely to bring about spatial shifts in cropping patterns. The areas which presently are adjudged to be most suitable for any crop, may no longer remain as such after climatic shift. Wheat belts may be replaced by barley, barley by maize, maize by soybean and so on. Similarly late maturing varieties of paddy, which require high temperature for cultivation, might be better suited to exploit new environmental conditions. It may also lead to shifts in the sowing time and length of growing seasons. Farmers in the south-western Punjab have reported that the sowing time of potato has shifted from September 10 to October 20 due to changing climatic patterns.

Forests

Forests play very important role to protect our environment and climate as they store about 80% of the above ground and 40% of the below ground carbon, which would otherwise be floating around in the atmosphere as carbon dioxide leading to green house effect and global warming. Forests are highly sensitive to climate change as forest distribution is generally limited by water availability or temperature. Thus climate change may lead to change in forest composition, shift in geographic range of forests as well as their health and productivity. It has been observed that a sustained increase of 1°C may cause substantial differences in the distribution of tree species. It may lead to irreversible losses in biodiversity. As tropical forests usually fulfill their large water requirements



from rainfall, thus decrease in rainfall and hence soil moisture can have adverse impacts on their growth and productivity.

Water Resources

Apart from increase in temperature, climate change is also expected to disrupt the distribution and intensity of rainfall events, which may result in the more frequent extreme weather events that may bring into more number of flood and drought events with increased intensity. Increase in sea level and glacier melting is another major challenge caused by the climate-change-led global warming. This may lead to changes in water supply, water quality and increased competition for water. The accessibility to quality drinking water is also projected to affect the millions with major impacts on the low-income population from the developing nations. Variability in precipitation directly affects droughts and floods resulting in detrimental consequences. Direct and indirect losses resulting from floods are continuously rising in India due to the country's large and dense population base. Floods are known to cause major losses to household items, machinery, transport and storage etc. In agriculture, they create the problem of water logging and soil erosion, etc., which results in partial or complete loss of agricultural produce. Livestock sector also gets badly affected due to floods. Water logging reduces the availability of oxygen to the plant roots which causes less root respiration and may result in the reduction of the cell permeability or even complete death of root cells. It also creates loss of nitrogen to the soil through the process of denitrification, nitrate leaching and runoff in addition to the soil nitrogen mineralization.

Livestock

The climate change has a great impact on livestock of any region. Climate change affects livestock production mainly due to its impact on feed quality, quantity, heat stress, water availability, livestock diseases and disease vectors as well as biodiversity including herbage and pasture composition. Climate change can have several impacts on feed crops and grazing systems due to changes in CO₂ concentration and temperature. Warming alters heat exchange between animals and environment, feed intake, mortality, growth, reproduction, maintenance and production. Heat stress declines physical activity, feed intake and milk production. It also decreases cow fertility, fitness and longevity. Generally hot environment impairs production (growth, meat and milk yield and quality, egg yield, weight and quality) and reproductive performance, metabolic and health status, and immune response. Thus, efficient livestock production systems under increasing temperature and extreme events require better information regarding biophysical and social vulnerability.

Industry

Climate change will have a significant impact on energy sector including thermal power stations, nuclear power plants and generation of hydroelectricity in addition to insurance industry as well as transportation. Oil and natural gas infrastructure is vulnerable to the effects of climate change and the increased risks of disasters such as storms, cyclones, floods and rise in sea levels. Thermal and nuclear power stations need fresh water for cooling as salt water can be corrosive, but climate change can increase the likelihood of drought and fresh water shortages. In addition, rise in temperature also reduce the efficiency and output of thermal power stations. Similarly, lower river flows because of drought, climate change or upstream dams and diversions, will reduce the amount of live storage in reservoirs, thus reducing the amount of water to be used for generation of hydroelectricity (Kukul and Kingra 2019). Insurance industry is also directly affected by the risks of climate change as insurance premiums rise due to increase in the weather disasters and become unaffordable for the people with lower income. Increasing costs related to insurance and disaster relief due to increase in frequency of severe climatic events burden the customers, taxpayers and the insurance industry. Similarly roads, airport runways, railway lines and pipelines (including oil pipelines, sewers, water mains etc.) may require increased maintenance and renewal as they become subject to greater temperature variations.

Coastal Areas

If the average global temperature continues to rise, then two important potential impacts of global warming



include the effects on sea levels and on the ecosystems. Recent estimates suggest that global sea level has risen by about 15cm during the 20th century, with most of the rise occurred since 1930. Some scientists believe that because of green house warming, average sea level may rise by atleast 30cm and as much as 1.4m by the year 2030. This is likely to cause extensive instability in the economic and social life in the coastal areas throughout the world. Climate change induced sea level rise may lead to inundation of coastal lands and erosion of beaches, which require heavy costs to defend coastal communities.

Species and Natural Habitats

Climate change represents an additional global threat to natural habitats, ecosystems and biodiversity stability in the long term. Extreme temperatures and increased frequency and intensity of precipitation or drought are known to directly affect species distribution, communities and ecosystem functions with indirect effect on food resources available for animals. Climate change may lead to shift in ecological zones along with loss of natural habitat and extinction of species. Natural habitats have been destroyed by anthropogenic activities for several decades, exacerbated by climate change. Rising temperatures and loss of natural habitats can make it difficult for species to adapt, leading to population decline. E.g. polar bears are losing their sea ice habitat, making it difficult to hunt and den. The biodiversity of south-east Asia has been under threat over the past decades and is expected to decline between 13 and 85% by 2100. The main threats include habitat loss and degradation owing to extensive logging, agricultural expansion and hunting pressure. The natural forests have been degraded both in lowland with a 50% loss over the past 20 years and in montane areas facing increased agricultural expansion.

Food Security

Climate change has emerged as the major risk to food security. Increased climatic risks such as floods, droughts and hurricanes etc. are expected to result in production and price volatility. The increasing risks from unpredictable weather patterns are likely to threaten food output levels. According to model predictions, under nutrition may lead to 62% increase in severe stunting in South and 55% increase in east and south sub-saharan Africa by 2025. According to IPCC, 200 to 600 million more people could suffer from hunger globally by 2028. The changes in production systems induced by climate change may induce changes in dietary patterns and food utilization. Hence, climate change will affect the stability and resilience of food systems with consequences in terms of long-term food security.

Agriculture plays a significant role in the nation's food security and economy especially in developing countries like India. Climate is the key factor having direct bearing on agricultural productivity. Thus, weather variability is the most important cause of year to year variability in crop production, even in high yielding and high technology environments. There has been considerable concern in recent years about the possibility of climatic changes caused by human activities, because any change in weather will increase uncertainty regarding food production. Alterations in our climate are governed by a complex system of atmospheric and oceanic processes and their interactions. In the context of crop production, relevant atmospheric processes consist of losses in beneficial stratospheric ozone concentration (O_3) and increasing concentrations green house gases viz. of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFC's) etc.

The crop growth and yield under normal conditions are largely determined by weather during the growing season. Thus, even minor deviations from normal weather conditions can lead to decreased efficiency of applied inputs and hence crop productivity. The most important meteorological factors influencing the development of crop plants are precipitation, temperature, radiation and sunshine duration. Different crops require all these weather parameters in optimum range for maximum growth and productivity. Any deviation from optimum, positive or negative, leads to decline in crop productivity, which is already being experienced due to changing climatic patterns over different parts of earth.

Mitigation / Adaptation Strategies

Thus, it is evident that climate change is going to affect all the social, health, economic and environmental



aspects of human life. However, the ability to predict how climate change may affect industry, settlement and society is limited by uncertainties about climate change and future developments in social and economic systems. Weak economic conditions and lack of infrastructure facilities in the developing countries have made the communities more vulnerable to climate change and extreme weather events. Similarly, children and elderly people are more vulnerable to climate change triggered health disorders. Thus, there is a great need to create awareness among the masses in relation to impending climate related risks and their management.

To manage climate change and its effects, usually two types of approaches are practiced i.e. mitigation and adaptation. Mitigation involves those measures, which are taken up to reduce the emissions of greenhouse gases, whereas adaptation measures deal with reducing the vulnerability of systems towards the effects of climate change. In other words we can say that mitigation addresses the causes while adaptation addresses the impacts of climate change. Thus, in view of the effects of climate change, there is dire need to adopt mitigation (preventive) and adaptation (protective) strategies to combat the situation.

Mitigation

Mitigation aims at reducing the climate change by reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing sources of these gases (such as the burning of fossil fuels for electricity, heat, or transport) or enhancing the sinks that accumulate or store these gases (such as the oceans, forests, and soil). The major goal of mitigation is to avoid significant human interference with Earth's climate and stabilize the greenhouse gas levels in a time frame sufficient to allow ecosystems to adapt naturally to climate change and ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner. Thus, practically mitigation means implementing policies to reduce GHG emissions and enhance sinks. Different mitigation measures to reduce the emissions of greenhouse gases are as following:

- Use of more efficient renewable energy
- Electrification of industrial processes
- Efficient means of transportation viz. electric public transport, bicycle, shared vehicles etc.
- Carbon tax and emissions markets
- Nutrient management in agriculture: Application of N fertilizers is possibly the largest human-induced source of N_2O emissions in developed countries. N_2O has approximately 300 times the radiative forcing as that of CO_2 . Build-up of N_2O and CH_4 in the atmosphere through enteric fermentation in ruminants, manure management and standing water in paddy.
- Efficient water management in rice instead of standing water viz. intermittent wetting and drying, direct seeding etc.
- Improved crop and grazing land management to increase soil carbon storage
- Restoration of cultivated peaty soils and degraded lands
- Improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions
- Improved nitrogen fertilizer application techniques to reduce N_2O emissions
- Dedicated energy crops to replace fossil fuel use
- Improved energy efficiency
- A large proportion of the mitigation potential of agriculture (excluding bioenergy) arises from soil carbon sequestration, which has strong synergies with sustainable agriculture and generally reduces vulnerability to climate change
- Considerable mitigation potential is also available from reductions in methane and nitrous oxide emissions in some agricultural systems
- Biomass from agricultural residues and dedicated energy crops can be an important bioenergy feedstock, but current concerns with food prices make this a questionable alternative.
- Forest-related mitigation options can be designed and implemented to be compatible with adaptation, and can



have substantial co-benefits in terms of employment, income generation, biodiversity and watershed conservation, renewable energy supply and poverty alleviation.

The introduction of more efficient cooking stoves and industrial processes could reduce fuelwood requirements by 25-70% at a low investment cost and contribute to reduced GHG emissions. The use of mass transport and discarding personal transport can definitely reduce CO₂ emission and clean the environment of our choked cities substantially. As the forests act as sinks of CO₂, so they must be conserved to enhance the capacity to fix and store carbon. The development and expansion of non-wood products may provide increased incentives to maintain and protect forests and thus to mitigate the impacts of climate change to some extent. As its repercussions are very important for the future welfare of mankind, hence the general public needs to be made aware of it and the governments world-wide should work-out plans and policies to contain the global warming and climate change.

Use of biofuels and natural sources of energy (solar, wind and hydroelectric energy) should be preferred to check the emission of green house gases to the atmosphere rather than fossil fuels. Techniques of carbon sequestration need to be developed and adopted at field level. Intermittent wetting and drying in paddy fields is another option to minimize CH₄ emission from paddy fields. Instead of burning straw, in-situ crop residue management should be encouraged to enrich soil organic matter to maintain soil health and to check the emission of gases to the atmosphere.

Adaptation

Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes. The Intergovernmental Panel on Climate Change defines adaptation as adjustments in natural or human systems in response to actual or expected climatic stimuli or effects, which moderates harm or exploits beneficial opportunities. It also refers to actions that people, countries, and societies take to adjust to climate change that has occurred. Adaptation has three possible objectives: to reduce exposure to the risk of damage; to develop the capacity to cope with unavoidable damages; and to take advantage of new opportunities. While AR4 focused on climate change, future impacts, and potential adaptation strategies, the main determinant of agricultural production is still the seasonal variation of temperature, precipitation, sunshine, etc. Droughts, floods, frost-freezes, and heat waves affect both crops and livestock. It is the changing frequency of these events due to climate change that is the concern. Different adaptation measures to reduce vulnerability to the effects of climate change are as following:

- Restoration of natural landscapes
- Reforestation
- Diversified cultivation to be prepared for natural catastrophes
- Research and development on possible catastrophes, temperature behavior, etc.
- Changing planting dates
- Planting different varieties or crop species
- Development and promotion of alternative crops
- Developing new drought and heat stress resistant varieties
- More use of intercropping
- Using sustainable fertilizer and tillage practices (improving soil drainage, no-till, etc.)
- Improved crop residue and weed management
- More use of water harvesting techniques
- Better pest and disease control for crops
- Implementing new or improving existing irrigation systems
- (Reducing water leakage, soil moisture conservation - mulching);
- Planting of drought resistant varieties of crops
- Crop diversification



- Change in cropping pattern and calendar of planting
- Mixed cropping
- Improved irrigation efficiency
- Adopting soil conservation measures that conserve soil moisture
- Planting of trees (afforestation) and agroforestry
- More use of agroforestry practices
- Improved forest fire management (altered stand layout; landscape planning; dead timber salvaging; clearing undergrowth; insect control through prescribed burning)
- Development of early-warning systems and protection measures for natural disasters (droughts, floods, tropical cyclones, etc)
- Improved livestock management (Providing housing and shade, change to heat-tolerant breeds, change in stocking rate, altered grazing and rotation of pasture)
- Livestock management systems and capacity building for livestock keepers
- Management practices to increase fertiliser use efficiency i.e. fertiliser placement / schedules
- Increase fuel efficiency in agricultural machines
- Improvement in irrigation efficiency of crop plants
- Evolving suitable crop management practices like cultivation of short duration, temperature resistant and low water requirement varieties
- Manipulation of crop microclimate by means such as wind breaks, mulches to reduce the effects of climate change

Adaptation strategies in agriculture is need of the hour to mitigate the impact of climate change and to reduce the emission of green house from agriculture sector. Planting date adaptations have been found effective to mitigate the negative impacts of temperature and precipitation change on many crops. Similarly, intermittent wetting and drying of soil in case of paddy instead of continuous wetting has a potential to reduce the emission of methane. Efficient crop residue management, fertilizer and irrigation management and techniques like zero tillage can be of great help in reducing green house gas emission and saving water and energy. The emission of CO₂ can also be reduced by using hydro, solar and wind energy sources for generating power. Techniques for harnessing these energy sources should be developed to substitute fossil fuels and check the emission of green house gases. Breeding and screening of cultivars able to withstand the climatic stresses in future in the need of the hour to meet the continuously increasing demand of food by the ever-increasing population. For this, plant breeders, crop physiologists, agronomists and agrometeorologists need to work together to find long-term viable solutions towards sustainable agriculture.

Breeding of short duration as well as heat and water stress resistant varieties need to be developed and the inclusion of early maturing, high yielding and heat tolerant wheat lines should be made in the breeding program under Indian conditions. Resource conservation technologies like direct seeding of rice, integrated nutrient management, bed planting in wheat, use of laser land leveler, tensiometer, leaf colour chart etc. need to be adopted. Accurate and timely weather forecasts and agro-advisories should be available to the farmers for short and long term agricultural planning. Farmers must have awareness and ability to adjust to the impending weather changes by adopting suitable farming practices. Efficient use of water and fertilizers should be made for enhancing input use efficiency and sustainability of agriculture under changing climatic conditions.

No doubt, the climate change will affect the crop productivity but due to the complexity of crop environment interactions, a multidisciplinary approach to the problem is required in which plant breeders, crop physiologists, agrometeorologists, agronomists, entomologists and plant pathologists need to interact for finding long term solutions for sustaining agricultural production and attaining food security under future climate change scenarios. There is a need for integration of mitigation and adaptation frameworks into sustainable development planning. Addressing climate change should be considered an integral element of sustainable development policies.



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Organic Farming: Advancing Sustainability and Resilience in Modern Agriculture

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Agriculture is the backbone of the Indian economy, but the prolonged use of synthetic fertilizers has resulted in significant environmental challenges. These issues have encouraged farmers to consider alternative methods such as organic farming. This sustainable approach not only addresses the food and nutritional needs of the population but also conserves natural resources. By combining organic inputs with high-yielding crop varieties and modern technologies, India has managed to enhance food production while simultaneously reducing environmental pollution, pesticide toxicity, and improving the sustainability of agricultural practices. Organic farming also contributes to soil enrichment by providing essential macro and micronutrients, and it improves the physical, chemical, and biological properties of the soil. To overcome the limitations and challenges of organic farming, it is vital to integrate advanced technologies. Innovative techniques and new approaches are leading the way toward sustainable farming systems that increase agricultural productivity and improve the quality of life for many farmers in an environmentally responsible manner. Despite its potential, organic farming requires significant support in the form of subsidies, agricultural extension services, and research to ensure its widespread adoption. A gradual approach is recommended for the successful implementation of organic farming, focusing on strategies that ensure an adequate supply of organic fertilizers. This can be achieved by enhancing production and availability through a well-developed distribution system across the country, thereby making organic farming a viable and scalable solution for India's agricultural future.

Introduction

Agriculture is the foundation of human activity, involving both the cultivation of crops and the domestication of animals. Agricultural land is, therefore, one of the most essential resources on Earth, providing food and shelter for the global population. Agriculture plays a vital role in the household economy on a global scale. People depend on agriculture to provide food for their families, generate income, and even start small businesses (Dorosh and Thurlow 2018, Abhilash et al 2022). While agriculture is less commonly relied upon for income in affluent countries, its benefits extend to everyone, directly or indirectly. The increasing global demand for agricultural products has also created diverse employment opportunities (Mathlouthi et al 2022). Modern agriculture is a continuously advancing field that incorporates innovative agricultural techniques and farming practices, utilizing high-yielding seed varieties, chemical fertilizers, irrigation systems, pesticides, etc. (Gamage et al 2021). The Green Revolution has led to major advancements in agricultural technology and policies aimed at boosting food production to meet the needs of a rapidly growing global population. While the use of chemical fertilizers, herbicides, insecticides, and pesticides has increased food availability and production, consumers have become more quality-conscious in recent years, seeking ecologically safe, chemical-free, and healthful foods (Chander et al 2011). To meet the ever-growing food demands, many countries are increasingly pressured by population growth to use pesticides and fertilizers to enhance farm productivity. However, the excessive and prolonged use of these chemicals has resulted in environmental pollution and health risks for both people and soil. As a result, farmers in affluent nations are being encouraged to transition their conventional farms to organic farming. The demand for organic food is primarily driven by consumers' health consciousness and their willingness to pay a



premium for higher-quality products. Typically, buyers of organic products are well-educated, health-conscious, and affluent, motivated by strong consumer demand, a significant price premium, and environmental concerns. These benefits have made organic farming increasingly attractive to traditional farmers.

Organic farming presents a viable option for safeguarding the quality of food, air, water, and soil, ensuring a safe environment for both current and future generations. Long-term field studies have highlighted the detrimental effects of continuous chemical fertilizer use on soil health. Organic farming practices emphasize the management of soil organic matter to improve the soil's chemical, biological, and physical properties, ultimately optimizing crop production (Manida, et al 2020). Effective soil management regulates nutrient availability for crops, which in turn supports livestock and human nutrition. Additionally, soil processes play a crucial role in controlling weeds, pests, and diseases. A key distinction between organic and conventional farming systems lies in their problem-solving approaches. Conventional agriculture often focuses on short-term, targeted solutions, such as applying soluble fertilizers or herbicides (Tudi et al 2021). In contrast, organic systems adopt a different strategy, emphasizing long-term, preventative solutions at the systems level. An example of this approach is the careful design of crop rotations to enhance nutrient cycling, conserve resources, and manage weeds, pests, and diseases.

Organic farming is essential not just from the consumer's perspective but also from the farmer's viewpoint. It has the potential to transform rural agriculture into a sustainable model, serving as a key solution for achieving long-term agricultural sustainability. By promoting organic farming, we can establish a foundation for sustainable agriculture, offset conversion costs, and ensure the continued health of the soil (Yadava 2017). This review aims to evaluate the existing literature on organic farming, focusing on the challenges and issues farmers encounter when adopting organic farming practices, as well as the strategies for effective implementation.

What is Organic Farming?

Numerous studies argue that excessive conventional farming can lead to contamination across the entire food chain, highlighting the importance of adopting safer and more sustainable practices, such as organic farming. Organic farming is a distinctive practice that not only promotes environmental sustainability but also mitigates harmful effects, thereby developing a positive perception among consumers regarding their safety (Mendon et al 2019). The International Federation of Organic Agriculture Movements (IFOAM) defines organic farming as an agricultural method that relies on ecologically based bio-fertilizers and pest control, primarily derived from plant and animal waste, as well as organic manure (Das et al 2020). Essentially, organic farming focuses on natural methods for growing crops and raising animals, in contrast to conventional farming, which predominantly uses synthetic pesticides and chemical fertilizers. According to Elayaraja and Vijai (2021), organic farming can ensure the production and consumption of eco-friendly and genuine food products, embodying environmentally conscious farming practices. Dey et al (2021) emphasizes that organic farming utilizes biological inputs to maintain and enhance soil fertility and ecological balance, thereby reducing waste and pollution while promoting human health. Both developing and developed nations are increasingly focusing on the environmental sustainability of agricultural production, methods, and practices (Olveira et al 2023).

Principles of Organic Farming

Health: Organic agriculture should enhance and maintain the well-being of the land, plants, animals, humans, and the planet as a whole.

Sustainability: It should be grounded in living ecological systems and cycles, supporting and aligning with the natural processes to ensure their continuity.

Equity: Organic agriculture should foster fair interactions with the environment and create equal opportunities for all life forms.

Safety: It must be conducted in a responsible and secure manner, safeguarding the health and well-being of current and future generations, as well as protecting the environment.

Conventional Farming v/s Organic Farming



The primary distinction between conventional and organic farming lies in their approach to pest and weed management. Conventional farming relies on chemical products to control these issues, while organic farming excludes chemical interventions and instead employs techniques such as crop rotation, mulching, composting, and green manuring to produce food free from chemicals. Conventional agriculture accelerates productivity through the use of chemical fertilizers, which is appealing to farmers due to the rapid results. However, the toxic elements in these fertilizers and pesticides can accumulate in the produce and potentially cause serious health problems for consumers. Additionally, these chemicals negatively impact the environment by leaving residual effects on soil and air. In contrast, organic farming may take longer to achieve optimal productivity but offers a viable alternative to conventional methods. It avoids pollution and protects human health, adhering to the principle that health is invaluable. Organic farming contributes to lower carbon emissions and aids in restoring natural soil properties. The use of compost or vermicompost enhances soil characteristics, such as organic matter content, buffering capacity, and cation exchange capacity. Crop rotation not only preserves soil fertility but also helps reduce pest and disease occurrences by interrupting the disease cycle.

Growing food organically tends to be more expensive than conventional farming. However, over time, the costs for both methods tend to level out due to the higher market prices for organic products. In the initial two to three years, organic farmers may not see significant revenue gains, but after this transition period, organic farming often becomes more profitable than conventional methods. Research indicates that organic farming can be nearly three times as profitable as conventional farming. Organic farming involves higher labour costs compared to conventional farming, but it eliminates the expenses associated with purchasing chemical fertilizers, pesticides, and GMOs. As a result, the overall cultivation costs for both methods eventually align. Additionally, organic farming utilizes available farm materials efficiently, minimizing waste. Organic foods tend to be more expensive due to higher demand relative to supply. The price of organic products reflects not only production costs but also factors such as food security and environmental impact. Post-harvest handling of organic foods, which involves separating them from conventional produce for processing and transportation, further contributes to higher prices. Additionally, the marketing and supply chain for organic products are less efficient, leading to increased costs. A study on the resilience of organic crops found that organic corn yields were 31 percent higher than conventional yields during drought conditions. Furthermore, organic varieties outperformed genetically modified 'drought-tolerant' varieties. In terms of energy efficiency, organic farming is superior to conventional methods. Organic systems use 45 percent less energy overall, while conventional farming's energy costs are largely driven by nitrogen fertilizers, which account for 41 percent of energy expenses. Organic farming requires 84 percent more land than conventional farming to achieve equivalent yields. This is primarily due to nutrient limitations, and sometimes due to challenges with weeds, diseases, or pests. Organic farming prioritizes the conservation of natural resources and biodiversity. Organic farmers use natural methods to enhance the population of beneficial insects and control harmful ones. While modern agricultural techniques have advanced the sector, they often replace human labor with machinery and chemicals, contributing to unemployment issues. In countries like India, where unemployment is a significant concern, organic farming offers a sustainable solution by preserving the natural ecosystem and creating employment opportunities.

Need for Organic Farming

Sustainability has become a key focus across all sectors worldwide, with organic farming playing a leading role in agriculture. The organic lifestyle is increasingly becoming a central concern in the 21st century, as it seeks to benefit human health and the environment. Elayaraja and Vijai (2021) point out that embracing organic farming is essential for reducing reliance on chemical pesticides and fertilizers. This approach prioritizes natural techniques for managing weeds and pests, avoiding the harmful residues that chemical methods can leave in food and products, which could negatively affect human health and the planet. Kumari and Raj (2020) also concludes that



adopting organic farming is vital for environmental protection. The pressing global issue of climate change highlights the imminent threats to our environment, underscoring the need for practices like organic farming in agriculture to maintain a healthy and unpolluted ecosystem. In this context, ecological farming methods play a crucial role in supporting biodiversity, unlike conventional farming practices. Karunakaran (2021) further stresses that organic farming can enhance the nutritional value of foods compared to conventional farming methods. Recent research has shown that organic ingredients contain substantially higher levels of antioxidants and other beneficial compounds that offer health advantages, such as anti-inflammatory effects (Madhavi et al 2021). Additionally, organic farming empowers local producers while safeguarding their environment from harmful chemicals (Kumara et al 2015). The growing demand for organic foods allows farmers who produce them to meet market needs and reap the associated benefits. Purchasing organic products ensures that their production does not harm local communities or their environments. Moreover, organic farming is effective in avoiding genetically modified organisms (GMOs), as it relies on natural practices instead of GMOs, reducing the risk of health and environmental issues linked to GMOs. Consequently, organic farming offers significant advantages for both people and the planet, making it a crucial practice to promote for sustainable living.

Methods of Organic Farming

Organic farming employs a diverse array of methods designed to ensure ecological balance and sustainability in agricultural practices. Unlike conventional farming, which often relies on synthetic chemicals and monocultures, organic farming focuses on enhancing soil health, promoting biodiversity, and reducing environmental impact through natural and holistic techniques. Key methods include crop rotation, which helps maintain soil fertility and control pests; companion planting, which supports beneficial plant relationships; and organic fertilizers, which enrich the soil with natural nutrients (Soni et al 2022). Other practices such as cover cropping, mulching, and integrated pest management work in harmony to create a resilient farming system that not only produces healthy crops but also preserves and restores the natural environment (Bhujel and Joshi 2023). Through these approaches, organic farming aims to create a sustainable agricultural model that benefits both the land and the people who depend on it.

Crop Rotation and Intercropping

In organic agriculture, which emphasizes maintaining soil health and enhancing biological activity, practices such as crop rotation and intercropping are essential for improving soil quality and vitality. Crop rotation involves planting different crops in various sections of a farm to avoid the continuous cultivation of the same crop in one area. This method helps preserve soil structure, improve nutrient levels, and reduce soil-borne pests. Intercropping, on the other hand, involves growing multiple crops simultaneously in the same field. This technique enables farmers to grow at least one high-value crop while also using the combination of crops to control weeds and minimize soil erosion (Yadava 2017). Both methods contribute to a more resilient and productive agricultural system by enhancing soil health and promoting ecological balance.

Integrated Pest Management (IPM)

IPM seeks to manage pest populations to levels that do not cause significant economic damage. IPM involves a comprehensive approach that integrates various control strategies based on ecological principles. This includes biological and cultural methods for managing pests. Practices associated with IPM encompass crop rotation, strategically scheduling planting and harvesting times, and creating environments that support beneficial organisms. These measures work together to keep pest populations in check while minimizing the impact on the ecosystem.

Soil Fertility

Organic soil fertility is defined as "the use of natural materials and the harnessing of biological processes to supply essential nutrients to the soil." Several methods to enhance and maintain soil fertility organically include the application of bio-fertilizers, organic manures, and vermicomposting.



Biochar with Organic Fertilizers

Biochar is produced from a range of carbon-rich materials, including animal waste, food waste, sludge, industrial byproducts, wood chips, agricultural residues, and forestry byproducts, each with distinct chemical and physical properties. Various technologies are employed in the production of biochar, such as torrefaction, pyrolysis (slow, fast, and intermediate), hydrothermal carbonization, gasification, and flash carbonization. Among these, pyrolysis is the most commonly used method for converting biomass into biochar (DeLuca and Gao, 2019). In agriculture, both organic fertilizers and biochar amendments are utilized to enhance soil properties and boost crop yields. Zhang et al (2020) highlighted the significant role of plant roots in plant functions, noting that while organic fertilizers and biochar affect root systems, the specific impacts on root morphology and physiology are not fully understood. Gamage et al (2023) found that compost from anaerobically digested rice straw and urea coated with rice husk biochar substantially improves soil nutrient content. Additionally, biochar-fertilizer mixtures, whether with chemical or organic fertilizers, tend to perform better in terms of yield and plant nutrition compared to using pure fertilizers. Combining chemical fertilizers with biochar or using biochar alongside organic fertilizers can serve as a slow-release fertilizer and help reduce the pollution of water bodies caused by inorganic fertilizers (Glaser et al 2015; Agu et al 2022; Gamage et al 2023).

Biofertilizers

Biofertilizers are products that contain one or more species of microorganisms capable of mobilizing essential nutrients through biological processes. These processes include biodegradation in soil, composting, nitrogen fixation, phosphate solubilization, and the release of plant growth-promoting substances or cellulose. Biofertilizers are natural fertilizers composed of living microbial inoculants, such as bacteria (e.g., free-living nitrogen-fixing bacteria like *Azotobacter* and *Rhodospirillum*), algae, and fungi, either individually or in combination, to enhance nutrient availability for plants. Combining decomposed organic materials with plant growth-promoting bacteria offers an environmentally friendly alternative that reduces the need for chemical fertilizers in crop production. Kumar et al (2017) demonstrated that using bio-organic fertilizers improved soil organic carbon by 6-13% and increased the population of plant growth promoting bacteria compared to relying solely on chemical fertilizers. Furthermore, bio-organic fertilizers can help cut chemical nitrogen use by 30% and eliminate the need for triple superphosphate (TSP) in rice cultivation. The use of biofertilizers thus plays a significant role in decreasing the reliance on chemical fertilizers and mitigating their detrimental effects on soil health (Kumar et al 2017). Additionally, mycorrhizae, a symbiotic relationship between fungi and plants, is a key aspect of sustainable organic farming (Kunal et al 2020). Soni et al (2022) describe biofertilizers as "preparations containing either live or latent cells of beneficial microorganisms that enhance nutrient uptake by crops through their interactions in the rhizosphere when applied to soil or seeds."

Organic Manure

Organic manures are natural materials farmers use to provide essential nutrients for crops (Dey et al 2021). These manures come in several forms, such as green manures, farmyard manures, vermicompost, biological

Table 1. Nutrient content of some organic manure

Sources	Nutrient content		
	N	P ₂ O ₅	K ₂ O
FYM/Compost	0.5-1.0	0.15-0.20	0.5-0.6
Poultry manure	2.87	2.90	2.35
Cattle dung	0.3-0.4	0.10-0.15	0.15-0.2
Sheep and goat manure	0.65	0.05	0.03

Source: Nazir et al 2016



wastes, compost manures, and oil cakes. They are crucial in enhancing soil organic matter, increasing the soil's ability to retain water, and improving drainage.

Sludge

Sludge is a semi-solid slurry generated from various industrial processes, water treatment, wastewater treatment, or on-site sanitation systems. It contains valuable organic matter and nutrients like nitrogen and phosphorus, making it a useful resource for improving soil fertility. Table 2 presents several studies examining the use of wastewater treatment plant sludge for enhancing soil.

Vermicomposting

Vermicomposting is an essential practice that enhances physical, biological, and chemical properties of soil.

Table 2. Usage of sludge and importance

Uses of sludge	Importance
Organic mineral fertilizer	Sustainable use of locally available renewable resources and the provision of low-carbon nitrogen supply.
Application of sewage sludge soil	Sewage sludge provided certain micronutrients and nitrogen to maize plants more effectively.
Mineral fertilizer in maize crop	Sewage sludge can be used to enhance plants' nitrogen reserves, particularly during silking, improve nitrogen translocation to grains, and support nitrogen uptake after silking.
Organo-mineral fertilizer based on olive waste sludge	Organo-mineral fertilization is an effective approach for improving the efficiency of both low-phosphorus and high-phosphorus mineral fertilizers in alkaline soils, through direct and indirect mechanisms that enhance soil properties and increase phosphorus solubilization.
Sewage sludge as manure	N content- 2.0-3.5%, P_2O_5 content- 1.0-5.0%, K_2O content- 0.2-0.5%
Phosphorus sources for organic agriculture	A study in Germany found that recovered phosphorus has the potential to replace 43% of the demand for commercial fertilizers.
Valuable agricultural products	Its high levels of phosphorus and nitrogen make it particularly well-suited for use as a fertilizer.
Application of sludge on cropland	Sustainable management practice
Gamma-irradiated sludge as fertilizer	The material was comparable in quality to conventional fertilizers.
Phosphate fertilizer from sewage sludge ash	The plant uptake efficiency of fertilizer produced from sewage sludge ash is equivalent to that of standard phosphate fertilizers.
Sewage sludge ash as a phosphorus source for fertilizer production	The plant uptake efficiency of fertilizer made from sewage sludge ash has been demonstrated to be on par with that of standard phosphate fertilizer.
Organo mineral fertilizer	Comparable crop yield response as conventional fertilizers
Sewage sludge as organic fertilizer	Increase the economic yield of wheat while improving soil productivity.
Gamma irradiated sewage sludge as fertilizer in radish	No significant differences were observed between the fertilizer sources. The levels of metallic micronutrients and heavy metals in the soil remained below the limits recommended by the US Environmental Protection Agency (USEPA), and even after two years of higher application rates, no notable changes were detected.
Sewage sludge for fertilizer	It offers a promising solution for managing sewage sludge, enabling the Zywiec wastewater treatment plant (WWTP) to recycle 42-73 tonnes of nitrogen (N) and 82-140 tonnes of phosphorus (as P_2O_5) annually.

Source: Gamage et al 2023



Vermicomposting involves converting biodegradable waste into organic manure using earthworms, resulting in compost production that is quick, odorless, and requires no pile turning. Earthworms are cultivated in a mix of animal waste, soil, agricultural residues, or decomposed leaf litter. This mixture is transformed into vermicompost, which serves as an organic fertilizer for various types of plants. Zhou et al (2023) highlighted the versatility of different earthworm methods and the role of earthworms and microbes in the composting process. Their study found that these methods effectively control and reduce pathogenic genes, harmful microbes, and greenhouse gases, while preserving and enhancing soil nutrition. However, they also noted that there are still several limitations and areas for improvement in composting and vermicomposting technologies, which merit further investigation by future researchers. Olle (2019) describes vermicomposting as "a process that uses earthworms to transform organic materials into a humus-like substance." Numerous studies agree that vermicompost has a superior nutrient profile compared to traditional compost, making it an effective method for enriching soil nutrients, increasing productivity, and improving soil structure.

Bio-pesticides: Das et al (2020) and Dey et al (2021) explain that biopesticides are biological agents that produce toxins harmful to pests that attack crops. For example, secondary metabolites like alkaloids, terpenoids, and phenolics can combat, repel, and eliminate fungi, insects, nematodes, and other pests. Examples of biopesticides include substances such as nicotine, pyrethrum, margosa, and neem.

Organomineral fertilizers: They combine organic and mineral components and can be formulated with various proportions of nitrogen (N), phosphorus (P), and potassium (K) to meet crop needs. These fertilizers can be produced in granulated, pelleted, or powdered forms. They enhance soil fertility by improving soil physicochemical properties, increasing nutrient availability, enhancing water retention, and promoting phosphate solubilization. Additionally, organomineral fertilizers boost plant agro-physiological traits, leading to increased plant biomass and yield, better nutrient uptake, and improved physiological metabolism (Crusciol et al 2020).

Waste management: Kumari and Raj (2020) assert that waste management techniques like organic waste recycling and composting play a vital role in enhancing various soil properties. Organic farming offers an effective means to manage household and agricultural waste, often utilizing processes such as anaerobic digestion, composting, and thermochemical treatments. These methods reduce the reliance on conventional chemical pesticides, fertilizers, and other energy sources. Managing organic waste in this way boosts biological activity and improves soil pore structure, leading to a positive environmental impact.

Digital technology: Digital technology and tools offer organic farmers the ability to monitor and optimize crop and animal health, enhance resource efficiency, minimize environmental impact, and boost farm profitability. These technologies can be applied across various aspects of organic farming, including tillage, irrigation, fertilization, postharvest handling, storage, and transportation of farm products. While advanced digital technologies are predominantly utilized by large-scale farmers and play a significant role in promoting sustainable agriculture, they hold the potential to alleviate poverty and food insecurity among smallholder farmers globally. However, current digital services for smallholder organic farmers lack long-term sustainability. Future improvements are needed to enhance their economic and environmental sustainability (Mushi et al 2022).

Status of Organic Farming in India in the World Scenario

India, the second-most populous nation globally, has a large portion of its population dependent on agriculture for their livelihood. To sustain soil fertility and ecological balance, Indian farmers are increasingly turning to organic farming instead of traditional methods. They utilize farm, animal, and aquatic waste as fertilizers to promote soil health and preserve the environment. Asia ranks fourth globally in the land area dedicated to organic farming. Oceania has the highest organic share of total agricultural land by region at 55.2 percent, followed by Europe at 19.1 percent, and Latin America at 9.9 percent. Within the European Union, the organic share of total agricultural land is 19.1 percent, although several individual countries exceed this percentage. India has 4.73

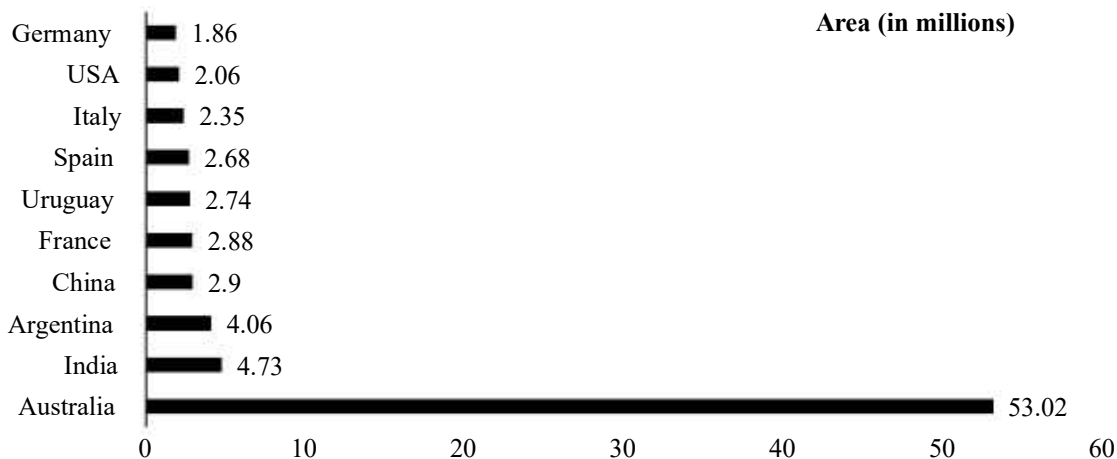


million hectares under organic farming, placing it in second position worldwide (Fig. 1).

India leads the world in the number of organic farmers, with 24,80,859 producers, followed by Uganda and Thailand. Moreover, over 93 percent of organic producers were located in Asia, Africa, and Europe. Compared to 2021, the number of producers grew by more than 9,19,000, or 25.6 percent. The number of producers increased in Asia, Europe, and Oceania, while Africa, North America, and Latin America experienced a slight decline in 2022 (Fig. 2).

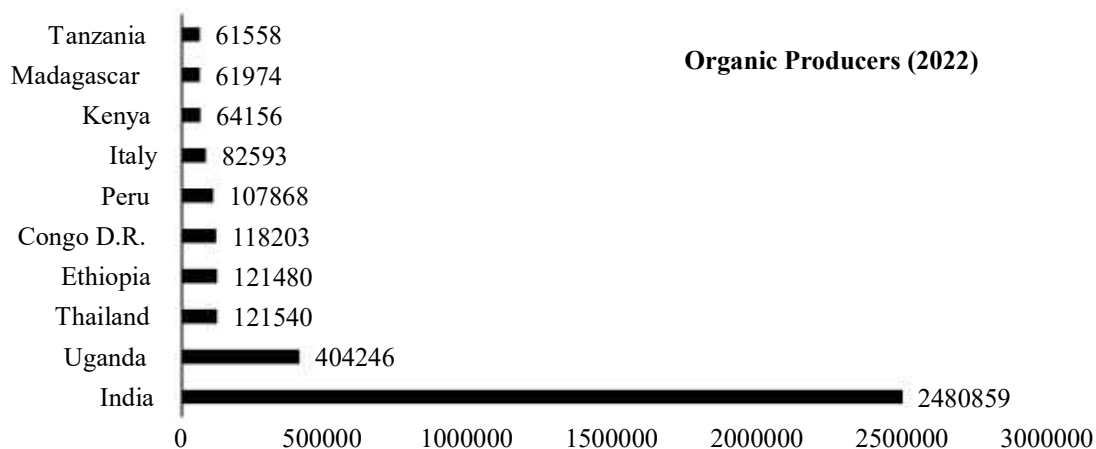
Status of Organic Farming in India

India's economy is largely driven by agriculture, which significantly contributes to the country's employment and GDP. This sector has historically been the primary source of livelihood for a large portion of the population, with more than half of the workforce engaged in agricultural activities. India's diverse topography, climate, and soil have encouraged a wide variety of agricultural practices. Major crops such as rice, wheat, pulses, and cotton are extensively cultivated across the country. In response to the negative effects of chemical fertilizers on the land, the government has initiated various programs, offered training, and implemented schemes to promote organic farming. The rising awareness of health concerns and the growing preference for organic products among consumers has increased the demand for organic farming, prompting Indian farmers to adopt these practices.



Source: FiBL 2024

Fig. 1. Countries with highest organic agricultural land



Source: FiBL 2024

Fig. 2. Top ten countries with most organic producers



According to the latest data from NPOP India, the country has 1,764,677 hectares of organic farmland, 3,627,116 hectares of land in the process of conversion to organic farming, and 4,780,131 hectares designated as wild harvest areas. Madhya Pradesh leads the nation in land dedicated to organic agriculture, with a total area of 1,517,377 hectares, including 6,86,208 hectares that are fully organic and 8,31,169 hectares currently in conversion followed by Madhya Pradesh are Rajasthan, Gujarat, and Maharashtra. Sikkim holds the distinction of being the first state in India to adopt 100% organic farming practices.

India leads the world in the number of organic producers, including companies and grower groups, and ranks sixth globally in terms of land dedicated to organic farming. However, the domestic market for organic products has been relatively small, leading to the majority of these products being exported to regions with high demand, such as the EU, USA, and Canada. Indian organic products have a significant market in the European Union, which imported 117,370 million tons of organic goods valued at Rs 2,726 crore in 2022–2023. The United States ranks second, importing 126,805 million tons of organic products worth Rs 2,041 crore. Switzerland, Canada, and Great Britain also rank highly in the import of Indian organic goods.

Benefits of Organic Farming

Better nutrition: Organic food is nutrient-rich and free from harmful chemicals. It also enhances soil nutrient levels, resulting in healthier crops that are better for consumption (Sreerag and Jayapraka 2015).

Higher income: Organic food typically costs 20-30% more than conventional food. This price premium is crucial for small farmers whose income is barely enough to provide a single meal for their families.

Free from toxic chemicals: In organic farming, synthetic chemicals are avoided for pest and disease control, reducing the risk of cancer and other health issues for consumers. Unlike conventional methods, organic farming does not use toxic chemicals (Bhattacharyya, 2017). Additionally, the use of such chemicals can lead to environmental pollution, as they seep into the soil and water. Organic farming minimizes chemical use, thereby protecting the environment from such pollutants.

Quality of food: Organic food is often of higher quality in terms of nutrients and taste compared to produce grown with synthetic chemicals, as taste is a key indicator of food quality. Brix analysis is commonly used to assess the quality of fruits and vegetables (Sarma and Brar 2015). Fruits and vegetables from organic farming typically have a higher nutrient content and better taste, as they are allowed adequate time to mature without the use of chemicals (Sims 2014).

Enhancing the storage period: Organic food can be stored for a longer period compared to crops grown with

Table 3. Top ten states of India with the highest organic land

State	Cultivated area (ha)		Total area (ha)
	Organic area	Conversion area	
Madhya Pradesh	6,86,208	8,31,169	15,17,377
Maharashtra	2,58,639	10,25,676	12,84,314
Gujarat	84,404	8,51,527	9,35,931
Rajasthan	2,16,440	3,64,239	5,80,680
Odisha	77,951	1,17,129	1,95,079
Uttarakhand	32,634	65,760	98,394
Telangana	7,289	77,185	84,474
Karnataka	44,342	38,673	82,016
Sikkim	75,453	22,096	75,475
Uttar Pradesh	52,422	15,585	68,007

Source: Babu et al (2024)



synthetic chemicals, thanks to its enhanced metabolic and structural integrity at the cellular level (Kumar and Satyanarayana 2014).

Low input cost: Organic farming incurs lower costs because it relies on animals for tilling, readily available manures that can be homemade, and biofertilizers that require minimal investment. Unlike conventional farming, which depends on costly chemicals and fertilizers, organic farming reduces production expenses for farmers (Chriki-Adeeb and Chriki 2015).

Less environment pollution: Organic farming reduces fossil fuel consumption by avoiding synthetic fertilizers, which helps mitigate global warming compared to conventional farming methods (Teshome and Kibert, 2015). It operates with minimal environmental pollution, playing a crucial role in protecting the environment and promoting the sustainable use of natural resources.

Improved water holding capacity of the soil: Organic farming enhances the soil's water-holding capacity. Unlike chemical fertilizers, which need large amounts of water to activate their compounds, organic fertilizers do not have such requirements.

Improves soil fertility: Organic farming helps preserve the carbon-to-nitrogen ratio in the soil, boosting both its fertility and productivity.

Profitability of organic agriculture: Numerous studies indicate that organic agriculture can achieve comparable or better economic performance than conventional farming, even when not factoring in external production costs (Teshome and Kibert, 2015). This advantage largely results from lower production costs and the 20-50% higher prices that organic products get compared to conventional ones.

Promising for less developed countries: Organic farming presents a promising solution for Eastern and Central Europe from both economic and environmental perspectives. The potential and implications of transitioning to organic agriculture in less developed countries have been viewed positively.

Challenges of Organic Farming in India

Despite the widespread adoption of organic farming in India, several challenges persist. The key challenges predominantly faced by organic farming in India are discussed below:

Absence of domestic market and import policy: Bhujel and Joshi (2023) highlights that India's existing organic farming policy primarily focuses on production for export, with minimal emphasis on developing a policy for the domestic market and imports. As a result, there is a significant risk that consumers and farmers may struggle to distinguish between organic and conventional products due to the lack of regulations on labeling standards and organic logos. Consequently, fraudulent practices may arise, preventing legitimate producers from receiving the premiums that consumers are willing to pay for authentic organic products.

Table 4. Export of Indian organic food products

Country	Quantity exported (MT)	Total value (Rs crore)	Value (USD million)
European Union	117370	2726	359
U.S.A	126805	2041	262
Canada	38726	332	43
Great Britain	11671	146	19
Switzerland	4630	93	12
Australia	1046	45	6
Vietnam	3649	21	3
Ecuador	1812	19	2
Israel	1720	16	2
Japan	223	16	2

Source: Babu et al (2024)



Decreased crop yield: Elayaraja and Vijai (2021) concluded that farmers transitioning to organic farming frequently encounter lower yields during the initial stages of production. Moreover, the time it takes for crops to reach sustainable levels under organic practices is uncertain, leading to potential economic losses and higher cultivation costs.

Limited availability of organic seeds: Fertilizer-sensitive genetic planting materials and seeds tend to favor varieties that respond well to chemicals and fertilizers, putting traditional indigenous varieties at a disadvantage (Elayaraja and Vijai 2021). This creates significant gaps in the availability of high-quality organic seeds, which hinders farmers from fully adopting organic farming practices. Addressing these issues will require a collaborative effort from all stakeholders involved in India's organic farming sector. This could include developing policies that provide infrastructure and support services for organic farmers, increasing awareness and education about the advantages of organic farming, and investing in research and technology to help farmers adapt to climate change impacts. For instance, the government could support the production and distribution of organic seeds by collaborating with seed companies and offering subsidies to farmers who use them. Additionally, promoting the use of organic fertilizers and composting could reduce reliance on chemical fertilizers and enhance soil fertility, leading to improved crop yields over time. Ultimately, overcoming these challenges is essential to ensure the long-term sustainability and success of organic farming in India.

Absence of specialized infrastructure: Many large organic farms continue to operate using an industrialized agriculture model, which includes the mass transportation of food from field to table. Unfortunately, this often involves the use of environmentally damaging practices similar to those of factory farms, despite being labeled as organic.

Government Initiatives to Promote Organic Farming

Paramparagat Krishi Vikas Yojana (PKVY): The Paramparagat Krishi Vikas Yojana encourages organic farming through a cluster-based approach with certification via the Participatory Guarantee System (PGS). The scheme provides support for cluster formation, training, certification, and marketing. Farmers receive assistance amounting to Rs. 50,000 per hectare over three years, with 62 percent (Rs. 31,000) allocated as an incentive for organic inputs.

Mission Organic Value Chain Development for North Eastern Region (MOVCDNER): The scheme supports third-party certified organic farming of niche crops in the northeastern region, emphasizing exports through Farmer Producer Organisations (FPOs). Farmers receive Rs. 25,000 per hectare over three years for organic inputs such as organic manure and bio-fertilizers, among others. Additionally, the scheme offers support for the formation of FPOs, capacity building, and post-harvest infrastructure, with funding of up to Rs. 2 crore.

Capital Investment Subsidy Scheme (CISS) under Soil Health Management Scheme: This scheme offers full financial assistance to state governments and government agencies for establishing mechanized compost production units for fruit, vegetable, and agro-waste, with a maximum limit of Rs. 190 lakh per unit (3000 total per annum capacity). For individuals and private agencies, the scheme provides assistance covering up to 33 percent of the cost, with a maximum limit of Rs. 63 lakh per unit as capital investment.

National Mission on Oilseeds and Oil Palm (NMOOP): The Mission offers financial assistance with a 50 percent subsidy, amounting to Rs. 300 per hectare, for various components. These include bio-fertilizers, *Rhizobium* culture, Phosphate Solubilizing Bacteria (PSB), Zinc Solubilizing Bacteria (ZSB), *Azotobacter*, *Mycorrhiza*, and vermicompost.

National Food Security Mission (NFSM): Under NFSM, financial support is provided for the promotion of bio-fertilizers such as *Rhizobium* and PSB, covering 50 percent of the cost, up to a maximum of Rs. 300 per hectare.

Conclusion

Organic farming presents a viable alternative to conventional agricultural practices, offering numerous environmental, economic, and health benefits. The adoption of organic farming methods can lead to improved soil health, enhanced biodiversity, and reduced pollution from synthetic chemicals along with more sustainable food



production. Economically, while organic farming may involve higher labour costs and lower yields in some cases, it can also command premium prices and reduce dependency on costly chemical inputs. Moreover, organic farming does not come without challenges but its potential to contribute to a more sustainable and health-conscious agricultural system is significant. A gradual adoption of organic farming is recommended, starting with the establishment of effective strategies to ensure a reliable supply of organic fertilizers. This includes increasing domestic production and improving distribution mechanisms. Importing compost could harm local biodiversity, so efforts should be made to produce eco-friendly pesticides (bio-pesticides) domestically to manage pests, diseases, and weeds effectively. Robust research and development are crucial for achieving food self-sufficiency. Before implementing a blanket ban on non-organic practices, it is advisable to designate specific regions as organic zones and offer subsidies to farmers to facilitate the transition and ensure premium prices for their products. Successfully transitioning to a more sustainable and organic agricultural system requires coordinated efforts, involving both the public and private sectors. Policy development and implementation should be carried out through public-private partnerships with input from various stakeholders, including consumers, decision-makers, farmers, and scientists. A comprehensive strategy supported by effective communication on both supply and demand sides is essential.

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Agrarian Crisis in Punjab and Policy Interventions

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Punjab has demonstrated remarkable growth in both the production and productivity in agriculture, especially in wheat and paddy, becoming the largest contributor to the central pool of foodgrains. Despite being a benchmark for agricultural success since the green revolution in the mid-1960s, the state's agriculture sector is currently facing a crisis. The state maintained a steady pace of agricultural growth until early 1990s, the area under wheat and paddy increased from 16.08 and 2.85 lakh ha in 1966-67 to 35.1 and 31.6 lakh ha in 2022-23, respectively. During the same period, the production of wheat and paddy increased from 24.5 and 5.07 lakh tonnes to 165.6 and 205.2 lakh tonnes, respectively. The growth slowed down thereafter largely due to exhaustion of natural and technological resources resulting in rising input costs, a depleting resource base, and declines in productivity, profitability, and farm incomes. The wheat-paddy mono cycle led to environmental degradation, including alarmingly depleting underground water levels, soil degradation, chemical contamination in food etc.

The state's agriculture, in general, and small farming, in particular, has become less lucrative over the years due to the stagnant crop yields, rising costs of cultivation, shrinking land holdings and non-remunerative sale prices of crops which have increasingly pushed them to leave farming altogether. The number of small and marginal holdings, which stood at 5 lakh in 1991, dropped to 317824 in 2005-06, and slightly increased to 361850 in 2015-16, leading to a significant exodus from Punjab's agriculture. A large chunk of these farmers were pushed away from agriculture to informal labour market where employment opportunities are already limited and uncertain.

The farmers and farm workers of Punjab are grappling with an ever-increasing burden of debt. The amount of debt on Punjab farmers was Rs 5770 crore in 1998, which increased to 32250 by 2009-10. According to National Bank for Agriculture and Rural Development (NABARD), the total institution debt on Punjab's farmers in 2022-23 was Rs 73673 crore, excluding non-institutional debt. The National Sample Survey Office (2019) reveals that of the total outstanding loans of agricultural households in Punjab, 78.7 per cent are from institutional sources, while 21.3 per cent are from non-institutional sources, which means the burden of debt on Punjab's farmers may very well be more than Rs 90 thousand crores. Without alternate sources of income, basic requirements such as high costs for healthcare, education, and cooking gas strain rural families' finances. Farmers and farm workers have to rely mainly on loans from institutional and non-institutional sources to make ends meet. This vicious cycle of taking more costly loans just to carry on cultivation in the hope of turning around their finances and repaying previous loans with high accrued interest burdens pushes farmers into accepting exploitative informal lending at an exorbitant rate of interest, which leads to indebtedness. The heavy debt burden has wrecked the condition of farmers making them helpless and distressed, which ultimately pushes them towards dying by suicide.

In Punjab, between 2000 and 2018, there were a total of 16594 recorded suicide cases in six districts of the state. Among these cases, 9291 (56%) were identified as farmers, while 7303 (44%) were agricultural labourers. Both farmers and farm workers have become victims of suicide at an almost proportionate rate, highlighting the severity of the distress faced by the agricultural community. Moreover, the proportion of suicide of women among agricultural labourers is higher than that of farmers. This has happened due to lack of employment in Punjab's agriculture mainly due to mechanization, which led to limited seasonal jobs and surplus labour. Low and inconsistent incomes hinder their ability to support their children's education, trapping them in poverty. The absence of access to formal credit forces them to rely on costly non-institutional loans, which enhanced their debt burden. Additionally, farm labourers face social disparities and exploitative practices, including long hours and unsafe working conditions.



In so far as natural resources are concerned, the state is on the brink of a water emergency because of the unregulated and excessive utilization of water resources. This approach not only lacks sustainability, but also poses significant harm to the region's water ecosystem. The groundwater extraction in Punjab has already reached 150-200 meters in most places of Central Punjab and the overall stage of groundwater extraction is 178 per cent for the state. If the present rate of depletion continues, Punjab's groundwater is expected to drop below 300 meters by 2039. At present, out of 150 blocks, 15 blocks have stage of groundwater extraction exceeding 300 per cent, 16 blocks have stage of groundwater extraction between 251 per cent to 300 per cent, 29 blocks between 201 to 250 per cent, 53 block between 101 to 200 per cent and 37 blocks have stage of groundwater extraction below 100 per cent groundwater exploitation.

A comprehensive agricultural policy is essential for the welfare of farmers and overall prosperity of the state, with the aim to increase farm income, reduce debt burdens, generate productive employment, curb the suicide epidemic and ultimately restore Punjab's agricultural prosperity. The Punjab State Agriculture Policy, 2023 marks a significant step toward achieving these goals, with a focus on making Punjab's agriculture healthier, profitable and globally competitive.

Agricultural Policy: Salient Recommendations

- In Punjab State Agricultural Policy (2023), it is recommended that different crops/alternatives of diversification are to be promoted in their respective Natural Growing Areas (NGA) which should be the primary areas of research, extension, quality production, value addition and marketing efforts. Natural factors will help in producing quality with minimal costs to make it globally competitive. Government should ensure a regular and timely supply of all agriculture inputs including seeds, fertilizers, bio-fertilizers and pesticides to cooperative societies on priority. In the same vein, Government should set up silo/multi-chamber cold storage facilities at the Multi-Purpose Cooperative Societies (MPCS), Progressive Farmers' Societies, and Horticulture Estates. Punjab Mandi Board should arrange cold storage facilities on rent at distant domestic markets. The appointment of secretaries of MPCS with improved qualifications should be made by the department of cooperation and the transfer policy of the secretary must be put in place. Each cooperative society should be allocated at least one acre of suitable Panchayati/government land in order to make societies able to avail benefits of various central schemes such as setting up cold stores, petrol pumps, warehousing, etc.
- It is recommended that 18 Centres of Excellence (CoE) should be set up in Punjab. To balance demand and supply, the Agricultural Marketing Research and Intelligence Institute (AMRII) should be set up as a Special Purpose Vehicle at Punjab Agricultural University, Ludhiana and shall be the global market eye of the crop specific Progressive Farmers Societies.
- It is recommended that Attari-Wagah land route should be opened up for trade between India and Pakistan. Similarly, Chandigarh-Jaipur corridor having connectivity with Kandla port, should be developed to reduce the transportation expenses by avoiding long routes through Delhi.
- To encourage diversification and increase farmers' income, it is recommended to establish Punjab as seed hub by developing seed village clusters in the state. Similarly, area under paddy should be replaced with cotton, maize, basmati, sugarcane, pulses and horticultural crops.
- Organic farming should be promoted, and third-party organic certification should be ensured as an effective marketing tool to build confidence and assurance of produce/product quality to the consumers.
- With a view to water emergency like situation in Punjab, set a policy target of saving a minimum of 30 per cent (20 BCM) of state's total water demand (66.12 BCM). Punjab State Power Corporation Limited should supplement the agriculture purpose tubewells with grid connected solar panels. The *Pani Bachao Paisa Kamao* (save water, save money) scheme should be effectively advocated and implemented through cash incentives to the farmers for saving water and electricity.
- Farm workers should be registered by the government so that they can avail benefits of various government



schemes. The ownership land rights for women should be looked upon. Priority should be given to the landless women engaged in small-scale agricultural activities while leasing out village common land.

- Adequate financial support should be given to public sector research institutions for need based agricultural and livestock research, education and policy making.
- It is essential to bolster the accredited laboratory at PAU's Horticultural Post-Harvest Technology Centre in Ludhiana, broadening its testing capabilities.
- The land tenancy laws need updating. The informal lease (contract) system creates unregistered tenants, depriving them of benefits like crop insurance and access to MPCs.
- The livestock sector in Punjab should be declared as special sector with separate policies regarding change of land use, bank finance, electricity tariffs, pollution control certification, etc. for facilitating ease of doing business.
- Set up separate Directorate of Agriculture Engineering in the state for implementations of mechanization, post-harvest processing, soil water/irrigations, and renewable energy schemes. Additionally, build Punjab as a machinery hub for innovative manufacturers as a hub of farm machinery, for domestic and global market.
- Farm workers and small farmers (with up to 5 acres of land) should be given pension coverage upon reaching age of 60. Provide compensation of Rs. 10 lakhs to the suicide victim families of farmers, farm workers/rural artisans. Similarly, free healthcare should be provided to farmers, farm workers/rural artisans.
- It is recommended to fix Minimum Support Price (MSP) of all crops as per Swaminathan formula ($C2 + 50\%$), along with a legal guarantee of procurement of MSP crops. The Punjab government should hold a dialogue with the Union government for this matter. Additionally, the public distribution system should be strengthened. Design Punjab's own crop insurance scheme by generating crop insurance fund to mitigate crop loss. Similarly, a scheme for livestock insurance should be initiated through the Milkfed and Dairy Development Department.
- Finally, it is recommended that a mission mode strategy should be adopted for the development of Kandi area, bet area, border area and for water logged area in the state. Under this mission, Departments of Agriculture, Horticulture, and Forestry may jointly work for addressing the specific issues of these regions.

Implementing these policy recommendations will significantly alleviate the ongoing crisis in Punjab's agriculture sector.



Agroforestry Research, Transfer of Technology, Adoption and Marketing Mechanism

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Agroforestry is a sustainable option for achieving timber requirements outside forest without compromising on food security. Agroforestry concept is changing each and every decade since seventies and now it involves science and technology interventions to meet the multiple requirements of the farmers/industry including environmental amelioration. It is seen as a tool for transforming the lives of millions of people world over through multidimensional approaches to produce multifaceted benefits. The concept of agroforestry is aimed at conservation and optimum use of land, water, biodiversity and other climatic resources for production of food, fodder, fuel, timber, etc. The vast solar energy available, nutrients present at different soil depths and water available in the soil are efficiently utilized and environment is ameliorated through the agroforestry plantations. It is a way-out to practice agriculture without deteriorating agro-ecosystem services while maintaining or improving productivity, stability or in other words sustainability. There is dire need to hike the research and awareness efforts on the role of trees on the farms [i.e., conservation of natural resources- the hydraulic lift hypothesis suggests that water redistribution by deep-rooted trees from deep (moist) to shallow (drier) soil layers benefit shallowrooted crops; the safety-net hypothesis suggests that trees in tree-crop systems are capable of recycling soil nutrients that leach down the shallow rooting zone of crops, multilayer farming- making use of vertical horizon in land constraint situation].

Agroforestry, a sustainable landuse management system requires careful planning to address the challenges being faced by the farmers and industry in the changing climate scenario. The choice of trees for agroforestry system depends upon the purpose of the farmer whether to grow them for personal use or industrial use (ecological or economic). Trees for industrial uses catch the attention of farmers to grow economically because of sustainable management and green felling restrictions from the forest area. There are around 890 paper mills and 3300 plywood units (majority in unorganised sector) and around 90 per cent raw material to run these units is sourced from outside forests, three to four per cent from Govt. forests and six to seven per cent from import. However, other wood based industries (furniture, construction, packaging, sports, agriculture implements, etc.) are equally important to project the importance of adopting and extending agroforestry area. The SWOT analysis at state level (due to differential capacities of agroforestry adoption and wood based industries) would be appropriate so that the appropriate steps are taken at state/regional scale with National projections. At the moment poor adoption of agroforestry is constraint by the following multiple (social, economic and ecological) factors

- Agroforestry as an adaptation measure in changing climate scenario could not gain impetus and provision of payment for environmental services could be counterproductive.
- Standardization of best agronomic/management practices under different agroforestry system to increase the productivity of the system and their testing at different agro-climatic zones for higher productivity, sustainability and adoptability. Intensive efforts are required to identify the suitable species/crops/genotypes for agroforestry with marketing acceptability. Diagnosis of exiting status should be a periodic activity to refine the designs for adoption.
- Below ground studies are lacking to justify the natural resource exploitation (co-existence of functional rooting strategies).
- Non-availability of superior quality planting stock, no provision of accreditation of nurseries in agroforestry species (provision exists in fruit plants).



- Marketing system is not regularised, which results in malpractice in market system and farmers feel cheated. Dedicated marketing intelligence system is not in place.
- Permit system of harvesting and interstate/within the state transit is still an issue of concern for adopters of agroforestry
- Industrial units for wood processing are distributed at limited scale and they are not ready to extend helping hand to the farmers for providing raw material at affordable prices.
- Extension activities are lacking; proper benefits of research are not reaching to the poor farmers due to reluctance of line departments.
- Financial support in the form of subsidies/loan/support price including institutional credit facilities are reluctantly available on plantation projects.
- Capacity building of the farmers on some important issues i.e., planting technology including geometry of planting, pruning schedule, age specific cropping sequence, resource depletion, marketing channels, etc. are limited.
- Farmers have a fixed mind that only the prices of wood govern the prices of processed product (paper, plywood, etc.), industries have their own issues including treating wood based industries as green initiative.
- Export of nutrition with agroforestry produce from the cultivated land, etc. have to be compensated for sustainability.
- Legal disputes because of common field boundaries are increasing, which did not receive attention from the policy planners.
- National/international collaboration in agroforestry research is essentially required and farmers/scientists must be trained for this programme.

Majorities of the above mentioned constraints have to be addressed. Still there is need for way forward strategies to achieve the objective of extending area under agroforestry for diversification of traditional crop rotations, enhanced farmers income, conservation of natural farming (soil/water/biodiversity), ameliorate deteriorating environment, mitigate/adapt to changing climate, conserve of traditional forests, meet the targets of Nationally Determined Contribution of CO₂ sequestration/clean energy under Paris convention, employment generation, etc.

SWOC ANALYSIS



Issues and Challenges

It has been rightly emphasized, that, second green revolution should focus on tree crops, agro forestry and mixed livestock pastures & crops. Farm forestry has a greater future role for ensuring environmental sustainability and meeting sociological and economic objectives for meeting sustainable development goals. Moreover, crop diversification is need of the hour to meet the challenges of surplus food grain production, higher costs of inputs, ground water depletion, financial burden of MSP on government, poor economic health, marketing of produce, promoting green technologies, etc. The objective of increased income and amelioration of environment will remain a distant dream, unless, suitable measures are adopted for ensuring sustainable and proper linkages between sellers and buyers and rational protection to the farmers. The sustainable afforestation efforts under Agroforestry can continue only if the raw wood produced by primary producers is absorbed by the market at reasonable profits and returns. This also requires incentives for establishment of more wood based industries, wood use diversification, production of quality wood based finished products at competitive prices, strengthening of linkages between farmers and buyers, decentralized value addition, etc. The market structure should be properly developed including market intelligence and information. There should be inbuilt checks and regulatory mechanisms for timely interventions and minimizing exploitation of primary producers. Farmers should get reasonable returns for their produce in terms of productivity and economics.

More than 85 per cent timber is sourced from outside forests (private land) for wood based industries when all the forests are under the control of the Govt. Productivity of forest plantations is very low ($4-6\text{m}^3\text{ha}^{-1}\text{yr}^{-1}$) in comparison to the agroforestry plantations ($20-25\text{m}^3\text{ha}^{-1}\text{yr}^{-1}$), therefore it is appropriate to encourage and invest in agroforestry to meet the domestic/industrial requirements directly, conserve the traditional forests indirectly for environmental services including conservation of natural resources, and generate employment in the complete channel from nursery, plantation management to processing and marketing.

Farmers have made committed efforts for the viability of the wood-based industries on one hand and conservation of forests on the other but their efforts have not been recognised appropriately. Dedicated ward to honour the individual farmer/association would encourage the others to realise the importance of adopting trees. Even supporting farmers during initial lean period would be counter-productive. Some of the issues have been identified (not in the order of priority/importance) for consideration to boost the agroforestry adoption. These issues need discussion for clarification and narrowing down the priorities of farmers and industry.

- Regular monitoring of state of agroforestry area and timber demand/supply data is not appropriate to address the sustainable future production/utilization projections. Effective area and demand/supply figures are essential to put efforts for appropriate planning, which is still missing and require concerted efforts.
- Many states have liberalised tree harvesting and transit rules for timber, NAP 2014 has candidly addressed these issues but still the practical problems exist on ground, which discourages farmers from adoption of tree cultivation.
- Monoculture in species/genotypes, export of nutrients, depletion of water resources, invasive species, competition with inter-cultivated crops, etc. are words of caution and need proper attention.
- Identifying niche area for agroforestry plantations would facilitate aggregation of wood based industries – Bihar and eastern UP have potential (raised poplar with the support of ICFRE) but no buyer in the area resulted to abort the tree growing. On the other hand, the Yamunanagar-Jagadhri, Haryana has transformed the region as a hub for wood based industries. There are 273 plywood manufacturing units, 297 peeling units and 331 saw mills in Yamuna Nagar district. Yamuna Nagar city has emerged as the biggest market of farm-grown timber in the country as about 35-40 lakh tonnes of timber worth about Rs150 -180 million is being traded annually, of which about Rs75-90 million is going back to farmers. Yamuna Nagar city now has heavy concentration of wood-based units, which manufacture wood products worth Rs.500-600 million annually and provide direct and indirect employment to about 1 lakh people. Surprisingly, Yamunanagar district alone produces about 60



per cent plywood of the country, which has helped this city in earning the reputation of being called as the 'plywood capital of the country'. Hoshiarpur district in Punjab also has aggregation of wood based industries, resulting in large scale agroforestry plantations in Hoshiarpur and adjoining districts of Nawanshahr, Ropar, Ludhiana and Jalandhar.

- Marketing at present is unregulated/non-transparent with inefficient supply chain. Tree growers and wood based industries need complete harmony and there is complementary relationship between them. Both are not mutually exclusive rather dependent on progress of each other. Therefore, incentive for the farm grown wood based industry is equally important and these industries should be treated at par with agro-industries/green industry. Compulsory industrial support under CSR for research, technology transfer and farmers support, etc. should be mandated for the wood based industry.
- Value addition at farmers level would generate subsidiary occupation – debarking, chipping, peeling/veneer, toys and sports articles, mementos, sculptures, pre-finished products, etc. decentralised biomass based power units (residue based) at village level and processing residue for ethanol.
- Market intelligence and information system is essential but in poor state of affairs, resulting in direct loss to the farmers and handsome earning for the middlemen. Financial institution support on plantation projects - credit facility and insurance cover for plantation projects is also discouraging farmers adoption because of initial juvenile phase of tree harvesting. Bankable projects are missing and small farmers cannot afford to shift to agroforestry interventions.
- Ecotourism and provision of payment of environmental services - the enhanced uptake of carbon dioxide in agroforestry system and reduced emissions of GHGs and locking of CO₂ through non-destructive use of wood have significant potential to remove CO₂ from the atmosphere. Evidences have emerged that agroforestry systems increase above ground and soil organic carbon to mitigate GHGs. The payment of environmental services through onfarm grown trees could be additional incentive income to the farmers, which states like Punjab, UP, etc. have started sharing the benefits under voluntary marketing system of carbon trading.
- State forest development corporation can operate wood based industry [Tamilnadu newsprint and paper Ltd. (TNPL) – a public service and Government agency] to regulate the marketing, which otherwise is controlled by private players and timber prices of short rotation trees keep on fluctuating. Mechanism on market based support system on the pattern of Quad-partite agreement in Consortium of Industrial agroforestry (Tamilnadu), Tri-partite agreement of ITC, or Haryana State Forest Corporation Model or WIMCO Model to popularize poplar or Non-timber forest produce as in tribal affairs ministry (agroforestry is not only timber but other products as well) is appropriate and workable. Selling prices of timber are almost same what existed in 2001-02 but cost of cultivation has increased substantially, thus posing major challenge for expansion in area (even though major industrial timber demand is fulfilled from agroforestry plantations). Present timber rates have shown substantial rise but these rates still keep on fluctuating, which shakes the confidence of farmers in adopting tree cultivation.
- Legal dispute of raising trees on common boundary- there is no directive/recommendation on this important aspect - NAP 2014 is also silent on the issue.
- Planting stock and timber certification are important issues and often discussed but with little progress (procedure exist in fruit plants for the accreditation/grading of nurseries by National Horticulture Board) to support the intervention.
- Skill development - KVKs and VVKs should extend technical support – provision of an agroforestry cadre for capacity building, which is lacking at present. ICFRE can extend support at regional scale or in identified districts with positive adoption potential of onfarm trees.
- A dedicated cadre in the state to boost agroforestry – State forest dept. field functionaries are trained for trees, whereas, Agriculture Department technocrats are trained for crops, resulting for long time agroforestry



remained no body baby. A dedicated cadre in either of the dept. to boost on farm plantation and intensive inter-cultivation is an essential requirement.

- Provision of establishment of an Agroforestry Board at par with other development boards (National horticulture Board, Jute Board, Rubber Board, Coffee Board, Tobacco Board, TeaBoard, Silk Board, Spices Board, etc.) to address the issues of concern on ecology, economics and social aspects. Sub-mission on agroforestry should be upgraded as Mission to enhance the impetus to the on farm tree adoption, however recently support under RKVY has been strengthened for the research, technology transfer and adoption by the farmers.
- Addition of trees on agricultural landscape limit the resources (above/below ground) for the crops but very little emphasis has been placed on the management of trees rather major emphasis has been placed on suitability of understorey crops. Focus must shift to best management practices of trees for tree-crop interface. No focused emphasis has been placed on developing shade tolerant varieties.
- Digital agroforestry - periodic assessment of area, demand-supply, productivity, digitization of weight/volume tables to know the quantity of timber produce. Decision support system for best cultural practices, market information and trading, traceability of timber to avoid complication in free transit would be added advantage.
- Upgrading Education, research and extension capacities and collaboration between ICAR and ICFRE - National School on Agroforestry under ICFRE at par with IIT in Engineering would attract good talent in the discipline including international students. Regional training centres for trainers training/stakeholders capacity building will also strengthen the support base. Only limited number of species (poplar, eucalyptus, dek, casuarina, subabul, bamboo, chandan, ailanthus, sagwan, kopok, ebony, sambal, kadam, gamar, rubber, etc.) are being adopted at present, which needs diversification with a greater number of species and superior genotypes with respect to their endues.
- Policy provision for diverting 3-5% cultivated area by each farmer for any tree (timber/fruit/avenue) would meet the aspiration of honourable Prime Minister for Har Med Pe Ped/Natural Farming/increased tree cover/enhanced income.
- Timber Import/export? - Govt. is cautious on the issue and farmers are mainly adopting short rotation species and import is targeting cheap and large size logs/lumbers, therefore posing no competition with the farmers.
- Targeting future projections – Future expansion of on farm plantations and wood based industries requires action plan with minimum area coverage annually under agroforestry (say minimum 5000-10000ha). It is possible and unutilized land can be leased out to the industries/NGOs/Corporations or a dedicated unit, Plantation Corporation/Govt. owned timber based industries.
- Changing climate is an opportunity for mitigation and adaptation but challenge for the short rotation trees as well. The judgement of the honourable High Court of J&K regarding felling of poplar trees and a ban on new plantations from Kashmir valley is an eye opener. Similar PIL have been filed for eucalyptus as well, which is required to be defended scientifically to serve the economic interests of the farmers.

It has been rightly emphasized, that, second green revolution should focus on tree crops, agroforestry and mixed livestock pastures & crops. By judicious use of tree-crop combinations, every piece of land can be made to produce maximum goods and services required for increasing human and cattle population. The objective of farmers in adopting agroforestry is simply stated in terms of socio-economic issues as productivity and sustainability. By introducing trees, the soil agro-ecosystem like physical, chemical and biological properties of soil are improved. The water holding capacity, improvement of permeability, aggregate stability and rhizospheric micro-environment is improved. Agroforestry system modifies the microclimate of the place and offers environmental benefits including resilience against the changing climatic conditions. In order to realize the benefits of agroforestry, a complete package of technology have to be adopted after taking into account the needs,



customs and tradition of the local people. Agroforestry research and development is emerging as a major agenda for environmental services. Policy reforms, institutional innovations and market/industry support will generate win-win situation for the farmers and resolve conflicts among the stakeholders. The country will witness the real green revolution only when countryside is clothed with greenery. The present administrative and political environment is also in favour of green technologies. The National Agroforestry Policy initiative in 2014 was a step forward but present report offers number of positive steps to capture greater domestic recognition to make multifunctional agroforestry adoption and expansion a reality in the country.

Forests, trees and agroforestry can deliver one third of the climate mitigation solution. It's a critical investment in both our future and the future of our planet. In addition, its contribution of multifunctional landscape value, livelihood, employment, natural resource conservation, etc. are invaluable to account.



Mushrooms in Indian Food System

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Introduction

After World War II, ammonia produced by the Haber-Bosch process was increasingly used to produce nitrogen (N) fertilizers, which augmented the world's food supply to keep up with the pace of the growing population. Globally, fertilizer N use in agriculture increased 9.4 times from 11.5 Mt in 1961 to 108 Mt in 2022. India, the second largest user of fertilizers in the world after China, used 29.84 Mt of fertilizer nutrients in 2022, of which 67.7% was N. With the advent of the Green Revolution era in India in the late 1960s, farmers were initially hesitant to use fertilizers but once they realized that high yields of cereals could not be achieved without applying fertilizers, and the Government of India subsidized the price of urea, the most used N fertilizer, many farmers started applying fertilizer N doses even higher than the recommended. Thus, based on the dose of fertilizer N, three distinct groups of farmers can be recognized: those applying optimum doses and those applying more than, and less than the optimum doses. Due to the emphasis on producing more food, very little attention was paid to linkages between fertilizer use and soil health.

Soil organic matter (SOM) is the storehouse of N, and it is the most important indicator of soil health. The N contained in SOM is also referred to as soil N pool and it is maintained by a portion of N applied as fertilizer or manure, crop residues, atmospheric N deposition, and biological N fixation. Both loss of SOM itself via mineralization or erosion, and depletion of soil N pool through inadequate enrichment by fertilizers and manures over time lead to deterioration of soil health.

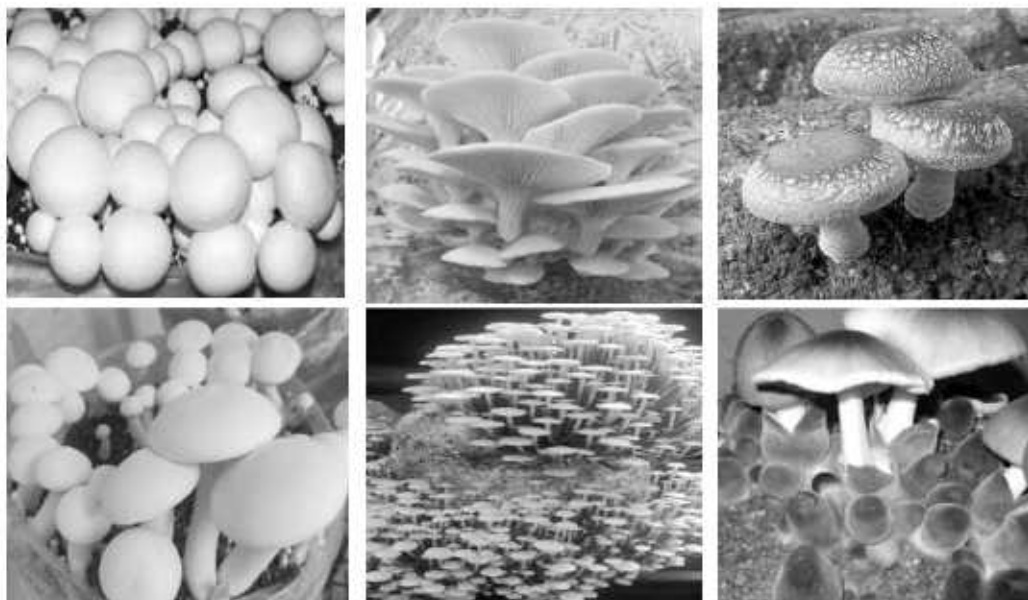
The country-level trends showing increasing food grain production with increasing fertilizer N use over the years create a misconception that crop plants depend mostly upon N applied through fertilizers. However, the fact is that in a current season, more N is supplied to crop plants through the mineralization of SOM than the fertilizer N, even when applied at high rates (Bijay-Singh and Sapkota, 2023). Therefore, the notion that fertilizer N acts as a simple replacement for N mineralized from soil N pool needs to be revisited.

Effect of long-term application of more than optimum doses of fertilizer N on soil health: Long-term application of fertilizer N at rates more than the optimum does not increase yield levels more than those observed at the optimum N level but leads to the accumulation of residual inorganic N in the soil. Increased residual inorganic in the soil accelerates the mineralization of SOM by supplying N for the growth of microbes involved in the mineralization process (Russell et al., 2009). Application of fertilizer N in excessive doses also reduces the C:N ratio of crop residues thereby accelerating their decay.

If the soil starts losing organic matter, its health deteriorates because SOM is not only the storehouse of N in the soil but also positively regulates the physical, chemical, and biological properties of the soil. When to avoid the risk of yield loss due to deficiency of N, excessive fertilizer N doses are applied to soil on a long-term basis, a spiral of decline in soil health may occur. It necessitates the application of even higher N doses year after year to achieve the same yield level. Thus, soil may become addicted to fertilizer N when soil health deteriorates due to long-term use of high fertilizer N rates in crop production.

Effect of long-term application of less than optimum doses of fertilizer N on soil health: Yan et al (2020) compiled data from 230 published papers and found that based on ^{15}N and zero-N control crops derived 59.8% and 52.6% N from soil N, respectively. But soil N pool is enriched by fertilizer N applications in the current and previous seasons and N contained in it becomes available for uptake by crop plants in the current and subsequent seasons for decades to come. Sebilo et al (2013) found that only 61 to 65% of ^{15}N was used by the crops up to three





decades after its application and 12 to 15% of the ^{15}N could still be recovered in the soil N pool after three decades. As only less than half of the N applied to a crop in the current season is assimilated by plants, a substantial portion of the remaining applied N is incorporated into SOM to become a part of the soil N pool. Therefore, the application of inadequate amounts of fertilizer N to crops year after year will lead to the gradual depletion of soil N pool and soil health will be adversely affected. Application of less than optimum fertilizer N rates on a long-term basis if not accompanied by sufficient application of N through organic manures or recycling of leguminous crop residues will neither be able to maintain soil health nor achieve full yield potential and adequate soil biodiversity.

Effect of long-term application of fertilizer N at optimum doses: Application of fertilizer N at agronomically optimum rates increases net primary productivity and production of both above- and below-ground plant biomass which in turn leads to build-up of SOM. (Bijay-Singh and Sapkota 2023) have cited several studies including four meta-analyses based on long-term experiments with different crops and cropping systems from all over the world in which optimum fertilizer N applications resulted in substantial increases in SOM content. Application of optimum fertilizer N rates as per the crop demand neither depletes soil N pool nor leaves inorganic N in the soil to accelerate mineralization of SOM because the major portion of the applied N is either assimilated by the crop or becomes a part of SOM and rest is lost from the soil-plant system. Therefore, long-term application of fertilizer N as per crop N demand leads to sustainable high-yield levels while maintaining soil health.

Conclusions

Long-term application of fertilizer N in doses higher or lower than the optimum may lead to soil health deterioration through accelerated mineralization of SOM and gradual depletion of soil N pool. To sustain high yield levels, long-term fertilizer N application should be neither more nor less than the optimum and ideally be managed on a site-specific basis. This strategy ensures sustainable high yields, healthy soils, and minimal N-related degradation of the environment.

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Integrated Pest Management: Business as Usual

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Introduction

It has been over six decades since the book *Silent Spring* was published (Carson 1962) that brought wide recognition that insecticides had become pervasive environmental pollutants. It has been six and a half decades since the development of threshold theory (Stern et al. 1959) and harmonious control strategies in pest management (Smith and Bosch 1967) are in place in the USA, Canada, and some parts of Europe. In the 1970s the work on developing and validating integrated pest management (IPM) technologies started in developing countries. The policy decision for research and extension work of IPM was taken by the USA (1972), India (1985), China (1975), Malaysia (1985), the Philippines (1986), Indonesia (1986), Germany (1986), Denmark (1987), Sweden (1987), and the Netherlands (1991) (Peshin and Zhang 2014). The implementation of IPM and pesticide reduction programs have been in place in more than 60 developed and developing countries (FAO 2011) for the last five decades however, there are plausible questions raised about achieving the envisioned objective of IPM, adoption of IPM practices to reduce pesticide use. The IPM was envisioned to reduce the pesticide use, however in reality this is often converted into “Integrated Pesticide Management” (Peshin and Zhang 2014), “Intelligent Pesticide Management” (Nicholls and Altieri 2004) and “Improved Pesticide Marketing” (Dufour 2001). This has resulted in increase in global pesticide use from 2,047,088 tons to 2,61,124 tons between 2000 and 2020 (FAOSTAT 2023), an increase of 29 percent.

Integrated Pest Management & Farmer Field School

The Food and Agriculture Organization (FAO) Inter-Country Program for Rice IPM in South and Southeast Asia in the early 1990s gave rise to farmer field school (FFS) methodology for dissemination of IPM technologies. As a result, IPM dissemination programs were intensified, employing the FFS extension methodology. The FFS extension methodology focuses on non-formal education of farmers on their farms. These farms act as field laboratories and trainers act as facilitators. The early success of the IPM-FFS program in enhancing farmers' knowledge about pests and natural enemies in the rice ecosystem was reported in several studies (van de Fliert 1993, Peshin and Kalra 2000). After an in-depth analysis of 25 studies, van den Berg (2004) found that the immediate impact of IPM-FFS was a reduction in pesticide use in Indonesia, Bangladesh, China, Sri Lanka, Vietnam, Philippines, Peru, Bolivia, Burkina Faso, and Kenya. However, the same researcher also acknowledged that these immediate impact evaluation studies varied in focus and lacked methodological robustness. Feder et al. (2004) employed the difference-in-differences (DD) methodology to evaluate impact. They questioned the long-term impact of the IPM-FFS program in Indonesia, which was considered successfully implemented from 1989 to 1999 (Resosudarmo 2014). Questions were raised by Yamazaki and Resosudarmo (2007) regarding the household panel data set used by Feder et al (2004). A few studies also provided empirical evidence of IPM-FFS-trained farmers who returned to applying pesticides (Pincus 2002). Waddington et al (2014) in their systematic review of IPM-FFSs concluded that positive outcomes such as knowledge enhancement, reduction in pesticide use, reduction in estimated environmental impact quotient of pesticide use, and yield increase were largely limited to short-term evaluations, but these positive impacts were not observed in follow-up surveys more than two years after implementation. In 2020, two articles in peer-reviewed journals on the impact of IPM-FFS programs pointed to mixed results (Rejesus and Jones 2020, van den Berg et al 2020). In their review article, Rejesus and Jones (2020) pointed towards short-term gains in knowledge and a reduction in pesticide use; however, they found that intermediate to long-term outcomes of reduced pesticide use and increased profits presented mixed results. van



den Berg et al (2020) in a review of 65 impact studies of FFS highlighted that core FFS principles were abandoned as the program scaled up. A few researchers have also indicated inadequate attention paid to training farmers on the judicious use of pesticides and other aspects (Feder et al 2004, Sharma and Peshin 2016). In the case of India, the studies reported knowledge enhancement of farmers regarding IPM practices and a reduction in pesticide (insecticide) use (Peshin 2002, Mancini 2006, Sharma et al 2015; Sharma and Peshin 2016). The short-term and intermediate impacts studied by researchers have been a change in participant farmers' knowledge, adoption of IPM practices, and a reduced level of pesticide use (Peshin et al 2009, Waddington et al 2014). Mid-term/intermediate impact indicators are useful to find out the extent to which the IPM-FFS participants continued the adoption of IPM practices, maintaining reduced amounts of pesticide applications (Feder et al 2004). After the training interventions are withdrawn, long-term impact evaluation data are difficult to collect regarding higher sample attrition (Peshin et al 2021, Peshin et al 2022), resources required for data collection, the spillover effect of trained and other farmers (Waddington et al 2014), and technological advances.

Vegetable IPM-FFS in Jammu & Kashmir Subtropics

In Jammu and Kashmir (J&K), India, IPM-FFS programs have been in place since 1994. IPM-FFS programs provide knowledge to participating farmers on insect pests, natural enemies, and non-pesticidal management practices of pests in rice (*Oryza sativa* L.) and vegetable crops (Peshin et al 1997, Sharma and Peshin 2016). However, *ex post facto* with/without comparisons show that although participating farmers gained knowledge, there was no significant difference in pesticide use between trained and untrained farmers (Sharma et al 2015). Field studies on a farm scale at different points in time allow for documenting long-term impacts of adoption, socioeconomic and environmental benefits of agricultural innovations and programs for dissemination of these innovations (Carpenter et al 2002, Rogers 2003, Qaim et al 2006, Qaim 2009, Peshin et al 2021, Peshin et al 2022). Peshin et al (2022) reported that the IPM-FFS programs on okra, brinjal, and tomato crops resulted in the higher adoption of secondary agronomic and manual mechanical practices without reducing insecticide/ fungicide use; consequently, there was no reduction in the environmental impact and human health hazards of pesticides. In general, insecticide and fungicide use in vegetable crops, especially summer vegetables, is high and indiscriminate (Karanth 2002, Bond et al 2009, Sharma et al 2015, Rahman et al 2018, Peshin et al 2020, Peshin et al 2023). In vegetable crops, insecticides and fungicides accounted for more than 98.4% of the total pesticide use in the IPM villages and 99.8% in the non-IPM villages. In Bangladesh, pesticide use in vegetables increased by 135% between 1984-1985 and 2010-2011, and the per hectare pesticide use (a.i.) in vegetables was estimated at 1.247 kg/ha in 2010-2011 (Rahman et al 2018). The field use environmental impact quotient (FEIQ) in the IPM-FFS villages was about 59% higher than that of the non-IPM-FFS villages. IPM-FFS farmers reduced the number of pesticide applications by 7% but used 27.8% higher amounts of pesticide active ingredients, mainly driven by the higher fungicide use, which resulted in higher FEIQ and use of probable carcinogenic fungicides. Although monocrotophos and phorate (Class Ia) are restricted for use in vegetable crops, farmers did apply these pesticides. The use of the riskiest pesticides (probable and possibly carcinogenic) in vegetables is a major cause of concern; farmers do not wait for the mandatory pre-harvest interval after pesticide applications although they are aware of pesticide health hazards as they do not apply pesticides on vegetables grown for their consumption (Sharma and Peshin 2016).

Through seed-cum-pesticide stores, the pesticide industry has created a vast network that lures farmers into excessive use of pesticides. Pesticide sale agents/store handlers lack knowledge of handling and educating vegetable farmers on pesticide selection, application, and other information (Sharma et al 2015). Longitudinal comparison of the *ex post facto* impact evaluation studies of the vegetable IPM program conducted from 2003 to 2008 (Sharma et al 2015) and the difference-in-differences impact evaluation studies of the IPM program conducted during 2008-2010 (Sharma and Peshin 2016) showed that the reduction in pesticide applications in brinjal and okra was not sustained over time. Thus, the reduction of pesticide applications remained largely ephemeral. It has been reported that the



benefits of IPM-FFS are not sustained over a long time (Waddington et al 2014, Peshin 2021). In the short term (1-3 years after participating in IPM-FFS), vegetable farmers reported a lower number of pesticide applications compared to farmers trained 4-7 years before data collection. There is a need for IPM-FFS refreshments periodically. Nevertheless, we cannot reach millions of farm households through FFS alone.

Why Business as Usual?

During the expansion phase, IPM training shifted to the trainers who were comfortable neither with the science of IPM nor with the extension methodology (Peshin and Kalra 2002, Peshin et al 2009, Peshin 2013, Clark and Hillocks 2014). Similar findings have been reported from Indonesia regarding the scaling up of the IPM-FFS program and the quality of training; the adherence of trainers to the FFS extension methodology was greatly compromised. Counteracting forces even in public extension services confuse farmers and the lack of commitment of the extension agencies to IPM principles limits the spread and adoption of IPM. Lack of master trainers, insufficient training, and technical support have been the obstacle to the adoption of IPM (Parsa et al 2014). Parsa et al (2014) conducted a survey of IPM practitioners and professionals from 96 countries to identify the major obstacles to the adoption of IPM in terms of research weaknesses, outreach weaknesses, IPM weaknesses, farmer weaknesses, pesticide industry interference, and weak adoption incentives and found that the primary obstacle was the insufficient training and technical support to farmers. In high-income developing countries, the shortage of IPM experts and extensionists was listed as a major constraint in implementing IPM programs. Access to a vast network of pesticide retailers as a source of information affects the pesticide use decision of farmers.

IPM adoption is patchy and unsatisfactory and has largely failed to deliver on its promise (Peshin et al 2009). The pesticide industry being the principal source of farmers' pesticide use decisions, lack of commitment to IPM among researchers and extensionists, development of pest and discipline-specific IPM modules, lack of crop-specific IPM technologies, poor implementation of IPM programs and FFS, negligible use of alternative diffusion methods such as mass media for media campaigns, newspapers, and online technology transfer tools like social media are some of the reasons for IPM programming and extension having failed. We should use other than the FFS extension to sustain short-term outcomes after the withdrawal of IPM program interventions. Additional field studies using panel data should be conducted periodically to address the effects of unobserved heterogeneity associated with cross-sectional data. Factors affecting diffusion and adoption are predominantly driven by the inappropriateness of the technology and technology attributes (Rogers 2003, Peshin et al 2009, Peshin 2013). Socio-economic, resource endowments and access to information sources are also expected to influence technology adoption (Githiomi et al 2019).

Conclusion

From the above discussion and the review of the peer-reviewed literature, it is concluded that although properly implemented IPM-FFS programs (not pseudo-IPM FFS) have positive short- to medium-term (three-year follow-up) effects for participating farmers in terms of knowledge gain, adoption of IPM practices and reduction in pesticide use, these are not sustained over time. Farmers attending IPM-FFS 1–3 years before the survey, on average, reported a lower number of pesticide use than farmers participating in IPM-FFS 4-8 years before the survey (Peshin et al 2022). The proliferation of pesticides and pesticide brands has made things more complex for farmers. Deguine et al (2021) in their review of IPM have highlighted that, despite good interventions, IPM in the recent decades has been in a state of confusion. Since the 1970s IPM has moved full circle from 'True IPM', which envisaged pesticide use as a last resort, to 'false IPM' in which IPM stands for "Integrated Pesticide Management" (Peshin and Zhang 2014). To overcome the obstacles in the dissemination of IPM technologies and the misuse of pesticides, we need to improve the FFS model and use alternative diffusion methods for the development and validation of simple and specific IPM technologies with decision support tools using social media and short message service (SMS).



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Aquatic Food Systems- BlueFood for Food and Nutritional Security

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As per the World Population Clock (2020), the global human population is estimated to increase to over 9 billion in 2050, mainly due to a rapid population growth in the developing countries. Consequently, achieving food production targets to feed the anticipated human population is going to be one of the biggest challenges, in special reference to climate change and food safety concerns. Further, the socio-economic and socio-political environment has also impaired the already-weakening food environment during the last few years, which is expected to threaten the global food security in a larger context. As per the Global Food Security Index, the affordability score has fallen by 4% (from 71.9 to 69) between 2019 and 2022 due to rise in food cost after COVID-19 pandemic, high input costs and the Ukrainian-Russian conflict (Özkaya and Özkaya 2022), which is expected to aggravate further with the ongoing middle east conflict. Overall the noxious concoction of cross border conflicts, climate change and the COVID-19 pandemic had affected global supplies and prices of food, fertilizer and fuel (Baumeister and Giurgiu 2023), with emerging food insecurity and food safety issues. As per Department of Economics and Social Affairs (DESA) of the United Nations, fisheries sector (capture and culture fisheries) has an imperative role to play in feeding the world population. Aquatic food systems (AFS) are very diverse, offering assorted socio-economic and environmental benefits. They are globally recognized for their contribution to livelihood support and food security; ii) nutritional value; and iii) ecosystem services.

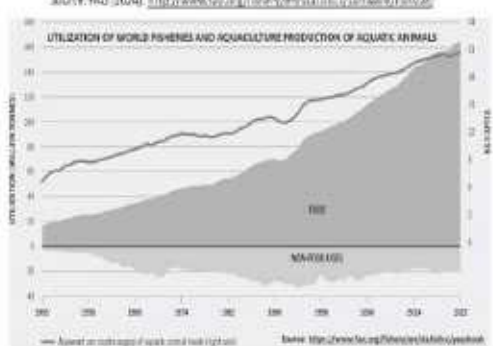
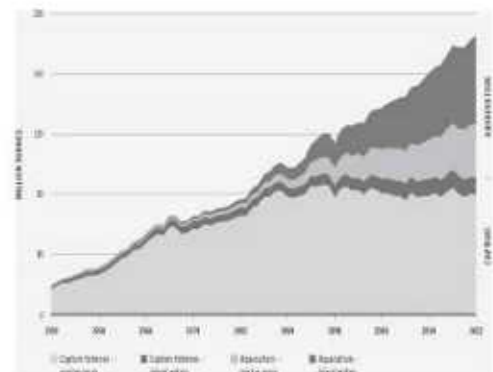
Global Fisheries Production

In 2022, the global production of fish and other aquatic animals (OAAs), collectively referred as “Blue Food”, reached a new world high of 185 million metric tons (MMT), with an estimated share of 94 MMT (51%) from aquaculture, surpassing capture fisheries for the first time, which produced 91 MMT (49%). Production from marine water was 115 MMT (62%), including 69% from capture fisheries and 31% from aquaculture. While, inland waters contributed 70 MMT (38%), including 84% from aquaculture and 16 %from capture fisheries (FAO 2024a).

Aquatic Food: Consumption Trends

Of the total 185 MMT of aquatic animals produced in 2022, about 164.6 MMT (89%) were destined for human consumption and the remaining 20.8 MMT (11%) was used for non-food purpose, mainly to produce fishmeal and fish oil. Aquaculture supplied about 57% of aquatic animal food (AAF) for human consumption in 2022.

In 2021, global apparent consumption (GAC) of AAF (i.e. excluding algae) surged to an estimated 162 MMT, which was only 28 MMT in 1961. Historically, Europe, Japan and the United States of America (USA) accounted for a significant portion of the global AAFs available for human consumption (47% of world supply in 1961). However, by 2021, their combined share had dropped to 18% and meanwhile, China, Indonesia and India experienced significant increases in their shares of global AAF consumption from 17% in 1961 to 51% in 2021, with China alone



representing 36%. It was mainly due to increasing influence of Asian countries in fisheries and aquaculture production, along with substantial increase in urbanization and proportion of middle-class population in the continent. In 2021, Asia accounted for 71% of global AAF consumption, followed by Europe (10%), Africa (8%), Northern America (5%), Latin America and the Caribbean (4%) and Oceania (1%).

The AAF contributed at least 20% of the per capita protein supply from all animal sources to 3.2 billion people (over 40% of the world's population). Globally, AAF supplied 15% of animal proteins and 6% of all proteins in 2021. However, the extent of their contribution varies from country to country, with non-high-income countries generally relying more heavily on proteins from AAF, compared with high-income countries. This reflects their affordability, availability and accessibility, making them a staple in many culinary traditions. In 2021, AAF accounted for 14% of animal proteins supply in low-income countries, 18% in lower-middle-income countries, 17% in upper-middle-income countries, and 10% in high-income countries (FAO 2024a).

Between 1961 and 2021, the average annual growth rate (AAGR) of global AAF consumption (3.0%), outpaced the annual population growth rate (1.6%). Africa and Asia experienced the strongest annual consumption growth rates of 3.8% and 3.7%, respectively. Furthermore, during the same period, AAF consumption exhibited more robust growth than all terrestrial meats combined (AAGR- 2.7%). Likewise, it also outpaced individual meat categories such as bovine, sheep and goat and pig, except poultry meat (AAGR- 4.7%).

Per capita apparent consumption of AAF grew on an average by 1.4% per year, from 9.1 kg in 1961 to 20.6 kg in 2021, mainly due to increased supplies; advanced preservation and distribution technology; changing consumer preferences; and income growth. As per FAO (2024a) estimates, out of the 227 countries and territories of the world, AAF consumption in 2021 was below the world average in 135 countries and above the world average in 92 countries. The said differences between countries can be attributed to diverse factors like availability of and access to AAF and other foods. The availability of AAF is influenced by various factors such as proximity and access to aquaculture facilities, landing sites and markets. Further, differences in prices, income levels, nutritional awareness, culinary traditions, food habits and consumer preferences also contribute to these variations. For instance, per capita average apparent AAF consumption varied significantly among the low-income (5.3 kg), lower-middle-income (12.5 kg), upper-middle-income (30.6 kg) and high-income (26.7 kg) countries. Although, per capita apparent AAF consumption was significantly lower in low-income countries than in high-income countries in 2021, AAFs contributed to a larger share of animal protein supply in low-income than in high-income countries. For instance, per capita apparent AAF consumption averaged 9.4 kg in Africa, but contributed 18% (above world average) to its total animal protein consumption in 2021.

TOTAL AND PER CAPITA APPARENT CONSUMPTION OF AAFs BY REGION AND ECONOMIC CLASS, 2021

Region/economy class	Apparent consumption of aquatic animal foods		Per capita apparent consumption of aquatic animal foods (kg/year)
	million tonnes, live weight equivalent	(Percentage of availability)	
Source: FAO (2024)			
World	142.3	100	20.6
World, excluding China	102.2	64	13.9
Africa	13.3	8	9.4
Americas	16.8	10	16.3
Northern America	8.8	5	23.4
Latin America and the Caribbean	7.9	4	10.7
Asia	116.1	71	24.7
Europe	16.5	10	22.2
Oceania	1.0	1	21.8
High-income countries	33.2	29	26.7
Upper-middle-income countries	46.2	33	30.6
Lower-middle-income countries	39.5	24	12.5
Low-income countries	3.4	2	5.3

Capture fisheries production has remained relatively stagnant during the last 3 decades, while aquaculture production (mainly freshwater and brackish water aquaculture) has registered a significant surge, boosting consumption of AAF. The proportion of AAF from aquaculture has increased from 6% in the 1960s to 56% in 2021, with further estimated growth to 57% in 2022.

Aquatic Food Systems: Livelihood Support and Employment

The fisheries sector (capture fisheries and aquaculture) also generate significant employment and support livelihoods among coastal, riparian and rural communities. In 2022, about 62 million people were engaged in the



primary sector of fisheries and aquaculture as full-time, part-time, occasional or unspecified workers, including 54% in capture fisheries and 36% in aquaculture, while the remaining 10% could not be distinctively divided between fisheries and aquaculture (FAO 2024a). Around 10–12% of the world's population depends on “*Blue Food*” for their livelihoods (Tidd et al. 2022).

AAF: Trade Value

After a decrease of 6.7% in 2020 because of the COVID-19 pandemic, the trade value of AAF or aquatic animal products (AAP) recorded rapid recovery in late 2020, driven by a robust retrieval in global supply-demand chain and increasing commodity prices. Subsequently, a significant rebound was witnessed in 2021 and 2022, with 19% increase in trade of AAF/AAP in 2022 compared with the pre-pandemic trading in 2019. Seventy (70) MMT of AAPs (38% of total production), worth USD 192 billion, were exported worldwide in 2022 (FAO, 2024a), representing about 9% of total agricultural trade (excluding forest products).

As per UN Trade and Development (UNCTAD), global export of aqua food, including fish, crustaceans, molluscs, seaweed and many value-added aquatic by-products, hit USD 186 billion in 2022, with 63% surge from USD 114 billion in 2012. Further, South-South trade (commerce between developing countries) also surged across various fisheries sectors, including marine fisheries, aquaculture, fish processing and fishing vessels, almost doubling the trade from around USD 19 billion in 2012 to USD 39 billion in 2022.

AAF: Nutritive Value

AAF protein is one of the cheapest sources of animal proteins in comparison to other animal protein sources, due to wide range of species naturally occurring in the gigantic aquatic resources (marine, brackish and fresh waters), covering 71% of the earth surface. Aquatic food need to be an integral part of a healthy diet that is environmentally, socially and economically sustainable. However, role of AAF in sustainable food systems is often under-recognized. Aquatic foods are considered among the healthiest foods linked to improved public health outcomes (UN Nutrition, 2021).

Recognized as an excellent source of protein, AAF is even more important source of essential nutrients, in particular long-chain omega-3 fatty acids and various micronutrients difficult to find in many other foods, such as iodine, selenium, calcium, iron and zinc. Aqua food is a rich source of complete protein (containing all essential amino acids); healthy fat consisting of poly unsaturated fatty acids (PUFAs) like omega -3 and omega-6 fatty acids; vitamins (Vit. A, D and B12) and minerals (Calcium, Magnesium, Phosphorus, Iodine, Selenium, Zinc and Iron) offering multiple health benefits due to its anti-oxidation, anti-inflammation, wound healing, neuroprotection, cardioprotection, and hepatoprotection properties. Omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are vital for human health, contributing to structural composition of cell membranes; optimal brain and nervous system development of unborn child; strengthening of bones and muscles; and healthy functioning of the cardiovascular system. The human body cannot produce EPA and DHA on its own and hence, need to obtain these essential fatty acids through diet. Aqua food, enriched in these fatty acids, are capable of fulfilling human nutritional requirements of EPA and DHA, especially of resource deficient riparian/coastal populations catching fish for food and livelihood.

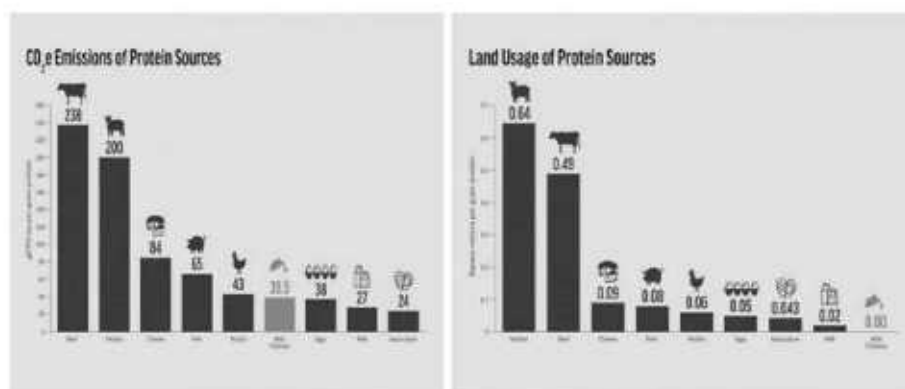
Globally, AAFs/AAPs contributed 6% of riboflavin, 6% of thiamin, 8% of calcium, 9% of vitamin A, 11% of zinc, 12% of iron, 13% of phosphorus, 13% of potassium and 17% of magnesium supplied by animal products, with notable variations among countries (FAO 2024a). Small indigenous fish (SIF) species (attaining length of 25 cm to 6 inches at maturity) provide better nutrition, because they are consumed as whole (with head, bones and eyes) and hence, provide all the available nutrients to the consumer. The SIF are major source of nutrition for rural populations in developing countries like Bangladesh, Cambodia and Vietnam (Sinha et al 2024). With multiple nutritional attributes and existing diversity of species, fish and OAAs constitute a huge resource capable of reducing food and nutrition insecurity, as even small quantities of aqua food can provide essential nutrients to prevent malnutrition, especially in the low income groups.





Aquatic Food System: Unique in Many Ways

- Among the animal food systems, the aquatic food systems (AFSs) are unique in many ways.
- Almost 50% of aquatic animals are harvested from wild fisheries (Capture resources- marine, brackish and freshwater), while the rest are farmed.
- As per Fish Base (<https://fishbase.de/search.php>), 35,700 fish species have been documented as of June, 2024, which is more than the combined total of all other vertebrate species - mammals, amphibians, reptiles and birds.
- Worldwide, 494 aquatic species (freshwater, brackish water and marine water) are cultured, including 313 cultivable fish species, 88 molluscs and 49 crustaceans. Such diversity is not found in any other agriculture or livestock food production systems. About 70% share of world's AAF production comes from farming of 20 aquatic species.
- AFSs have lower carbon footprint and fewer environmental impacts. Nutrient density of aquatic foods and their greenhouse gas emissions demonstrates their exceptional nutritional value and lesser climate impact as compared to other livestock food systems (Hallstrom et al 2019, Bianchi et al 2022)
- Fish is one of the most efficient converters of feed into high quality protein rich food, with a lower carbon footprint compared to other animal production systems. In terms of Feed Conversion ratio (FCR), fish also performs the best. For example, carp fish, pangasius catfish, salmon and shrimp can be produced with an FCR ranging from 1.2 to 1.7, which is lower than average FCR of 2.0, 3.0 and 8.0 for chicken, pig and cow, respectively. In terms of carbon footprint of popularly consumed proteins, aquaculture is far more sustainable than other food production systems. In terms of CO₂ equivalent (e) emission per gram (g) protein production, carbon foot print of beef, mutton, cheese, pork and chicken is 6.02, 5.06, 2.1, 1.64 and 1.09 times higher than wild (capture) fisheries, while it is 9.9, 8.3, 3.5, 2.7 and 1.8 times higher than aquaculture, respectively (Nunez, 2021).
- By shifting to aquaculture-based diets even land-use savings are greater, if land used for grazing is considered. Roughly three-quarters of all agricultural land is currently used for grazing/feeding ruminants like cows, sheep, and goats (Froehlich et al 2018). In terms of land use (square meter per g protein production), land requirement for mutton, beef, cheese, pork, chicken and eggs is reported to be 14.88, 11.39, 2.09, 1.86, 1.39 and 1.16 times higher than aquaculture (Nunez 2021), while for wild (capture) fisheries, no land is required; hence, offering a land use free food system.
- The growth rate of aquaculture production exceeds that of most other food production systems and still has great potential for expansion. The AAGR of supply of AAFs has increased (3%) globally faster than annual population growth (1.6%), increasing global per capita annual consumption from 9.1 kg in 1961 to 20.6 kg in 2021.



Source: Nunez (2021) <https://oceans.org/blog/author/emilypetsko/>

Indian Fisheries Sector-An Overview

- With total fisheries production of 17.54 MMT during 2022-23 (13.11MMT from Inland and 4.43 MMT from marine resources), India is the third largest fish-producing nation, accounting for about 8% to global fish production; and contributing 1.09% to national Gross Value Added (GVA) and 6.72% to its agricultural GVA.
- The sector registered double figure growth rate of 10.34% from 2020-21 to 2021-22 and 8% from 2021-22 to 2022-23.
- During the period from 2012-13 to 2022-23, share of fisheries production of inland resources increased from 9.04 MMT (63.27%) to 13.11 MMT (74.74%).
- In India, 3246 fish species have been documented by the National Bureau of Fish Genetic Resources (NBFGR) of Indian Council of Agricultural Research (ICAR), including 1569 marine, 961 freshwater, 15 brackish water and 701 euryhaline species.
- In India, more than 20 food fish and shell fish species are being cultured in freshwater and while about 10 species are reared commercially in brackish water. Carp fish (mainly Indian major carps), contribute the major share (>90%) to freshwater aquaculture production and shrimp is the major contributor in brackish water sector (FAO 2024b). About 450 SIF inhabiting Indian waters hold immense potential in providing essential nutrients to low income population. The SIF, possessing superior nutritive value than larger fish, has higher consumer preference in the north eastern Indian states.
- India achieved an all-time high seafood exports, both in terms of volume and value by exporting 17,35,286 metric tons (MT) of seafood worth Rs. 63,969.14 crore (USD 8.09 billion) during 2022-23. Frozen shrimp remained the major export item in terms of both quantity and value. Frozen shrimp earned Rs 43,135.58 crore (USD 5481.63 million) and retained its position as the most significant item in the basket of seafood exports, accounting to 40.98% share in quantity and 67.72% of the total USD earnings. USA and China remained major importers of India's seafood.
- About 28 million fishers (fishermen and fish farmers) are engaged in the sector, including 23.1 million in inland sector and 4.9 million in marine sector.
- According to recent studies undertaken as part of CGIAR initiative on *Aquatic Foods* (Padiyar et al 2024), patterns and trends of fish consumption in India has been documented for the period from 2005 to 2021 by World Fish, Malaysia and Indian Council of Agricultural Research (ICAR), India. The major highlights are as given below.
- The domestic fish consumption accounted for 82.36% of total production in 2005-06; 86.2% in 2015-16 and 83.65% in 2019-20. While the rest of the production was used for export to other countries and non-food use within country



- Total domestic fish consumption within India increased from 5.428 MMT to 11.924 MMT and among the fish-eating population, annual per capita fish consumption increased by 66%.
- Per capita fish consumption increased from 4.9kg to 8.89 kg with an annual growth rate of 4.05%, which is however, much below the world average of 20.6kg and recommendation (12 kg) of the Indian Council of Medical Research (NABARD, 2018).
- India's fish-eating population increased from 66 to 72.1% (6.1 percentage points or PPs). During this period, egg consumers increased by 7.35 PPs, followed by fish (6.1 PPs) and Chicken or meat (5.45 PPs).
- Among fish eating population, 5.95%, 34.8% and 31.35% population ate fish daily, weekly and occasionally, respectively.
- Kerala (53.5%) and Goa (36.2%) had highest percentage of daily fish eaters, while Assam (69%) and Tripura (69%) had highest percentage of weekly consumers.
- Among the States, Tripura had the highest fish-eating population (99.35%), while Haryana recorded the lowest fish-eating population (20.55%).
- The eastern and northeastern states, Tamil Nadu, Kerala, and Goa had the highest fish-eating population (>90%), while northern states like Punjab, Haryana and Rajasthan had the lowest (<30%).
- Jammu and Kashmir evidenced the highest surge (20.9 PPs) in fish-eating population, while it declined by 3.9 PPs in Punjab.
- As per Statista (2024), per capita fish consumption in Andaman Nicobar Islands (114kg) is exceptionally high, being largely dependent on sea food due to geographic location within the sea. While it was recorded above world average (20.6 kg) in Kerala, Karnataka and Tripura and above ICMR recommendation (12 kg) in Jharkhand, Uttar Pradesh, Assam, Himachal Pradesh, West Bengal, Puducherry, Chhattisgarh, Odisha and Manipur. As per FAOSTAT Food Balance Sheet for the year 2020, India held global ranking of 129 out of 183 nations in terms of per capita fish food supply and ranked 123 in term of protein supply through AAF.

Statewise per Capita Fish Consumption in India (2023)



Source: Statista (2024)
<https://www.statista.com/statistics/1391262/india-fish-consumption-per-capita-by-state/>

AFS and SDGs

The AFSs have been undervalued in respect to its contribution to world food systems and the environment. Both capture fisheries and culture fisheries (aquaculture) are important food production systems, having prospective role in achieving UN *Sustainable Development Goals* (SDGs), involving *Life Below Water* (SDG14), *No Poverty* (SDG1) and *Zero Hunger* (SDG2). Global fish trade offers big opportunities for sustainable and inclusive economic growth while advancing key SDGs, particularly improving food security and eliminating hunger and protecting life below water. The AFS provide affordable nutrient rich food to low income group population preventing malnutrition, especially through whole consumption of small indigenous fish and supporting livelihoods through catching and culturing fish and OAAs.



Aqua Food System: Viable Solution to Sustainable Food Production

Aqua Food Systems represent viable solutions offering opportunities to improve global food and nutritional security; support livelihoods and conserve the environment. Through consumer shift to aqua foods, nutrient rich animal protein can be produced i) with lesser carbon foot print and ii) without intensive land use, which is otherwise required for grazing or fodder/feed production to support animal food systems such as beef, mutton, cheese, pork and chicken. The earth is gifted with diverse aquatic resources (fresh, brackish and marine waters) naturally laden with diverse AAF. These resources need to be conserved for optimal economic utilization as a sustainable food resource to feed the human population. Aquaculture has been recognized as a powerful industry occupying an important stature in the socio-economic development of farming community in Asian countries, which contributes about 90% to world's aquaculture production, with 85% of the global fisher population engaged in the fisheries and aquaculture sectors (FAO 2018). With anticipated world population growth to 9.0 billion in 2050, demand of food is going to increase more in Asian countries than in rest of the world.

As land and freshwater are squeezing due to human activities and global warming, the marine waters need to be managed for more aqua food production through stock enhancement and open water aquaculture (cage culture), without deteriorating the aquatic ecosystem. This can be achieved by transforming the open sea cage culture sites into in-situ integrated multi trophic aquaculture (IMTA) system. This will prevent nutrient enrichment of cage culture sites through phytoremediation, involving seaweed culture within the vicinity of aquaculture cages. Further, it will also prevent eutrophication of cage culture sites through farming of filter feeding aquatic animals (edible or pearl mussels or oysters) near the fish cages. Seaweed biomass will not only serve as potential food resource for human consumption and provide pharmaceutical byproducts, but also serve as an efficient CO₂ sink (CO₂ sequestration), reducing carbon foot print of aqua food production besides reducing environmental load of greenhouse gases. In view of growing global population and mounting environmental challenges, nutrient rich seaweeds offers prospective solution for boosting food security and restoring aquatic ecosystems. The filter feeding molluscs can be reared in the plankton rich IMTA environment without any feed and fertilizer inputs, further reducing the carbon foot print of the IMTA based AFS. Auto-cleaning aqua food systems like IMTA need to be developed for freshwater aquaculture systems as well to make the AFS more diversified and environmentally more sustainable.

Further, climate smart freshwater aquaculture technologies, in special reference to species and culture system diversifications, need to be developed to produce more aqua food per unit volume. For instance, through pangas catfish farming 3-4 times more fish can be harvested per unit volume as compared to carps; while through recirculatory aquaculture system (RAS) and biofloc based aquaculture system, water requirement per kg fish production can be reduced to 10-15% of required for traditional pond culture system. However, economically



Source: <https://x.com/UNinIndia>
(Recompiled)



viable RAS and biofloc aquaculture systems need to be developed as per regional climate and demand.

Furthermore, consumer preference shift to smaller fish also need to be explored to reduce aqua food production cost, in terms of feed and water requirement, with smaller production cycles at optimal carrying capacity of the culture system. Table size fish of <500g can be produced with lesser FCR as compared to 1 kg fish (USAID 2011), which can release pressure on costly conventional feed resources (e.g., fish meal and soybean meal) to feed high value carnivorous/omnivorous food fish like salmon and trout.

Sustainable production and consumption of *Blue Food* requires upgraded value chains that ensure social, economic and environmental viability of aquatic food systems. Overall, aqua food systems remain a good nutritional and environmental alternative compared to production of meats such as beef, pork, mutton and chicken; and is foreseen as an economically and ecologically viable “Future Food” to feed the human population.

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Mushrooms: A Superfood for Promoting Healthy Well-being

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The growing population, climatic variations, different edaphic factors and diminishing natural resources led to the search for sustainable and quality food sources. Among the various solutions, mushrooms have emerged as a promising contributor to sustainable food security. Early Greek, Egyptian, Roman, and Chinese civilisations has also acknowledged their beneficial nutritional and pharmaceutical impacts. Mushrooms are regarded as the super foods as well as functional foods owing to their potential powerful natural allies in promoting a health system. They are valuable additions to a balanced diet because of their distinct nutritional profile and abundance of bioactive substances. Their unique taste, immense health benefits, culinary versatility, nutritional properties, medicinal impact and pharmacological properties has increased their consumption and thereby, production and market worldwide. Mushrooms either consumed in fresh or processed forms which impart health benefits due to the presence quality proteins (essential amino acids), low glycaemic content, low fat content, presence of micronutrients, low sodium content and presence of vitamins. Mushroom are also known as “mini pharmaceutical factories” due to the presence of polysaccharides, beta-glucans, dietary fibres, antioxidant compounds, phenolic compounds, antimicrobial compounds and anti-inflammatory compounds that impart miraculous impact in disease management. The mushroom can be used as adjunct in treating/preventing metabolic disorders (such as obesity, type-2 diabetes, cardiovascular disease), inflammation, ageing, hypertension, tumours, weak immune system, kidney and liver disorders. Apart from mushroom's nutritional and medicinal impacts, the mushroom cultivation has a positive impact on environmental sustainability. Being a saprotrophic organism, mushrooms are cultivated under indoor conditions on agro-industrial residues (after minor pretreatments); making it independent of climatic and edaphic factors as well as environment friendly crop. Additionally, shorter life cycle and small growing area as compared to other crops made them accessible even in urban or land-scarce environments. Thus, making mushroom production a reliable food source under challenging conditions.

Diversity of edible and medicinal mushroom: Kingdom fungi is very diverse kingdom in which mushrooms are classified under macro fungi group belonging to basidiomycetes and ascomycetes. It has been estimated that there are around 12,000 species of mushrooms worldwide, of which 2,000 species has been recognised for edible and medicinal purposes. About 25 to 35 species of edible mushrooms are under commercial cultivation throughout the world. Mushrooms are classified on the basis of their consumption and functionality into two major classes that is edible and medicinal mushrooms. Some of the most important commercially cultivated mushrooms are *Agaricus bisporus* (agaric or button), *Lentinula edodes* (shiitake), *Pleurotus spp.* (oyster mushroom), *Pleurotus eryngii* (king trumpet mushroom), *Volvariella volvacea* (paddy straw mushroom), *Calocybe indica* (milky mushroom), *Hericium erinaceus* (lion's mane mushroom), *Auricularia auriculae* (wood ear mushroom), *Flammulina velutipes* (enoki or winter mushroom), and *Agrocybe aegerita* (pioppini). These are the edible mushrooms that can be cultivated under artificial growing conditions. While, mushroom like *Grifola frondosa* (maitake or hen of the woods mushroom), *Chanterelles*, *Boletus edulis* (King Bolete mushrooms), *Morchella spp.* (Morels) are the foraged edible mushrooms with high nutritional and medicinal values. Notably, about 85% of the world's cultivated edible mushrooms is represented by only five genera viz. *Agaricus*, *Lentinula*, *Pleurotus*, *Auricularia* and *Flammulina* with highest production of *Agaricus bisporus*, followed by *Lentinus edodes*, *Pleurotus spp.*, and *Flammulina velutipes*. Some edible mushrooms such as *Auricularia auriculae*, *Flammulina velutipes*, *Lentinula edodes*, *Pleurotus eryngii*, *Hericium erinaceus* possess important polysaccharides that have pharmaceutical properties. In addition to edible mushrooms, some mushrooms are not edible but possess potential medicinal



properties which were cultivated and later used in pharmaceutical industries. *Ganoderma lucidum* (Reishi), *Cordyceps militaris*, *Cordyceps sinensis*, *Trametes* spp., and *Schizophyllum commune* etc. are the major medicinal mushrooms that are cultivated for harnessing their medicinal potential. These mushrooms are also cultivated under submerged fermentation conditions for obtaining mycelium with potential medicinal properties thereby, avoiding contamination, maintaining uniform distribution of substrates and reducing the time period for cultivation.

World production of mushrooms: Globally, mushroom production has increased more than fivefold during last 1.5 decade to 48.33 million tonnes in 2023 (FAOSTAT 2023). The Asian continent contributes 92 per cent followed by Europe (5.6%) America and other countries (2.3%). Major mushroom-producing countries such as China, Poland, and the Netherlands are the major exporters, contributing significantly to global trade (Fig. 1a). Dried and processed mushrooms, especially shiitake and button mushrooms, are high-demand products in international markets, especially in Europe and North America, with China being a major supplier of dried and processed mushrooms to international markets. Poland is Europe's largest exporter of mushrooms, particularly button mushrooms. It produces over 300,000 metric tons annually and exports a significant portion to neighbouring European countries like Germany, U.K and France. Japan, South Korea, Italy, Spain and France are also known for cultivating and exporting high-value mushrooms like shiitake, maitake, enoki, and gourmet varieties.

Among Asian countries, during last decade, mushroom production in India has increased from 0.03 to 0.31 million tonnes with annual CAGR of 8.0% (FAO 2023). However, the CAGR of China during the same period had remain static at 3.81% (2012–2021). Additionally, over the period of fifty years, the biological efficiency of mushrooms has increased from a modest level of 7% to a high of 25% owing to better and hybrid strains of commonly cultivated mushrooms and advancements in cultivation practices at the commercial scale.

The commercial production of mushrooms in India is emerging at the higher pace, especially in the states of Bihar, Maharashtra, Odisha, Punjab, Himachal Pradesh, and Haryana. As per National Horticulture Board, Bihar is India's leading producer of mushrooms with a share of 10.82 % of the total mushrooms produced in the country followed by Maharashtra at 9.89% share. While Punjab contributes approximately 6.0% of total Indian mushroom production (Bijla and Sharma 2023). In India, five major mushroom species are cultivated commercially: button mushroom (*Agaricus bisporus*), oyster mushroom (*Pleurotus* spp.), paddy straw mushroom (*Volvariella volvacea*), milky mushroom (*Calocybe indica*), and shiitake (*Lentinula edodes*) (Fig. 1b). This rise in mushroom industry is due to continuous government assistance, training programs, and increased awareness in mushroom consumption public.

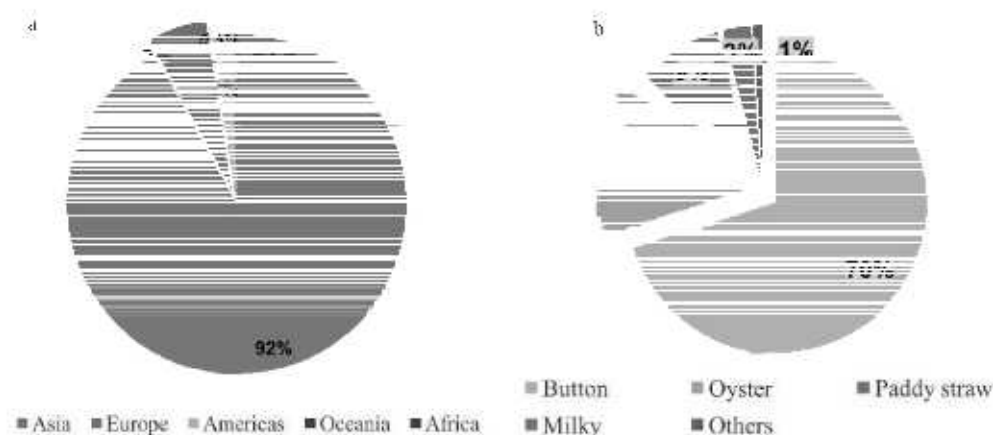


Fig. 1. Pie charts indicating a) World contribution towards mushrooms and b) Mushroom production statistics in India (FAO 2023)

Mushroom as nutritional sources: Mushrooms are a great source of soluble/non-soluble carbohydrates (26-87% d.w), dietary proteins (3.87-37.4% d.w), fibres (16-53% d.w), minerals (6.2-9.7% d.w), and vitamins while being low in fat (1-5% d.w) and calories (50-70 Kcal) making them suitable for managing metabolic disorders (Assemie and Abaya 2022). In all edible and medicinal mushrooms, the nutritional values vary depending upon the type of species, stage of development and environmental parameters. In mushrooms, the digestible carbohydrates profile includes various sugars such as hexoses, pentoses, disaccharides, starch, sugar alcohol and sugar acids.

While the non-digestible carbohydrates include polysaccharides, chitin, trehalose, mannans and glucans. The crude fibres present in mushrooms include partially digested polysaccharides and chitin. The non-digestible fraction of mushrooms, act as potential prebiotics that helps in maintaining gut microflora thereby, healthy digestive system (Table 1). The protein content of mushroom includes all essential amino acids required by humans. Mushrooms are rich in threonine and valine but deficient in sulphur containing amino acids such as cysteine. The high digestibility of mushroom makes them potential substitute of muscle proteins. In addition to this, mushrooms are good source of vitamins (B1, B2, B12, C, D, and E), nutrients and micronutrients (iron, copper, zinc, manganese, selenium etc.) (Table 2). On the other hand, mushrooms are relatively fat free, gluten free, cholesterol free and contain very small amount of sodium, making it a suitable food option for obesity, gluten allergic, hypertension, cardiovascular patients. The relatively higher presence of oleic, linoleic, palmitic, and stearic acid in mushrooms in comparison to other fatty acids make them ideal for human consumption. Consumption of these fatty acid rich mushrooms can enhance insulin sensitivity and decrease the chances of type-2 diabetes (Sganzerla et al 2022).

Table 1. Nutritional profile of various edible mushrooms

Mushroom	Protein (%)	Fat (%)	Carbo-hydrates (%)	Dietary fiber (%)	Calories (kcal/100g)	Notable nutrients
Button Mushroom (<i>Agaricus bisporus</i>)	20-35%	2-4%	45-55%	8-12%	350-380	B vitamins (B2, B3), Selenium, Potassium
Shiitake (<i>Lentinula edodes</i>)	25-35%	4-6%	55-65%	7-10%	300-350	Vitamin D, Iron, Copper, Fiber
Oyster Mushroom (<i>Pleurotus ostreatus</i>)	25-30%	2-5%	55-65%	10-14%	350-380	B vitamins (B1, B2), Iron, Potassium
Enoki Mushroom (<i>Flammulina velutipes</i>)	25-30%	1-3%	55-65%	10-12%	320-370	B vitamins, Potassium, Fiber, Antioxidants
Paddy Straw Mushroom (<i>Volvariella volvacea</i>)	20-30%	1-3%	55-65%	8-12%	310-350	B vitamins, Vitamin D, Potassium, Fiber
Milky Mushroom (<i>Calocybe indica</i>)	25-30%	2-4%	50-60%	10-13%	320-370	Protein, Calcium, Potassium, Fiber
Maitake (<i>Grifola frondosa</i>)	20-28%	1-3%	55-65%	10-12%	330-380	Vitamin D, Fiber, Beta-glucans
Porcini (<i>Boletus edulis</i>)	20-35%	2-4%	50-60%	10-15%	300-350	Antioxidants, Selenium, Potassium
King Oyster Mushroom (<i>Pleurotus eryngii</i>)	25-30%	2-4%	50-60%	10-13%	320-370	Antioxidants, Fiber, Vitamin B3
Lion's Mane (<i>Hericium erinaceus</i>)	20-30%	1-3%	50-60%	8-12%	330-370	Antioxidants, Beta-glucans, Potassium

*Data Sources U.S. Department of Agriculture (USDA, Food Data Central. (2021)); Das et al (2021); Das and Prakash (2022); Lysakowska et al (2023)



Medicinal properties of mushrooms: Mushrooms contains various bioactive compounds with potential therapeutic effects for boosting immunity, protecting against chronic diseases, supporting mental health, and promoting overall well-being. Their inclusion in the diet, either as food or supplements, can offer significant health benefits. They are known to have immunomodulatory effects, anti-cancer, anti-inflammatory, anti-oxidant, antibacterial, antiviral, hepatoprotective properties and neuroprotective effects.

Different types of polysaccharides specially beta-glucans, polysaccharopeptides (PSP) and polysaccharide-K (PSK) are abundant in medicinal mushrooms such as shiitake, maitake, cordyceps and reishi mushrooms that have the ability to boost the immune system. These mushrooms boost the immunity against infections and tumours by activating natural killer (NK) cells, macrophages, and other immune cells. Mushrooms also aids in the production of cytokines like TNF- α , interleukin-1 (IL-1), and interleukin-6 (IL-6) which are signalling molecules that control pro-inflammatory immunological responses (Zhao et al 2019). *In vitro* and animal studies have demonstrated the anti-tumor properties of compounds such as polysaccharides, triterpenoids, and lectins present in them; strengthens the immune system against tumours and hinders the proliferation of cancerous cells. Turkey tail (*Trametes versicolour*) contains polysaccharide-K (PSK), which is known to improve immune function during chemotherapy, it has been utilised as an adjuvant therapy for cancer in Japan (Bains *et al* 2021). The beta-glucans also improves the insulin sensitivity and maintains the blood glucose levels which can be useful in treating the diabetic patients (Table 3).

Compounds like ergothioneine, glutathione and terpenoids that have powerful anti-inflammatory effects and antioxidant properties also helps in neutralizing free radicals and protect the body from oxidative stress, reduces

Table 2. Mineral composition of various edible mushrooms

Mushroom type	Potassium	Phosphorus	Selenium **	Copper	Zinc	Iron	Magnesium	Calcium	Sodium
<i>Agaricus bisporus</i>	373.0	93.0	20.0	0.4	0.5	0.2	10.2	5.0	6.0
<i>Lentinula edodes</i>	243.0	76.0	1.2	0.05	0.7	0.1	14.1	1.0	1.0
<i>Pleurotus ostreatus</i>	294.0	90.0	1.2	0.05	0.6	0.3	13.5	2.0	1.0
<i>Grifola frondosa</i>	260.0	72.0	3.3	0.3	0.7	0.2	11	2.0	0.0
<i>Flammulina velutipes</i>	402.0	84.0	2.0	0.09	0.48	1.2	0.09	1.0	2.0
<i>Volvariella volvacea</i>	260.0	100.0	3.5	0.2	0.7	1.2	13	2.0	0.0
<i>Calocybe indica</i>	315.0	90.0	4.0	0.3	0.9	1.5	16	6.0	0.0
<i>Hericium erinaceus</i>	443.0	94.0	1.8	0.2	0.7	0.7	11.7	2.0	0.0

* Values are in mg/100g; ** values in mcg/100g; #U.S. Department of Agriculture (USDA), Agricultural Research Service. FoodData Central (2021)

Table 3. Medicinal properties of mushrooms

Mushroom	Bioactive compound	Properties
<i>Ganoderma lucidum</i>	Ganoderic acids, Polysaccharides, glucans, Terpenoids	Anti-metastatic, Immunomodulatory, Anti-cancerous, Hepatoprotective, anti-inflammatory
<i>Lentinula edodes</i>	Lentinans, Glucan	Immunomodulatory, Anti-cancerous, cholesterol-lowering, anti-inflammatory
<i>Grifola frondosa</i>	Glucans	Anti-cancerous, immune support, blood sugar regulation
<i>Trametes versicolor</i>	PSK, PSP, Glucans	Immunity, Anti-cancerous, Hepatoprotective, Aids in digestion
<i>Cordyceps sinensis</i>	Cordycepin, glucans	Immunity, Adaptogen, energy booster, anti-depressant
<i>Hericium erinaceus</i>	Erinacines, Hericenones Glucans	Neuroprotective, cognitive enhancement, anti-inflammatory
<i>Pleurotus ostreatus</i>	Polysaccharides, Glucans, pleurostrin	Cholesterol-lowering, anti-inflammatory, hyperglycemia



the risk of chronic diseases like cardiovascular disease and neurodegenerative disorders. It is also known to delay the ageing process. Notable compounds present in Lion's mane, such as hericenones and erinacines, enhances the production of nerve growth factor (NGF), that stimulates the functionality of the neurons. These may help in the treatment of neurodegenerative diseases like Alzheimer's, Parkinson's diseases etc. Bioactive compounds in edible mushrooms like shiitake and oyster mushrooms like eritadenine and lovastatin lowers the blood cholesterol levels and improves the cardiovascular health. Cordycepsins, the bioactive compound present in the *Cordyceps spp.* is used to improve the physical endurance, reduces fatigue and is particularly used to improve the health, immunity and performance of the athletes. Mushroom polysaccharides have prebiotic properties; as these are nondigestible in human gut, however, serve as food source for probiotic bacteria (e.g., bifidobacteria and lactic acid bacteria) thereby, boosting the gastrointestinal and immune system. Additionally, mushrooms can modulate the diversity of gut microflora and enhance the secretion of metabolites that improves the absorption of calcium and magnesium, influence blood glucose levels, and improve plasma lipids.

Mushrooms in combating malnutrition and food insecurity: Mushrooms offers an environmentally friendly food source which is highly nutritious playing a significant role in combating malnutrition and food insecurity. Owing to its nutritional significance, adaptability, and efficient production methods, provides an affordable and healthy alternative to meat and other animal products, which require more area, water, and energy inputs. Their nutritional value along with low cost of production, makes it an accessible food source for populations in both rural and urban areas.

Micronutrient deficiencies, referred as "hidden hunger," are widespread in developing countries, contributing to malnutrition, particularly in children and pregnant women. Mushrooms can help to overcome these deficiencies as they are rich in micronutrients like iron, zinc, and selenium. For instance, in Kenya, the "Mushroom for Good Nutrition" initiative promotes mushroom farming to combat protein and vitamin deficiencies which also generates income for the people. In Nigeria, the 'Mushroom farming initiative' by local NGOs has been used to tackle food insecurity, especially in regions with limited farming land. Similarly in Uganda, mushrooms are being used as a means to economically empower women in rural areas under the project Women's Mushroom Project that has trained hundreds of women in mushroom farming techniques, allowing them to sell mushrooms at local markets (Tsegaye and Tefera 2018). They can also be marketed as a sustainable superfood, tapping into the growing global demand for eco-friendly, plant-based diets. Mushrooms are an incredibly versatile and sustainable food source with the potential to combat malnutrition and food insecurity on a global scale. Their high nutritional value, ease of cultivation, and low resource requirements make them an ideal solution for addressing protein and micronutrient deficiencies, especially in resource-poor settings. By promoting mushroom farming, the developing countries can improve food security, support economic empowerment, and provide an environmentally sustainable alternative to traditional agriculture.

Mushrooms are well adapted to grow in the regions of natural calamities like floods or drought and can mitigate those environmental conditions. In the regions of Ghana, its farming is well adopted as climate-resilient agricultural practice, as this region is affected by droughts and poor soil conditions. In Ghana, farmers have adopted mushroom cultivation to ensure food security and generate a reliable income source. Similarly, the International Centre for Integrated Mountain Development (ICIMOD) has promoted mushroom farming in Nepal and the Himalayan region to combat malnutrition and food insecurity (Sharma 2017).

The Food and Agriculture Organization (FAO) has highlighted the importance of mushroom cultivation as a tool for poverty alleviation, food security, and nutrition improvement, especially in developing countries. Given that mushrooms are rich in proteins, vitamins, minerals, and bioactive compounds, they have nutraceutical potential to alleviate malnutrition. With limited input costs, such as minimal water and no need for fertilizers, they offer a sustainable protein source for people at risk of food insecurity. In India, the cultivation of mushrooms like oyster mushrooms has been promoted in rural areas as a source of food and income. Women in rural communities



are being trained to grow mushrooms on agricultural waste, providing an inexpensive source of protein for their families and local markets.

Innovations in value addition of mushrooms: The edible and medicinal mushrooms were dried, canned or processed while tinctures, powders and capsules were made from the medicinal mushrooms. The value addition of mushrooms through formation of various products is the key to boost profitability as well as also improves the nutritional, therapeutic, and functional qualities present in mushrooms.

Mushrooms powders can be used to partially replace wheat flour in baked goods and as a dietary fibre supplement in food. Dehydrated mushrooms are quite adaptable and can be used in a variety of goods, including cookies, soups, snacks, and nuggets. Products that contain mushrooms infusions, such as cakes, bread, oil-roasted mushrooms, and pâté, offer extra nutritional advantages that make them appealing, especially to kids and the elder ones (Sangeeta et al 2024). According to studies, using sweet potato flour and mushroom powder in place of wheat flour in biscuits improves their sensory qualities and raises their mineral content. Murraba, ketchup, candies, and mushroom chips are some ways to preserve mushrooms. Noodles, spaghetti, biscuits, stuffed mushrooms, mushroom tikki, and mushroom chips, sauces are examples of snacks made from mushrooms that have the potential to provide both enticing sensory appeal and substantial health benefits (Dhanapal and Rajoo 2023). The high protein content, dietary fibre, antioxidants, and phenolic components of these items make them extremely valuable in terms of nutritional and health potential.

Turkey tail, chaga, and reishi mushroom extracts, tinctures, powders, or capsules are standardised for their anti-inflammatory, anti-cancer, and immuno-modulating qualities. Mushroom coffees and mushroom teas with Reishi or Chaga, Lion's Mane-based nootropics are used in brain health supplements to improve memory, focus, and mental clarity, and are often combined with other beverages for the value additions to improve flavor and nutritional content. Mycelium-based supplements like AHCC (Active Hexose Correlated Compound), derived from the mycelium of shiitake mushrooms, are used for immune system enhancement and cancer support. Nano-encapsulated Cordyceps or Reishi supplements, which offer enhanced energy, endurance, and immune support are also available in market.

Mushrooms' adaptability to be transformed into various value-added products aligns perfectly with the increasing demand for health-conscious and functional foods. Their addition as a key ingredient in modern nutritional diet reflects their potential to meet the needs of consumers seeking more nutrient-rich vegan options. These strategies maximize the health benefits of mushrooms, catering to the growing demand for sustainable, natural, and effective health supplements in various forms.

Conclusion

The uncontrolled increase in population, immense mushroom biodiversity, diverse climatic conditions, cheap agricultural residues and skilled labour made India as a potential player in world mushroom industry. The mushroom being nutritionally rich food should be included in daily diet in fresh form or as a value-added product. The mushrooms not only serve the source of quality protein and nutrition but also have polysaccharides and plethora of antioxidant compounds that maintain healthy well-being, improves digestive tract health and ultimately maintains the overall immune system of the consumer. The increase in investments in mushroom R&D, enhancing awareness among consumers and growers, expanding market access, enhanced the value chains and connections, entrepreneurship etc. can further upsurge the production of edible mushrooms in nation. These positive changes will act as pivot in growth and sustainability of mushroom industry.

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Overcoming Challenges Related to Pesticide Residues in Food Commodities in India

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India is one of the largest producers of food grains, fruits, vegetables, spices and pulses (FAO India 2022) and contributes significantly to the world's food basket by providing a stable supply of safe and high-quality food commodities thus ensuring global food security. However, factors such as higher demand for food by the increasing population, limited land availability for agriculture and crop losses due to infestation by insect-pests and diseases threaten food security (Popp et al 2011). In the last few decades, agricultural practices have undergone various transitions including use of chemical fertilizers and pesticides for effective and efficient crop protection as well as to ensure quality food production for the fast-growing population around the world (Damalas et al 2011). However, the non-judicious use of pesticides may lead to detection of their residues in food commodities above the prescribed limits and pose challenges for consumer safety and trade (Tudi et al 2021).

In India, pesticides are registered for import, manufacture, sale, transport, distribution and use of insecticides under the Insecticide Act, 1968 and Insecticide Rules, 1971 by Central Insecticide Board & Registration Committee (CIB&RC) which is under the administrative control of the Ministry of Agriculture and Farmers Welfare. Before registration, CIB&RC assesses scientific evidence pertaining to pesticide chemistry, mode of action, bioefficacy, phytotoxicity, toxicity to non-target organisms, and pesticide residues on crops, soil, and water. After approval by the regulator the pesticide gets a 'label claim' for that crop implying the legal sanction for its approved use in the country. No pesticide is registered in India without fixation of Maximum Residue Limit (MRL) and label claims on the crop on which it is intended to be used. Label claim means the pesticide product in reference has legal sanction for use in that particular crop.

Food safety aspects related to presence of pesticide residues in food commodities are extremely crucial and need to be addressed. MRLs are the highest levels of pesticide residue that are legally tolerated in or on food crop/commodity when a pesticide is applied correctly in accordance with recommended dosages and Good Agricultural Practices (GAP) of the regulatory bodies of the respective countries and taking into account the toxicity of the pesticides. In India, the Food Safety and Standards Authority of India (FSSAI) fixes MRL of pesticides on specific food commodities. Internationally, Joint Food and Agriculture Organization (FAO)/ World Health Organization (WHO)/ Codex Alimentarius Commission (CAC) fixes MRLs based on risk assessment of global consumers and many countries adopt these MRLs for food safety. Sometimes countries adopt stringent standards for MRLs based on their capability of detecting the pesticide residues at low levels. In such cases, when residues of pesticides are detected, the exports are unable to meet the strict standards of the importing country leading to their rejection. Detection of pesticide residues above the MRL has become a major bottleneck in trade of food commodities under the World Trade Organization (WTO) agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). Since national, regional, and the Codex MRLs of pesticides in foods significantly differ especially among the developed and developing countries, there is a need to harmonize pesticide regulations including different MRLs of different countries or region to avert the threat in international trade (Yeung et al 2017).

One of the major challenges related to pesticide residues in food commodities in India is that at present there are label claims for only 15-20% of the available pesticides. Out of 339 registered pesticides, the labeled use is restricted to about 100 crops of the more than 500 crops grown in India. While a number of the major cereal, vegetables and fruit crops are granted valid label claims for a large number of pesticide formulations many crops,



mostly minor crops like spices etc. remain without any label claims. Thus, the choice of approved pesticides in spices is limited due to the low number of pesticides with label claims. In the absence of registered pesticides, farmers resort to application of pesticides available in the market to protect their crops. This is termed as the application of 'off label' chemicals (unregistered pesticides). In case a crop has limited cropping area, pesticide manufacturers do not find it lucrative to invest resources in developing bio-efficacy and pesticide residue data as their investment will not fetch viable returns. There is therefore a need to bring as many major and minor crops under the umbrella of crop protection and encourage industry partners to generate pesticide residue data as per regulatory requirements. This challenge can also be addressed to some extent by adopting the concept of crop grouping which aims at uniting similar types of crops into a group or subgroup to facilitate use of pesticides in as many crops as scientifically possible. It eliminates the need for fresh data for each individual crop in the group. Thus, the MRL fixed for the representative crop in a group can be extended to all the members of the same group/sub-group as Group MRL.

In India, two major on-going projects are playing a major role to address the challenges related to pesticide residues. The All India Network Project on Pesticide Residues (AINP-PR), previously known as All India Coordinated Research Project on Pesticide Residues was initiated under the aegis of Indian Council of Agricultural Research (ICAR) in year 1984. It aimed at developing uniform protocols for the safe use of pesticides by recommending 'good agricultural practices' based on multi-location 'supervised field trials' to evaluate the pesticide residues in different crops at harvest. Currently, AINP-PR is constituted of 18 coordinated centers located in State Agricultural Universities and ICAR institutes across different agro-climatic zones of the country. During the last two decades, the project has seen the completion of over 2500 multi-location supervised field trials conducted on more than 500 crop-pesticide combinations in different agro-climatic zones of India. The critical information generated on safe waiting periods/ pre harvest intervals of pesticides on particular crops under AINP-PR has facilitated Central Insecticide Board and Registration Committee (CIB&RC) in granting label claim approval of various pesticide crop combinations and Food Safety and Standards Authority of India (FSSAI) in fixing their respective MRLs. This has ensured an increase in the availability of plant protection options for farmers as well as domestic MRLs which facilitate smooth trade.

Another national level project implemented by All-India Network Project on Pesticide Residues, ICAR is the Monitoring of Pesticide Residues at National Level (MPRNL). On the recommendation of the Joint Parliamentary Committee (JPC), the scheme was initiated by the Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare in 2005-06 to ascertain the status of pesticide residues in food commodities at national level so that the risk involved in their use can be scientifically assessed. The main aim of the scheme is to monitor pesticide residues in food commodities and water in India. It is the most systematic study on the status of pesticide residues in the country and has pioneered in producing the national database on status of pesticides in different food commodities in the country. Presently, 35 laboratories representing various ministries and State Agricultural Universities randomly collect samples of different food commodities (vegetables, fruits, spices, herbs, cereals, meat, egg, tea, milk, fish and marine products) from various sources such as retail outlets and farmers' fields and analyse them for the possible presence of pesticide residues. The monitoring results related to the pesticides detected, their levels, samples above Maximum Residue Limits (MRLs), off-label pesticide detection, banned pesticides detection, etc. are shared with the state governments for promoting the safe and judicious use of pesticides among farmers and for Integrated Pest Management (IPM) interventions. Inputs from the scheme are also considered while making national policies and for providing replies to parliament questions and queries under RTI and court cases. Based on the monitoring data generated in the last few years, dietary risk assessment for a number of pesticides on tomato, cabbage and other vegetables (Sharma et al 2019, 2021, 2022), on vegetables like brinjal, capsicum, cucurbits, tomato, and fruits like mango and pomegranate (Tripathy et al 2021, 2022a, 2022b) has been conducted based on various risk parameters. The risk assessment showed that the



pesticide residues in Indian vegetables and fruits were within safe limits and the consumption of such Indian vegetables and fruits did not pose any appreciable risk to the consumers.

Keeping in view the challenges associated with consumer safety and export of spices from India, the ICAR- All India Network Project on Pesticide Residues (AINP-PR) has established linkages with the FAO/ WHO/ Joint Meetings on Pesticide Residues (JMPR) and Codex Committee on Pesticide Residues (CCPR) for the fixation of Codex MRLs on spices. The pesticide residue monitoring data generated on various spices under MPRNL is being regularly submitted to FAO/WHO/JMPR for risk assessment and fixation of Codex MRLs. Till now Codex MRLs (CXLs) for 22 pesticide-spice combinations on five different spices (cardamom, coriander, fennel, cumin, pepper (black and white) has been fixed based on the data submitted by India. Most of these CXLs are adopted by many countries worldwide including EU. Such multi-institutional linkages can help meet the challenges of limiting pesticide residues in crops and food commodities to the benefit of the common person. These projects also serve as a national facility for capacity building and human resource development in the field of pesticide residues and food safety. To update the skills of the researchers/analysts and apprise them on the latest development in the methodologies and analytical techniques, regular hands-on trainings and skill development programs are conducted in the area of pesticide residue analysis. These trainings have helped the participating scientists/researchers become accomplished in pesticide residues analysis while disseminating the knowledge acquired to their colleagues in the laboratories and contributed in building a robust system and skilled workforce for pesticide residues testing across the country. Under the guidance of these projects, participating laboratories have developed and validated several simple and cost-effective protocols for pesticide residue analysis in cereals, pulses, oilseeds, vegetables, fruits, tea, milk and milk products such as butter, oil, ghee, and spices.

To ensure generation of reliable and quality data, all the testing laboratories under the project are NABL accredited as per ISO 17025 and regularly participate in proficiency testing (PT) at national and international level wherein the performance of each participating laboratory is evaluated against the pre-established criteria (z score) provided by ISO/IEC 17043:2010 guidelines.

The AINP on Pesticide Residues with the regular support of regulatory authorities, industry partners and other concerned stakeholders is continuing to make efforts for label claim approval for new pesticide crop combinations, fixation of MRLs and their harmonization with international standards, and expansion of label claim through crop grouping to overcome challenges related to pesticide residue affecting crop protection, consumer safety and smooth trade.

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Global Climate Change vis-à-vis Insect Dynamics

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Rice is the world's most vital food crop, advanced technologies boosted rice productivity for livelihood security of farmers. This is especially true in developing countries across Asia, much of Latin America, and increasingly in Africa. In India, rice is considered a sacred grain and is highly revered, as reflected in the ancient Vedas, where it is referred to as "annam," meaning food. It represents Prajapati or Janardana and is one of the earliest known cereals to humanity. The changing climatic variables like global warming, frequent droughts, fluctuating atmospheric carbon dioxide (CO₂) levels and weather disturbances continue to challenge crop yields. These abiotic factors also affect pest biology, behaviour, population dynamics, and their interactions with plants and natural enemies, all of which are crucial in determining crop yield. Climate change is evident through rising global average temperatures, shifting rainfall patterns, and extreme weather events. These seasonal and long-term changes will impact the fauna, flora, and population dynamics of insect pests. Abiotic factors directly influence insect population dynamics by affecting their developmental rates, survival, fecundity, voltinism, and dispersal.

Climate change refers to the gradual rise in the average temperature of the Earth's atmosphere and oceans, a shift that is significantly altering the planet's climate (1). This topic has become widely discussed, with increasing scientific research and political interest. Since 1900, global temperatures have risen by approximately 1°C, with the most notable increases occurring in northwestern North America. In contrast, India's temperature rise has ranged between 0.2°C and 1°C. The majority of the warming observed in the past 50 years is largely due to human activities. Projections indicate that the global mean surface temperature could rise by 1.4 to 5.8°C from 1990 to 2100. If temperatures increase by around 2°C over the next century, the adverse effects of global warming would intensify across most regions of the world (40).

The declined survival rate of brown plant hopper *Nilaparvata lugens* (Stal) and rice leaf folder, *Cnaphalocrocis medinalis* (Guen) at higher temperature indicates the impacts of rising temperature could do the changes in the pest population dynamics of rice ecosystem (2). This review article comprehensively analyze and synthesize current research on the impact of climate change on the behavior, distribution, and population dynamics of rice stem borers, including how alterations in temperature, precipitation patterns, and other climatic factors influence the interactions between rice stem borers, their host plants, and associated viral diseases. It also provides insights into potential future trends, identify gaps in existing knowledge, and suggest directions for further research to mitigate the adverse effects of climate change on rice production.

Impact of Climate Change on Insect Pests

Impact of rising temperatures on insect pests: Insects are cold-blooded (poikilothermic) organisms, meaning their body temperature aligns with their environment. The temperature is one of the most crucial environmental factor influencing the behaviour, distribution, development, survival, and reproduction of insects. The effect of increased temperatures on insects is significantly correlated due to these direct effects (Reference). As exothermic creatures, insects are likely to become more active in warmer conditions. Bugs and termites significantly contribute to global warming and for every degree increase in global temperature, the life cycle of each bug shortens. A quicker life cycle leads to a higher population of pests (4). Moreover, the temperature may change sexual category ratio of some pest species such as thrips affecting reproduction rate (5).

Insects that spend significant portions of their life cycle in the soil may be more gradually affected by temperature changes compared to those above ground, as the soil acts as an insulating medium that can buffer temperature fluctuations in the air (6). The prevailing weather variables (temperature, relative humidity, rainfall,



sunshine hours and evaporation) in specific environmental conditions such as rising temperatures and reduced rainfall, and significantly impact the physiological regulation and susceptibility Klok and Chown (8). Likewise, Coops and Waring (9) developed a spatial modeling approach to assess the persistent climate changes that alter the geographic distribution of species.

Consequences of Increasing Temperatures

Temperature can influence insect species in numerous ways. Since insects are poikilothermic, their growth, development, and reproduction are primarily influenced by temperature. The changes in temperature inevitably alter insect dynamics. Species that cannot adapt to higher temperatures may struggle to sustain their populations, while others may thrive and multiply rapidly. Temperature impacts metabolism, metamorphosis, mobility, and host availability, all of which play a role in the potential changes in insect pest populations and dynamics (10).

Rise in Pest Numbers

The previous researchers have found that increased temperatures can affect insect survival, development, geographic range, and population size and the effects of temperature differ depending on the development strategy of the insect species (11). Temperature can influence insect physiology and development both directly and indirectly through the physiology or presence of their hosts. Insects that take longer to complete one life cycle will impact the pest population. Those that spend significant portions of their life cycles in the soil may be affected more slowly by temperature changes than those above ground, as soil acts as an insulating medium, buffering temperature fluctuations more effectively than air (11).

Climate Change and Strategies for Managing Insect Pests

It is generally expected that a changing climate and more erratic weather patterns will lead to more unpredictable and severe pest attacks. As CO₂ levels and temperatures rise, precipitation patterns become more variable, and non-native insect species expand into new areas, significant and unforeseen changes in insect-plant interactions and integrated pest management (IPM) practices are likely to occur (12). Changes in agro-ecosystems could make pests that are typically found in greenhouses more problematic in open pastures and fields. According to Morris (13) short-lived species may experience increased population growth and longevity. One of the main factors contributing to the rise of insect pests in new areas and an extended growing season in existing regions could be the reduction of cold constraints (14).

Impact of Climate Change on Crop Production

Agriculture heavily depends on climate factors such as temperature, water availability, and weather conditions for crop production. Consequently, any alterations or disturbances in these factors can significantly impact crop yield and productivity. The yield losses in various crops due to insect pest are presented in Figure 1.

The effects of climate change on the prevalence and behavior of pests: The agro-ecosystem environment is predominantly shaped by the interaction between abiotic factors (such as temperature, humidity, rainfall, soil conditions, and pollutants) and biotic factors (including crops, weeds, insect pests, pathogens, and nematodes). Abiotic stresses influence the impact of biotic stresses and are particularly damaging when they occur in combination (16).

Impacts of rising CO₂ levels on pest populations: The

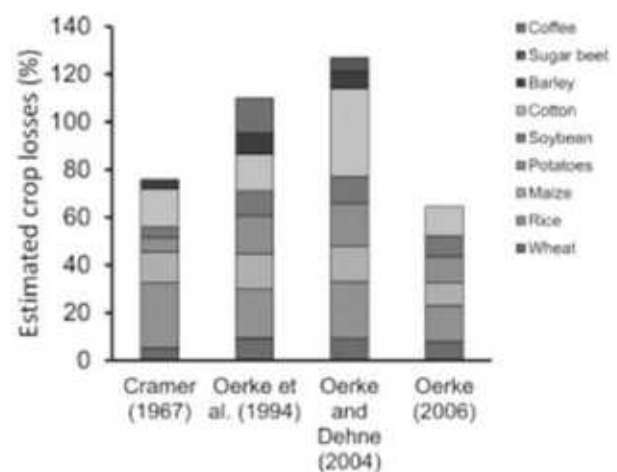


Fig. 1. Global estimates of crop losses due to insect pests/animal pests (15)



CO₂ plays a significant role in increasing temperature as compared to all other greenhouse gases (CH₄, N₂O, Freons, CFC). While higher CO₂ levels may not directly harm insects, the resulting temperature rise from increased anthropogenic CO₂ profoundly impacts insects, affecting their distribution, nutrition, phenology, and role as disease vectors. Elevated CO₂ levels can influence both hosts and pathogens in various ways, with some effects potentially offsetting others. Research indicates that plants grown in high CO₂ environments often exhibit rapid leaf and stem growth, leading to dense canopies with higher humidity that promote pathogen development (17). The trend shows that the severity and prevalence of diseases tend to increase with elevated CO₂ levels, a consequence of climate change (18). Generally, higher plant density is likely to increase leaf surface wetness and the duration of this wetness, making infection by foliar pathogens more probable (19). The performance of insect herbivores is positively linked to leaf nitrogen concentrations (20).

The impact of elevated CO₂ levels on the growth, development, and fecundity of *A. gossypii* was primarily indirect; however, the host plants growing under high CO₂ levels were directly affected (21). Leaf sugar levels increased by 31% under elevated CO₂, which coincided with a significant rise in the density of the invasive species *Popillia japonica*. The higher sugar content in leaves grown in high CO₂ conditions may serve as a phagostimulant for the Japanese beetle. The elevated CO₂ levels positively influenced BPH reproduction, resulting in a population more than twice as large at its peak compared to those exposed to ambient CO₂ levels (22). The effects of elevated CO₂ on *Helicoverpa armigera* and crop diseases, several noteworthy observations were made. The larvae of *H. armigera* exhibited an extended lifespan in their third generation when feeding on the milky grains of spring wheat cultivated under higher CO₂ levels. Furthermore, the pupal weight of this pest was found to be lower across all generations under these conditions. Regarding crop diseases, the study evaluated 27 different diseases under elevated CO₂ conditions. Of these, 13 diseases were found to cause greater crop losses than previously estimated, indicating a heightened impact on agriculture. Conversely, 10 diseases had a reduced effect on crop yields, suggesting a mitigated impact in the elevated CO₂ environment. Four diseases showed no change in their impact compared to current levels. This comprehensive analysis highlights the varying effects of increased CO₂ on both pest behaviour and disease dynamics in crops (23).

Managing Insect Pests in the Context of Climate Change

It is generally expected that shifting climate conditions and increasingly erratic weather will lead to more unpredictable and intense pest outbreaks. Rising CO₂ levels and temperatures, along with fluctuating precipitation and the movement of non-native insect species into new areas, will result in significant and unforeseen changes in insect-plant interactions and integrated pest management (IPM) strategies (28). Changes in agro-ecosystems could make pests that are currently managed in glasshouses more problematic in open pastures and fields. According to Morris (29), short-lived species might exhibit greater population growth and longer lifespans. A reduction in cold constraints could be a major factor driving the spread of insect pests into new areas and extending the growing season in existing regions (30).

Cultural Practices

Adapting eco-friendly farming practices and management strategies will be essential to mitigate the impact of agricultural pests on crops (31). This may involve measures such as planting different crop varieties, varying sowing dates, using mulching, creating raised beds, providing shelters, protecting crops from heavy rain, high temperatures, and flooding, preventing soil degradation, and increasing habitat diversity on field edges to boost natural predator populations. At both the farm and microclimate levels, adapting farming strategies is crucial. Crop rotation, for instance, can help manage diseases that are expected to become more common with climate change. For example, incorporating oilseed, pulse, and forage crops into a cereal cropping system can disrupt disease cycles (32). Expanding the genetic diversity of crops can also help suppress diseases, such as fungal blast, across different rice varieties.

Semiochemicals



Signaling chemicals that influence the behavior of other living organisms are crucial in Integrated Pest Management (IPM) (33). Insects release pheromones and allelochemicals as a primary means to interpret their environment. These chemicals are essential for various IPM techniques, including monitoring, trapping, mating disruption, push-pull strategies, and biological control (34,35). According to Cork et al. [36] used PVC resin controlled release formulations to deliver sex pheromones to the yellow rice stem borer at a range of temperature (from 22 °C to 34 °C). The temperature used highly influenced pheromone rates, with half lives of the sex pheromone decreasing with an increase in temperature.

Conclusion

Agricultural insect pests represent a substantial threat to food security, which is further exacerbated by climate change. It requires the implementation of comprehensive management strategies. Understanding how pests' biology and behaviour are influenced by environmental factors is essential, as climate change will affect their distribution and activities in various ways. To effectively manage these pests, monitoring is crucial. Traditional pest monitoring methods, coupled with advanced remote sensing technologies and citizen science initiatives, provide valuable insights for timely intervention. For example, traditional methods might include field surveys and trap captures, while remote sensing can offer broader coverage and real-time data on environmental conditions. Integrated Pest Management (IPM) should be employed to minimize pesticide use and mitigate environmental impacts. IPM strategies involve a combination of cultural practices, such as crop rotation and habitat manipulation; biological controls, such as introducing natural predators; and targeted chemical treatments. This multifaceted approach helps to manage pests sustainably while reducing reliance on harmful chemicals. Forecasting systems that integrate historical data, remote sensing information, and reports from citizen scientists can offer early warnings about potential pest outbreaks. For instance, analyzing historical pest patterns alongside current weather data can help to predict future infestations, allowing for proactive measures.

Developing crop varieties that are resistant to pests and drought is another critical step. For example, breeding crops that can withstand pest attacks or adverse weather conditions can reduce the need for chemical controls and enhance food security. Insurance programs and financial tools also play a role by helping farmers to manage risks associated with pest outbreaks and invest in effective pest management strategies. These financial supports can provide a safety net and encourage farmers to adopt sustainable practices. Finally, educating and engaging farmers, communities, and other stakeholders is vital for successful pest management. Workshops, training sessions, and collaborative efforts can enhance understanding and implementation of pest management strategies. By implementing these comprehensive recommendations, we can better manage pest threats, improve food security, and ensure the resilience of agriculture in the face of a changing climate.

Future Scope

Evaluating the impact of climate change on agricultural yields due to increased pest pressure is still in its developmental stages. However, it is becoming increasingly apparent that human-induced climate change will influence all facets of Integrated Pest Management (IPM) systems. For instance, changing climatic conditions can lead to more frequent and severe pest outbreaks, disrupting the balance of pest populations and potentially causing greater crop damage. Additionally, climate change can affect the timing of pollinator activity and flower blooming, leading to mismatches in their synchronization and potentially reducing crop yields. The effectiveness of crop protection technologies may also be impacted, as shifting climate conditions could alter the efficacy of pesticides and other control measures. Moreover, the efficiency of natural pest controllers, such as parasitoids and predators, might be compromised if their life cycles and habitats are disrupted by changing weather patterns. Overall, the evolving climate will have far-reaching consequences for IPM systems, highlighting the need for adaptive strategies and ongoing research to mitigate these impacts effectively (24).

In addition to strategies for advancing research on breeding climate-resilient crop varieties, adjusting crop calendars, mapping crop pest risks using GIS, and evaluating new pesticide modes of action, GIS, GPS, and



remote sensing technologies collectively offer methods for collecting, integrating, and analyzing spatial data. By leveraging GIS, researchers can study how climate change impacts the development, occurrence, and population dynamics of insect pests. This involves predicting and mapping potential shifts in geographical distribution (26), identifying agro-ecological hotspots, and assessing future pest risk areas (27).

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Strategies of KVKs for Enhancing Farmers' Income in Punjab-Evidences and Key Lessons from the Farmers Who Actually Doubled their Net Income

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Punjab is one of India's most agriculturally advanced states. Its role in ensuring food security during the 1970s and 1980s, when India faced a food grain shortage, is legendary. For years, a large portion of the country's food grain procurement has come from Punjab. This has led farmers to align their practices with government policies. The dominance of the wheat-rice farming system reflects the long-standing success in procurement. However, doubling farmers' incomes remains difficult within the current wheat-rice system or food grain cultivation as a whole.

Status of agricultural land holding size and corresponding number of farm-families: In the state, about 34 percent farmers are classified as semi-medium, with land holdings between 2 to 4 hectares, averaging 2.67 hectares each (a total of 3.68 lakh farmers). Following them are medium farmers, who hold between 4 to 10 hectares, with an average agricultural land of 5.67 hectares (27.93% of farmers, or 3.05 lakh). Small farmers, owning 1 to 2 hectares, make up 18.98% and have an average of 1.40 hectares (2.07 lakh farmers). Marginal farmers, with less than 1 hectare, account for 14.13%, holding an average of 0.60 hectares (1.54 lakh farmers). Large farmers, who own more than 10 hectares, represent 5.28%, with an average of 14.85 hectares (0.86 lakh farmers). Overall, there are 39.54 lakh farmers in the state, with an average land holding of 3.62 hectares.

No. of KVKs in the state: Punjab has so far 22 (23rd one is under the process of being started) Krishi Vigyan Kendras (KVKs) hosted by three organizations. The Punjab Agricultural University (PAU), Ludhiana is the host organisation of 18 KVKs located in Pathankot, Gurdaspur, Amritsar, Hoshiarpur, Jalandhar, Kapurthala, Nawanshahr, Ropar, Ludhiana, Fatehgarh Sahib, Patiala, Sangrur, Bathinda, Mansa, Moga, Ferozepur, Faridkot, and Muktsar Sahib while the 19th KVK viz., Malerkotla is under the process of being started under the same PAU, Ludhiana. Guru Angad Dev Veterinary and Animal Science University, Ludhiana runs 3 KVKs in Barnala, Mohali, and Tarantaran. Additionally, the ICAR-Central Institute of Post-Harvest Engineering and Technology, Ludhiana is the host organisation for one KVK situated in Fazilka.

Mandated activities of the KVKs: Each KVK (Krishi Vigyan Kendra) has a team of experts from different fields to meet all the needs of the stakeholder farmers. Their key role is to assess and improve agricultural techniques developed by the host organizations, i.e., state agricultural universities (SAUs) and ICAR institutes. Once these techniques are evaluated and refined, KVKs demonstrate them on the farmers' farms to ensure they convince and reach a large number of farmers. They also focus on transferring technology through various communication methods, training programs for building farmers' skills for higher income opportunities in agriculture and related areas (even the non-agricultural sectors), and acting as advisors to farmers for practical agricultural solutions. Through these efforts, KVKs provide a wide range of services aimed at improving the overall welfare of farmers under their mandate.

KVKs' for enhancing farmers' income: The KVKs of Punjab implemented a comprehensive plan to help enhance farmers' incomes. This plan focused on several key areas: increasing productivity through technical support and efficient input management, adopting more intensive cropping systems, and shifting from low-value to high-value crops. They also promoted agroforestry and the protected cultivation of fruits, vegetables, and flowers. Efforts were made to reduce costs by encouraging conservation agriculture, organic farming, and careful use of inputs. Additionally, farmers were supported in adding value to their produce through processing and



adopting precision farming techniques like laser levelling and micro-irrigation. Training programs were provided to help farmers diversify into other income-generating activities such as dairy, poultry, goat and sheep farming, piggery, fishery, and mushroom cultivation. Lastly, they focused on developing skills for starting non-farm businesses to further boost household income of the farmers in the state.

Doubling Farmers' Income (DFI) Initiative by KVKs

The seed of Doubling Farmers' Income (DFI) emerged in a political rally in Bareilly on 28 February 2016, when the Honourable Prime Minister asked a key question to the personnel associated with farmers' welfare: "Can we double farmers' income by 2022?". This challenging goal was met with a positive response from the entire government machinery. The very next day, on 29 February 2016, the then Union Finance Minister, Sh. Arun Jaitley, announced the DFI initiative during his budget speech. The government quickly mobilized its efforts, fully committing to achieving the goal by 2022, coinciding with India's 75th Independence anniversary (Chand 2017a, 2017b, Bihar et al 2019, Rana et al 2019a). To guide the initiative, GOI formed a committee on 13 April 2016, chaired by Sh. Ashok Dalwai, Additional Secretary of the Ministry of Agriculture and Farmers Welfare (MoAFW). The inter-ministerial committee, chaired by Sh. Dalwai, proposed a 7-point strategy and produced a comprehensive 14-volume report offering recommendations (GOI 2018). Brief sketch of the 7-point strategy has been presented in Figure 1.



Fig. 1. Seven-point strategy for doubling farmers income in India (Rana et al 2022)

Key Strategies of KVKs under DFI Initiative

Field crops: Three prominent strategies adopted by the KVKs of Punjab for pursuing DFI in Punjab were i) yield enhancement through promotion of potential technologies such as varieties and scientific package of practices followed by ii) promotion of agroforestry and inter-cropping for enhancing farmers' net income, and iii) reduction in cost of cultivation through alternative cropping choices.

The first category of strategies covered mainly the provision of healthy seed of high yielding varieties of various crops to farmers at reasonable prices such as rice (PR-126, PR-121, PB-1121, PB-1637, PB-1718, PB-1509), wheat (HD-2967, HD-3086), conolasanson (GSC-6, GSC-7), sugarcane (COPB-92, CO-118), potato (KufriKhyati, Kufri Pushkar), maize (PMH-1), cotton (PAUBT-1), peas (Punjab-89, AP-3), tomato (Punjab Swarna, Punjab Sona Cherry) and chilli (CH-27, Punjab Sindhuri) (Monga et al 2022, Rana et al 2022). This strategy also covered promotion of integrated nutrient and integrated pest and weed management, especially targeting the management of white fly, pink ball worm and fall army worm along with promotion of precision farming options such as laser labelling and drip or sprinkler irrigation for targeting higher yield of crops in the state.

Agroforestry, as a component of second strategy for enhancing farmers' income, has not only been found a strong contributor towards income enhancement of the farmers for a long time (Rana 1995) but it has also been a potent source of environmental rehabilitation by serving as strong and efficient source of carbon sink (Keprate et al 2024, Srinidhi et al 2007). Similarly, enhancing cropping intensity with the help of intercropping options as well as taking additional short duration crops is also the part of this strategy (Chand 2017b).

The third strategy to reduce the cost of cultivation for the farmers included promotion of cost effect agronomic



practices such as direct seeded rice, regenerative farming (use of Happy Seeder Technology for no till agriculture, Singh et al 2019, Duddigan et al 2022, Laishram et al 2022, Sood et al 2024) etc., promotion of intercropping of vegetables in sugarcane crop and wheat and/or turmeric in poplar crop (agroforestry based cropping system, Rana et al 2022b, Dhillon et al 2007) and other options like natural farming (Rana and Singh 2018, Singh et al 2022b, Rana et al 2024b), conservation agriculture and fertilizer use based on soil health cards recommendations.

Horticultural crops: Promotion of protected cultivation of high value horticultural crops (parthenocarpic cucumber, red-yellow capsicum, tomato, carnation, English rose, Gerbera and musk melon/ chilies (low tunnels), etc. (Thakur et al 2024a, 2024b) and open fields cultivation of high-priced crops like gladiolus, dragon fruit, strawberry, broccoli, cucumber, and onion-garlic seed production etc., was the most prominent strategy of KVKs for enhancing farmers' income through horticultural component of agriculture (Rana et al 2019b). Further, providing advisories to the concerned farmers on status of current market prices, management of farm inputs, promotion of direct marketing (including self-marketing) and brand building for selling on various e-commerce platform etc. (Rana et al 2022a), constituted another strategy adopted by the KVKs of Punjab for enhancing farmers' income. KVKs also adopted the strategy of promoting aeroponic seed-potato production to large farmers along with production of high value vegetables crops like lettuce, parthenocarpic cucumber, strawberry and cherry tomato using hydroponic method of crops production (Kaur et al 2021, Rana et al 2019b). Last but not the least, promotion of production of nursery of horticultural plants such as fruits, vegetables and flowering plants, being quite remunerative, was also adopted as strategy for enhancing income of farmers from the state of Punjab (Rana et al 2024b, 2024c).

Animal husbandry: Animal husbandry being one of the most potential components of agriculture for enhancing farmers' income was considered very seriously by the KVKs of Punjab during the entire DFI initiative (Rana et al 2024c). As a strategy, promotion of integrated nutrient management of different categories of animals, integrated management of diseases of various animals, area specific mineral mixture, urea molasses mineral blocks (UMMBs), scientific breeding practices, popularization of silage/ Azolla feeding, feed and fodder management, and management of stress among the animals was adopted as an integrated strategy by the KVKs to affect enhancement of farmers' income in Punjab (Singh et al, 2019, 2024a).

Fishery: Fishery sector has tremendous potential of enhancing farmers' income in Punjab, however, pisciculture is not very common in the state. KVKs, therefore, adopted the strategy of promoting fishery production as an integrated fishery-piggery model developed by the GADVASU Ludhiana. KVKs provided advisories to the interested farmers on various aspects of fish farming including scientific feeding practices for quality fish production, construction and management of fish-ponds and management of different diseases and other pest in fish farming (Rana et al 2022b).

Farm or non-farm enterprises: On the recommendations of the nodal officer for the initiative on doubling farmers income at ICAR ATARI Ludhiana, the KVKs realised that secondary agriculture will lead agricultural development in the future hence several farm and non-farm supplementary enterprises were promoted as an important strategy for enhancing farmers' income the state. In order to harness the potential of value addition, mini-food processing units were promoted to process turmeric, paddy, honey, oil extraction, wheat into flour, grinding, packing and branding of spices, grading and packing of pulses along with splitting and de-husking of different pulses etc., as an important strategy for enhancing farmers' income in Punjab. Home scale processing of various processed products such as pickles, squashes, jam, fruit candy, jelly, cheese, ice cream and ghee making etc., were also promoted (Rana et al 2019b, 2022b, 2024c).

Further, capacity building of the aspiring agri-entrepreneurs, linking them to different agencies and persons through the network of KVKs, promotion of Farmers Producer Companies/ Farmer Interest Groups/ Farmers Producer Organisations, and promotion of emerging agri-business ideas such as vinegar making, piggery, mushroom production, goatery, jaggery making, poultry, integrated bee farming, and vermicomposting etc., were



also undertook seriously by the KVKs of Punjab for this purpose (Singh et al 2022a, 2023, Rana et al 2024a, 2024c, Singh et al 2024b, 2024c).

Custom hiring centres, especially for providing machinery for crop residue management along with other farm machines was promoted by the KVKs not only for enhancing farmers' income but for ensuring no burning of crops residue in order to protect environment and ecology. Pursuit to doubling farmers' income was beyond agricultural enterprises for the KVK hence, various non-farm enterprises viz., candle making, phulkari making, apparel making, bakery and providing services as beautician etc., were also promoted (Chandregowda et al 2023, 2024a, 2024b).

Impact of DFI Initiative

The study: This study is a part of nation-wide survey of 75,000 success stories of farmers whose incomes have actually been doubled during 2016-17 and 2020-21 (Birthal et al 2022). The survey was carried out during 2021-22 in all the KVKs of India. However, results presented in this study pertain only to the KVKs of Punjab including the agroforestry farmers who actually doubled their income during the study period. A total of 2043 farmers out of the total surveyed farmers were selected for this analysis and out of these 2043 farmers 76 farmers were the agroforestry based farmers, whose analysis was separately carried out. In addition to the basic profile of the farmers, an account of crops grown, livestock and other enterprises adopted by the farmers along with crop/enterprise wise production and income details during 2016-17 (bench mark year) and 2020-21 (assessment year) was prepared. Component wise detailed analysis of production and income during bench-mark year as well as during assessment year was carried out at nominal prices.

Farm category wise enhancement of net income: Size of the farmers' land increased, the percentage growth in their average household income gradually decreased. Landless farmers saw their income grow by 3.22 times, while farmers with over 4 hectares of land had 2.2 times increase in the net income (Table 1a). These results are encouraging, as the goal of the Government of India's Doubling Farmers' Income (DFI) initiative was to prioritize improving the incomes of resource-poor small and marginal farmers rather than the big ones.

Net income enhancement scenario of agroforestry farmers: Table 1b presents the scenario of farmers who have agro-forestry as a dominant source of income enhancement. The overall income of farmers who adopted agro-forestry for enhancement of their farm income increased by 2.2 times without any consistent trend of income enhancement in relation to the farm category size. However, the enhanced net income ranged between 2.1 times for large farmers to 2.5 times for the small farmers. By and large the income enhancement of smaller farmers was higher compared to the larger ones which is quite as per the intention of the government to ensure economic welfare of resource poor smaller farmers in the country.

Farm component wise enhancement of net income: Table 2a clearly depicts that the average net income of the farmers of Punjab grew by 2.34 times between 2016-17 and 2020-21. The biggest increase was seen in farm and

Table 1a. Income level and change in household income of respondents from Punjab by land class

Land class	No. of households	% share in total household	Income level (Rs/ household)		% change in household income
			2016-17	2020-21	
Landless	143	07.00	119223	383852	221.96
Marginal (<1 ha)	414	20.26	135885	420510	209.46
Small (1-2 ha)	488	23.89	229177	565275	146.65
Medium (2-4 ha)	493	24.13	381551	886797	132.42
Large (>4 ha)	505	24.72	1004848	2219030	120.83
Total	2043	100.00	431080	1009612	134.21

Rana et al 2022



non-farm enterprises, which rose by 6.15 times, followed by livestock by 4.89 times, horticulture by 4.39 times, fishery by 3.81 times, and field crops just by 1.53 times (only component of farming where income could not be doubled). The share of field crops in total income dropped from 76 percent to 50 percent during this period, while other farming activities saw an increase in their share (Fig. 2a). Despite this, field crops remained the largest contributor to farmers' net income enhancement in 2020-21, accounting for 30 percent, followed by livestock with 26 percent share, horticulture with 22 percent share, supplementary enterprises with 20 percent share and fishery with just 1 percent share.

Farm component wise income enhancement scenario of agroforestry farmers: The average net income per household of the surveyed farmers increased 2.2 times in the period of 2016-17 and 2020-21 (Table 2b). The

Table 1b. Income level and change in household income of agroforestry respondents by land class (Exclusively estimated for this study)

Land class	No. of households	% share in total household	Income level (Rs/ household)		% change in household income
			2016-17	2020-21	
Landless	Nil	n/a	n/a	n/a	n/a
Marginal (<1 ha)	9	11.84	190425	436575	129.26
Small (1-2 ha)	13	17.11	405404	1017738	151.04
Medium (2-4 ha)	17	22.37	609045	1420199	133.18
Large (>4 ha)	37	48.68	1006947	2134406	111.97
Total		100.00	718336	1582553	120.31

Table 2a. Level and change in household income (Rana et al 2022)

Component of farming activity	Net income (Rs/ household)		% increase in income	% share in total income		% share in additional income
	2016-17	2020-21		2016-17	2020-21	
Field crops	328978	503299	52.99	76.31	49.85	30.13
Horticulture	38261	167844	338.68	8.88	16.62	22.40
Livestock	39038	190877	388.95	9.06	18.91	26.25
Fishery	2137	8150	281.38	0.50	0.81	1.04
Farm/ non-farm enterprises	22666	139442	515.20	5.26	13.81	20.18
Overall	431080	1009612	134.21	100.00	100.00	100.00

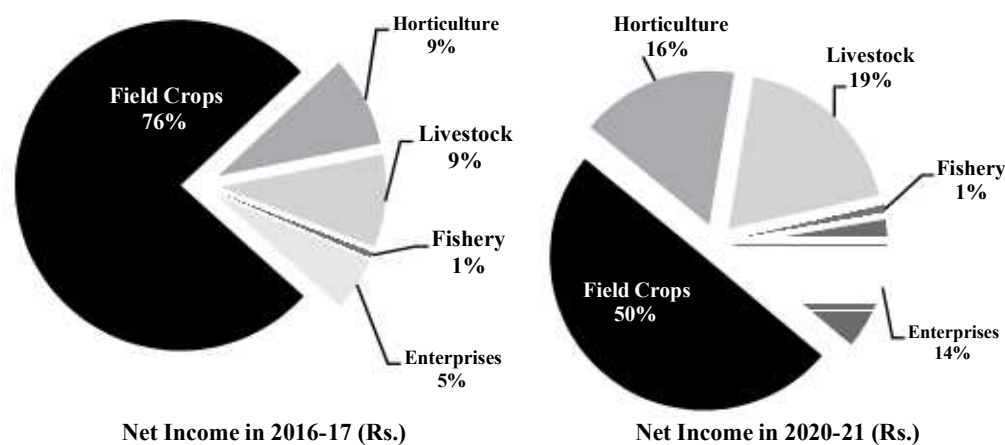
Table 2b. Level and change in household income of agroforestry farmer (Exclusively estimated for this study)

Component of farming activity	Net income (Rs/ household)		% increase in income	% share in total income		% share in additional income
	2016-17	2020-21		2016-17	2020-21	
Field crops	480430	694777	44.62	58.99	39.17	22.35
Horticulture	0	24650	n/a	0.00	1.39	2.57
Livestock	48320	110897	129.51	5.93	6.25	6.52
Agroforestry	264425	905228	242.34	32.47	51.04	66.81
Farm/non-farm enterprises	21200	38000	79.25	2.60	2.14	1.75
Overall	814375	1773553	117.78	100.00	100.00	100.00



biggest highest enhancement in average net income was affected by agroforestry (3.4 time) followed by livestock (2.3 times), supplementary enterprises (1.8 times) and field crops (1.45 times). However, the contribution of field crops in the total farm income of respondents decreased from 59 % to 39 % during the period of the study while the share of agroforestry increased from 32.5 % to 51 % during this period (Fig. 2b). Share of livestock component increased slightly while the share of supplementary enterprises in the total income of the surveyed households decreased marginally during this period. Agroforestry was also the biggest contributor (66.8 %) to the income enhancement during 2016-17 and 2020-21 followed by field crops (22.35 %), livestock (6.5 %), horticulture (2.6 %) and supplementary enterprises (1.75 %).

Component and farm category wise CAGRs: Compound Annual Growth Rates (CAGRs) of average household net income enhancement of Punjab farmers for various farming components and farm size categories were computed and presented in Fig. 3a. enterprises showed the highest CAGR in net income enhancement (57.5 %)



Source: Rana et al 2022

Fig. 2a. Contribution of different components farmer's net income (%) of Punjab State farmer

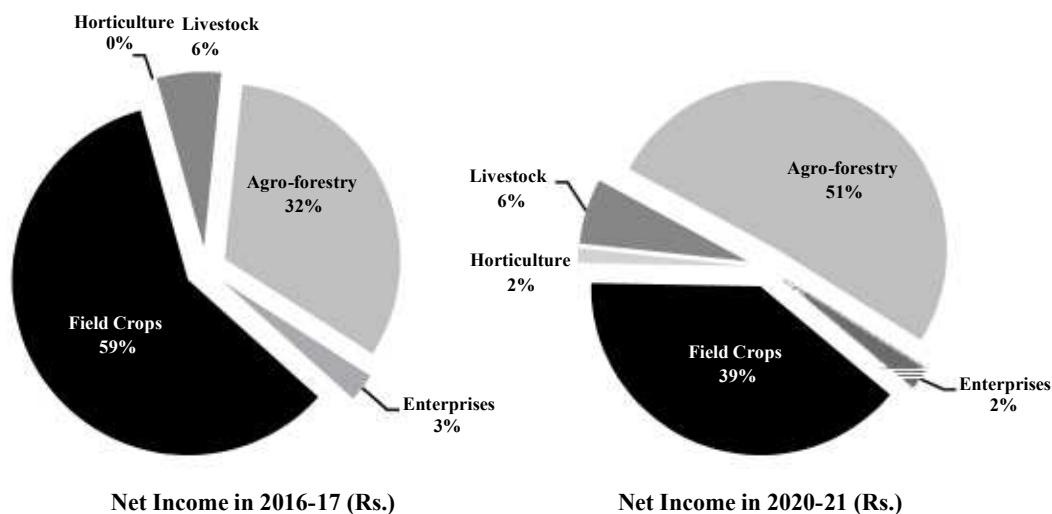


Fig. 2b. Contribution of different components farmer's net income (%) of agroforestry farmer (exclusively estimated for this study)



followed by livestock component (48.7 %), horticulture (44.7 %), fishery (39.75 %) and field crops (11.2 %) while the overall CAGR of net income enhancement was 23.7 % during the study period. Similarly, for landless farmers the CAGR of income enhancement was 33.95 % followed by marginal farmers (32.63 %), small farmers (25.32 %), medium farmers (23.47 %) and large farmers (21.9 %).

Component and farm category wise CAGRs of agroforestry farmers: The CAGR of agroforestry component of farming was the highest (36.02%) followed by livestock (23.08 %), supplementary enterprises (23.08 %) and field crops (9.66 %). The overall CAGR of income enhancement for agroforestry farmers was slightly lower at 21.48 % compared to the overall farmers of the state (23.7 %). The farm size category wise CAGRs stood the highest for small farmers (25.87 %) followed by medium farmers (23.6 %), marginal farmers (23 %) and large farmers (20.7 %).

Lessons Learnt and Way-forward

Following meaningful insights were derived out of this study which can be emulated in order to replicate the success of respondent farmers by other aspiring ones. In agriculturally developed states like Punjab, adoption of various enterprises, in addition to the existing farming, is the most important source of enhancement in farmers' income (Chandregowda et al 2023, 2024a, 2024b). Study of agroforestry farmers clearly demonstrates that this farming practice or incorporation of agroforestry as a practice in the existing farming system has strong potential of enhancing farmers' income. Farmers of India in general and farmers of Punjab in particular are generally unorganised hence, promotion of cooperative culture in the form of FPOs and CHCs etc., carries very high significance for reducing cost of production of various agricultural products and their marketing (Singh et al 2022a, 2023). Further, the KVKs of Punjab have been doing yeoman's job in terms of providing precise technical knowledge on various aspects of agricultural and farm-technologies along with ensuring availability of quality seed and other inputs to the stakeholder farmers at affordable price (Rana et al 2023a). Hence, development of

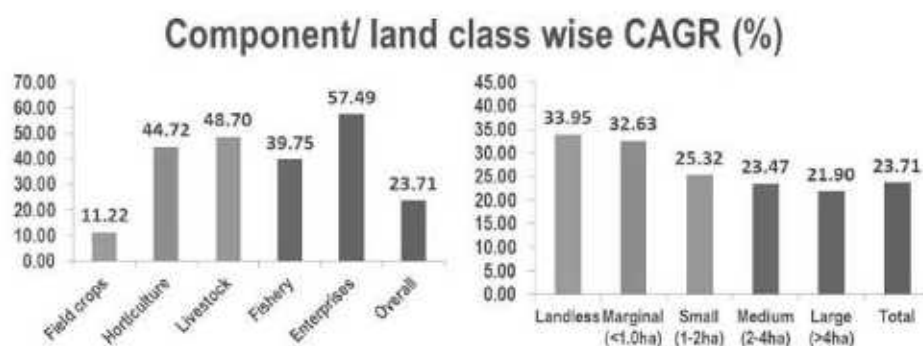


Fig. 3a. Overall CAGRs of Punjab farmers (Rana et al 2022)

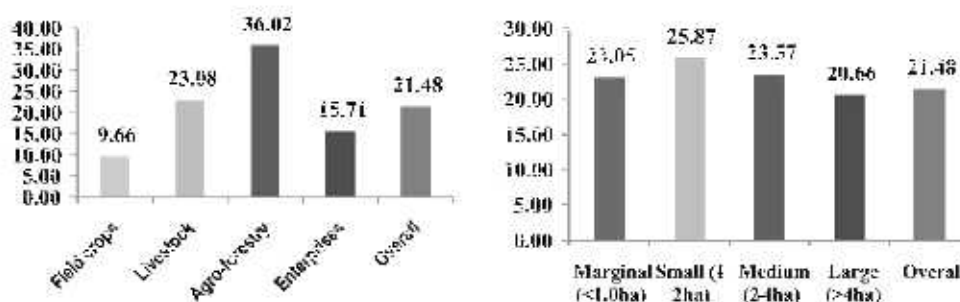


Fig. 3b. CAGRs of agroforestry farmers in Punjab (exclusively estimated for this study)



KVK infrastructure including the manpower (as the existing manpower at KVKs is not enough to cater to every need of the district) is not only desirable but imperative for getting desirable results in the near future. The conventional rice-wheat system of farming being stagnant in terms of yield and profitability there is very strong need of farmers' capacity building along with the needed handholding for efficiently and effectively shifting agricultural land from the low-income conventional crops to the high-income specialty crops carries very high importance (Rana et al 2023b).

Intended Policy Support for Enhancing Punjab Farmers' Income

The issue of enhancing Punjab farmers' income emulating the experiences of their fellow farmers who actually doubled their income in short period of time is not very simple. As a matter of fact, the income of farmers in already an agriculturally advanced state like Punjab needs a lot of technical and policy support as policy actions have been reported affecting farmers' choice for adopting technologies (Rana et al 2023c). While technical support can be easily provided due to strong KVK system in the state, however, policy support becomes crucial. Following points need to be considered seriously in this direction:

- Professionally apt entrepreneurship development, in various sub-sectors of agriculture and even the non-agricultural field, is the need of the hour for further advancement of already advanced agriculture in Punjab (Shirur et al 2017, 2018, 2019, Rana et al, 2024d).
- Though KVKs are doing commendable work for the cause of farmers, yet strengthening their infrastructure will yield better results across larger areas as currently the staff strength at KVKs is grossly meagre to cater to the needs of their concerned entire district comprehensively.
- Shifting area under agriculture from low-value crops to high-value crops should be promoted based on the principle of comparative advantage for effective implementation of this strategy.
- Getting remunerative prices for farm produce is crucial for enhancing farmers' incomes and farmers in the state being unorganised there is a strong need for strengthening cooperatives, direct marketing, and e-platforms through FPOs/SHGs is essential.
- The Punjab KVKs provide quality farm inputs to farmers at reasonable price, but other agencies must also be strengthened/ revived to support these efforts and educate farmers against the biased input seller advice.
- Credit availability for agriculture is rather good in the state, but farmers need awareness of the benefits of institutional credit over private sources and the importance of long-term creditworthiness as some farmers are compromising on this issue due to short sightedness.
- Adopting new crops and enterprises requires specific skills, so the GOI's focus on skill development should be expanded to cover more and farmers for realising the sweeter results of the entire diversification drive from the existing wheat-rice cropping system.

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Agroforestry for Sustainable Livelihoods: The Way Forward

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Agroforestry as has been a practice since time immemorial but as a scientific discipline it is relatively new compared many other agricultural science disciplines. As a scientific discipline of enquiry agroforestry evolved since 1970s. It is sustainable land management system which increase the overall production of the land by combining the production of trees, crops and or animals simultaneously or sequentially on the same unit of the land. Initially the emphasis was on cataloguing and developing new prototypes to increase the overall productivity of the land. Trees in agroforestry play one or more important role(s) in farmers' livelihoods- increased well-being, provide higher income and savings, reduced vulnerability to various vagaries and ensuring sustainable resource use. Besides, the trees in agroforestry recently have received additional impetus in climate change mitigation and adaptation due to its ability to sequester carbon and offsetting the losses due to deforestation and forest degradation. There has been an overall increase in area under agroforestry at the global level in 2000-2010. The overall population in the world living in agroforestry landscape has increased from 746.7 million to 837.6 million during 2000-2010 which implies that more farmers have realized the importance of agroforestry and consequently adopted it. Keeping in view the importance of agroforestry, there is a need to further accelerate its adoption and its intensification to increase the area under agroforestry for overall benefit of the world farming community. In India also agroforestry has received the attention of Policy makers as a sustainable land use as evident from that fact that India is the first country in the world to have Agroforestry Policy. Inspite of numerous benefits, there are number of constraints which needs to be overcome to enhance the adoption of agroforestry. Also, there is a need to have agroforestry Policies at provincial levels in India to promote agroforestry.

Roles of Agroforestry

Agroforestry systems play the following important roles in livelihoods of the farmers:

Increased well-being: Trees in agroforestry meets multifarious needs of the people for fruits, fuel, fibre, fodder, timber and other non-timber forest products. Trees like Aonla, Jamun, Bael etc provides edible fruits. Farm trees play an important role in household food security (FAO 1992). For example, in Java (Indonesia), 60% of all food comes from home-gardens (Hoskins 1990). Tree-based foods are also consumed in most agricultural communities and even in many urban areas in the developing world as regular food supplement to diet (Arnold 1995). Tree based foods add variety to diets, improve palatability and provide essential vitamins, minerals, proteins and calories. Tree products like tree food or fodder are extensively used to supplement seasonal shortage of these items. The fodder from Dhaman (*Grewia optiva*) grown in agroforestry systems in Western Himalayas also help to overcome the seasonal shortage of green fodder during winters (Sood and Mahajan 2018). Agroforestry also reduces the need to fetch the fuelwood, mainly the domain of women, from the forests. This reduces the pressure on women's time which can be utilized either for leisure or other productive works besides saving the natural forests.

Income and savings: A number of tree products from the trees are sold in the market which provide income to farmers both for subsistence as well commercial purposes. For example, over the centuries olive trees have played an important role in rural development both as one of major sources of income and employment in relatively poor rainfed areas of Spain (de Graaff and Eppink 1999). In India also a number of tree products from agroforestry systems like fruits like of Jamun and Aonla, wooden carvings, wooden utensils, ropes, tree based vegetable etc are sold by small farmers in most part of India to fulfill their subsistence needs. Trees grown in commercial



agroforestry systems not only provide raw material to wood based industries but also contribute significantly to the income of the farmers. For example Poplar grown in agroforestry systems in Punjab, Haryana and part of Uttar Pradesh provides wood to paper industries and provides a considerable income to the farmers. A new source of income has become available by trading carbon credits which may provide income to farmers, diversifying their agricultural portfolio further. Policy analysis has shown that at prices of \$100 per Mg C, carbon sequestration in agroforestry systems would have the potential to raise per capita incomes of farmers by up to 15% (Antle et al 2007).

Reduce vulnerability: Trees help households to check the exposure to risk and contingencies of various kinds. Trees provide food and biomass to farm households during floods and droughts when crop fails. Fruit trees help in overcoming a number of nutritional deficiencies in children and adults. Trees help to even out seasonal peaks and troughs in flows of produce or income of the household and demands on farm labour. Trees are used to meet the contingent social necessities such as funerals and weddings. Tree foods are important in emergencies or busy periods like crop harvesting, famines and wars (Chambers and Longhurst 1986). Trees provide medicines for households to cure many ailments reducing health risks of the household (Choudhary et al 2022). Trees like Harad, Bahera, Aonla and Jamun are used in preparation of many Ayurvedic medicines in India. Trees in agroforestry provide fuelwood to cook food which helps them make the food edible and in some cases removing the poisonous contents. The role of trees in meeting contingencies as a last resort for buying food for survival during the famine in Bangladesh has been explained by Chambers and Leach (1989). In difficult times (like famines, wars) trees can provide food and incomes to the households to buy food which reduces risk to household food security or meet exceptional cash outlays (Falconer 1990). Agroforestry also improves the farm level biodiversity and results in farm diversification and hence minimizes the risks to farm households. There are number of tree species grown in agroforestry systems which help in their conservation. The availability of trees products from agroforestry reduces the need to collect from the forests which reduces pressure on forests which consequently conserve the biodiversity in the forests.

Sustainable resource use: Trees and woodlands in agriculture landscape can protect crops from direct or indirect effect of erosion (wind or water) and conserve soil and can contribute to maintaining site productivity. Trees improve the soil organic matter and nutrient content by addition of organic matter to upper layer of the soil. Trees take up nutrients from deeper layers of soil through their deep tap root system and add it to upper layer through litter decomposition. Thus trees act as nutrient pump. Many agroforestry systems rely on tree cover to restore nutrients to the upper layer of the soil and enhancing site productivity (Dhyani et al 2021). Tree leaves also intercepts the rain and thus reduces the surface runoff which consequently help in maintenance of soil fertility. Further many tree species fixes atmospheric nitrogen into soil which help in improving the soil fertility. The examples of such nitrogen fixing trees include Khair (*Acacia catechu*), Kikar (*Acacia nilotica*), Shisham (*Dalbergia sissoo*) and Kachnar (*Bauhinia variegata*) etc. This improvement in soil properties and nutrient content helps in sustainability of agricultural production. Further trees also moderates the extreme weather conditions like temperature. These microclimatic modifications lead to improvement crop productivity.

Carbon sequestration and climate change adaptation: Agroforestry systems act as effective carbon sinks (Jose and Bardhan 2021). There are different estimates of carbon storage through agroforestry systems. The quantitative importance of agroforestry as carbon sink derives from its wide applicability in existing agricultural systems and degraded lands. For smallholder agroforestry in the tropics, potential carbon sequestration rates range from 1.5-3.5 Mg C ha⁻¹ yr⁻¹ (Montagnini and Nair 2004). Figure 1 shows that the carbon sequestration potential of agroforestry is highest compared to other land uses. This is because of large extent of the area (630 x 10⁶ ha) available for worldwide agroforestry (IPPC 2000).

The IPCC Third Assessment Report on Climate Change (IPCC, 2001) states that “Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. Agroforestry



interventions provide the best “no regrets” adaptation measures in making communities resilient to the impacts of climate change. A number of agroforestry practices like Agrisilviculture (growing trees alongwith crops), Silvipasture (Growing trees alongwith grasses or rearing of livestock), Agri-silvipasture (growing of trees, crops and grasses/rearing of livestock) holds the potential for carbon sequestration as well climate change mitigation. Agroforestry is also reported to have higher carbon stocks under deeper soil profiles than treeless agriculture or pasture land systems under similar ecological conditions (Prabha et al 2014).

Some of risks that landowners may face due to climate change and how agroforestry practices might be used to adapt to those risks (Table 1).

Adoption of Agroforestry

The agroforestry system has been in existence as traditional landuse in the various parts of the world since time immemorial and has been promoted as important sustainable land use option by various national and international agencies since its institutionalization in 1970s. Notwithstanding this, there was almost no attempt until 2009 to estimate the area under agroforestry adoption at the global level (Zomer et al 2009). Zomer et al (2014) classified agroforestry into three categories: tree cover > 10%, tree cover > 20% and tree cover > 30%. At global level the largest increase (692,531 km²) between 2000-2010 was noticed in agroforestry system of with tree density > 10%. This represents an increase of 3.1% between 2000-2010 (Zomer et al 2014). However, during the period the area under agroforestry systems with tree cover >20% and >30% increased by 395966 km² and 258868 km² constituting 1.8% and 1.2% respectively. The area under agroforestry with >10% tree density was 9,646,847 km²

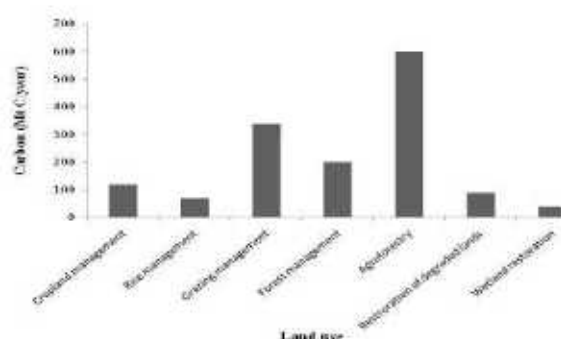


Fig. 1. Carbon sequestration potential of different land use by 2040

Table 1. Risks due to climate change and role of agroforestry in its adaptation

Risk	Adaptation	Agroforestry Practice
Intense precipitation events	Slow water runoff to reduce flooding, soil erosion, and water pollution	Riparian forest buffers, alley cropping
Increased temperatures	Reduce heat stress on animals by providing shade	Silvipasture, Agrisilvipasture
Increased frequency and intensity of drought	Reduce evapotranspiration by reducing windspeed	Windbreaks (Agri-silviculture)
Increased storm intensity (wind & precipitation)	Protect crops from wind damage	Windbreaks (Agri-silviculture), alley cropping (Agrisilviculture)
Changes in growing season due to temperature and precipitation	Protect crops by creating microclimates	Windbreaks (Agri-silviculture), Agrisilvipasture, alley cropping (Agri-silviculture)
Winter storms and cold temperature extremes	Reduce cold stress on animals by providing shelter	Silvipasture, windbreaks (Agri-silviculture)
Increased insect and disease problems	Control pests by providing habitat for beneficial insects	Windbreaks (Agri-silviculture), riparian forest buffers, alley cropping (Agri-silviculture)
Increased possibility of crop failure due to other risks	Reduce total crop loss by increasing crop diversity	All agroforestry practices

Adapted and modified after: USDA (2015)



forming 40.4% of the total global agricultural area of 22183294 km² in 2010 (Zomer et al 2014). This implies that there is a considerable increase in area adopted under agroforestry systems of varying tree cover densities. It has been estimated that a total of 1.8 billion people (24.6% of world's population) all over the world live in agricultural landscape (Zomer et al 2014). Of these 746 million (41%) lived in agroforestry landscape with tree cover > 10% in 2000-2002 which increased to 837.6 million in 2000-2010. This represents an increase of 90.9 million (5%) during the period 2000-2010. The highest number of people lived in agroforestry landscape in East Asia, South Asia and Southeast Asia respectively. Thus it is implicit that area under agroforestry adoption and its intensification with tree cover has increased in the decade (2000-2010). Further, the number of people living in agroforestry landscape has increased all over the world. This implies that agroforestry as a land use practice has received increasing impetus from the farmers almost through the world. Notwithstanding this, initiatives are required for the development and acceleration of agroforestry adoption, and its intensification in all regions of the world to improve the livelihoods of the farmers and enhance the environmental benefits at local, regional and global level. The various constraints need to be overcome to develop and promote agroforestry. These constraints not only vary from one region of the world to other but also from country to country (Sood and Mitchell, 2011). In India the constraints in adoption of agroforestry varies from state to state. Further studies on trend of area under agroforestry option at global, regional and local scale (after 2010) are scarce.

Constraints in Promotion and Conditions for Agroforestry Adoption

The broad constraints, specially with reference to India, in development and promotion of agroforestry are as:

- Lack of institutional setup solely devoted to develop, manage and encourage agroforestry land use as a whole and there is a lack of coordination amongst various departments and organisations working individually and in isolation on different aspects (agriculture, forestry and livestock) of agroforestry (Chavan et al., 2015).
- Poor or partial implementation of Indian National Agroforestry Policy (2014) by various states.
- Insufficient funding for agroforestry research and development due to lack of technical and economic data on different agroforestry models.
- Legal restrictions imposed by the governments on harvesting and intra and inter-state and inter country transport of agroforestry produce and inadequate attempts to ease out these restrictive regulations (Sood et al 2018). A number of states have *de-jure* exempted a number of tree species from harvesting and transport restriction, however, *de-facto* such restrictions exists.
- Dearth of certified quality planting material and lack of certified tree nurseries
- Poor market linkages and infrastructure for proper sale of agroforestry produce.
- Insufficient work on standardization of post-harvest processing technologies for tree produce.
- Non-availability of economic data of different agroforestry models
- Poor extension mechanisms for the promotion of agroforestry.
- Apprehension amongst the farmers that their land use will be changed after planting trees.
- Long time taken by the trees to produce desired tree product (long gestation period) compared to agricultural crops.
- Lack of research on reducing gestation period of many forest tree species and their poor domestication.
- Lack of institutional mechanisms to link agroforestry practitioners to carbon credits
- There are a number of conditions under which farm households may or may not adopt agroforestry as:

Table 2 implies that a number of conditions like land tenure, tree ownership, management arrangements, security of future produce, right to harvest, transport and sell, prices and marketing conditions must be favourable to encourage agroforestry adoption. However, the broad strategies to encourage agroforestry development and its promotion are as:

Promotion of Agroforestry: The Way Forward

The following strategies need to be adopted for promotion of agroforestry:



Table 2 . Conditions for agroforestry adoption

Conditions	Adopt	Do not adopt
Land tenure	Secure	Insecure
Access to usufruct	Vested primarily in household	Subject to government control or taxation or ambiguous
Choice of tree species	To meet farmer's priority	To meet official's priority
Tree ownership	Owned by household by law or in practice	Owned by or shared with government or local authority or ambiguous
Management arrangements	Participative or semi-autonomous	Centralised and prescriptive
Security to future produce	Provided and binding	Uncertain
Rights to cut and fell trees	Unrestricted and practiced at will by owners	Restricted or believed to be restricted
Rights of transit to market	Unrestricted and practiced by at will by owners	Restricted or believed to be restricted
Marketing	Competitive	Monopolistic
Prices of tree produce	Known, stable or rising	Not known, unstable or dropping
Target concerns	Specific household needs	Social welfare
Production goal	Immediate household needs	Conservation

Based on: Chambers et al (1989); Pasicolon et al (1997); Sood (2003); Sood et al (2018)

- Quantification of contribution of existing agroforestry to farmers' income. This
- will help in the framing strategies to promote agroforestry models which enhances the income of the farmers.
- Identification of superior germplasm of agroforestry tree species for production of quality planting stock having short gestation periods (GOI 2014).
- Domestication of forest tree species
- Studies on tree-crop interactions, management practices and development of post-harvest technologies for tree produce and their value addition (Sood and Mahajan 2018). This will assist the farmers in adopting better tree-crop combinations and management practices on their farms to enhance overall productivity of the land in a sustainable manner.
- Creation of awareness about agroforestry amongst the farmers and popularization of success stories on agroforestry adoption amongst the farmers and policy planners.
- Setting up of a separate institutional mechanism at global, regional and national levels for promotion of agroforestry and ensuring coordination amongst the stake holders.
- Adoption of recommendation of National Agroforestry Policy (2014) in India to promote agroforestry. Similar policies needs to be framed at state levels.
- Liberalisation of legal restrictive regime on harvesting, transport and sale of tree produce. Also the officials or staff needs to be made aware of already *de-jure* exemptions of various species from felling and transport rules so that these exemption can be *de-facto* implemented.
- Integrating agroforestry development with other rural development plans.
- Estimation of economics of different models of agroforestry so that it can help farmers to avail loans.
- Quantification and modeling of carbon sequestration potential of agroforestry at global level, regional and farm level. This will help in estimating the revenue potential to be earned through carbon credits.

Agroforestry is one of the sustainable land uses which not only fulfills the food based needs but also provides the tree products from same unit of land. Agroforestry has recently received impetus due to its role in carbon sequestration and adaptation. Since 1970s agroforestry as a science has developed from merely qualitative description of agroforestry systems to recently designing agroforestry models in light of climate change scenario



and REDD+. The carbon sequestration potential of agroforestry by 2040 is highest compared to other land uses. This is because of large extent of the area (630×10^6 ha) available for worldwide agroforestry (IPPC 2000). The extent of area under agroforestry has shown an increasing trend since 1990s at the global level. In India also the promotion of agroforestry has been viewed seriously as evident from the fact that India is first country in the world to adopt National Agroforestry Policy. Notwithstanding this, constraints promotion of agroforestry, its intensification in all regions of the world are required to overcome so as to improve the livelihoods of the farmers and realize its potential for carbon sequestration at local, regional and global level. This would, consequently, offset the loss from deforestation and degradation, result in sustainable land use and, climate change mitigation and adaptation. The studies need to be carried at regular interval to know the extent of area under agroforestry using remote sensing and GIS technologies. The policies solely devoted to agroforestry needs to be enunciated by each nation to provide scaffolding to agroforestry development and research. In India also there is a need to have Agroforestry Policies at provincial level.

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IESIC-2024
12-15 November, 2024



ABOUT THE INDIAN ECOLOGICAL SOCIETY

The Indian Ecological Society (IES) was established in 1974 at College of Agriculture, Punjab Agriculture University, Ludhiana, Punjab, India, under Prof. A.S. Atwal, an eminent ecologist, educationist and administrator, as the Founder President. The Society, one of the pioneering organizations of India, is engaged in advances in ecological sciences and environmental protection. It is managed by senior faculty members, assisted voluntarily by scientists from various fields, in addition to their regular assignments. During that era the main emphasis was on increasing production which leads to 'Green Revolution', however, its impact on ecology, natural resource, environment etc were not the prime issues. These objectives were amended time to time keeping in mind the priority areas in the field of ecology and environment. Moreover, there is change in definition and area of ecology during the last five decades; the updated objectives have also been included in 'Web Site'

The specific aims and objectives of the society are

- To advance the cause of ecology in India
- To encourage and promote ecological studies in the country and to integrate research in different fields of ecology
- To cooperate with organizations with related aims and interests, and provide opportunities for communication among ecologists
- To provide technical know-how for reducing environmental pollution through proper recycling of industrial and agricultural wastes
- The Society attempts to fulfill the above objectives by publishing the Indian Journal of Ecology, proceedings and such other publications as may be considered desirable. The journal is considered a premier journal reporting research findings in the field of basic and applied ecology.

Focus and Scope

- Multidisciplinary agricultural and environmental research
- Sustainable agriculture
- Natural resource management
- Ecological monitoring, biodiversity and ecosystem research
- Natural resource management

Special Interest Groups

- Agricultural Ecology
- Aquatic Ecology
- Conservation Ecology
- Ecological Genetics
- Forest Ecology
- Invasive Species
- Ecology & Evolution
- Soil and Plant health
- Tropical Ecology
- Environmental Pollution
- Climate change

Fellow of Indian Ecological Society

All life members can submit brief bio data for fellow of Indian Ecological Society after three years and must have published 2 manuscripts in Indian J Ecology



State Chapters

Further, to have more interaction in the related fields, the Society has initiated 'State and Institution Chapters'

Jammu and Kashmir

Jammu Chapter

- Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Srinagar Chapter

- Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar- 190025, Srinagar

Himachal Pradesh

- Directorate of Research, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan

Gujarat

- Department of Silviculture and Agroforestry, College of Forestry, ACHF, Navsari Agricultural University, Navsari Gujarat 396 450

North -East

- ICAR- Complex for NEH Region, Lembuchera, Agartala, Tripura)

Tamil Nadu

- Department of Entomology, Annamalai University, Annamalianagar, Tamil Nadu – 608 002

Uttar Pradesh

- Department of Silviculture and Agroforestry, CoHF, RLBCAU, Jhansi

Kerala

- Department of Natural Resource Management, College of Forestry, Vellanikkara, Kerala Agricultural University, KAU, Thrissur district – 680656

Odisha

- Directorate of Research, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha-751003

Maharashtra

- National Institute of Abiotic Stress Management, Malegaon, Baramati, Pune

MEMBERSHIP

The Society has both Annual & Life Members & Institutional Subscription, from India & Abroad. More than 200 members joined as 'Life members' during the last five years (total 594) and 936 joined as 'Annual members' in 2023. All member are listed at web site. Life member are provided with certificate. All authors, submitting papers in the journal for publication, must be member of the society. Membership is required only if paper is accepted for publication. All life member are provided with log in password

Editor/ Reviewer:

Scientist can submit bio data for consideration and editor/ reviewer.

INDIAN JOURNAL OF ECOLOGY

The 'Indian Journal of Ecology' (ISSN-0304-5250 since 1974) is an official publication of 'Indian Ecological Society' and is refereed and peer reviewed journal for the members of 'Indian Ecological Society'. The 'Journal' is considered 'a premier journal' (NAAS rating 5.38) reporting the research findings in the field of basic and applied ecology. The 'Journal' is not paid but it is only for the members of IES. It is an open assessed 'Journal'. Due to the tremendous response and participation of number of institutions within/outside India, the issues per year were raised from 2 (2016) to 4 (2018) and to 6 (2021). The Indian Ecological Society published research article has good citation index.



Editorial Workflow

The entire editorial workflow is performed using the online Manuscript Tracking System. Once a manuscript is submitted, the manuscript is assigned to an Editor most appropriate to handle it based on the subject of the manuscript and the availability of the Editors. If the Editor determines that the manuscript is not of sufficient quality to go through the normal review process or if the subject of the manuscript is not appropriate to the journal scope, the Editor rejects the manuscript with no further processing within 10 days of submission. If the Editor determines that the submitted manuscript is of sufficient quality and falls within the scope of the journal, he/she assigns the manuscript to a minimum of 2 and a maximum of 4 external reviewers for peer-review. The authors have to revise the paper within 3 weeks for further processing.

Once the revised manuscript is submitted, the Editor can then make an editorial recommendation to accept for publication. If the Editor recommends rejecting the manuscript, the rejection is immediate.

The editorial workflow gives the Editors the authority in rejecting any manuscript because of inappropriateness of its subject, lack of quality, or incorrectness of its results.

CONFERENCES/SEMINAR/SYMPOSIA

- The Society is arranging various Conferences (both National & International)/Seminar/Symposia in different areas of ecology. Since its inception it had already arranged 14 (4 international – 1 in Thailand) such programmes in collaboration with different institutes & this is the 15th one.
- National Symposium on “Land and Water Management in the Indus Basin (India)”, November 9-11, 1978 at Punjab Agricultural University, Ludhiana
- Seminar on “Status of Wild Life in Punjab”, November 1-8, 1983 at Punjab Agricultural University, Ludhiana
- Seminar on “Status of Environmental Pollution in Punjab”, February 4, 1985 at Punjab Agricultural University, Ludhiana.
- International Conference on “Ecological Agriculture; Towards Sustainable Development”, Nov. 15-17, 1997 in collaboration with center for research in Rural and industrial Development, Chandigarh.
- Conference on “Biopesticides: Emerging Trends” (BET 2001), February 7-9, 2001 Chandigarh in collaboration with Society of Biopesticide Sciences India and Punjab State Council for Science & Technology, Chandigarh.
- Conference on “Biopesticides: Emerging Trends” (BET 2005), October, 2005 at Palampur, in collaboration with Society of Biopesticide Science India.
- Conference on “Iufro Symposium on Short Rotation Forestry: Synergies for Wood Production and Environmental Amelioration”, February 10-12, 2011 Punjab Agricultural University, Ludhiana in collaboration with Department of Forestry & Natural Resources, PAU, Ludhiana.
- Workshop cum Conference on “Eco-restoration of Lentic-Lotic Systems through Six Pillar Approach of Integrated Lake Basin Management” was organized by Shirshi Environment and Sustainable Society (SESS) Society for Environment Education Research and Management (SEERAM), Pune, Maharashtra in collaboration with Indian Ecological Society (IES), PAU, Ludhiana – 141 001, India and Youth for Sustainable Development, Shimla – 01 held at Dumra Auditorium, DMC, Ludhiana, India on dated January 7-8, 2014.
- International Conference on “Natural Resource Management: Ecological Perspectives (IESIC 2016)”, February 18-20, 2016 in collaboration with Sher-e Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu, India
- Conference on “Climate Change and Agricultural Production” March 6-8, 2017 in collaboration with Bihar Agricultural University, Sabour-813210, Bhagalpur, India
- National Conference on “Alternate Farming Systems to Enhance Farming Income” September 19-21, 2017 at YSP University of Horticulture and Forestry Nauni -173 230, Solan, India
- International Conference on “Sustainable Agricultural Innovations for Resilient Agri-Food Systems” October 13-15, 2022, SUKAST, Jammu.



- National Conference on “Fisheries and Aquaculture: An Ecological Perspective”, February 22-24, 2023 in collaboration with Guru Angad Dev Veterinary and Animal Sciences University (GADVASU), Ludhiana, Punjab India.

GOLDEN JUBILEE YEAR (2024)

The society is celebrating 2024 as its Golden Jubilee year. During which the society. Is organising different conference. IES has taken decisions for more interaction as below:

- In the 1st phase the society is initiating Best Theses Award (Gold Medal & cash prize of Rs 7500/- in field of Ecology and Environment in 11 state Agricultural Universities in first phase and in remaining all SAU in second phase.
- In 1st phase the society has already had 7 State Chapters and in 2nd phase, 11 more states will be covered.
- IES will honour best editor, reviewer and best paper at biannual conference

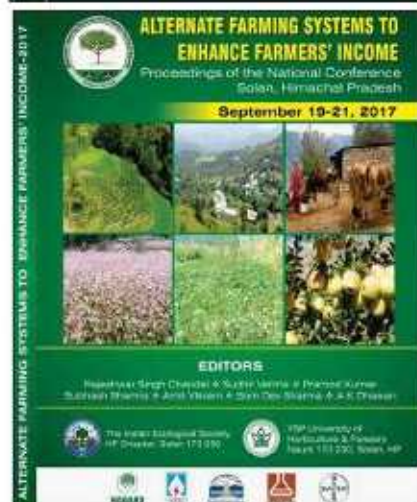
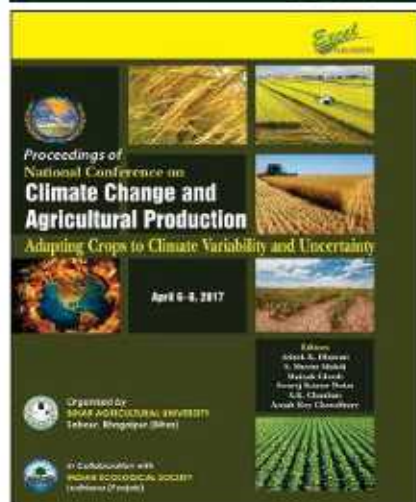
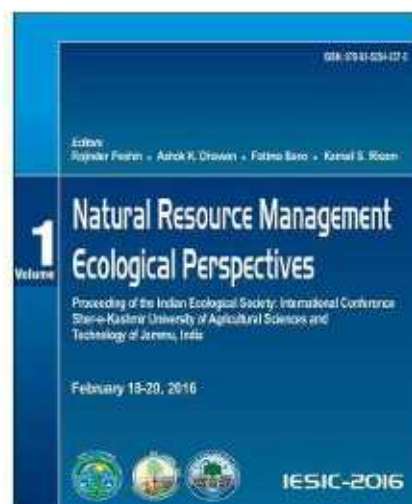
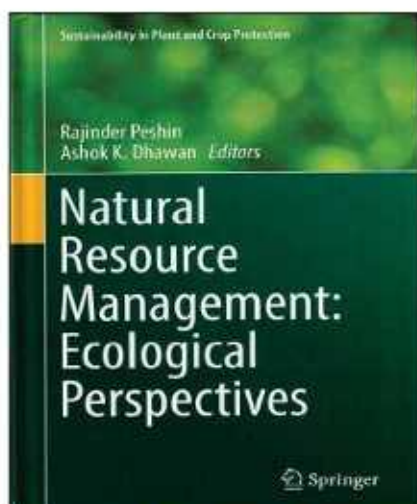
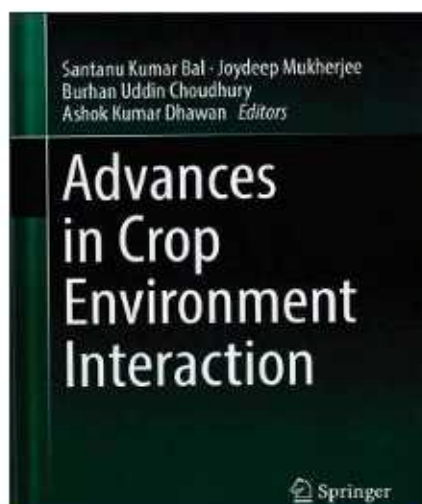
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**International Conference on Ecological Agriculture:
Towards Sustainable Development, Chandigarh (1997)**



**International Conference on Natural Resource
Management Ecological Perspectives, Jammu (2016)**



**International Conference on Climate Change Adaptation
and Biodiversity, Andaman and Nicobar Islands (2016)**



**National Conference on Climate Change and
Agricultural Production, Bhagalpur (2017)**



**National Conference on Alternate Farming Systems to
Enhance Farmers' Income, Solan (2017)**



**International Conference on Global Initiatives
Sustainable Development: Issue and Strategies
Bangkok (2019)**



**International Conference on Sustainable Agricultural
Innovations for Resilient Agri-Food Systems
Jammu (2022)**



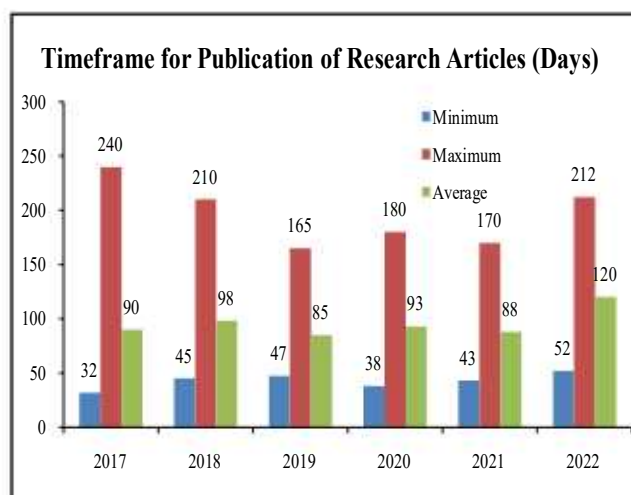
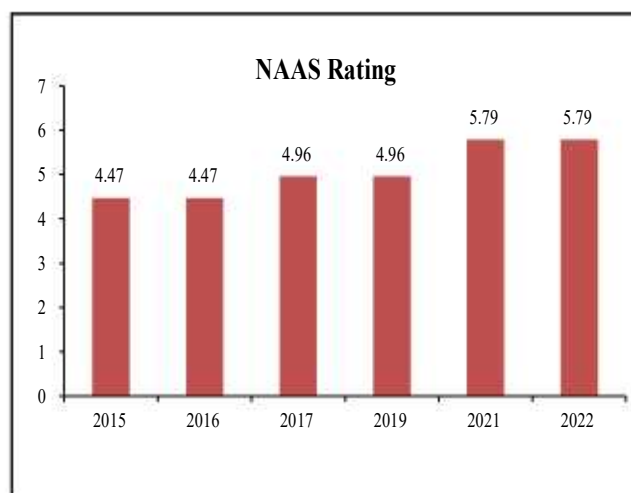
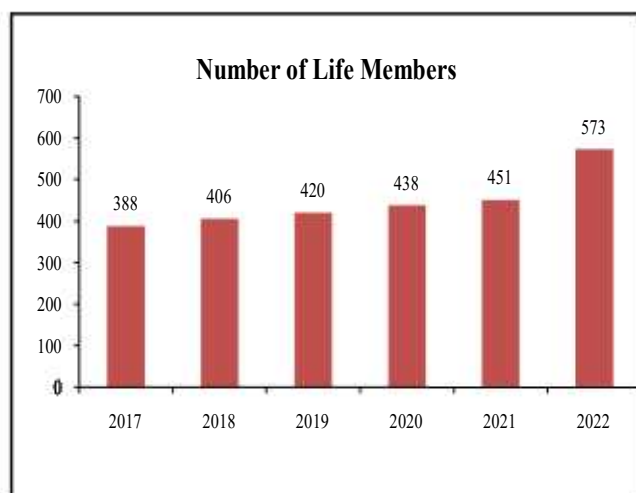
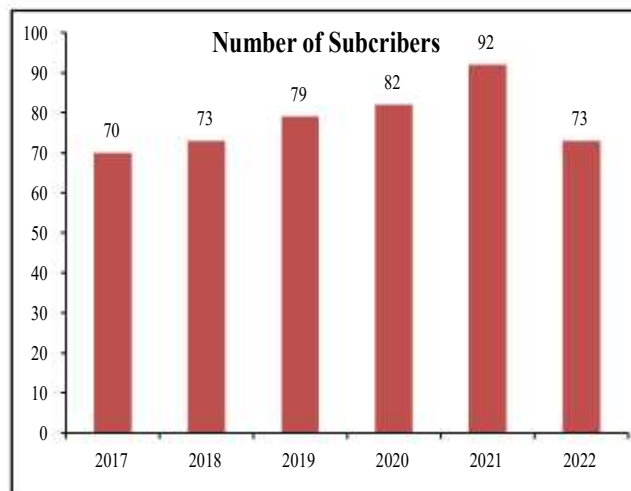
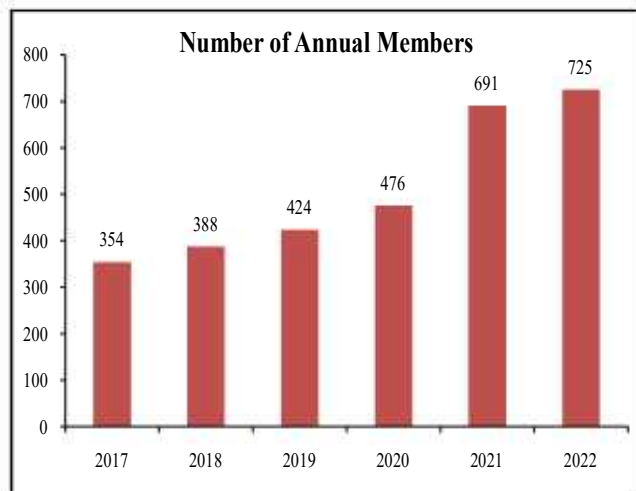
**National Conference on "Fisheries and Aquaculture:
An Ecological Perspective", February 22-24, 2023**



**International Conference on Enabling Sustainable Food
Systems through Natural Farming, Solan (2024)**

IESIC-2024
12-15 November, 2024





ABOUT THE PUNJAB AGRICULTURAL UNIVERSITY

Punjab Agricultural University (PAU) was established on October 17, 1962. It was formally inaugurated by the then Prime Minister of India, Pandit Jawaharlal Nehru, on July 8, 1963. On trifurcation of Punjab State in November 1966, Haryana Agricultural University (HAU) was carved out of PAU by an Act of Parliament in February 1970. Later, HAU received its present nomenclature Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar in 1991. Subsequently, Lala Lajpat Rai University of Veterinary and Animal Sciences, Hisar, was carved out of CCSHAU in 2010. In 2006, the College of Veterinary Science was upgraded to Guru Angad Dev Veterinary and Animal Sciences University (GADVASU) at Ludhiana. College of Agriculture, Palampur, established under the aegis of PAU, was transferred to Himachal Pradesh University in 1970, which later led to the establishment of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya (CSKHPKV), Palampur, in 1978. Later Dr Yashwant Singh Parmar University of Horticulture & Forestry, Solan, was carved out of CSKHPKV in 1985. Punjab Agricultural University rightly reserves the claim to be the vanguard of multiple State Agricultural Universities.

Modeled on the pattern of Land Grant Colleges of the USA, the Punjab Agricultural University (PAU) is committed to impart teaching, research and extension education in agriculture and its allied fields. Its immense contribution in the overall growth in agriculture and in human resource development has given it the status of the prime engine of development in Punjab and one of the best Agricultural Universities in Asia. The PAU is a pioneer state agricultural university (SAU) in India for research, education and extension in India. The university has played a pivotal role in making the country self-sufficient in food grain production and is known as “Mother of Green Revolution”. Punjab, with 1.53% geographical area, contributes about 60% wheat and 45% rice to the central food grain kitty. This is the result of path-breaking research at PAU backed by world-class teaching and extension services provided at the door-step of the farmers. The University is a focal point of several new scientific discoveries and innovations which have triggered rapid agricultural transformation in the country. This is a consequence of path-breaking research at PAU backed by world-class teaching, and extension services provided at the door-step of farmers, and the continuous Government policy support. Since inception, the University has developed/recommended 945 varieties/ hybrids of different crops out of which 229 varieties have also been released at national level. The varieties developed by PAU became popular not only in Punjab but also in other states. These include, “HB 1”, world's first grain pearl millet hybrid, 'Paras' the first single cross hybrid of maize, 'PGSH 51' the first hybrid of gobhi sarson in India, first hybrid muskmelon n (Punjab hybrid) in India, first biofortified (high grain zinc) wheat variety (PBW1 Zn) in India, first public sector Bt cotton variety (PAU Bt 1) in India, first canola quality raya hybrid (RCH1) in the country, first canola gobhi sarson (GSC 6) variety in India, first hull- less seeded pumpkin (PAU magaz kadoo 1) in India. PAU is the first State Agricultural University to develop two potato varieties Punjab Potato 101 & Punjab Potato 102 through its in-house breeding programme. The varieties of wheat, rice, maize and chickpea developed by PAU were put under commercial cultivation in other countries too. In horticulture, development of improved varieties/hybrids of vegetables, new introduction of fruits, production of healthy nursery and improved cultivation led to significant increase in their area and production. Kinnow occupies the first position among fruits in the State. Recently released less seeded variety of Kinnow, namely, PAU Kinnow-1 is more suitable for processing. The Soil Reclamation Technology developed by the University helped reclaiming 6 lac ha of salt affected soils in the State. Recent efforts on conservation of agriculture have led to the development of micro-irrigation and fertigation regimes in field and horticultural crops, laser land leveling, PAU Super Straw Management System, Happy Seeder, Smart Seeder, PAU Straw Cutter-cum-Spreader technologies and agronomic practices under residue retention in fields. Biofertilizers (Consortium inoculants) have been recommended for 17 crops for enhancing yield and improving soil health. Technology development has also focussed on nutrition through variety development and processing intervention. Research



in agricultural engineering led to the emergence of Punjab as a hub of farm machinery manufacturing and mechanization. 45% of the agricultural machinery recommended by ICAR at National Level has been developed at PAU.

In recognition of these outstanding achievements in agricultural research, education and effective transfer of technology, PAU was the first to win the 'ICAR Best Institution Award' in 1995 and again got 'Sardar Patel outstanding ICAR Institution Award' in 2017. PAU has been accredited with overall A⁺ grade by ICAR for five years (2019-2024). During 2020, PAU was ranked 5th among Agricultural Universities and Institutes of India by ICAR with 2nd position among State Agricultural Universities. PAU was ranked 1st among all Agricultural Institutes of the country by Society of Genetics and Plant Breeding for development of landmark varieties in 2017. It was also ranked 1st by Confederation of Indian Industries-Indian Citation Index (CII-ICI) among all State Universities (including agricultural and non-agricultural universities) of the country with respect to total number of publications and total number of citations.

Mission

- Excellence in teaching, research and extension.
- Developing quality human resource.
- Undertaking basic, applied and adaptive research.
- Developing and promoting appropriate technologies for supporting agro-based industries for enhancing farm income and generating self-employment opportunities for the youth.
- Developing effective mechanism to transfer knowledge, skills and technology to farmers and agricultural organizations through extension services.
- Improving socio-economic conditions of the farming community through cost-effective technologies.
- Seeking appropriate solutions to emerging problems and challenges.



Some facts about PAU

Campus area	1222 acre	Seed Farms	04
Off-campus area	5742 acre	Faculty*	788
Regional Research Stations	09	Non-teaching Staff*	1642
Fruit Research Stations	03	Students on roll**	4033



Awards and Honours Bestowed Upon PAU

During the last 61 years of its existence, the University produced distinguished alumni who, in recognition of their outstanding achievements, have brought laurels and won many prestigious awards at national and international levels which include World Food Prize, Rafi Ahmed Kidwai Memorial Award, Shanti Swaroop Bhatnagar Award, Om Parkash Bhasin Award for Science and Technology and Team Research Awards of ICAR, apart from several other awards including the prestigious Padma Bhushan and Padma Shri. The PAU alumni have also served on distinguished positions in national and international organizations. Many faculty members have also been bestowed with professional fellowships, like NAAS, FNA, FNASc, German Academic Exchange (DAAD) Fellowships, Alexander von Humboldt Fellowship, Fulbright Nehru Fellowship, and academic scholarships/ fellowships, like Commonwealth Academic Staff Scholarships and several others.

The College of Agricultural Engineering & Technology and the College of Agriculture received the Federation of Indian Chambers of Commerce and Industry Awards in 1975 and 1977, respectively. The PAU received the Best Institution Award of ICAR in 1995, in the very first year of the institution of this prestigious award. A first ever special grant of ` 100 crore was awarded to the University by the Government of India in 2006, in recognition of its contributions towards Green Revolution and for promoting basic and strategic research in agriculture. The University earned the distinction of being the first State Agricultural University to be conferred with the first International Potash Institute (Switzerland) and Fertilizer Association of India (IPI-FAI) Award for transfer of technology in the balanced use of fertilizer in 2009. PAU was again decorated with Krishi Shiksha Samman in 2011 by the Mahindra & Mahindra for Best Agricultural University. It received the Agriculture Leadership Award 2015 for pioneering initiatives and leadership in heralding the Green Revolution. The University has been bestowed with the prestigious 'Sardar Patel Outstanding ICAR Institution Award 2017' by the Indian Council of Agricultural Research, New Delhi. The University received this coveted award for the second time after 22 years, the first was received in 1995. The University has been identified as Institution of Excellence under the "Institution of Eminence" scheme by the MHRD/UGC New Delhi.

Academic Excellence

First among state Agricultural Universities, Adjudged under NIRF-2024 by NBA, Ministry of Education (MOE), GOI

Best State Agricultural University and Third Best amongst Agricultural Universities and Institutes, Adjudged under NIRF-2023 by NBA, Ministry of Education (MOE), GOI

Institution of Excellence in Agriculture, under Institute of Eminence Scheme, Empowered Expert Committee of MHRD/UGC- 2018

Sardar Patel Outstanding ICAR Institution Award 2012-2017 (first time received in 1995)

Best State Agricultural University and Second Best among Agricultural Universities and Institutes, adjudged by ICAR, 2019

Best State Agricultural University and Third Best Research Institute, adjudged by ICAR, 2017

Certificate of Award from National Agricultural Higher Education Project (NAHEP), ICAR for 'Green and Clean Campus' 2020-21

Best Award for Excellence in Agri-food Business Incubators, Agri Food India Awards, 2021

Agriculture Leadership Award 2015

32 Prime Minister Fellowships till date

Special Grant of Rs 100 crore by the GOI (First University to receive a grant as large as Rs 100 crore for Basic and Strategic Research in Agriculture in 2006)



First International Potash Institute-Fertilizer Association of India (IPI-FAI) Award-2010 (First SAU to get this award). Also received FAI Golden Jubilee Award 2020 for excellence in plant nutrition

ICAR Best Institution Award-1995 (First SAU to receive this Award from Indian Council of Agricultural Research)

First Agricultural University of the Year 2011 Award (First SAU to receive this award)

Mahindra & Mahindra Krishi Shiksha Sanman 2011 (First SAU to receive this award)

Honoured by Indian Society of Genetics and Plant Breeding, 2017 for highest number of landmark varieties among all SAUs and ICAR institutes

Icons of Modern India, adjudged by India Today special issue (on 70 years of Independence), 2017

Gene Stewardship Team Award by Borlaug Rust Initiative, 2018

PAU in top 100 institutes in India rankings 2017 as per NIRF, MHRD, GOI, New Delhi. Ranked 1st in Universities of Punjab, 2nd in Agricultural Universities of India, 3rd out of Agricultural Institutions, 24th out of Universities and 40th out of all Educational Institutions

International & National Awards Won By PAU Alumni, Faculty and Students

Name of award	No.
World Food Prize	2
Asian Maize Champion Award	1
Padma Bhushan	7
Padma Shri	12
Dr BP Pal Memorial Award	3
Rafi Ahmed Kidwai Memorial Award	58
Shanti Swaroop Bhatnagar Award	2
Om Parkash Bhasin Award	3
Life Time Achievement Award	3
Jeanie Borlaug Laube Women in Triticum (WIT) Mentor Award	1
Stanford University's Most Highly Cited Scientists' List	1
Outstanding Women Scientist Award (ICAR)	1
FNAAS	80
FNA	15
FNASc	5
ICAR Jawaharlal Nehru Award	26
Arjuna Award	3
Sahitya Academy Award	3

Advance Centres

Centres of Advanced Faculty Training	5
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Coveted Positions Held by PAU Alumni

Member, Niti Aayog	1
Director General, Indian Council of Agricultural Research	1
Director General, Council of Scientific & Industrial Research	1
Director General, Indian Council of Forestry Research & Education	1
Director, PP&IC (GoI)	1



Director, NITTTR, Chennai	1
Plant Protection Advisor (GoI)	1
Chairman, Agricultural Scientists Recruitment Board	4
Chairman, Commission for Agricultural Costs and Prices, Govt. of India	3
Chairman, Punjab State Farmers' & Farm Workers Commission	3
Chancellor	1
Vice Chancellors in India	44
Vice Chancellor in Foreign Country	2
Deputy Director General, Indian Council of Agricultural Research	10
Deputy Director General/Director, International Organisations	8
Agriculture/Horticulture Commissioner, Govt. of India	6
Assistant Director General, Indian Council of Agricultural Research /Directors of Institutes	40
National Professors/Fellows	7
Indian Administrative Services (IAS)	14
Indian Police Services (IPS)	5
Union Minister in Kenya	1
Head, Industrial Units	14

Infrastructure and Support Facilities

The main campus of Punjab Agricultural University is spread over an area of 1222 acres (Colleges and Residential 531 acres and Research Farms 691 acres). The administrative building Thapar Hall has been named after the founder Vice Chancellor of the University, Dr PN Thapar.

College Buildings

Each constituent college has its own double/triple storeyed buildings, housing various departments. College of Agriculture, being the largest, has many additional buildings viz. PG building (Lal Singh Labs and Labh Singh Labs), Soil Science (Dr N S Randhawa building), Food Science & Technology, Agronomy and Biotechnology (Dr Gurdev S Khush Labs).

Classrooms and Laboratories

Each college is provided with sufficient number of classrooms, teaching and research laboratories, seminar rooms, committee rooms and computer rooms.

AR/VR Laboratory

Augmented Reality and Virtual Reality Lab has been established in the department with support from ICAR under the NAHEP programme. VR headsets have been provided by the ICAR. Modules of Tractor simulation, hydroponics and protected cultivation technologies, fish anatomy, advanced irrigation methods and technologies, Nematology - Study of nematodes, assisted reproductive technologies (OPU-IVF and cloning) in dairy animals etc. are provided.



Smart Class Rooms

In addition to well furnished classrooms, there are sufficient number of state-of-the-art smart classrooms in each college, equipped with LCD projector, computer with power back- up, interactive board, internet connectivity and recording facilities. Facilities are available for video-conferencing in College of Agriculture,



College of Agricultural Engineering & Technology, College of Basic Sciences & Humanities, College of Community Science and College of Horticulture & Forestry.

Auditoria

The University has several auditoria of varying capacities suited for different kinds of uses. Each auditorium is equipped with latest audio-visual equipment and fitted with comfortable seating arrangement. Except the Open Air Theatre, all auditoria are air-conditioned with proper stage, light and sound arrangements.

Name of Auditorium	Location	Seating Capacity
Dr Manmohan Singh Auditorium	Near PAU Golden Jubilee Gate No. 1	1160
Dr B P Pal Auditorium	College of Agriculture	630
Dr N E Borlaug Auditorium	Department of Economics & Sociology	180
Dr C M Jacob Hall	College of Agril. Engg. & Technology	200
Library Auditorium	Mohinder Singh Randhawa Library	70
Shaheed Bhagat Singh Auditorium	Students' Home	110
Dr A S Khehra Open Air Theatre	Kisan Mela Ground	4000
Dr Khem Singh Gill Farmers' Service Centre	Directorate of Extension Education	100
Dr Kulwant Singh Virk Auditorium	School of Business Studies	64



Examination Halls

There are two Examination Halls to accommodate 1000 students, namely, Dr D S Dev Examination Hall and Dr K S Aulakh Examination Hall-cum- Lecture Theatre Complex.

Hostels

Separate hostels for girls and boys are available. All hostels have wi-fi connectivity and facilities for indoor games. Important newspapers and magazines are made available in each hostel. A separate International Hostel with special facilities is also available for foreign students.

Note: Provision of Hostel accommodation is subject to availability

Sports and Games Facilities

The University has excellent facilities for sports and games. Amongst sports infrastructure, Astroturf Hockey Ground, Shooting Range, Cycling Velodrome and Swimming Pool stand out as



landmark facilities, which are as per the specifications of International competitions. In addition to these, there are athletic tracks, courts for Lawn Tennis, Badminton, Volleyball, Handball, Basketball and grounds for Cricket and Football. The University also has a modern gymnasium facility with seating capacity of 2000, housing indoor badminton courts, table tennis, body building and weight lifting facilities, in addition to other indoor games.

University Health Centre

To meet the medical needs of students, faculty and staff of the University, there is a 12 bed health centre in the campus, equipped with a clinical laboratory, digital X-Ray facilities, and an ambulance. Emergency facilities are available round the clock.

Dr Mohinder Singh Randhawa Library

Dr M S Randhawa Library is an intellectual hub of academic and research activities for all the departments, Krishi Vigyan Kendras and Regional Research Stations for dissemination of agricultural information generated within the country and abroad. It is housed in a five-storey majestic building with a seating capacity of 760. In addition, the library has two outer reading halls namely Sh. T P Saxena and Dr Kulbir Singh Gill reading halls with Wi-Fi connectivity which remain open 24X7 for the readers.

The library's web page is a gateway to the latest information about its resources, rules and regulations, and services of the library. It has a collection of 4,24,014 documents which includes books, theses, bound periodicals and CDs to fulfil the needs of its members. The Library subscribes to 12 newspapers and 13 popular magazines. About 3000 e-journals and 1174 e-Books are accessible through CeRA (Consortium for e-Resources in Agriculture). Further, the library also provides access to scholarly content covering agriculture and allied areas through different databases like Indiatat.com, ISO Standards on food products (full text standards) etc.

The library is fully computerized through cloud based KOHA, the integrated library automation software which enables working in an integrated multi-user and networked environment. The entire library collection is accessible through OPAC (Online Public Access Catalogue). The library has digitized the theses, dissertations and PAU journals & magazines which are accessible through PAU Repository. Furthermore, Krishikosh repository provides access to 2,75,006 documents contributed by all State Agricultural Universities and ICAR institutes.

One of the salient features of the library is the latest collection of competitive books like ARS, NET, UGC, GRE, IELTS, CAT, JRF etc. Besides, the library also preserves as well as the cultural heritage of country. The ambience of the library supports a quiet and peaceful place for self study.

Museums and Art Gallery

Museum of Social History and Rural Life of Punjab: It is a unique museum built on the PAU campus in 1974 which reflects the university's involvement with state folklore and mirrors village life. The museum displays the old agricultural implements and tools used to decorate draught animals. It is also a repository of cultural ethos and traditions, kitchenware, persian wheel, free-time vocations that engage the women; and depicts typical real-life situations of rural Punjab. It is an attraction for people from various profiles of society, especially, students, non-resident Indians, etc.



Dr H L Uppal Museum of Water and Power Resources of Northern India: The museum was built in 1986 under the supervision of renowned hydrologist Dr H L Uppal. Its model shows the land, water and power resources of Northern India and parts of Pakistan.

Soils Museum: Soils Museum, located in the Department of Soil Science, is one of its kinds in Northern India, depicting detailed information based upon research carried out at PAU about the soil resources of Punjab.

Dr Mohinder Singh Randhawa Art Gallery: This air-conditioned art gallery was established at PAU to house exhibitions of paintings, photographs, sculptures, etc. It is amongst the best art galleries in the state.

Museum of History of Agriculture: Museum of History of Agriculture is located in Mohinder Singh Randhawa Library. A number of oil paintings depicting the evolution of life and history of agriculture prepared by renowned artist Sardar Jaswant Singh are displayed in the museum.

Museum of Natural History: The museum located in the Department of Zoology, showcases the evolution, distribution, anatomy and functional organization of the representative fauna of animal kingdom, through specimens, models and wall mountings.

Apiculture Gallery: The Gallery located at PAU's *Apis mellifera* apiary depicts the pioneering role of PAU in successful introduction, multiplication and release of *A. mellifera* in India. Besides, it showcases indigenously developed high-end technologies towards enhancing hive productivity, including adoption of apicultural diversification.

Farm Machinery Museum

The Farm Machinery Museum at the Department of Farm Machinery and Power Engineering, Punjab Agricultural University in Ludhiana, stands as a testament to the rich history and evolution of agricultural technology. This unique museum shows how farm machines have changed over the years, telling the story of their development and the important improvements that have taken place over the years. Visitors to the museum are taken on a fascinating journey through time, exploring the evolution of plows, cultivators, harvesters, tractors, and other farming equipment. The Farm Machinery Museum at Punjab Agricultural University serves as an educational hub, inspiring future generations to appreciate the importance of technological innovations in sustainable farming practices.



Our Keynote Speakers

Prof. John H. Perkins

Prof. John H. Perkins received his Ph.D. (biological sciences, Harvard University, 1969) and then developed interests in "troublesome technologies:" innovations with many benefits but also damages to health and the environment. Insects, Experts, and the Insecticide Crisis (1982) followed development of Integrated Pest Management (IPM) technology as a response to damages from insecticides. Wheat, Genes, and the Cold War (1997) recounted development of Green Revolution technology in India, USA, and UK. Changing Energy (2017) explored development of energy technologies, their benefits, and risks from climate change. In October 2022, he assessed major links between innovations in agricultural and energy technologies. Dr Perkins will deliver keynote lecturer on 'Agrifood Systems are Energy Systems (ERIC-AFS): Using Eric to guide Research and Teaching on Agrifood Systems'.



Prof. Zeyaur Rahman Khan

Prof. Zeyaur Rahman Khan is a scientist with the International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya. He is an Adjunct Professor of Entomology with Cornell University, USA and Visiting Professor with University of Wisconsin at Madison, USA. He is internationally lauded for his development and Africa-wide dissemination of the innovative system of "push-pull farming," which simultaneously addresses issues of crop pests, soil improvement, food security, climate change and sustainability. He obtained his M.Sc. and Ph.D. degrees from IARI, New Delhi. He is winner of Louis Malassis International Scientific Prize in Agriculture; Honorary Fellow of the Royal Entomological Society; Fellow of Entomological Society of America; Fellow of African Academy of Sciences; Council Member, International Congress of Entomology; author of 180 scientific papers and 20 books and book chapters. Dr Khan will deliver keynote lecturer on 'Adapting Agri-food Systems for Resilience: Climate-Smart Push-Pull Farming Systems for Sustainable Development in Sub Saharan Africa'.



Dr. Kathleen Saul

Dr. Kathleen Saul brings to her analyses of the energy-climate change-agriculture nexus all she has learned in obtaining degrees Chemical Engineering, Business Management and Environmental Studies, and her doctorate in Energy and Environmental Policy. For over a decade, Dr. Saul inspired a future generation of interdisciplinary thinkers in the Graduate Program on the Environment at The Evergreen State College in Olympia, Washington. Although she stepped away from teaching in June 2024, she continues to mentor students and write about the transition to a clean energy future. Dr. Saul also serves as a Senior Research Fellow and editor for the Foundation for Renewable Energy and Environment (FREE). Dr Saul will deliver keynote lecturer on 'Energy Regulatory and Industrial Complex (ERIC): A Network Framework'.



Dr. Patrick Baur

Dr. Patrick Baur is in the Sustainable Agriculture and Food Systems Program, Department of Fisheries, Animal, and Veterinary Sciences at the University of Rhode Island (USA). His research in agriculture and food systems examines how people collectively navigate, at different scales, the complex dynamics of ecological sustainability, social justice, economic production, and human health. Previously, he was a US Department of Agriculture Postdoctoral Fellow and received his PhD in Environmental Science, Policy, and Management with a designated emphasis in Science and Technology Studies from the University of California, Berkeley. Dr Baur will deliver keynote lecturer on 'Transition to Sustainable Agrifood Systems depend upon understanding the history and the Political Economy of the Lock-in held by Fossil Fuels'.



Dr. Robyn Roberts

Dr. Robyn Roberts is an Assistant Professor in the Agricultural Biology Department at Colorado State University, USA. Her research focuses on diseases of wheat and other field crops with motivations to understand the molecular interactions between plants and microbes. Particularly, her research group studies viral and bacterial diseases, molecular plant-pathogen interactions, and plant immunity. Her group has worked extensively on emerging diseases and examining changes in diseases and pathogen populations in the face of climate change. Dr. Roberts will deliver keynote lecturer on 'Climate Changes , Plant Pathogens and Yields: Experiences from the High Plains of the United States'.



Dr. Kyle Davis

Dr. Kyle Davis is an Assistant Professor at the University of Delaware (UD) in the Department of Geography and Spatial Sciences and the Department of Plant and Soil Sciences and a Resident Faculty in the UD Data Science Institute. His work focuses on food systems, water sustainability, and global environmental change. His current research in India, Nigeria, China, and the US combines environmental, economic, and social considerations with direct stakeholder engagement to inform agricultural decision making and to improve nutrition, environmental sustainability, and climate adaptation strategies. Prior to joining UD in 2019, he was a Data Science Fellow and Earth Institute Fellow at Columbia University (New York) and a NatureNet Science Fellow with The Nature Conservancy. He earned his PhD in Environmental Sciences with a focus on Hydrology from the University of Virginia and is a proud graduate of UD. Dr Davis will deliver keynote lecturer on 'Measuring the Sustainability of food systems: Exploring the solution Space'.



Dr. Menale Kassie

Dr. Menale Kassie Principal Scientist and heads the Social Sciences and Impact Assessment Unit at the International Centre of Insect Physiology and Ecology (ICIPE). Before joining icipe, he assumed positions at the International Maize and Wheat Improvement Center (CIMMYT) and the University of Gothenburg, Sweden. He is a prominent development economics scientist in Africa, recognized for his exceptional contributions in the field. He has been ranked among the top 2% of scientists globally in the 2021 Sanford University survey and identified as a highly cited researcher by Clarivate in 2023. His research has primarily focused on addressing knowledge gaps and establishing a research agenda for inclusive and resilient development in sub-Saharan Africa, particularly within the context of agricultural development interventions. Through his work, he has advanced the measurement and evaluation of the adoption and impacts of multiple sustainable agricultural intensification technologies and practices on social, economic, and environmental sustainability (SEES). Dr. Kassie will deliver keynote lecturer on 'Effects of Sustainable Agricultural Intensification on Socio-economics and risk reduction in sub-Saharan Africa'.



Dr. Pratap S. Birthal

Dr. Pratap S. Birthal is an ICAR Natinal Professor and Director at the National Institute of Agricultural Economics and Policy Research in New Delhi, India. Previously, he served as Principal Economist at the International Crops Research Institute for the Semi-Arid Tropics in Hyderabad, and as Director at the Institute of Development Studies Jaipur. He has been consultant to World Bank, FAO, and several CGIAR institutions. Dr. Birthal is a Fellow of the National Academy of Agricultural Sciences (NAAS) and the Indian Society of Agricultural Economics and is a recipient of the prestigious Rafi Ahmad Kidwai Award from the Indian Council of Agricultural Research. He has authored over 150 research articles in high-impact national and international journals. Dr. Birthal will deliver lecturer on 'Ecosystem services for Sustainable Agrifood systems Transformation'.



Dr. Pramod Kumar Jha

Dr. Pramod Kumar Jha is a Professor Emeritus at Tribhuvan University, where he served as the Head of the Central Department of Botany for nearly a decade. With 46 years of teaching and research experience at Tribhuvan University, he has led numerous international research projects and visited over two dozen countries for academic purposes. Dr. Jha is a Fellow of The World Academy of Sciences (TWAS), an Academician of the Nepal Academy of Science and Technology, and a recipient of several national and international awards. He has published over 250 research and review papers in national and international journals, authored and edited 23 books, and contributed to various proceedings. He is actively involved with several professional societies and journals. In 1992, he founded the Ecological Society (ECOS) of Nepal and has supervised 11 Ph.D. students in the country. He will deliver keynote lecturer on 'Climate Change and invasive Alien Plant Species with special reference to Nepal'.



Dr. B.M. Prasanna

Dr. B.M. Prasanna is the Director of the Global Maize Program of CIMMYT (International Maize and Wheat Improvement Center), based in Nairobi. Since 2010, he has led the multidisciplinary CIMMYT Global Maize Program team, focusing on maize improvement in sub-Saharan Africa, Latin America, and Asia. From June 2015 to December 2021, he also served as the Director of the CGIAR Research Program on Maize Agri-food Systems (MAIZE). Prior to joining CIMMYT, Prasanna served the Indian Council of Agricultural Research (ICAR) at the Indian Agricultural Research Institute (IARI) in New Delhi for over two decades. He has received several prestigious awards for his research in maize genetics and breeding.



Dr. Yves Vigouroux

Dr. Yves Vigouroux is the Director of Research at the French Sustainable Development Institute (IRD). He currently leads the “Diversity, Adaptation and Development of plants” laboratory in Montpellier, France, a team of 120 researchers, professors, engineers and technicians, post-doctoral fellows, Ph.D. candidates and master's students. He holds a master degree in Ecology and Evolution from the University of Montpellier, an engineering degree in Agronomy from AgroParisTech, a Ph.D. in Population Biology from the University of Burgundy, France. He did a Post-doctorate at the J Doebley laboratory in Madison, Wisconsin, USA before joining IRD. His research focus on cultivated and wild plants, the origin of domestication, the response to ongoing climate changes and the study of mitigation strategy. He will deliver keynote lecturer on 'Crop adaptation to on-going climate changes: scenario to mitigation strategy'.



Prof. TVK Singh

Prof. TVK Singh, Fellow of Royal Society of Entomology, London, retired as Dean of Agriculture from PJTSAU, served as ICAR Emeritus Scientist. Guided more than 50 students of M. Sc and Ph.D.- 5. Bestowed with several prestigious awards, authored more than 155 research papers, 13 books, 4 chapters in books, 2 books edited besides participating in 35 symposia / seminars and workshops. Presently engaged as Chief content reviewer for 'Plantix' app, an android application that uses artificial intelligence developed by PEAT GmbH, a Berlin based company. He will deliver keynote lecturer on 'Invasive Alien Insects'.



Professor Bijay Singh

Professor Bijay Singh is a soil chemist and remained National Professors of the Indian Council of Agricultural Research from 2006 to 2012, He is presently associated with Punjab Agricultural University, Ludhiana (Punjab, India) as an INSA Honorary Scientist. He served as Senior Soil Chemist from 1994 to 2006 and as INSA Senior Scientist from 2012 to 2017. He has been working on different aspects of fertilizer management for more than three decades. His work on site-specific and need-based application of nitrogen fertilizers to rice and wheat using leaf colour chart, chlorophyll meter and optical sensors greatly economize fertilizer nitrogen usage. His research efforts on basic and applied aspects of integrated management of fertilizers, animal manures, green manures and crop residues have provided scientifically sound directions for achieving not only sustainable yields in rice-wheat systems but also for maintaining soil fertility for future generations. He is a fellow of the Indian National Science Academy, National Academy of Agricultural Sciences and Indian Society of Soil Science. He has been decorated with several awards including the Rafi Ahmad Kidwai Memorial Prize. National Academy of Agricultural Science honoured him with its Recognition Award in 2000 and Dr. N.S. Randhawa Memorial Award in 2008. He is a recipient of Professor KS Bilgrami award (2009) and Professor B.D. Tilak lecture award (2014) of the Indian National Science Academy. The Indian Society of Soil Science honoured him with its Platinum Jubilee Commemoration award for lifetime contributions to enhancing fertilizer nitrogen use efficiency in cereal crops in 2019. In 2020, the Fertilizer Association of India awarded him the FAI Golden Jubilee Award for Excellence for the best work done in the field of plant nutrition. Dr Singh will deliver lecturer on 'Impact of long term fertilizer nitrogen management in crop production on soil health –a rethinking'.



Dr Chandrashekhar M. Biradar

Dr Chandrashekhar M. Biradar is a distinguished scientist, founder and green growth leader with over three decades of experience in agroecosystem research, development, and outreach. His walk-the-talk work spans diverse landscapes across Asia, the Middle East, Eurasia, Africa, and the Americas, emphasizing inclusive system approach, regenerative agroecosystems, restoration, digital augmentation, agroforestry. A. I., green energy, and climate resilience. With a multidisciplinary background in agriculture, forestry, environmental sciences, biodiversity, big-data, AI, and space applications. Dr Biradar has held leadership positions in various international organizations, including several CGIAR Centers, US Universities, and Global Institutions. His expertise encompasses system modelling, functional production, and harnessing nature's infinite potential for improving the land, water, food, nature, off-the-grid living, farm-as-resorts, and resilient livelihoods towards the Net Zero transition. He has published over 400 research articles, tools, products, and trailblazer impacts, garnering numerous national and international awards. Dr Biradar is Chairman and Managing Director (MD) Global Green Growth Co. which is a trailblazing organization spearheading green growth through innovative, nature-centric solutions. Champions a holistic system approach that redefines sustainability, creating harmonious interactions between human progress and natural systems, and fosters cross-sector partnerships-from grassroots to global - to craft functional solutions addressing critical challenges in biodiversity, carbon, water, food nutrition, green energy, social equity and climate resilience, by fusing ecological wisdom with cutting-edge technology and citizen science engagement to empower producers, consumers, communities and industries in their journey towards net-zero and beyond. Dr Biradar will deliver keynote lecturer on 'Regenerative agroecosystems for green economic transition'.



Prof. Nazir A Ganai

Prof. Nazir A Ganai, graduated in Veterinary and Animal Sciences from RAU Bikaner in 1989, had his doctoral degree in Animal Genetics and Breeding from National Dairy Research Institute Karnal. This was followed by series of post-doctoral trainings at Wageningen University Netherlands, Durham University England and Wisconsin University USA. He has been associated with ICAR through series of programs under NATP, NAIP NASF, NAHEP, and has handled 11 research projects as Principal Investigator with a funding of over Rs 52 crores. He is credited with the establishment of the Divisions of Animal and Plant Biotechnology, Center of Bioinformatics, Center for Artificial Intelligence and Machine Learning in Agriculture, SKUAST-K Innovation, Incubation and Entrepreneurship Center. Dr Ganai is presently leading SKUAST-Kashmir as its 7th Vice Chancellor since Dec 2021. During this brief stint, university has earned the distinction of being the 6th best SAU, Brand Excellent institution under Atal Innovation ranking, and Grade A accredited institution. He has the distinction of developing the Model NEP-2020 tailored to Agricultural Education, which has been appreciated and has opened up the university for admissions to National and International Students. Under his leadership, SKUA! performing institutions under NAHEP in the country. Dr Ganai will deliver lecturer on 'Sustainable development goals for resilient food systems'.



Dr Rajeshwar Chandel

Prof. Rajeshwar S Chandel is the Vice- Chancellor of Dr. YS Parmar University of Horticulture and Forestry at Nauni, Solan (Himachal Pradesh). Before joining this assignment, Prof Chandel held the position of Executive Director of Natural Farming Mission in the Government of Himachal Pradesh. As a senior Entomologist and academician with over 28 years of experience, he has keen interest in the fields of Natural Farming, Agroecology and Sustainable Food Systems. He has been partnering with the Ministry of Agriculture & FW, Govt. of India, NITI Aayog, and many state governments. He is the member of the Global Consortium on Agroecology led by France, and also member of many committees constituted by Govt. of India. Recently he has been recognized as an International Trainer on agroecology.



Dr. Kibrom T. Sibhatu

Dr. Kibrom T. Sibhatu is a Scientist at the International Center of Insect Physiology and Ecology (ICIPE) based in Nairobi Kenya, researching on agrobiodiversity, sustainable food systems, and the socioeconomic impact of land-use change and agricultural technologies. Dr. Sibhatu earned his Ph.D. in Agricultural and Food Economics from the University of Goettingen, Germany, where his doctoral research on the link between on-farm production diversity and dietary diversity in smallholder farm households received an award from the University's Founding Council for exemplary contribution to the field. Previously, as a postdoctoral researcher at Goettingen, he studied land-use impacts on rural communities' livelihoods, mentored master's students, and led fieldwork in the Global South. He also lectured in agricultural economics at Hamelmalo Agricultural College in Eritrea and consulted for the International Fund for Agricultural Development. Dr. Sibhatu's research has been published in leading journals, including PNAS, Journal of Cleaner Production, Food Policy, Food Security, and the Annual Review of Resource Economics.



Dr Olivier Dangles

Dr Olivier Dangles is Deputy Chief Science Officer in charge of Sustainability Science at the French Research Institute for Development. His research, firmly rooted in an interdisciplinary approach to sustainability science, focuses on the response of biodiversity to global changes, both in natural and man-influenced ecosystems, mainly in the tropical Andes. He has been an associate researcher in several foreign universities for 15 years (Ecuador, Bolivia, USA), and is currently based at the Centre for Functional and Evolutionary Ecology, where he co-directs an International Joint Laboratory between Ecuador, Colombia and France. His work has been the subject of more than 200 scientific publications, five books and numerous scientific communications. He has been involved in various international panels including the IPCC, the conference of Parties for Climate and Biodiversity, the International Council for Science and the ERA-Net Latin America and Caribbean of the European Union.



Dr Mahalingam Govindaraj

Dr Mahalingam Govindaraj is a Senior Scientist at the Alliance of Bioversity International and CIAT. He manages the biofortification crop development research network and builds research capacities for biofortification and nutrition mainstreaming in CGIAR. He holds a Ph.D., in plant breeding and genetics from the Tamil Nadu Agricultural University, Coimbatore-India. He has 14 years' experience in crop improvement including genomic tools, breeding for end-use quality/nutrition traits, and rapid phenotyping methodologies. Steering the public-private partnership on millet and R4D biofortification. Previously, led the millet biofortification program in India, West Africa, and Central Africa at ICRISAT. Later he coordinated the Asia sorghum breeding program. Developed and disseminated 15 biofortified cultivars in India and Africa. Supervised the dissertation research of several master's and PhD scholars. A fellow and active member in numerous scientific societies. Research excellence acknowledged by various individual and group honors, specifically the Rockefeller Foundation USA and the World Food Prize Foundation's 2022 Norman E. Borlaug Award for Field Research and Application, and MS Swaminathan Best Scientist Award in 2018, and Outstanding Young Scientist in 2017. He is the author of over a hundred peer-reviewed publications. His research impact estimated 10 million people consuming biofortified grains.



Prof. Gurbir Singh Bhullar

Prof. Gurbir Singh Bhullar is currently active as professor of Sustainable Agroecosystems at the Bern University of Applied Sciences, Switzerland. Prof. Bhullar is a tropical Agroecologist with experience in farming systems research, organic agriculture, participatory on-farm research and technology development in arable and agro-forestry systems across Asia, Africa and South America. Besides the scientific focus, he has a keen interest in transdisciplinary approaches for technology transfer as well as stakeholder and policy engagement. Prof. Bhullar has published two books on 'Sustainable Agriculture' and 'Farming Systems Research' and has received recognition and awards at different fora.



Dr. Smita Sirohi

Dr. Smita Sirohi, an alumna of Delhi School of Economics and Jawaharlal Nehru University, has conducted extensive research on climate change impact, mitigation, and adaptation. She led the G20 Agriculture Working Group as Joint Secretary in the Ministry of Agriculture, Government of India, and previously served as Adviser (Agri. & Marine Products) to the Government of India at the Indian Embassy in Brussels. With vast experience as an Agricultural Research Scientist at ICAR, Dr. Sirohi has contributed to national agricultural policy through various expert committees. She has over 100 publications in reputed journals, authored four books, and contributed extensively to policy documents, book chapters, and review papers, with numerous presentations at academic forums globally.



Dr N. Ravisankar

Dr N. Ravisankar is working as Project Coordinator, AICRP on Integrated Farming Systems, ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut, Uttar Pradesh, India. He has 25 years of research experience in the coastal and other regions, presently involved in coordination of integrated farming systems and organic farming research activities at National level. He is looking after the national level research work organic and natural farming under All India Network Programme on Organic Farming. He has published 145 research and review papers. He developed package of practices for organic production of crops in cropping systems perspective for 79 cropping systems suitable for 16 states of India and published as "*Organic Farming: Crop Production Guide*". Three technologies on integrated farming systems and organic farming and one methodology on sustainable livelihood security index for evaluation of farming systems have been developed as Lead developer and recognized at National level by ICAR. Received 3 National awards, 8 Institutional awards and 6 Academic Societies awards. Visited Bhutan, The Netherlands, Mexico, Nepal and Thailand in connection with organic and integrated farming systems research collaboration and linkage. Recognised as Fellow of Indian Society of Agronomy. He worked /working as Member of national level committees constituted for preparing the course/syllabus on organic and natural farming, Member Secretary of ICAR constituted national level committee for Empirical validation of Subash Palekar Natural Farming (SPNF) model, ICAR constituted committee for developing crop plans. Acted as Convener of the Expert committee constituted to review the BIS standards for organic agriculture and worked as Member of committee constituted for preparing Standards and Certification methods for Natural farming.



The Indian Ecological Society Achievement Award: 2024

Dr S.V.S. Gopala Swamy

Dr S.V.S. Gopala Swamy was born on 30th April, 1974 in NTR District, Andhra Pradesh, India. After completing his graduation and post-graduation from Agricultural College, Bapatla, Acharya NG Ranga Agricultural University (ANGRAU), he obtained doctoral degree in 2005 from College of Agriculture, Rajendranagar, ANGRAU, Hyderabad. He started his professional career in ANGRAU as Scientist in 2006 and worked in different capacities. Presently, he has been working as Principal Scientist at Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh. His research finding on various insect like cotton pink bollworm and American bollworm, losses of food grains in warehouses, etc lead to development of plant protection strategies applicable in Integrated Pest Management. He developed simple and adoptable eco-friendly post-harvest preservation techniques suitable for small and marginal farmers for securing food grains from insect pests. He is active in dissemination and transfer of technology to the farming community. He guided four post-graduate research programmes as chairman. Dr Gopala Swamy has published 89 research articles and 6 review articles in peer reviewed journals. He presented 5 conference papers and 59 research abstracts in national and international conferences. He has written 65 popular articles and 31 information bulletins for the benefit of farming community. He is Life membership in nine professional societies and is serving as Editorial Adviser for few journals. He was conferred as Fellow of Entomological Society of India (2019) and Fellow of Plant Protection Association of India (2023). Various awards to his credit includes *Jawaharlal Nehru Gold Medal Award-2014*, *Meritorious Scientist Award -2016*, *SPPS Meritorious Scientist Award- 2018*, *Scientist Award-2020*, *A V Krishnaiah Memorial Gold Medal- 2018-19* and *Dr Anand Prakash Award-2022*.



Dr M.B. Tandel

Dr. M. B. Tandel joined College of Forestry, NAU, Navsari, Gujarat in 2009 and presently In-charge Dean of this college. He has completed his Bachelors, Master's and Doctoral degree in Forestry from NAU, Navsari. Dr. Tandel has experience of more than 24 years in forestry. During his tenure he has been pioneer in establishment and strengthening of College of Forestry, NAU, Navsari. He has guided 13 Master's and 6 Doctoral students in Forestry. Dr. Tandel has completed 3 externally funded projects as PI/Co-PI. At present, he has 4 externally funded research projects as PI/Co-PI in hand. He has 10 scientific & farming community recommendations to his credit. He has remained member of many research and development committees of NAU, Navsari. Dr. M. B. Tandel has published more than 70 research articles in esteemed national & international journals apart from book & proceeding chapters, 3 national and international conference/seminar proceedings, 4 laboratory/practical manuals 3 booklets and 22 popular articles in English and Gujarat. He has presented his research achievements in more than 20 national/international seminar/webinar/conference and earned 5 best oral/poster presentation awards. He has organized 4 national/international scientific events as organizing and co-organizing secretary. He is life member for 4 leading Indian professional societies. He is vice president of Indian Ecological Society Gujarat Chapter.



Dr M.S. Sankanur

Dr M.S. Sankanur is currently serving as Assistant Professor at College of Forestry, Navsari Agricultural University, Navsari since 2015. He completed his Bachelors and Master's degree in Forestry from University of Agricultural Science, Dharwad, Karnataka and Ph.D. in Forestry (Tree Improvement & Genetic Resources) from Dr. Y. S. Parmar University of Horticulture & Forestry, Nauni-Solan, Himachal Pradesh. Dr. Sankanur has outstandingly contributed to teaching, forestry research and development in a career spanning 12 years with his distinguished academic & research record. Dr. Sankanur was Co-Principal Investigator in the World Bank funded NAHEP-CAAST sub-project at NAU, Navsari. He has strengthened the existing infrastructure and created additional facilities for scientific utilization by establishing the State of Art Museum of NTFPs, State of Art Wooden & Bamboo Workshop, Strengthened Forest Biology & Tree Improvement laboratory, *etc.* Dr. Sankanur has published 32 Research Papers, 25 Book Chapters, 12 Proceedings of Seminars/Conferences/Symposia and 07 Popular Articles. He has made 3 scientific recommendations to his credit. He is a life member of 04 professional societies, has been conferred with most prestigious Early Career Research Award for implementation of the project funded by esteemed board SERB-DST, GoI, New Delhi. He also awarded with Young Scientist Award, Outstanding Achievement Award & Best Forestry Scientist Award by United Lightning Vision Association, Bangalore, Society for Scientific Development in Agriculture & Technology, Ghaziabad & National Agriculture Development Cooperative Ltd., J & K respectively and figures in Research Sub-Committees at NAU, Navsari.



Dr Thiru Selvan

Dr Thiru Selvan has been working as an Associate Professor in the Department of Forestry and Biodiversity, Tripura University, Suryamaninagar, Agartala, India. He holds a Doctoral degree in Forestry Specializing in Tree Improvement and Genetic Resources and has also been trained professionally in practical forestry and allied subjects. A Forester, Biodiversity Conservationist and Tree Breeder, he has been practising Forestry as a Researcher. He has efficaciously implemented 12 externally funded research projects and has more than 50 publications in reputed Journals as well as books, e-book, book chapters, technical manual, general articles and outreach publications. He is co-editor for 'Frontiers in Environmental Science' and as an Associate Editor for 'Ecological Indicators'. He has successfully guided about 45 Master's and 02 Doctoral students. He has organised about 20 Refreshers Courses, Seminars/Workshops Symposium and Conferences. Dr Selvan's initiative of researching on bamboo has bestowed him to provide consultancy to the bamboo Industries viz. Kontiki Bamboo Works Ltd, Uganda and Wodgra Bamboo & Briquetting Company Ltd., Tanzania. He is an Expert Member of Forestry for the Tripura State Level Expert Appraisal Committee (SEAC) for the award of environmental clearance. He was associated as a Mentor in the Project Learning Tree Canada/World Forestry Congress' (PLTC/WFC) Green Mentor Program, an initiative of the Sustainable Forestry Initiative®, Canada. Dr Selvan is also a member of the ISTF-Global- Nomination-Election Task Group/ Governance Sub-Committee. He is a member of many renowned National and International professional bodies and Organizations. Dr Selvan has been awarded with Indian National Academies Summer Research Fellowship; Pearl Foundation Researcher Award in Agricultural Sciences-Forestry, RASHI's International Conference Award. His current goal is to contribute to academic excellence and also to participate actively in policies related to forestry and environmental management. By engaging with governmental and non-governmental bodies, he aims to advocate for sustainable practices and policies that promote the well-being of our ecosystems.



Dr C. Kathirvelu

Dr C. Kathirvelu, has been working as Associate Professor in the Department of Entomology, Faculty of Agriculture, Annamalai University since 2002. Besides teaching undergraduate and post graduate students, he has completed research projects funded by University Grants Commission, Science and Engineering Research Board, New Delhi and RUSA 2.0, MHRD, New Delhi and evaluation projects of various agrochemical companies. He has to his credit 65 research papers published in national / international journals/ books and published 05 books. He has specialized in Storage Entomology and Lepidopterology. He has received five awards from Govt. and private organizations, notably Best Researcher award 2023 from Annamalai University. He has gathered 300 tribal pest control practices for field and horticultural crops and storage pests including tribal rat trap. Lepidoptera Repository was developed in the Department of Entomology to maintain and preserve the butterflies and moths collected from the coastal area of Tamil Nadu. He has been instrumental in maintaining Insect Museum housing all the known insect orders from India in the Department of Entomology, Annamalai University.



Prof. Sushil Kumar Gupta

Prof. Sushil Kumar Gupta has more than 33 years experience of teaching, research and extension in the discipline of agroforestry. He obtained his graduation in agriculture from HKKV, Palampur (HP) and Post Graduate and Doctorate in Forestry from Dr. Y.S. Parmar University of Horticulture & Forestry, Nauni, Solan (HP). He has won several academic awards, medals and fellowships during studies. Dr Gupta has also contributed in the development and modification of course curriculum of agriculture and forestry degree programme. He has handled several adhoc research projects as PI and Co-PI funded by ICFRE, Dehradun, NATP, NOVOD Board, Horticulture Technology Mission, GoI, NABARD. He was a Member Secretary, Board of Studies (UG), Board of Studies, PG Faculty, and member of Academic Council. He was awarded Fellow of Range Management Society of India, Jhansi and is the Councilor (North Zone) for Indian Society of Tree Scientists, Solan, India. He organised 3rd IES International Conference-2022 “Sustainable Agricultural Innovations for Resilient Agri-Food System” from Oct-13-15, 2022. As Head of the Department, he was instrumental in starting Ph.D. Degree programme Division of Agroforestry, AICRP on agroforestry got sanctioned, organized National level MTC and Winter School and attracted funds for research. He has authored three books, 14 book chapters and more than 61 research publications in referred national and international journals of repute, edited training compendiums, popular articles, and project reports besides presentations in national/international conferences / seminars / symposia. He has supervised four students of Masters and three Doctorates in Forestry. Dr Gupta is empanelled as Advisor/Subject Expert of Union Public Service Commission, New Delhi and expert member of National Core Group under Broad Subject Matter Area (BSMA) of Forestry by ICAR. He also served as Dean, College of Forestry, V.C.S.G. Uttarakhand University of Horticulture and Forestry, Bharsar, Uttarakhand. and Controller of Examination and Registrar in SKUAST-Jammu. Currently he is holding the responsibility of Director Research, SKUAST-Jammu.



Dr Rakesh Sharma

Dr Rakesh Sharma is working as Professor at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu. He started his career as Assistant Professor/Training Associate in 2004. He has worked in various capacities as Extension worker, researcher and teacher. Dr Sharma has handled/handling 18 research projects being funded by different organizations. He has developed two extension models which are being recognized and certified by Indian Council of Agricultural Research. He has guided two M.Sc. students and presently guiding 4 Ph.D. and one M.Sc. Student. He has published 52 publications in reputed international and national journals having h-index of 8 and 304 citations. He has edited 3 books and contributed 16 book chapters. He is life member of three societies namely Society of Extension Education, Society of Community Mobilization for Sustainable Development and Society of Indian Journal of Ecology. He was conferred with “Best KVK Professional Award-2020” by Society for Community Mobilization for Sustainable Development (MOBOLIZATION) New Delhi.



Dr Syed Sheraz Mahdi

Dr. Syed Sheraz Mahdi is currently serving as Associate Director Research at the Advanced Research Centre for Rainfed Agriculture, Dhiansar, under SKUAST-Jammu. His distinguished career spans over 12 years in teaching, research, and agricultural extension services. Before his current role, he held positions as Senior Assistant Professor in Agronomy at Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir (SKUAST-Kashmir) and Bihar Agricultural University, Sabour Bhagalpur. Dr. Mahdi has garnered international recognition as a Visiting Scientist at the University of Cambridge and Liverpool John Moores University in the United Kingdom, where he spent nine months under the prestigious SERB-DST fellowship. During his time in the UK, he focused on developing a model that simulates winter wheat yield to assess the impacts of climate change and adaptation strategies using AI and ML techniques. His research primarily revolves around the production of food crops and the impact of climate change on agriculture. His work includes field experimentation and the modelling of cereal crops to enhance crop management and resource conservation at the regional level. This cutting-edge research is aimed at maximizing crop productivity while safeguarding environmental resources. Dr. Mahdi served on the State Committee on Climate Change Studies. He has contributed 61 research papers, 16 review papers, 10 books, 35 book chapters, and 10 technical bulletins. He has successfully secured nine competitive research grants. Dr. Mahdi has guided 11 postgraduate students as a major advisor. His accomplishments have been recognized through 02 patents, 18 prestigious awards, including the Young Scientist Award (2013) and the SERB International Research Experience (SIRE) Award (2022). Dr. Mahdi has demonstrated exemplary managerial skills, having organized nine national and four international conferences. He has been a committed member of the Indian Ecological Society since 2016-2017 and played a significant role in journal editing and event organization. Notably, he is a founding member of the IES-Kashmir Chapter.



Dr Manmeet Brar Bhullar

Born on 7th November, 1966 in Jalandhar, Dr Manmeet Brar Bhullar obtained her B.Sc. from Panjab University, Chandigarh in the year 1986 and M Sc and PhD from PAU, Ludhiana in 1989 and 1994 respectively. Dr Bhullar joined as Assistant Acarologist in the year 1996 and held the position till 2004. Later, she held the position of Senior Acarologist (2004-2010) and Principal Acarologist (2010 onwards). Currently, she is holding the additional charge of Head, Department of Entomology, PAU, Ludhiana, since June, 2024



Dr Bhullar has vast research experience and specialisation in Agricultural Acarology. Her research interest areas are bio-ecological studies on mites, management of mite pests of horticultural crops under field and protected cultivation, resistance monitoring studies in mites to acaricides, genetic variability studies on family Tetranychidae and taxonomic studies on family Phytoseiidae and Prostigmatid predatory mites. She has been involved in development of 11 technologies for integrated management of mites on vegetable and fruit crops, besides being associated with varietal screening of vegetable crops for mites. She is currently managing All India Network Project on Agricultural Acarology, ICAR, New Delhi as Principal Investigator and Biosystematic studies of phytoseiid mites on fruit crops from Trans Gangetic plain and North Western Himalaya, SERB-DST, New Delhi as co-PI. She organised Vth and IXth Group Meeting of All India Network Project on Agricultural Acarology” from 6-7 November, 1996 and from 11-12 April, 2005 respectively at PAU Ludhiana, India.

She has published 96 peer reviewed research papers, 11 books/bulletins, 9 extension bulletins, 1 review chapter, 10 book chapters and 14 popular articles. She has presented 31 papers in conferences/symposiums /seminars at national and international level. She delivered 27 invited lectures in various summer/winter schools in Acarology and Systematics. She is involved in Post-graduate courses viz. M.Sc (Insect Morphology and Systematics; Principles of Insect Classification, Insect Taxonomy and General Acarology) and PhD (Advanced Insect Systematics). She has guided 7 MSc students and 3 PhD, as major advisor on different aspects of basic and applied aspects of plant associated mites.

She is the recipient of University Merit fellowship in PhD, CSIR Fellowship on Bio-ecological studies on parasitic Copepoda and Branchiura of fishes from North India from 1991 to 1995 and Jay A. Yoder Fellowship by the Acarology Development Foundation, Michigan, USA in 2011 for attending the Summer Acarology programme at Ohio State University, Ohio (USA).





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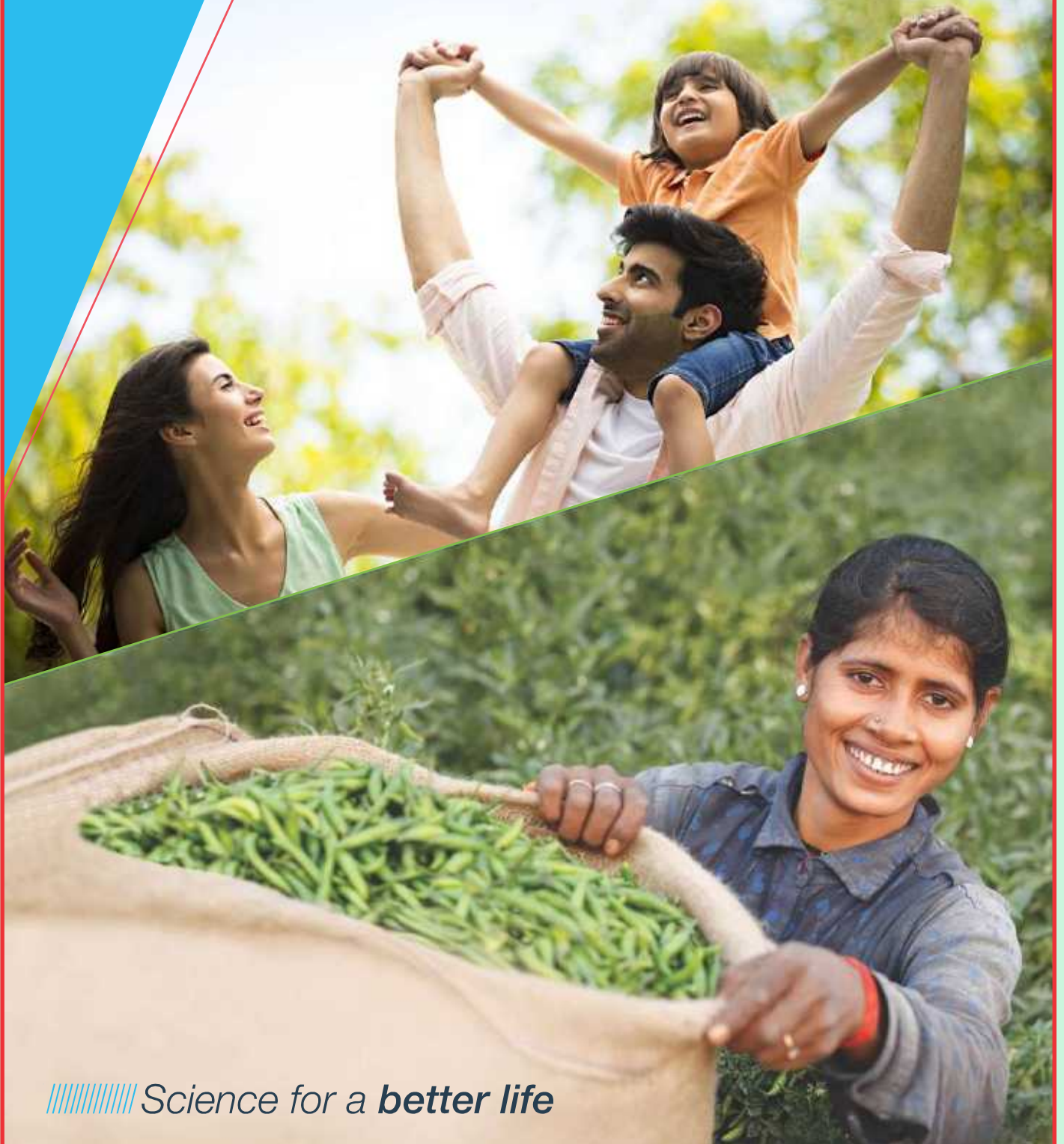
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