

SOUVENIR

National Conference on Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies

CLIMAHort - 2025

18th and 19th September 2025



Jointly Organized by

Sri Konda Laxman Telangana Horticultural University, Hyderabad

Department of Horticulture, Govt. of Telangana, Hyderabad

Dr. Rajendra Prasad Central Agricultural University, Samastipur, Pusa, Bihar

NABARD, Regional Office, Hyderabad

Supported by

Ministry of Earth Sciences, Govt. of India, New Delhi

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Edited by

Dr. A. Bhagwan

Dr. Veena Joshi

Dr. G. P. Sunandini

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Ministry of Earth Sciences, Govt. of India, New Delhi

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CLIMAHort 2025: Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies

SKLTGHU, Mulugu, Hyderabad
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Message

It gives me immense pleasure to extend my warm greetings to all the participants of the National Conference on "*Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies*" being organized by Sri Konda Laxman Telangana Horticultural University.

Climate change poses unprecedented challenges to horticulture, directly impacting productivity, sustainability and farmers' livelihoods. At this critical juncture, the collective wisdom of scientists, policymakers, industry partners and farming community is essential to develop innovative, climate-resilient solutions. This conference provides an excellent platform to share research findings, deliberate on strategies and explore approaches that can mitigate risks while harnessing new opportunities.

I sincerely thank our collaborating partners – the Ministry of Earth Sciences, Government of India; Department of Horticulture, Government of Telangana; Dr. Rajendra Prasad Central Agricultural University (RPCAU), Bihar; NABARD Regional Office, Hyderabad for their support and cooperation in organizing this conference.

I also extend my heartfelt gratitude to Dr. M. Ravichandran, Secretary, MoES, Government of India; Dr. M.L Jat, Director General, ICAR; Dr. Himanshu Pathak, Director General, ICRISAT; Dr. S.K. Singh, Deputy Director General (Horticultural Science), ICAR; Dr. CH.Srinivasa Rao, Director & Vice Chancellor, IARI; Dr. PS Pandey, Vice Chancellor, RPCAU; Sri.M. Raghunandhan Rao, IAS, APC & Secretary, Government of Telangana; Smt. Shaik Yasmeen Basha, IAS, Director of Horticulture and Sericulture, Government of Telangana; Dr. B. Gopi, Director of Agriculture, Government of Telangana; Sri. B Uday Bhaskar Chief General Manager, NABARD, Telangana for their valuable messages that encourage and inspire this conference.

I thank Sri. J. Shankaraiah, Managing Director, TG Oil Fed, Govt. of Telangana for their support and cooperation. I sincerely thank all the authors who have contributed to this publication.

I thank all the Lead and Invited Speakers for their valuable lectures that enrich the conference. I am confident that the deliberations of CLIMAHort-2025 will generate actionable recommendations and serve as a roadmap for strengthening horticultural development in the country.

I place on record my sincere appreciation to the organizing committee, partner institutions and all contributors who have worked tirelessly to make this event possible. I sincerely thank all the sponsors for generously supporting this conference.

I extend my best wishes for the grand success of the conference and hope that it will inspire collaborations for the benefit of farmers, stakeholders and society at large.

(D. Raji Reddy)

Vice Chancellor

Sri Konda Laxman Telangana Horticultural University



डॉ. एम. रविचंद्रन
Dr. M. Ravichandran

सचिव
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पृथ्वी विज्ञान मंत्रालय
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SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
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MESSAGE

Horticulture is the mainstay of Indian agriculture, contributing nearly 30% to the agricultural GDP from 13.1% of the cropped area and accounting for about 40% of the total agricultural export earnings. In 2023–24, horticulture production is estimated at 352.23 million tonnes from 28.77 million hectares. Beyond its economic value, horticulture plays a crucial role in ensuring nutritional security, generating rural employment, boosting exports and fostering crop diversification. India is the global leader in the production of fruits, vegetables, spices and several plantation crops, while steadily expanding into high-value crops such as dragon fruit, avocado and kiwi. This growth underscores both the opportunities and responsibilities that horticulture holds for the future of Indian agriculture.

However, the sector faces mounting challenges. Climate change, extreme weather events, resource constraints and post-harvest losses threaten to erode the hard-won gains. Meanwhile, growing domestic and international demand calls for high and sustainable productivity, improved technologies and stronger market linkages.

In this context, I am delighted that Sri Konda Laxman Telangana Horticultural University (SKLTGHU), in collaboration with the Ministry of Earth Sciences, Government of India, the Department of Horticulture, Government of Telangana, NABARD and Dr. Rajendra Prasad Central Agricultural University, Pusa, has taken the initiative to organize this “**National Conference on Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies**”.

This conference is both timely and significant, providing a platform for scientists, policy makers, industry leaders, NGOs and farmers to deliberate on the impacts of climate change on horticultural crops and to explore adaptation and mitigation strategies. The focus on climate-resilient technologies, precision farming, protected cultivation, digital innovations, and enabling policy support will greatly help in equipping farmers to cope with multiple risks while ensuring profitability and sustainability.

I commend SKLTGHU and its partners for their vision and commitment to strengthen the horticulture sector through research, innovation, policy, linkages and farmer empowerment. I am confident that this National Conference will generate valuable insights, practical solutions, and a roadmap for building a climate-smart, resilient and prosperous horticulture sector in India.

I extend my best wishes for the grand success of this conference and sincerely hope its outcomes will inspire resilience, innovation and inclusive growth in Indian horticulture.


(M. Ravichandran)



डॉ. एम. एल. जाट

सचिव (डेयर) एवं महानिदेशक (भाकृअनुप)

Dr M. L. Jat

SECRETARY (DARE) & DIRECTOR GENERAL (ICAR)

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Message

Horticulture has become a key driver of Indian agriculture, contributing nearly 30% to the agricultural GDP and accounting for about 40% of agricultural export earnings. In 2023-24, horticultural production is estimated at 352.23 million tonnes from 28.63 million hectares, underscoring its high productivity and value. Beyond its economic importance, horticulture ensures nutritional security, livelihood generation and diversification of cropping systems- making it a vital component of sustainable agriculture.

However, the sector faces unprecedented challenges due to climate change. Increasingly frequent droughts, floods, heatwaves, and pest outbreaks threaten both productivity and quality, directly affecting farmers' incomes and export potential. Addressing these risks requires a paradigm shift towards climate-smart, technology-driven and market-oriented horticulture.

In this context, Sri Konda Laxman Telangana Horticultural University (SKLTGHU), in collaboration with the Ministry of Earth Sciences, Govt. of India, Department of Horticulture, Govt. of Telangana, NABARD and Dr. Rajendra Prasad Central Agricultural University, Pusa is organizing National Conference on "Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies." This platform will enable scientists across the nation to share the research results and take up collaborative programmes for a resilient, climate-ready and globally competitive horticulture sector. The deliberations will yield actionable strategies that integrate science, technology and policy to safeguard Indian horticulture against climate change.

I extend my best wishes for the grand success of the National Conference.

(M.L. Jat)

Dated the 11th September, 2025
New Delhi

Message

Semi-arid regions constitute a major part of India's agricultural landscape and are home to millions of small and marginal farmers. Their livelihoods remain highly vulnerable to climate variability, water scarcity and soil degradation. In these fragile ecosystems, horticulture offers a sustainable pathway to enhance farm incomes, diversify production systems and build resilience to climate change.

Horticultural crops suited to semi-arid areas like dryland fruits (pomegranate, ber, custard apple, aonla), vegetables, spices and medicinal and aromatic plants—have demonstrated remarkable potential to improve both nutritional and economic security. With strategic interventions in water management, soil health restoration, crop diversification and resilient varieties, semi-arid horticulture can transform farming and contribute significantly to sustainable food systems.

Yet, Climate change magnifies risks such as heat stress, erratic rainfall and droughts that directly impact productivity and post-harvest quality. Addressing these challenges calls for climate-smart approaches, including precision horticulture, protected cultivation in water-stressed areas, efficient micro-irrigation, integrated farming and adoption of hardy crop varieties. Equally important are robust value chains, cold storage, processing and digital platforms that can link farmers with markets and ensure fair prices.

ICRISAT has long been committed to serve the semi-arid tropics with innovations that combine science, technology and farmer-centric solutions. By partnering with institutions such as Sri Konda Laxman Telangana Horticultural University (SKLTHU), national research organizations and development agencies, we aim to promote resilient and profitable horticultural systems that secure livelihoods and safeguard ecosystems.

I am delighted that SKLTHU, in collaboration with the Department of Horticulture, Government of Telangana, NABARD Regional Office, Hyderabad and Dr. Rajendra Prasad Central Agricultural University, Pusa, supported by Ministry of Earth Sciences, Government of India, is organizing this National Conference on "Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies". This timely conference offers a vital platform to deliberate on the challenges of horticulture in semi-arid regions and to chart practical strategies for adaptation and mitigation.

On behalf of ICRISAT, I extend my warmest congratulations to the organizers and wish the conference great success. I am confident that its outcomes will strengthen collaborative efforts to build a climate-smart horticulture sector in semi-arid regions, ensuring resilience, prosperity and sustainability for farming communities.



Dr. Himanshu Pathak
Director General

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Message

It is heartening to know that Sri Konda Laxman Telangana Horticultural University is organising a National Conference on **“Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies”**, on 18th and 19th September, 2025, bringing together various stakeholders, such as experts, policymakers, researchers, industry, farmers and students to meet and deliberate the most pressing agrarian challenge today – climate change – and its impact on horticulture sector.

There is no denying the fact that climate change is a reality no one can avoid. While horticulture has become the mainstay of farming sector and industry and more and more people are investing their time and money in horticulture sector to enhance their incomes and living conditions, erratic weather events and climate change are playing spoilsport. Horticultural crops are particularly sensitive to changing climatic conditions. Currently, the sector per se is facing unprecedented challenges, from shifting rainfall and temperature extremes to increased pest and disease outbreaks. However, challenges also present opportunities for growth, learning and improvement.

I am sure this conference will serve as a platform to explore innovative research, adaptive practices, and sustainable technologies aimed at mitigating climate-related risks, while enhancing resilience and productivity, and look forward to dynamic discussions and actionable strategies that will help shape the future of Climate-smart Horticulture and allied sector in India and beyond.

I wish the National Conference All the Best!!!


08.09.2025
(Sanjay Kumar Singh)

New Delhi
The 08th September, 2025



भा.कृ.अ.प. – भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली-110012 (भारत)
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Souvenir Message

It gives me immense pleasure to learn that **Sri Konda Laxman Telangana Horticultural University, Mulugu, Telangana** is organizing a **National Conference on “Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies”** in collaboration with Department of Horticulture, Govt of Telangana; RPCAU, Bihar; NABARD Regional Office, Hyderabad.

Climate change presents unprecedented challenges to agriculture and horticulture, threatening productivity, nutritional security, livelihoods, and the resilience of farming systems. At the same time, it offers a vital opportunity for scientists, policymakers, and farmers to collaboratively designed to deal climate change and implement innovative strategies that harmonize adaptation, mitigation, and sustainability.

I am confident that this conference will provide an outstanding platform for eminent experts, researchers, students, and stakeholders to deliberate on emerging issues, exchange cutting-edge knowledge, and chart a clear roadmap for climate-resilient horticulture in India. The meaningful participation of industry leaders, policymakers, and farming communities will undoubtedly enrich the discussions and ensure impactful outcomes.

I sincerely appreciate the efforts of the University and collaborating institutions in bringing together diverse stakeholders on such an important theme. I wish the conference grand success and hope that the deliberations will significantly contribute to strengthening climate-smart horticultural practices across the country.

With best wishes for the success of the conference.

(Ch. Srinivasa Rao)

M.Raghunandan Rao, I.A.S
Agriculture Production Commissioner &
Secretary to Government
Agriculture & Co-operation Department
Government of Telangana



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Souvenir Message

Horticulture has emerged as a growth engine of Telangana's agriculture, contributing significantly to the state's economy, nutrition and employment. With diverse production of **fruits, vegetables, flowers, spices, plantation crops and medicinal and aromatic plants**, the sector has brought prosperity to farmers and created new opportunities for exports and agri-based enterprises.

The Government of Telangana has prioritized **horticulture** through focused initiatives in **micro-irrigation, high-density planting, polyhouse cultivation, mechanization, integrated pest management and promotion of high-value crops for overall economic development of agriculture sector in the state**. These interventions are aimed at making farming systems more resilient to climate variability while improving productivity and profitability.

In the era of climate change, however, the sector faces mounting challenges such as **erratic weather, water scarcity, pest and disease outbreaks and post-harvest losses**. Addressing these requires a holistic approach that integrates **research, innovation, value addition, digital platforms, branding and market linkages**. Strengthening **Farmer Producer Organizations (FPOs)** and building robust supply chains will further empower farmers to benefit from new technologies and opportunities.

I am delighted that **Sri Konda Laxman Telangana Horticultural University (SKLTGHU)**, in collaboration with the **Department of Horticulture, Government of Telangana**, NABARD Regional Office, Hyderabad and Dr. Rajendra Prasad Central Agricultural University, Pusa, supported by **Ministry of Earth Sciences, Government of India**, is organizing a **National Conference on "Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies."** This timely initiative will provide a platform for **scientists, policy makers, industry and farmers** to deliberate on innovative strategies that can guide the sector towards a sustainable and climate-resilient future.

On behalf of the **Government of Telangana**, I congratulate SKLTGHU and its partners for convening this important conference and extend my best wishes for its grand success. I am confident that its outcomes will contribute significantly to build a **climate-smart, globally competitive and farmer-centric horticulture sector** in Telangana and the country.


M. Raghunandan Rao, IAS
APC & Secretary to Government
Agriculture & Cooperation
Department
Government of Telangana

SHAIK YASMEEN BASHA, I.A.S

**Director of Horticulture &
Sericulture**



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Souvenir Message

Horticulture is one of the fastest-growing sectors in Telangana, contributing significantly to the state's economy, nutritional security, and rural livelihoods. With a diverse production base of fruits, vegetables, flowers, spices, plantation crops and medicinal and aromatic plants, Telangana has emerged as a leader in crop diversification, innovative cultivation practices and farmer-centric initiatives.

The Government of Telangana has been at the forefront of promoting climate-smart horticulture through interventions in micro-irrigation, polyhouse and shade-net cultivation, tissue culture, mechanization and promotion of high-value crops. These initiatives not only enhance productivity but also ensure that farming remains sustainable in the face of climate variability and resource constraints.

Post-harvest management, value addition and market linkages are priority areas where the state is making rapid strides. Investments in pack houses, cold storage, processing units, and digital marketing platforms are helping farmers realize better prices and expand their reach to domestic and international markets. Going forward, greater emphasis on branding, certification and export facilitation will further strengthen Telangana's position as a hub for horticultural excellence.

I am delighted that Sri Konda Laxman Telangana Horticultural University (SKLTGHU), in collaboration with the Department of Horticulture, Government of Telangana, Dr. Rajendra Prasad Central Agricultural University, Pusa, and NABARD Regional Office, Hyderabad the supported by Ministry of Earth Sciences, Government of India is organizing this National Conference on "Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies." This event is timely and significant, as it brings together scientists, industry leaders, policymakers, finance institutions, FPOs and farmers to explore innovative strategies that will safeguard the future of Indian horticulture.

On behalf of the Department of Horticulture & Sericulture, Government of Telangana, I congratulate the organizers and extend my best wishes for the grand success of this conference. I am confident that its outcomes will guide the development of a climate-resilient, farmer-oriented, and globally competitive horticulture sector in Telangana and India.


(SHAIK YASMEEN BASHA)

डॉ० पुन्यव्रत सुविमलेन्दु पाण्डेय
कुलपति

Dr. Punyavrat Suvimalendu Pandey
Vice-Chancellor



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Dr. Rajendra Prasad Central Agricultural University
Pusa, Samastipur (Bihar) - 848 125

Date: 12/09/2025

Message

It gives me great pleasure to extend my warm greetings on the occasion of the *National Conference on "Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies"*, jointly organized by Sri Konda Laxman Telangana Horticultural University (SKLTGHU) supported by the Ministry of Earth Sciences, Government of India, in collaboration with the Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, Department of Horticulture, Government of Telangana and NABARD, Hyderabad.

Horticulture plays an increasingly important role in Indian agriculture, contributing significantly to nutritional security, livelihood opportunities, value addition and exports. At the same time, the sector faces enormous challenges from climate variability, extreme weather events, pest and disease outbreaks and post-harvest losses. Addressing these issues calls for collective action in developing climate-resilient technologies, sustainable farming practices and robust policy interventions. In the Indian context, climate change has already begun to affect the productivity and quality of horticultural crops such as fruits, vegetables, spices, and plantation crops. Rising temperatures, shifts in rainfall distribution, unseasonal frosts, and the incidence of new pests and diseases are threatening both yield stability and farmers' incomes. Furthermore, changes in flowering and fruiting patterns are impacting crop cycles, market availability, and export potential. Addressing these challenges requires region-specific strategies, scientific innovations, and strong institutional support.

As a collaborating partner, RPCAU is committed to advancing research, education and extension in agriculture and allied sectors, with a strong focus on climate resilience. Through innovative crop improvement, resource-efficient production systems, digital agriculture and value chain development, the university strives to empower farmers to adapt and thrive in the face of climate change.

I sincerely thank Sri Konda Laxman Telangana Horticultural University (SKLTGHU) for taking the lead in organizing this National Conference and bringing together diverse stakeholders to deliberate on such a crucial theme. This platform will not only facilitate knowledge sharing but also generate actionable strategies for a resilient and sustainable horticulture sector in the country.

I congratulate SKLTGHU and all collaborating partners for this timely initiative and extend my best wishes for the grand success of the conference. I am confident that its outcomes will contribute meaningfully to building a climate-smart, farmer-centric and globally competitive horticulture sector.

(P. S. Pandey)

Dr.B.GOPI, I.A.S.,
Director of Agriculture
Government of Telangana



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Message

Agriculture continues to be the backbone of Indian economy, providing livelihoods to millions and ensuring food and nutritional security. Within this sector, horticulture has emerged as a dynamic growth engine, offering higher returns, diversified cropping opportunities and immense export potential.

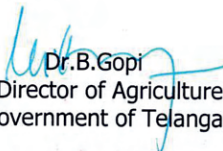
Though Indian agriculture has witnessed unimaginable growth, these gains have come with enormous consequences to the natural resource base and eco system. To address these, it is imperative to promote crop diversification, climate-smart technologies, efficient water management, precision farming and resilient varieties that can withstand climatic stress while enhancing productivity.

The Government of Telangana is committed to support the farmers through various initiatives in micro-irrigation, farm mechanization, crop diversification, post harvest management, infrastructure and promotion of Farmer Producer Organizations (FPOs) to create a strong and resilient agri-horti ecosystem.

I am delighted that Sri Konda Laxman Telangana Horticultural University (SKLTGHU), in collaboration with the Ministry of Earth Sciences, Government of India, the Department of Horticulture, Government of Telangana, NABARD and Dr. Rajendra Prasad Central Agricultural University, Pusa, is organizing this National Conference on "Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies." This platform will provide valuable insights and practical solutions to build a sustainable and climate-resilient horticulture sector.

On behalf of the Department of Agriculture, Government of Telangana, I extend my congratulations to the organizers and I believe that the deliberations during the Conference will culminate in developing strategies and an action-oriented roadmap to promote conservation of environment and natural resources and actions for combating the adverse effect of climate change.

I wish the National Conference a grand success.


Dr.B.Gopi
Director of Agriculture
Government of Telangana

Souvenir Message

Horticulture has become one of the fastest-growing sectors of Indian agriculture, contributing significantly to farm income, nutritional security, rural employment and exports. In Telangana and across the country, horticultural crops have enabled diversification of farming systems, making them more resilient and profitable, particularly for small and marginal farmers.

However, the sector faces multiple challenges due to climate change, resource stress, and post-harvest losses. Erratic rainfall, temperature fluctuations and frequent extreme events affect not only production but also market stability. This calls for climate-resilient technologies, improved infrastructure and institutional support to safeguard farmers' livelihoods.

NABARD has been actively supporting horticultural development through initiatives in micro-irrigation, watershed management, Farmer Producer Organizations (FPOs), cold chain and storage infrastructure and promotion of agri-startups. Going forward, greater emphasis on digital platforms, value addition, branding and climate-smart financing models will be crucial to ensure sustainability and enhance farmers' incomes.

I am pleased that Sri Konda Laxman Telangana Horticultural University (SKLTGHU), in collaboration with the Ministry of Earth Sciences, Government of India, the Department of Horticulture, Government of Telangana, NABARD, Hyderabad and Dr. Rajendra Prasad Central Agricultural University, Pusa, is organizing this **National Conference on "Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies."** This timely initiative provides a valuable platform for scientists, policymakers, industry and farmers to deliberate on innovations and strategies for a climate-resilient horticulture sector.

On behalf of NABARD, I congratulate the organizers for selecting appropriate themes in the national conference and the two days deliberations during the conference would bring new approaches, policies, strategies and collaborations for improving the production of horticulture and rural economy in the country in eco friendly manner.



B. Uday Bhaskar
Chief General Manager
NABARD, Regional Office, Hyderabad

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Lead Lecture - 1

Geospatial Tools for Horticultural Crop Production and Area Forecasting: Current State and Future Strategies

S. Bandyopadhyay

Director, Mahalanobis National Crop Forecasting Centre

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Introduction: The Strategic Importance of Horticultural Crops

Horticultural crops, including a diverse range of fruits, vegetables, spices, and flowers, are a cornerstone of the agricultural economy and a vital source of livelihood for millions of farmers, from small-scale growers to large commercial producers. Beyond their economic value, these crops are indispensable for ensuring national nutritional security, providing essential vitamins, minerals, and dietary fiber. The growth of this sector is a significant driver of national economic development, contributing substantially to agricultural GDP and export earnings.

India, in particular, holds a prominent position in global horticulture. During the 2022-2023 period, the nation's total horticultural production reached a staggering 355.48 million tonnes. This included an impressive 110.21 million tonnes of fruits and a substantial 212.54 million tonnes of vegetables. India is the world's second-largest producer of fruits and vegetables and holds the top position for several key crops, including mango, banana, papaya, guava, pomegranate, and sapota. This strong production base is crucial for meeting the rising domestic demand, which is fuelled by a growing population, improved income levels, and an increasing awareness of health benefits.

However, the horticulture sector faces significant uncertainties, particularly from the escalating risks of climate change. Extreme weather events, such as unseasonal rains, prolonged droughts, and heatwaves, pose major threats to crop production, creating a need for robust and reliable forecasting systems. To address these challenges and foster holistic growth, the Government of India launched the Mission for Integrated Development of Horticulture (MIDH) in 2014. This Centrally Sponsored Scheme provides financial incentives and technical support to states, covering a wide array of horticultural crops.

Considering the importance of horticulture towards food and nutrient security and its export potential and economic benefits, a remote sensing based programme called 'Coordinated programme on Horticulture Assessment & Management using geoinformatics (CHAMAN)' was launched in September 2014. The aim of the project was use of Remote Sensing and Geospatial techniques for horticultural inventory of 7 major horticultural crops and horticultural developmental planning. The proposal was jointly prepared by ISRO and Department of Agriculture and Cooperation & Farmers Welfare, under the Mission for Integrated Development of Horticulture (MIDH). The project's primary objectives are multifaceted, focusing on accurate area and production assessment, site suitability analysis, planning for post-harvest infrastructure,

promoting crop intensification, creating a comprehensive GIS database, and even addressing orchard rejuvenation and aqua-horticulture.

Current Status and Methodological Approaches

The field of assessing horticultural crop area and production is shifting from traditional, ground-based surveys to a more advanced, technology-driven approach.

Initially, these assessments relied on **conventional methods** like village-level surveys and historical data, which provided a baseline but couldn't adapt to real-time changes in weather or market conditions.

The shift is exemplified by projects like CHAMAN, which use **geo-informatics and remote sensing**. This involves using satellite imagery to map and quantify crop areas and **Geographic Information Systems (GIS)** to integrate and analyze data from various sources.

The process is further enhanced by **advanced technologies** which include:

- **Crop simulation models** to predict yields based on weather and soil data.
- **Machine learning algorithms** to analyze complex datasets and identify patterns for more accurate predictions.
- **Data assimilation techniques** that combine data from different sources to continuously update and improve forecasting models in real time.

This integrated approach offers a more scientific, scalable, and accurate way to monitor and forecast horticultural crop production.

Challenges and Strategies for Improvement

Despite the significant advancements, a number of challenges hinder the perfect accuracy and widespread application of horticultural forecasting systems. Addressing these requires a multi-faceted approach.

Inherent Challenges of Horticultural Crops: Developing accurate and widely applicable horticultural forecasting systems is challenging due to the inherent complexities of these crops. Unlike large-scale monoculture farms, horticultural crops are often grown on small, scattered plots, making them hard to track with lower-resolution satellite imagery. The variety of planting methods, such as mixed cropping and staggered planting, also complicates simple analysis because different crops and growth stages can appear in the same area. Furthermore, horticultural crops are highly sensitive to environmental factors like pests, diseases, and extreme weather, which can rapidly impact yields. Addressing these issues requires continuous, high-frequency monitoring to accurately forecast production.

Technological and Institutional Challenges:

The adoption of agricultural technologies faces two main challenges. Firstly, there are significant data gaps and a lack of standardization, which hinders the development of reliable models. There is a need for consistent protocols for data collection across different regions and government agencies. Secondly, the high cost and limited accessibility of technologies like satellites and drones remain a major barrier, especially for individual farmers and smaller research groups. This is further compounded by a lack of rural internet connectivity and the necessary technical expertise to utilize these tools.

Strategies for Overcoming Challenges:

To build a reliable forecasting system for horticultural crops, a comprehensive strategy is needed that combines technological advancements, institutional reform, and collaborative efforts. This involves using high-resolution satellite imagery and drone technology to accurately map diverse and fragmented landholdings. Advanced machine learning algorithms are necessary to process this complex data, with data assimilation techniques used to integrate various data streams like satellite, weather, and field survey information for continuous model refinement. Strengthening institutional frameworks is equally important, requiring better inter-agency coordination, capacity building for field staff and farmers to collect real-time data, and the creation of user-friendly digital platforms. Public-private partnerships (PPPs) can accelerate the development of these solutions by leveraging private sector expertise in data analytics. Finally, sustained research and development (R&D) is crucial to create crop-specific models and accessible technologies tailored for smallholder farmers.

Conclusion:

The assessment of area and production forecasting in horticultural crops is a dynamic field at a critical juncture. The shift towards geo-informatics, machine learning, and integrated data systems offers immense potential. However, the unique biological and socio-economic complexities of the sector demand a strategic and concerted effort. By investing in technology, strengthening institutional frameworks, and empowering stakeholders, we can build a robust and reliable forecasting system that ensures the sustainable growth of the horticulture sector and contributes to national food and nutritional security.

Lead Lecture - 2

Heat Stress on Horticultural Crops: Causes, Impacts, Adaptation and Mitigation Strategies

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Abstract

Horticultural crops are sensitive to climate change and climate variability. Heat (high temperatures) stress negatively impacts fruit bearing crops (e.g., fruits, vegetables, annual or perennials). This presentation highlights and presents the causes, impacts, and opportunities for adaptation and mitigation strategies, using tomato as case study for fruit crops.

Over the last century earth's surface temperatures has warmed up by about 1.6°C compared to the beginning of the previous century. In addition, the heat waves, defined as short episodes of high temperatures, has increased in terms of all indicators – number, intensity, duration, and season. Both increases in mean temperature and occurrence of heat stress events negatively impacts of productivity and quality of our agricultural or food products – including fruits and vegetables. The major cause of climate change and climate variability is the rapid and exponential increases in the greenhouse gas emissions (GHG) over the last century. The major GHG include – carbon dioxide, methane, nitrous oxide, and sulfur hexafluorides, which have significantly increased over many decades. At the end of 2024, the concentrations of carbon dioxide was 426 ppm, methane was 1938 ppb, nitrous oxide was 338 ppb, and sulfur hexafluoride was 11.99 ppt. If the increases in GHGs continue to increase, future climates will not only have increases in the overall average temperatures but also experience more episodes of extreme heat stress events.

Heat stress impacts growth, development, reproductive function, fruit-set, fruit-size and fruit quality. There are three major phases of development for most fruit crops (e.g. tomato) – vegetative phase (e.g., germination, emergence, leaf development, stem elongation, branching and shoot development), reproductive phase (e.g., gamete development, flowering, fruit-set, fruit formation) and fruit maturation phase (e.g. fruit growth and ripening). Reproductive stages of crop development are more relatively more sensitive to heat stress compared to other stages. Heat stress during reproductive phase negatively impacts gamete viability, fruit-set and fruit growth. More specifically, heat stress (even short episodes of few days) just before anthesis during flower bud development (coinciding with gamete formation and development) decreases viability of gametes. Male gametes (pollen grains) are relatively more sensitive to heat stress compared to female gametes (ovules or eggs). The stages of microsporogenesis (pollen mother cell, meiosis and tetrad formation) are particularly sensitive to heat stress resulting in the loss of

pollen viability. But heat stress can also cause loss of viability of female gametes negatively impacting fruit-set. Heat stress during flowering impacts the process of pollen dehiscence, pollen reception by stigma, pollen germination and fertilization. Heat stress impacts flower morphology and anatomy, including stamen and carpel. Heat stress decreases overall size of the flower, but more importantly it decreases stamen lengths. This leads to stigma exertion, causing lower pollen reception and pollen load on the stigma, resulting in poor pollination, pollen germination, and pollen tube growth. These events ultimately leads to poor fertilization, lower fruit-set resulting fewer fruit numbers. If heat stress occurs after fertilization and formation of fruit, it negatively impacts the fruit size due to shorter fruit development time from fruit formation to maturation. Heat stress during maturation also impact the quality of fruits, in terms of size, nutritional composition and postharvest storage quality. There is also faster leaf senescence and shorter green leaf area duration, which negatively impacts the overall photosynthesis impacting availability of carbohydrates and their partitioning, leading to smaller fruit size. Heat stress during flower bud development, flowering and maturation, and resultant decrease in fertilization, fruit numbers, fruit size and final harvestable yield occurs all crops, including fruits and vegetables (e.g., tomato, pepper), perennials (e.g., coconut), annual cereal grains (e.g., rice, wheat, sorghum), legumes (e.g., soybean, chickpea, mung-bean) or oil seeds (e.g., groundnut, canola).

There many opportunities for adaptation to heat stress, particularly, in terms of genetic improvement and development of heat stress tolerant genotypes. There is genetic variability that exists in crops for tolerance to heat stress. The impacts of heat stress on tolerant genotype are relatively lower compared to those of sensitive genotypes. The heat tolerant genotypes maintain higher pollen viability, pollen germination, pollen tube growth and fertilization leading to greater percent fruit-set and higher fruit numbers compared to susceptibility genotypes. Heat tolerant genotype also maintain leaf membrane stability, chlorophyll and longer green leaf area duration, resulting in larger fruit size and over yield. This genetic variability should be systematically explored to develop heat tolerant genotypes. There are multiple breeding methods that can be employed to develop stress tolerant genotypes. These include traditional conventional methods of pedigree breeding or population breeding; modern molecular breeding using marker-assisted selection or genome wide selection; transgenic approaches using genetic transformation or tissue culture techniques. In addition, more recent transformative gene editing approaches using CRISPR technology are available and being explored particularly for high value commercial crops.

Finally, there are also opportunities for mitigation or management of heat stress. These include agronomic and crop management practices, such as early or late planting to avoid the heat stress during sensitive stages, irrigation management, balanced nutrient management, allowing incidence of weeds, pest and diseases. All of these practices keeps plants healthy and allow them to cope or tolerate stress to a limited extent. There are prospects for using growth regulators or hormones (e.g., gibberellins, auxins, brassinosteroids, melatonin), antioxidants, biostimulants or microbes (e.g., plant growth promoting bacteria) to mitigate the negative impacts of heat stress. In the controlled agriculture – heat stress can be minimized or avoided using shade cloths, nets, employing air-vents/fans, humidifiers or sprinkler irrigation to manage air temperatures, and using appropriate soil cover or mulch along with drip irrigation to manage soil temperatures.

In conclusion, heat stress significantly decreases yield and quality of harvested economic product in horticultural crops. The lower yield is due to decreased fruit numbers, fruit size, and faster senescence. Developing appropriate and scalable technologies for adaptation, mitigation and management of heat stress will require strategic collaboration between plant biologists, breeders, and agronomists. The innovations and technologies must be productive, profitable, economically viable, socially acceptable, and environmentally sustainable.

Lead Lecture – 3

Mitigating Temperature Extremes in Horticulture: Scientific Approaches for Climate-Resilient Crop Production

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Introduction

Climate change has increased the frequency and intensity of thermal extremes, including both heat waves and cold snaps. For the horticultural sector—especially ornamental and foliage crops that are often cultivated outside or in minimally controlled environments—temperature stress directly reduces plant growth, aesthetic value, and marketability. Two complementary bodies of work have significantly advanced our understanding of plant responses to these stresses. Research by Natarajan and Kuehny (2005 and 2008) has illuminated physiological, morphological, and molecular responses to heat, with particular emphasis on the role of heat shock proteins (HSPs) in ornamentals. Parallel studies by Stamps and Natarajan (2010) have addressed strategies for protecting tropical foliage crops from chilling and freezing injury, with a focus on practical environmental interventions in shadehouses and greenhouses. Together, these contributions provide a framework that links plant-intrinsic defense mechanisms (e.g., HSP induction, anatomical adaptations) with grower-managed protective technologies (e.g., fogging systems, thermal curtains), offering dual strategies for climate-resilient horticulture.

Heat Stress: Morphological and Physiological Responses

Heat stress disrupts photosynthesis, respiration, water relations, and membrane stability. Natarajan and Kuehny (2005, 2008) used *Salvia splendens* as a model bedding plant to study varietal differences in heat tolerance. Sensitive cultivars such as ‘Sizzler Red’ exhibited sharp declines in photosynthetic rate, stomatal conductance, and visual quality under high temperature regimes, whereas tolerant cultivars such as ‘Vista Red’ maintained higher physiological performance.

Key morphological traits associated with tolerance included:

- **Thicker, broader leaves** with higher stomatal density.
- **Robust root systems** that enhanced water uptake and sustained growth.
- **Dense canopies and shorter internodes** that promoted rapid ground cover and reduced soil heat load.

Preconditioning: brief exposures to sub-lethal high temperatures further enhanced tolerance in both sensitive and tolerant cultivars. Preconditioned plants demonstrated greater root mass, leaf thickness, and overall aesthetic quality under stress.

Role of Heat Shock Proteins in Heat Tolerance

Beyond visible traits, Natarajan and Kuehny highlighted the crucial role of **heat shock proteins (HSPs)**, particularly small HSPs (~15–30 kDa), in conferring thermotolerance. These proteins function as **molecular chaperones**, stabilizing enzymes and membranes, preventing protein aggregation, and facilitating refolding of denatured proteins.

Findings from their work include:

- Heat-tolerant cultivars accumulated HSPs more rapidly and in greater quantities than sensitive cultivars.
- Specific proteins, such as a 27-kDa HSP, were consistently upregulated in tolerant genotypes like ‘Vista’.
- Preconditioning stimulated earlier and stronger induction of HSPs, correlating with improved physiological resilience.

Thus, HSP accumulation provides a biochemical safeguard that complements anatomical and physiological adaptations. Screening cultivars for HSP expression patterns, alongside morphological traits, offers a practical tool for breeding programs aiming to develop climate-resilient bedding plants.

Cold Stress: Chilling Injury and Protective Strategies

While heat threatens summer production, cold stress—especially chilling injury above freezing—poses major risks to subtropical foliage crops in winter. R.H. Stamps and collaborators (Stamps, Chen, Natarajan, & Parsons, 2010; UF/IFAS Extension publications) documented the vulnerability of tropical foliage to temperatures below ~10 °C. Symptoms include wilting, chlorosis, tissue necrosis, and accelerated senescence, which rapidly render ornamental plants unmarketable.

Passive Protection Measures

- **Site selection** to avoid frost pockets and use of windbreaks.
- **Grouping crops by sensitivity** and adjusting shipping schedules to avoid exposure.
- **Pre-irrigation of soils/media**, which increases heat capacity and delays chilling.
- **Use of claddings and thermal curtains**, which trap warm air and reduce radiative heat loss.

Active Protection Measures

Traditional heating is costly and water-intensive. Stamps’ trials with **misting and fogging systems** provided innovative alternatives:

- **Under-bench misting with retractable thermal curtains** raised interior air temperature by 10–17 °C compared with outside.
- **Among-plant fogging systems** were especially water-efficient, achieving comparable protection with up to 86% less water than misting.
- These systems successfully protected a wide range of foliage crops, except the most cold-sensitive species, from chilling and freezing injury.

While molecular cold acclimation mechanisms (cold-shock proteins, dehydrins) exist in plants, Stamps' research emphasizes that engineering and management interventions remain the most reliable strategies for growers facing sudden cold events.

Integration: Dual Approaches to Thermal Stress

The juxtaposition of these research programs illustrates the dual nature of climate adaptation in horticulture:

1. Intrinsic Plant Defense (Natarajan & Kuehny):

- Heat tolerance depends on a combination of morphological traits and biochemical resilience, with HSPs providing critical molecular protection.
- Preconditioning treatments and cultivar selection/breeding for HSP expression and structural robustness offer viable strategies for growers.

2. Extrinsic Environmental Management (Stamps et al.):

- Cold protection in tropical foliage crops relies heavily on passive and active interventions, such as site design, claddings, and fogging systems.
- These approaches conserve water, reduce energy demand, and offer practical, scalable protection to commercial operations.

Together, they highlight that **resilient horticulture in the era of climate change requires both plant-level and system-level solutions.**

Policy Recommendations for Climate Adaptation in Horticulture

1. Support Development and Adoption of Heat Preconditioning Protocols

- Fund extension programs and nursery training to implement acclimation techniques that improve heat tolerance.
- Encourage breeding programs focused on heat-resilient cultivars using identified physiological and molecular markers.

2. Promote Structural and Cultural Practices to Minimize Cold Damage

- Develop guidelines and incentives for best practices in greenhouse and shadehouse design, emphasizing insulation, sealing, and site selection.
- Support research and dissemination of crop covers, active heating, and frost mitigation technologies.

3. Integrate Climate Risk Awareness in Crop Planning and Management

- Facilitate weather monitoring and forecasting tools tailored to horticulture to inform planting and protection decisions.
- Encourage flexible planting schedules and phenological monitoring to avoid sensitive growth stages during extreme weather.

4. Invest in Energy-Efficient Technologies for Protected Cultivation

- Incentivize energy-efficient heating and cooling systems in horticultural structures to reduce environmental impact while safeguarding crops.

- Support development of passive design features to maintain stable microclimates.

5. Enhance Knowledge Transfer and Capacity Building

- Provide targeted outreach to growers, extension agents, and industry stakeholders on climate-resilient horticultural practices.
- Foster collaborations between researchers, policymakers, and industry for adaptive solutions.

Conclusion

Rising climate variability threatens horticultural productivity and profitability. The pioneering research of Natarajan and Kuehny on heat stress and HSPs, and of Stamps and colleagues on cold protection, provide complementary strategies for safeguarding crops against temperature extremes. By integrating biological adaptation (selection for tolerant cultivars, preconditioning, HSP induction) with technological intervention (fogging, thermal curtains, irrigation management), growers can sustain crop quality and marketability even under challenging climatic conditions. Implementing science-based adaptation strategies grounded in robust research on temperature stress tolerance and mitigation such as those by Natarajan, Kuehny, and Stamps will strengthen horticultural resilience against climate change. Proactive policies enabling preconditioning, cultivar selection, structural improvements, and energy efficiency are vital to protect plant health, ensure economic viability, and support sustainable agriculture in an era of increasing climatic uncertainty.

These insights remain directly relevant for ornamental and foliage industries, and also serve as models for broader horticultural systems navigating the challenges of climate change.

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Lead Lecture – 4

Impact-Based Forecasting (IBF): An Approach for Reducing Adverse Impacts of Extreme Weather Events in Agricultural and Horticultural Sectors

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Introduction

Over the past few decades, the global approach to weather forecasting has undergone a major shift, moving from traditional weather prediction to Impact-Based Forecasting (IBF). Despite improvements in meteorological accuracy, economic and human losses from weather-related disasters continue to rise. During 1970-2019, across the world, weather and climate-related disasters have resulted in nearly 2.06 million deaths and US\$ 3.64 trillion in economic losses and among all documented disasters, natural hazards were responsible for 62% of the total incidents, 80% of all fatalities, and nearly 99% of the economic losses (WMO, 2021a).

While achieving remarkable accuracy in predicting meteorological parameters, traditional weather forecasting systems have frequently fallen short in effectively communicating potential impacts to end-users, resulting in inadequate preparedness and response measures (UKMO, 2018). It has been generally noticed that although the forecast has been significantly improved in last few decades, the weather-related losses have not matched in that proportion. This disparity highlights a critical gap between technical forecast capability and practical disaster risk reduction, particularly in vulnerable regions and sectors, including agriculture and horticulture.

Impact-based Based Forecasting (IBF) emerged as a response to this fundamental disconnect, representing a revolutionary approach that transforms raw meteorological data into actionable intelligence for decision-makers and vulnerable communities. The concept fundamentally differs from traditional forecasting by incorporating three crucial elements: hazard characteristics, exposure patterns, and vulnerability factors. This integrated approach enables the translation of weather predictions into specific impact scenarios, facilitating more effective decision-making across various sectors and stakeholder groups (WMO, 2015, 2021b).

Climatic factors are responsible for approximately 32-39% of the observed fluctuations in agricultural yields worldwide (Ray et al., 2015). A recent study carried out by the Centre for Science and Environment (CSE), a public interest research and advocacy organization based in New Delhi, revealed that extreme weather events during January to September 2024 in India resulted in 3,238 fatalities and impacted 3.2 million hectares of agricultural land (Down To Earth, 2024). Extreme weather events like heatwaves, cold waves, unseasonal rains, and cyclones severely impact horticultural crops also in India. These events cause fruit and flower drop, reduce yields, and increase pest and disease outbreaks. Perishable crops like fruits and vegetables suffer post-harvest losses due to transport and storage disruptions. The losses

disproportionately affect small-scale farmers, who often lack access to sophisticated weather information systems or the ability to interpret traditional forecast products effectively.

Modern IBF systems can now integrate vast socio-economic data with weather predictions, enabling more nuanced and location-specific impact assessments (WMO, 2021b). However, the transition to IBF systems presents significant challenges, particularly in developing countries like India. These challenges include the availability of location-specific quality data, technical capacity limitations, resource constraints, and the need for enhanced cross-sector coordination (Mohapatra et al., 2023).

IBF for Agriculture and Horticulture in India

IBF for agriculture differs from conventional forecasts by predicting specific impacts on crops, livestock, and farming operations, rather than just meteorological variables. This allows farmers to make more informed decisions about sowing, irrigation, pest control, and harvesting.

Gramin Krishi Mausam Seva (GKMS) is a flagship scheme of India Meteorological Department (IMD) that provides Agromet Advisory Services (AAS) to the farming community of India. In this scheme, district and block-specific weather forecasts and district level agromet advisories are being provided to the farmers for improved decision-making of their day-to-day farming operations to achieve the optimal yield potentials of various crops. The AAS bulletins are prepared biweekly *i.e.* every Tuesday and Friday for all the agriculturally major districts (~700). Due to the dynamic nature of the atmosphere, there have been incidences of sudden changes in the weather patterns having potentially adverse impacts on the standing crops.

To address this issue, IMD started providing IBFs for Agriculture since December 2021 in case of severe weather warnings such as heavy rainfall, hailstorms, cold wave and frost, heat wave, strong surface winds etc.

Issuance of IBFs for Agriculture and Horticulture

IBFs for agriculture and horticulture are being issued for those districts where extreme weather warnings are forecasted and potentially can be detrimental to crops. The weather warnings at the district level are issued by the concerned Regional Meteorological Centres (RMCs) and Meteorological Centres (MCs) of IMD of the respective states and accordingly, the appropriate farm advisories are being prepared and issued by Agromet Field Units (AMFUs) and District Agromet Units (DAMUs) under GKMS scheme, in consultation with the subject matter experts from the various disciplines of agriculture such as agronomy, horticulture, soil science, entomology, plant pathology, livestock, fisheries etc., to minimize the risks and prevent the crops from adverse weather conditions.

These district-level IBFs received from various AMFUs and DAMUs are further compiled to prepare a consolidated IBF at state level by meteorologists at RMCs and MCs. The consolidated IBF is further disseminated to the district magistrate/collector and Agricultural officers of the concerned districts, enabling timely and informed decision-making for safeguarding crops, livestock, and livelihoods against weather-related risks on timely basis. This approach enhances resilience and promotes sustainable agricultural practices.

Verification of IBF for Agriculture and Horticulture

Verification of IBF for agriculture is crucial to ensure the reliability and effectiveness of these forecasts in supporting farmers and agricultural stakeholders which involves assessing the forecast accuracy by comparing predicted impacts with observed outcomes. By validating the effectiveness of IBF, stakeholders can maximize the benefits of weather information for better agricultural outcomes and livelihoods.

Efforts have been made to analyse the IBFs for Agriculture using various verification matrices such as Accuracy, Probability of Detection (POD), False Alarm Ratio (FAR) and Critical Success Index (CSI). It has been generally noticed that although the IBF accuracy values appear typically high, they can sometimes be misleading due to frequent “not forecast/not occurred” events. A seasonal and monthly analysis of IBF performance reveals trends such as declining POD and increasing FAR with extended lead times, highlighting the need for refinement of warning thresholds and better discrimination between impactful and non-impactful weather.

Limitations and Challenges

- Data inaccuracies, inconsistencies, and gaps hinder effective IBF implementation.
- India’s diverse agroclimatic zones require highly localized, region-specific IBFs, which are difficult to develop, especially in hilly areas.
- Increasing awareness among farmers and extension workers about IBF’s importance and interpretation is critical for its adoption and effective use.
- Sustained policy and institutional support, along with collaboration among stakeholders (policymakers, researchers, technology developers, and farmers), is essential to overcome challenges and improve agricultural resilience through IBF.

Conclusion

Impact-Based Forecasting is a critical tool for climate-resilient agriculture. It helps bridge the gap between forecast and action by providing farmers with actionable information tailored to their local context and crop conditions. While the system shows strong potential and promising results, particularly in the short term, efforts must be made to improve accuracy, reduce false alarms, and enhance data collection and verification methods.

Strengthening IBF in India will require advanced weather modelling, better integration of crop data, farmer outreach and training and stronger policy and institutional support. With continued improvement, IBF can play a pivotal role in reducing agricultural losses, protecting livelihoods, and building long-term resilience in India’s farming communities.

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Lead Lecture – 5

Leveraging Climate Information for Horticulture: The Path So Far and the Road Ahead

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Horticulture has emerged as a cornerstone of Indian agriculture, contributing nearly 33% to agricultural Gross Value Added (GVA) and playing a vital role in nutritional security, employment generation, and export earnings. These commodities sustain millions of livelihoods and hold strategic importance for national food and nutritional security. However, this progress is increasingly threatened by climate variability and change. Rising temperatures, erratic rainfall, unseasonal frost, heatwaves, floods, and the growing incidence of pests and diseases are undermining both productivity and quality.

Globally, climate services are recognized as a critical enabler of resilient and sustainable horticulture. Initiatives under the Global Framework for Climate Services (GFCS), Food and Agriculture Organization of the United Nations (FAO), Consortium of International Agricultural Research (CGIAR), and national meteorological agencies are embedding climate information into agrifood systems. Advances in subseasonal-to-seasonal forecasting, high-resolution remote sensing, and digital decision-support tools are enabling more precise advisories for sensitive and perishable crops. Partnerships between public agencies, research networks, and private platforms are expanding delivery, while integration with early-warning systems and risk financing is strengthening value-chain resilience. Evidence shows that farmer uptake improves significantly when services are co-designed and delivered through trusted channels, although challenges remain in achieving equitable access and long-term sustainability.

In India, despite strong institutional frameworks through India Meteorological Department (IMD), Indian Council of Agricultural Research (ICAR), Ministry of earth Sciences (MoES) and Ministry of Agriculture & Farmers' Welfare (MoA&FW), horticulture-focused climate services remain fragmented and underdeveloped. Forecasts and operational products often lack the spatial resolution and crop-phenology tailoring needed for orchard systems and protected cultivation. Early-warning systems are weakly linked to post-harvest management, cold-chain logistics, and risk-transfer mechanisms that are vital for high-value commodities. Last-mile adoption is further constrained by limited extension capacity, uneven digital literacy, and inadequate monitoring and evaluation. Strengthening horticulture's place in India's climate services agenda is critical to accelerate resilience and competitiveness in this high-value sector.

The India Meteorological Department (IMD) has been addressing these challenges through the Gramin Krishi Mausam Sewa (GKMS), operational since 2007 in collaboration with national and state agricultural institutions. Under GKMS, medium-range forecasts are translated

into crop- and location-specific advisories by a network of 130 Agromet Field Units (AMFUs) established across agro-climatic zones at State Agricultural Universities, ICAR institutes, and IITs. Advisories issued twice a week are disseminated through SMS, mobile apps (Meghdoot, Mausam), State Government portals, the Kisan portal, television, All India Radio, and Krishi Vigyan Kendras, supplemented by farmer awareness programs. These services now reach nearly 40 million farmers, supporting decisions on irrigation, sowing, fertilizer application, pest and disease management, and harvesting.

Recent innovations are deepening reach and relevance. The Panchayat Mausam Sewa now provides weather and advisory information at the gram panchayat level, ensuring hyper-local relevance. Simultaneously, IMD has upgraded forecasting capabilities and digital platforms to produce high-resolution, dynamic information tailored to agriculture. These represent important steps toward farmer-centric services, particularly valuable for horticulture where crop phenology and localized weather conditions are decisive.

Nonetheless, critical gaps persist. Horticultural advisories lack sufficient crop specificity and stage-wise detail, while the integration of pest and disease forewarning remains at an early stage despite the sector's vulnerability to biotic stresses. Last-mile delivery continues to be a challenge, especially in reaching smallholders in local languages and preferred formats. The capacity of AMFUs must be continuously enhanced to utilize advanced tools such as remote sensing, crop-weather modeling, pest and disease forecasting, and ICT-based dissemination effectively.

To address these challenges, IMD has launched strategic initiatives. A Memorandum of Understanding with ICAR–Indian Institute of Horticultural Research (IIHR) has been signed to co-develop commodity-specific advisory modules for fruits, vegetables, and flowers. Further partnerships with national institutions, international organizations, private sector entities, and NGOs are planned to enhance scientific robustness and outreach. A Next-Generation Decision Support System (DSS) is also under development, integrating forecasts, crop models, pest and disease forewarning, and automated advisories into a unified platform for dynamic, precise decision-making.

These horticulture-specific advisories will directly contribute to flagship national schemes such as the Mission for Integrated Development of Horticulture (MIDH), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), National Mission on Sustainable Agriculture (NMSA), and Paramparagat Krishi Vikas Yojana (PKVY). By aligning with these initiatives, IMD's services will enable farmers to optimize resource use, minimize crop losses, and better leverage government support.

Given horticulture's high sensitivity to climate variability, the sector faces both significant risks and immense opportunities. By bridging existing gaps, strengthening collaborations, enhancing scientific and human resource capacity, and aligning with national missions, India can transform horticulture advisories into a powerful tool for climate resilience. With timely, actionable, and crop-specific information, farmers will be empowered to manage weather risks, enhance productivity, and secure sustainable livelihoods.

Lead Lecture – 6

Impact of Climate Change on Fruit Crops and Adaptation Strategies

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The greenhouse gas emissions, due to anthropogenic activities in the postindustrial period, have contributed to the global warming. The climate change brought about by the global temperature rise due to greenhouse gases is affecting each and every aspect of humanity. Various sectors are affected by climate change adversely. The Indian horticulture sector is not an exception. India has made tremendous progress in the production of horticulture crops, mainly fruits and vegetables, due to various initiatives of the government. Fruits and vegetable crops due to their diverse adaptability are cultivated in across various agro-ecological regions. Together fruits and vegetables contribute to 90% of total horticulture production of 354.74 million tons during 2023-24. However, under climate conditions, fruit crops are affected due to extreme high temperatures, deficit or excess water stress. The temperature increase affects the growth and development of fruit crops. The additional evaporative demand due to rise in temperature leads to higher irrigation water requirements. Further, the increased frequency of extreme rainfall events would lead to water logging and deficit water conditions. Hence, the occurrence of climate change associated abiotic stresses like high temperature, excess or deficit water stresses may occur individually or in combination. The extent of adverse effects on fruit crops would depend on the susceptibility of a particular crop, variety and phenological stage of the crop. The extent of damage would be greater when the stresses occur at critical growth phases. The occurrence of extreme events also may provide congenial conditions for the emerge of various pest and diseases. The insect pest and disease dynamics change under varying temperature and humidity conditions. Therefore, the Interaction effects of both abiotic and biotic stresses would determine the extent of impacts of climate change on fruit crops.

Since, most of the fruit crops are perennial in nature and undergo different phenological stages during the year, any incidence of high temperature, excess and deficit water stresses at any of the critical stages would lead to reduction in productivity and quality of fruit crops. Water stress has considerable influence on the fruit set, retention and subsequent fruit growth. The deficit water stress effects would be on both vegetative growth and subsequent initiation of flower primordia, flowering and productivity. Intermittent or constant high temperatures cause morpho-anatomical and physiological changes, resulting in adverse effects on plant growth, development, fruit yield and quality. Hence, the extent of damage to fruit crops, due to both biotic and abiotic stresses associated with climate change, would depend on the climatic risks associated with the growing regions, susceptibility of crop, cultivar and phenological stage.

Adaptations strategies for sustainable production of fruit crops

The climate change poses challenges to sustain the production, productivity and quality of fruit crops. Climate resilient technologies enable the production systems to sustain the climate change impacts. The threat and adverse conditions need to be addressed with climate-smart horticulture

interventions. There is a need to devise crop, location-specific and knowledge-intensive adaptation strategies. Several climate resilient technologies have been developed in the ICAR institutes and universities in the NARES. Several of the them have been popularized and adopted by the farmers. Under rainfed situations, many fruit crops have been adopted. Such an adoption is enabled by supporting crop specific technologies. Because of the perennial nature and deep root system, fruit trees are able utilize the moisture stored in deeper profiles of the soil. Hence, to adapt to the water deficit situations caused due to deficit rainfall, efforts need to be intensified to conserve the moisture in situ and provide protective irrigation at critical stages.

Several water conservation and water harvesting measures developed have been adopted and are being followed by the farmers. Adoption of micro irrigation- drip and sprinkler along with mulching has enhanced the resilience of fruit and vegetable crops under water limiting conditions. In grapes- dogridge rootstock having tolerance to water stress and salinity is adopted by almost all grape farmers. Rootstocks are also being used in crops like mango, apple, guava, sapota, lime in limited scale. Arid crops, *ber*, *aonla*, pomegranate, Fig, Phalsa, Karonda, Custard apple, Wood apple and Jamun *etc.* have proven to be potential crops in scarce and limited rainfall regions. The resilience of fruit crops to climate change associated stresses could be further enhance by promoting climate resilient crops. Emphasis needs to be given on the development and promotion of climate resilient rootstocks. Nursery practices for raising resilient grafts through priming and growth promoting bioagents. Implementation of in-situ moisture conservation techniques, mulching and sensor based optimal irrigation practices to enhance water use efficiency and resilience of crops under deficit water conditions. Under water limiting conditions, in addition to drip irrigation and mulching, novel irrigation methods, like partial root zone drying (PRD), could be adapted in crops like grapes, mango, papaya and citrus. The pruning time may be altered to avoid deficit water stress situations at critical stages of growth. The anti-transpirants, osmo-protectants, biofertilizers may be used for overcoming water stress conditions. Disease and pest surveillance, forewarning, integrated management and phenophase based nutrient management is must for sustaining crop health under adverse conditions. Adoption of fruit tree based integrated farming system (IFS) to enhance resilience, productivity and profitability under climate change conditions. Resorting to conservation agriculture practices, minimum tillage, inter cropping/cover cropping and crop rotation in perennial horticultural crops. Integrating beekeeping in the farming system for enhancing productivity and income under adverse conditions. Strengthening the initiatives already taken for weather forecast based agrometeorological advisory services in the vulnerable areas. Though climate resilient practices are available, adaptation barriers still exist. There is lack of awareness about the climate resilient practices among the farmers and also required finances for investment to implement climate resilient technologies. Thus, linking adoption of resilient technologies with credit supply by the financial institutes and wide spread coverage of crop insurance is required. Thus, integration of all available adaptation options would be the most effective way to sustain the production, productivity and quality of fruit crops. Such concerted efforts would ensure the nutritional, income and livelihood security of farmers under climate change scenario.

Lead Lecture – 7

Development of Climate-Resilient Grape Cultivars Utilizing Precision Breeding and Gene Editing Technology

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Grape, the most valuable fruit crop in the United States, is grown on 0.97 million acres with an annual production of 6.8 million tons (FAOSTAT, 2022). Grape and grape products account for 30% of the value of all fruit crops and annually contribute \$ 162 billion to the US economy. Climate change-related effects negatively influence grapevine cultivation through increased biotic (disease and insect pressure) and abiotic (drought, and heat) stress factors and have serious consequences on the sustainability of the viticulture industry worldwide. Genetic improvement of grapevine for disease resistance is difficult using conventional breeding techniques due to obstacles such as inbreeding depression, incompatibility and a long juvenile period. Although several interspecific hybrids have been developed using conventional breeding, their acceptance in the marketplace is limited due to lack of consumer acceptance to products made from such cultivars. Consequently, producers continue to grow susceptible cultivars while relying on the intensive use of pesticides to control diseases, particularly in regions with high humidity and rainfall. In major grape producing regions of the United States, rising temperatures have been of serious concern with regions like California facing extreme heatwaves that are severe in intensity and longer in duration. Such events result in sunburn damage to fruit that lowers quality and post-harvest shelf life of the fruit and related products such as wine, juice and raisins. The development of climate resilient grapevine cultivars has the potential to decrease grape production costs worldwide, while helping to mitigate adverse human health and environmental effects.

Precision breeding and genome editing are approaches to genetic plant improvement that transfer or modify only specific desirable traits among sexually-compatible relatives without the genetic disruption imposed by meiosis. Precision breeding of grapevine enables the transfer of specific traits between sexually compatible species with minimum disruption of existing characteristics in commercial cultivars. Recent advances in *Vitis* genomics, cell culture and gene insertion systems have now made it possible to add or edit traits in existing elite wine and table cultivars without disrupting existing valued characteristics. Precision breeding and gene editing of grapevine for genetic improvement involves utilizing and modifying DNA sequences found solely in the *Vitis* genome and is a logical refinement of conventional breeding procedures. Precision breeding and gene editing achieves a greater precision in trait improvement while minimizing the unintended consequences and opposition to products developed through *transgenic* (GMO) technologies. Precision breeding and gene editing technology is only recently becoming available for an increasing number of crop species. Essential prerequisites for the implementation of precision breeding and gene editing in grapevine include 1) development of

cell culture and plant regeneration techniques that enable the recovery of totipotent cells and their conversion into whole plants, 2) utilizing these totipotent cells to insert genes and genetic elements that confer traits of interest to produce plants with improved traits and 3) the development of genomic resources and computational technology that allows researchers to identify and analyze sequences of interest for trait improvement. This keynote speech will cover technological development and advances made in grapevine precision breeding and gene editing for the development of improved, climate resilient grapevine cultivars.

Lead Lecture - 8

Impact of Climate Change on Horticulture

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Impacts of Climate Change on Horticulture

- **Temperature rise:** Many fruits like apple, pear, and peach require chilling hours. With rising temperatures, these crops are shifting to higher altitudes.
- **Water stress:** Droughts and erratic rainfall reduce yields of vegetables, fruits, and plantation crops. For example, mango flowering is disturbed by unseasonal rains.
- **Extreme events:** Cyclones damage banana, coconut, and coastal plantations. Heatwaves reduce tomato, chili, and leafy vegetable quality.
- **Pest and disease outbreaks:** Warmer, humid conditions favor new pests and pathogens. Farmers are spending more on crop protection.
- **Quality reduction:** Horticulture is highly sensitive to climate. Even small deviations affect taste, shelf life, and market value.

Adaptation Strategies

- **Crop diversification:** Shifting to climate-resilient crops like millets, drumstick, guava, pomegranate, and indigenous vegetables.
- **Protected cultivation:** Using polyhouses, net houses, and mulching to regulate microclimate.
- **Water management:** Drip irrigation, rainwater harvesting, and fertigation to use “every drop of water efficiently.”
- **Breeding climate-resilient varieties:** Developing heat-tolerant, drought-tolerant, and disease-resistant varieties.
- **Agroforestry and intercropping:** Combining trees with horticultural crops to buffer against climate shocks.
- **Digital advisories:** Weather forecasting and mobile-based advisories help farmers take timely action.

Mitigation Opportunities

Horticulture is not only a victim of climate change, it can also be a solution:

- **Carbon sequestration:** Orchards, plantations, and agroforestry systems act as “carbon sinks.” Mango, coconut, and cashew plantations capture huge amounts of CO₂.

- **Reducing chemical inputs:** By using biofertilizers, biostimulants, compost, and integrated pest management, we reduce greenhouse gas emissions.
- **Renewable energy in horticulture:** Solar pumps, biogas, and energy-efficient cold storage reduce fossil fuel dependence.
- **Waste utilization:** Converting horticultural waste into biochar, compost, or energy helps reduce methane emissions.
- **Urban horticulture:** Rooftop gardens, vertical farming, and peri-urban horticulture reduce “food miles” and emissions.

The Way Forward

- Scientists, policymakers, industry, and farmers must **work together**.
- Farmers should be trained in climate-smart horticultural practices.
- Governments should support with insurance, subsidies for protected cultivation, and climate-resilient infrastructure.
- Youth and women entrepreneurs can lead innovations in climate-smart horticulture.

Lead Lecture – 9

Nano Bionic Effect of Multiwall Carbon Nanotubes (MWCNT) and Graphene Oxides (GO) for Climate Resilient Horticultural Plants: A Strategy for Ensuring Food Security

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Abstract

Climate change presents some real hurdles for horticultural crops and its becoming clear that unseasonal temps, like warmer days in winter, water scarcity in summer, wild weather during cropping season especially flower bud differentiation and unseasonal rainfall creating huge crop loss. Now, there's evidence that Integrated Farming Management (IFM) techniques can actually help lessen the bad impacts and still align with current horticultural policies. IFM ensures horticultural practices are more resilient when faced with these climatic changes but in more environmental problems, using new materials like multiwall carbon nanotubes, graphene oxide, and hydrogen rich water (HRW) in horticultural could really help plants handle climate change better. Because the world's population is growing and the environment is getting worse, we need farming methods that don't harm the environment and can lessen the effects of pollution. These cool nanomaterials have impressive physical qualities, like being super strong and conducting electricity well, which can help plants grow better and withstand stress. Also, recent research in college of horticulture mojerla, Sri Konda Laxman Telangana Horticultural University on Ramanathapuram Gundu Malli (*Jasminum sambac* Ait.) shows that improved crop adaptability when it is introduced from Ramanathapuram, Tamil Nadu to Horticultural Instructional Farm, Madanapuram, Telangana and also shown extra abilities in increasing plant height, promotion of number of primary, secondary and tertiary branches, imparted good quality flower attributes and overall performance in changed climate.

Keywords: Multi-wall carbon Nano tubes, Hydrogen rich water, Graphene oxide, climate, resilience

Introduction

Severe impacts of climate change on horticultural crops requires the implementation of effective resilience strategies to strengthen horticultural crops and their vegetative phenology. Developing climate -resilient crops through traditional crop breeding is slow and costly process and time consuming but implementing multiwall carbon nanotube and graphene oxides techniques as it entails high efficient, simple to use by farmers and target alteration to make

resilient crops to changed climatic condition. Presently, the effect of crop root on crop root zone and thermal characteristics are poorly understood, and new fertilizers are rarely considered as remedy. College of Horticulture, Mojerla, Sri Konda Laxman Telangana Horticultural University explored the effect of applying multiwall carbon nano tube (MWCNT), Graphene oxide (GO), Hydrogen rich water hold significant potential for improving cultivar Ramanathapuram Gundu Malli (*Jasminum sambac* Ait.) and enhancing resilience to changed environment and abiotic stresses (Shankaraswamy et al., 2023). MWCNT surface charges may stimulate the production of water channel protein thus improving the plants water transport absorption. From the investigation two types nano inputs (MWCNT, GO) were directly uptake and translocated to roots, stems, and leaves at concentration of 10-50 mg/L that indicates that MWCNT, GO, enhance growth parameter and flower production under dwindling resources. Hydrogen rich water of 1000 ppb proved effective in freshness index of jasmine flowers while reducing the physiological loss of water. According to the several studies revealed that MWCNTs could be an alternative for control of pathogens due to activation of antioxidant defence system in plants by increasing the ascorbic acid, flavonoids content, and the glutathione peroxidase enzyme. Hence, application of MWCNT, GO, Hydrogen rich water (HRW) are promising strategy and found to be alternative to breeding approaches in plants to anticipate, prepare for, respond to, and recover from the impacts climate change, while maintaining their essential functions and adapting to new conditions. Therefore, exogenous application of MWCNT, GO, HRW are holistic and multidimensional approach that combines efforts to adapt to unavoidable changes and mitigate future warming to ensure food security in a changing climate.

1. Multiwall carbon nanotube

1.1. Physical properties of MWCNTs

Nanotechnology is quick progress has unlocked fresh possibilities for boosting horticulture's ability to bounce back from climate change. Of all the nanomaterials out there, multiwall carbon nanotubes, or MWCNTs, have really caught researchers' eyes. This is thanks to some awesome physical traits they have, like being super strong, conducting heat really well, and having great electrical properties. Because of these traits, MWCNTs are looking like a strong contender for use in growing plants that can handle climate change better. They can help plants get nutrients more effectively and also boost how well they deal with stress. We from college of horticulture, mojerla, Sri Konda Laxman Telangana Horticultural University are putting more and more weight on doing things sustainably these days, so we really need to use new materials that can soften the blow of environmental problems, especially when it comes to not having enough water and the soil getting worse. Our studies on effect of MWCNT on Ramanathapuram gundumalli (*Jasminum sambac* Ait) showing extra abilities in increased plant height, promotion of number of primary, secondary and tertiary branches, with more plant spread as well as superior flower growth attributes denoted that MWCNTs can work even better in horticulture crops (Shankaraswamy et al., 2023). So, really getting to grips with what MWCNTs can do and how we can fit them into farming systems is super important if we want to encourage horticulture that can keep going strong even as the climate changes.

MWCNTs, or multiwall carbon nanotubes, possess physical traits that really make them promising for use in horticulture designed to hold up against climate change. Think about it: They're super strong, and conduct electricity and heat remarkably well, which means they could make agricultural materials more stable and effective. Plus, their large surface area lets them

soak up a lot of stuff, which is great for cleaning up polluted water. A growing problem thanks to climate change (Reale et al., 2023) and get this: the way they're structured lets them mix easily with other materials. This leads to new composite materials that are stronger and handle heat better. This could be a big deal for making protective coatings or even improving soil, helping plants survive tough conditions and supporting sustainable farming. So, grasping these characteristics is key to using MWCNTs in forward-thinking horticulture farming approaches.

1.2 Mechanical and electrical properties that enhance plant growth and resilience

Multiwall carbon nanotubes, or MWCNTs, have mechanical and electrical properties that can really help plants grow and handle climate change better. These nanotubes are known for being strong yet flexible, which means they can make plant tissues stronger too. This extra strength helps plants deal with tough conditions like not enough water or really hot weather. Plus, MWCNTs can conduct electricity, and this can help roots absorb nutrients and water more effectively, leading to healthier and more productive plants overall. It's especially useful when we create nanocomposite materials that go into the soil or coat the plants, making it easier for essential resources to get where they need to go. By using these properties, scientists can come up with new ways to farm sustainably and tackle the problems caused by our changing climate (Dincer et al., 2024).

1.3 Use of MWCNTs in soil enhancement and nutrient delivery systems for climate-resilient crops

Climate change's persistent problems demand find new ways to do horticulture, especially when it comes to making soil healthier and getting nutrients to horticultural plants so crops can survive. Multiwall carbon nanotubes (MWCNTs) are proving to be a good answer, as they help improve soil and how well plants absorb nutrients. It's largely because of how MWCNTs are made that they can improve soil aeration, keep water in the soil, and hold onto nutrients—all really important for helping plants grow when the weather is not cooperating. Putting MWCNTs into soil improvement plans can also boost how easily plants can use the necessary nutrients, helping plants stay healthy and produce more. Studies lately have been pointing out how MWCNTs help turn on plant defences, which then makes them better at handling stress and still produce a good amount even when climate change is causing problems. This mix of nanotechnology and farming doesn't just back sustainable methods, but it fits right in with needing environmentally friendly new ideas in growing food, pushing us toward a more tough horticultural cropping system (Shankaraswamy and Thirupathi, 2022). By preliminary research with MWCNTs and Graphene oxides and Hydrogen rich water revealed strength of these nano-material to accelerate physiological and molecular level adaptation under shifting atmospheric conditions.

1.4 Significance in Horticultural Crops

Multiwall carbon nanotubes, or MWCNTs, have become quite important in nanotechnology, drawing attention for how they might be used in today's farming practices. What makes them special is their design, which features several layers of graphene sheets rolled into cylinders; because of this structure, MWCNTs have impressive mechanical, electrical, and thermal characteristics that can help plants withstand climate change. These nanotubes can assist plants to grow better even when the environment is tough by making it easier for nutrients and water

to reach them. This addresses important problems related to having enough food and maintaining farming for the long term. It seems that these nanotubes might also be good at soaking up contaminants from water used in agriculture, which is getting more and more important because of environmental damage and a lack of resources. Furthermore, there's evidence that MWCNTs might make soil better and help plants stay healthy, opening up a wide array of possibilities that could drastically change how farming is done to cope with climate change.

2. Graphene oxide (GO)

The integration of graphene oxide into horticultural practices offers a potentially significant step forward in bolstering plant production against climate change effects. With global climate shifts creating substantial obstacles for conventional horticulture, the need for creative solutions to maintain food availability and long-term viability is clear. Graphene oxide, with its notable physical attributes, such as considerable mechanical robustness, thermal resilience, and impressive electrical conductivity, appears well-suited for enhancing both plant health and development. It can improve absorption of nutrients and also act as a shield against environmental pressures to plants. Additionally, the well-considered use of organic fertilizers has been shown to help revitalize soil and lessen climate change's adverse effects on how much crops produce (Kakura I et al.). This intersection of materials science with horticultural practices might just transform how we approach farming that can withstand climate-related challenges. In the same line experiment was conducted in order to see the Effectiveness of GO on Jasmine phenology and climatic adoptability when introduced from Ramanathapuram to Horticulture Instructional farm, Madanapuram, college of horticulture, Mojerla, Sri Konda Laxman Telangana Horticultural University. From results it was evident that graphene oxide had a positive impact on shelf life of Yower. It could be as result of reestablishment of redox homeostasis in Yower (Thirupathi et al., 2022).

2.1 Overview of Graphene Oxide and its significance in modern science

Graphene oxide, or GO, has really grabbed the interest of scientists lately because it's so useful and has some pretty amazing properties. It's basically a single layer of carbon atoms arranged in a honeycomb pattern. Because of this structure, GO is super strong, conducts electricity well, and has a large surface area. This makes it an exciting material for lots of different uses. What's neat is that we can change its properties to fit specific needs, particularly when it comes to helping plants withstand climate change. GO can help soil hold onto water and deliver nutrients more effectively, potentially making crops more resilient to environmental challenges, which is important given our changing climate. Plus, GO's ability to have a significant impact in several fields, from health to sustainability, shows just how vital it is to pushing science forward (Engineering C et al.). Support for research, like funding from Shell Global Solutions UK, shows how important it is to invest in GO research for future innovations (Ajovalasit et al.).

2.2 Physical Properties of Graphene Oxide

Graphene oxide's characteristics really matter when we think about how it can be used, especially for helping plants handle climate change. Its surface is really big, about 2630 m²/g, which helps it connect with living things easily, so plants can grab nutrients better. Plus, the oxygen stuff in it helps it dissolve in water, making it simple to use on farms. Because it's both strong and light, it makes things like plant containers last longer. Also, it might help soil and plants conduct electricity better, which can help plants grow and stay strong when things get tough. Because of

this, it's super important to study how GO can store energy, which ties into making farming more sustainable.

2.3 Unique structural characteristics and their implications for material performance

Graphene oxide (GO) has some pretty neat features, like a large surface area, chemistry that can be tweaked, and impressive mechanical strength. Because of these qualities, GO is uniquely suited to tackle some of today's farming problems related to our changing climate. Its properties don't just make GO perform well in different uses; they also lead to fresh ideas in climate-smart agriculture. For instance, it can make nutrient delivery systems that work well and protect crops, boosting both crop resilience and how much we can grow, as noted in (Giannini et al.). In addition to that, GO affects soil and the tiny organisms that live there, greatly improving how sustainable our farming is. It helps soil hold onto nutrients, all while trying not to mess with the environment too much. These developments show how important new materials, like graphene oxide, are in encouraging sustainable farming methods. These methods can fight the bad effects of climate change and, ultimately, help horticulture industry to make enough food to cater the needs of growing populations.

2.4 Applications of Graphene Oxide in Horticulture

Graphene oxide (GO) shows considerable promise when integrated into horticulture. Consider its potential to improve climate resilience specifically in plant production. GO's physical properties— it has exceptional strength and a high surface area and allow it to effectively deliver nutrients. That delivery significantly increases how much of the essential elements plants can actually use. Climate change presents major obstacles to horticultural crops productivity, so the use of climate-smart horticultural strategies including innovative uses for graphene oxide is very important for reducing negative impacts on yield and soil health (Munaweera et al., 2023). Ultimately, graphene oxide's multifunctionality makes it an important part of the push for more sustainable horticultural technologies and practices.

2.5 Role of graphene oxide in enhancing plant growth and resilience to climate stressors

Generally speaking, incorporating graphene oxide (GO) into horticulture shows promise for improving plant growth and helping plants withstand climate-related stresses. GO has some interesting physical characteristics, like a large surface area and good conductivity, which can help plants take up nutrients and encourage root growth. This better nutrient absorption is really important for plants dealing with abiotic stressors such as drought and salinity, where it's often harder for them to get the nutrients they need. Research suggests that GO can boost plant metabolism, leading to increased photosynthetic efficiency and biomass production— both crucial for maintaining horticultural output in tough conditions. Plus, GO's ability to create a protective layer around plant roots can improve stress tolerance, lessening the harm from extreme environmental conditions. As climate change continues to threaten our food supply, using graphene oxide might be an innovative approach to strengthen plant resilience, potentially making it a key element in sustainable farming practices.

3. Hydrogen rich water (HRW)

The horticultural sector's need for resilience, especially given climate change, has spurred interest in hydrogen-rich water (HRW). This particular water, containing extra hydrogen

molecules, might help plants grow faster and handle drought conditions better. Cities are starting to use clean energy, as noted in initiatives like (Cleveland et al.), to combat climate and environmental issues. Therefore, it is crucial to look at sustainable methods in horticulture, too. We can see how HRW affects plant health in studies that show how it helps plants thrive in different environments, similar to how forests recover as described in (Abella et al., 2027). This all leads to a detailed look at what HRW is made of and how it could help horticultural crops to withstand climate change.

3.1 Overview of Hydrogen Rich Water (HRW) and its significance in Horticulture

In the realm of horticulture, Hydrogen Rich Water (HRW) has become quite important because it may help plants better handle climate change. HRW, which has a lot of dissolved hydrogen in it, is thought to give plants protection from oxidative stress. Because of this, plants grow healthier and produce more, which is really important as the environment changes more and more. It seems that using HRW can make crops hold onto water better and take in nutrients more effectively, which are very important for farming practices that are good for the environment and follow the United Nations Sustainable Development Goals (SDGs). Also, because people are paying more attention to farming that doesn't harm the environment, HRW is being looked at as a good way to deal with the money and environmental problems that modern horticulture faces. So, it's really important to understand how HRW can help plants grow in a way that can withstand climate change.

3.2 Physical Properties of Hydrogen Rich Water

Looking into what makes hydrogen-rich water (HRW) special shows us some interesting things about how it could help plants handle tough climate conditions. HRW seems to dissolve things better and has less surface tension than regular water. This might mean plants can soak up nutrients and water more easily. Because it's more permeable, plants could grow better and be tougher when things get stressful, like during a drought. On top of that, some studies hint that the antioxidants in HRW could fight off oxidative stress in plants, helping them grow in a healthier way. If we use these HRW qualities in farming, we might not only get more crops, but also manage our resources more sustainably. As cities try to grow food in a way that matches climate goals, really understanding how HRW and plants work together is key. This can help us find more sustainable ways to produce food, which fits in with plans like the ones talked about in (Cleveland et al., 2019).

3.3 Chemical composition and unique characteristics of HRW

Hydrogen-rich water, or HRW, mainly features dissolved hydrogen (H_2) gas, and this is what gives it its potential to help plants grow and become more resilient. Because it has a high concentration of molecular hydrogen, it can act as a useful antioxidant, reducing oxidative stress in plants, which is quite important for horticulture that can withstand climate change. HRW also appears to help plants absorb nutrients better by improving how their roots work, helping them hold onto water in the soil, which then leads to higher crop yields. It's also worth noting that HRW can affect different physiological processes in plants, like photosynthesis and metabolism, so it plays a significant role in horticultural practices that are sustainable and given the growing need for new solutions to deal with climate change, it's increasingly important to grasp the chemical composition and properties of HRW for creating robust strategies that boost plant production.

3.4 Applications of HRW in Climate Resilient Plant Production

The rising relevance of plant production that is climate-resilient has spurred the investigation of creative answers, one being Hydrogen Rich Water (HRW). It's worth mentioning that HRW displays physical characteristics unlike any other, properties that boost a plant's ability to deal with stress, as well as encourage growth, and improve overall crop quality when conditions are tough. It serves as a key tool in farming that is sustainable. Studies, for example, propose that when HRW is used, the germination rates of seeds can be increased significantly, and it can encourage root development, a factor that is critically important for plants dealing with drought and soils that don't have enough nutrients. This kind of resilience is especially pertinent, considering that horticultural practices have to adjust to climate change's looming impacts. Moreover, bringing HRW into crop management strategies can support broader environmental goals. This includes a decreased reliance on fertilizers that are chemical and improved water use efficiency, aligning it with circular resource management principles as mentioned in current literature on sustainable farming practices (Cleveland et al., 2019).

3.5 Impact of HRW on plant growth and stress resistance

The use of Hydrogen Rich Water (HRW) in horticulture to boost plant growth and resistance to stress has been getting some notice lately. HRW might actually make things like photosynthesis and nutrient absorption work better, which could mean bigger harvests when things get tough. It seems to help them deal with drought and not having enough nutrients, which makes them stronger overall. It's also been noted from our research that HRW can protect against oxidative stress and decreased the post-harvest deterioration and senescence during storage by modulating the antioxidant defence system in Jasmine Flowers (Shankaraswamy, 2023). HRW is becoming pretty important for building farming systems that can withstand climate change because it helps plants deal with tough environmental issues. By increasing intercellular H₂ Synthesis by lowering the incidence of rot, limiting the intensity of reproduction, lowering the amount of lipid peroxidation and enhancing superoxide dismutase activity (Shankaraswamy and Thirupathi, 2022).

Conclusion

Integrating multiwall carbon nanotubes, graphene oxide, and hydrogen-rich water shows a remarkable possibility for improving horticultural methods that withstand climate change. These high-tech materials not only boost the overall physical health of plants but also greatly strengthen their ability to resist climate-related stress. Putting MWCNTs and Graphene oxides and Hydrogen rich water to work in horticultural crops production can bounce back from climate change looks like a real step in horticulture. Combining insights from material science and horticulture might just lead to major advances in making crops more resilient in tough conditions. This kind of comprehensive research approach should be encouraged in production practices of horticultural system. Future studies should probably concentrate on refining how we make and use MWCNTs, graphene oxide, HRW to customize its characteristics for different horticultural crops situations.

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Lead Lecture – 10

AI Driven Smart Pheromone Trap for Real Time Pest Monitoring and Novel Microbial Volatiles as Attractants

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Traditional insect pest monitoring relies on the subject matter expert manually identifying pests, a process that is labour-intensive for area-wider applications. With the proliferation of sensors and embedded devices equipped with cameras and internet connectivity, computer vision technology offers a transformative solution for automated pest monitoring over a larger area in modern agriculture. This innovation significantly enhances monitoring efficiency by enabling real-time, automated systems, which empower farmers to make informed, timely decisions and implement swift interventions, ultimately managing the pests efficiently, reducing costs and labour, and minimizing adverse environmental impact. Artificial intelligence (AI) is increasingly being leveraged for critical tasks, including pest identification, counting, and predicting pest spread across key crop ecosystems, paving the way for smarter and more sustainable agricultural practices.

To manage sucking pests in various field and horticultural crops, farmers largely depend on conventional insecticides. However, the continuous and indiscriminate use of insecticides has resulted in the resistance of pests to insecticides. In addition to resistance development in sucking pests, environmental pollution in terms of the accumulation of pesticide residues in soils, adverse effects on natural enemies (predators and parasitoids), and the resurgence of minor pests have also been reported in India.

Real time monitoring of Lepidopteran insect pests

Sex pheromones have been identified from the females of nearly 530 Lepidopteran species and sex pheromone-related attractants have been identified from another 1,300 species, with research constantly adding to these numbers. For some of these identified pheromones, the synthetic versions are used in IPM strategies, such as mass trapping and mating disruption, for controlling pest populations. Sex pheromone traps are pivotal for monitoring the adult stage of insect pest populations, and these traps enable early detection and provide crucial insights for timely and targeted pest management interventions. The decision of insecticidal spray for the management is arrived at using the moth catches in the traps which signal the onset and intensity of pest attack.

Nevertheless, the conventional pheromone trap technologies have inherent limitations. The collection of trap data consists of repeated field surveys, where visual observation of traps is performed by a human operator to record the number of captured insects. The process is

laborious, time consuming, costly and prone to human error. The manual data only gives the trap catch *i.e.*, insect trapped between two consecutive surveys, usually between 7-15 days. Timely application of insecticide spray is difficult due to the poor temporal observations and the dynamics of pest population density in the field cannot be accurately monitored. Multi location trap data cannot be synchronized to measure the target pest population in a wider area.

Real time monitoring over a larger area is desired for a timely and cost-effective management strategy. AI tools are effectively being tried in insect pest identification; pest counting and pest-spread prediction in important crop ecosystems. Several machine learning algorithms and methods are being used for the classification and detection of pests and diseases through computer vision using feature extraction and image processing. Image processing is used for analysis and manipulation of graphical images from sources such as photographs and videos.

The ICAR – Central Institute for Cotton Research has developed an AI based Smart pheromone trap to circumvent the limitations of the conventional pheromone trap. The smart trap system consists of a single board computer; camera module; weather sensor, GSM transmitter powered by solar panel with a rechargeable battery. The trap catch of pink bollworm adult moths is recorded as an image and transmitted to a remote server via GSM communication network along with weather parameters recorded simultaneously at set interval. The remote server receives the information and stores it in a cloud storage device. The machine learning algorithm (YOLO), developed and integrated in the remote server identifies the PBW adult moth and counts the number of moths trapped in each of the time stamped image. The server then sends the information to the client (farmer/end user) as PBW insect count, trapped PBW insect image along with weather parameters. The information reaches the end user through mobile phone and desktop computer. An android based mobile application and a Windows based desktop application is developed to access the information on the trap catch in real-time. By investigating the real-time trap catch with corresponding weather data, the pest dynamics over a wider area could be comprehended in a better way and subsequently it helps to establish a reliable pest forewarning system and better pest management practices in cotton.

The AI Smart trap was deployed for the real-time monitoring of PBW in Punjab state with the financial assistance from the Department of Agriculture & Farmers Welfare, Government of India. The smart traps are installed at 18 locations in three major cotton growing districts of Punjab *viz.*, Mansa, Bathinda and Sri Muktsar Sahib at the identified farmers' fields at the rate of 6 units per district. At all the locations conventional pheromone traps were also installed @ 3 per village and the weekly trap catch data are being observed for comparison. A dedicated web portal <https://cicr.indianmark.com/> is developed for the real-time information of PBW trap catch and corresponding weather data.

Based on the data from the AI Smart trap, daily alerts and weekly advisories on PBW damage status and management strategies are being issued to all the stakeholders and cotton farmers in Punjab through voice messages of 30 seconds duration through the GSM network at weekly intervals. These services reached to a total of 28,190 cotton growers in state in addition to outreach through social media. With the area wide monitoring and issue of timely alerts, the infestation of PBW has been brought down significantly during the current season. The pest infestation ranged from 30-65% in Punjab during the last few years and due to the focused efforts

of ICAR-CICR, the PBW occurrence is being brought down to below 10% levels in the project implemented areas.

Artificial Intelligence (AI) and the Internet of Things (IoT) in cotton cultivation hold significant potential to address critical challenges faced by farmers today. These technologies reduce reliance on manual labour for pest monitoring and management, enable the judicious use of agro-inputs such as pesticides and enhance crop productivity while promoting environmental sustainability and maintaining soil health. However, the adoption of IoT and AI comes with certain challenges. AI systems require extensive spatial and temporal data to train models and generate accurate predictions. Developing location-specific machine learning algorithms demands substantial initial investment, focused research and development, and ongoing operational and maintenance costs. Additionally, limited internet connectivity and bandwidth in remote agricultural areas can hinder the implementation and scalability of these technologies. Despite these hurdles, technological advancements in AI and IoT are progressing rapidly. Numerous agricultural enterprises are integrating AI solutions into plant health management systems, providing innovative tools to support progressive farmers and facilitate precision farming practices. Successful AI based monitoring of PBW in cotton in Punjab has demonstrated the potential and scope for establishment of a county-wide grid network of AI traps for spatial monitoring and timely management of this key pest in cotton.

Microbial volatiles as novel attractants in sucking pest management

Similarly, the use of plant-based volatiles has been reported to manage sucking pests' infestation; however, they were not widely accepted by farmers due to their low field efficacy and high costs. Likewise, although yellow sticky traps (YST) have been popularly used as mechanical control options for sucking pests, the expected field attraction of sucking pests has not yet been achieved. Hence, enhancing the attraction of sucking pests to YSTs is expected to be useful for cotton farmers.

In recent years, microbial volatile organic compounds (mVOCs) have represented a new frontier in bioprospecting, where they produce complex volatile compounds, which are defined as compounds that have high enough vapour pressures under normal conditions to significantly vaporize and enter the atmosphere. Although several thousand volatiles emitted by plants have been identified so far, only several hundred compounds have been identified from microorganisms. Chemical ecologists consider mVOCs as potential semiochemicals that function as attractants and repellents to insects. Some mVOCs attract or repel insects, inhibit the growth of microorganisms competing with associated insects, stimulate oviposition, mimic plant hormones, or even induce plant resistance. mVOC emission is now recognized as an important aspect of plant-microorganism interactions. Recently, a few studies have shown the wealth of mVOCs for the modulation of crop growth, development, defense, and inter- and intraspecific communication. Insects exhibit strong aggregation behaviors to specific microbial communities, although few researchers have reported mVOCs directly as pheromonal communications as a signal for food sources, oviposition sites, or mating opportunities. Although substantial advancement has been made in our understanding of mVOCs and their multifunctional roles in crop growth promotion, including biocontrol of insects under laboratory conditions, we remain far from implementing that knowledge under field conditions. Till date, no microbial-based

volatile attractant has been utilized for sucking pests' attraction or its management under field scale. In the era of the promotion of non-chemical agriculture, the applicability of microbial-based volatile attractants in agriculture has great potential to reduce cultivation costs and improve the environment.

ICAR-CICR has been granted 5 patents (Whitefly- 541777; Aphids- 553413; Thrips- 554409; and Beneficial Insects- 546146) and Jassids. These attractants can be used along with sticky traps in horticultural crops for monitoring and management of sucking pests. Apart from controlling resistance development and the resurgence of sucking pests, the use of volatile attractant formulations is expected to reduce environmental pollution through the reduction of insecticidal sprays, reduction in cultivation cost, enhancement of farm income and crop productivity. Furthermore, there is great scope and potential for extending the use of the ICAR-CICR volatile attractants for managing pest infestation in other agricultural and horticultural crops, and thus has wider commercial application and business potential prospects in agriculture.



AI driven smart pheromone trap

Lead Lecture – 11

Black Soldier Fly – Role in Circular Economy and Bioconversion in Horticulture

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Abstract

The Black Soldier Fly (BSF), *Hermetia illucens*, is revolutionizing horticulture through efficient bioconversion of organic wastes, aligning with circular economy principles. This concept note centers on BSF's applications in horticultural systems, emphasizing waste valorization from crop byproducts to enhance soil health, reduce environmental impacts, and boost productivity. Incorporating current statistics, real-time nutrient dynamics, and examples like coffee grounds, oil palm byproducts, sugarcane molasses, and spent grains, it explores BSF's role in bioconversions, GHG mitigation, and livestock manure integration for horticultural benefits. With promising future scope, BSF positions horticulture as a leader in sustainable practices, addressing global challenges like waste management and climate resilience.

Introduction to Black Soldier Fly in Horticulture

In horticulture, where organic waste from pruning, harvesting, and processing accumulates rapidly which needs a rapid turnover to reuse it for the nutritional amendment and also as alternative mulch stock for which the black soldier fly offers a sustainable solution. BSF larvae convert diverse horticultural residues into valuable resources, reducing waste volumes by 50-80% and producing protein-rich biomass and nutrient-laden frass. This insect's life cycle optimized for controlled rearing, integrates seamlessly into greenhouse or farm settings, promoting circularity by recycling nutrients back into soil systems. By focusing on horticultural applications, BSF not only minimizes landfill contributions but also enhances crop yields through organic amendments, fostering resilient ecosystems amid climate variability.

Role in Different Bioconversions and Real-Time Nutrient Conversion in Horticulture

BSF bioconversion is tailored for horticultural wastes, where larvae digest substrates via enzymatic processes, achieving real-time nutrient efficiencies. With bioconversion rates (BCR) of 8-20% and feed conversion ratios (FCR) of 1.4-2.5, larvae outperform traditional methods, retaining 70-87% nitrogen and accumulating 32-53% protein and 18-33% lipids. Innovations like AI-optimized rearing boost yields by 25%, making it ideal for horticultural integration.

Some of the horticultural examples include oil palm byproducts (e.g., empty fruit bunches and fronds), which are pretreated for digestion, yielding biomolecules for soil enrichment. Sugarcane residues like bagasse and molasses support robust larval growth, with

BCRs matching premium feeds, recycling nutrients for cane fields. Spent grains from horti-processing (e.g., brewery-integrated orchards) are reduced by 60-70%, producing frass that improves soil structure. Coffee grounds, fermented for better palatability, enable BCRs of 10-15% at 25-100g/day feed rates, converting waste into fertilizers for coffee plantations. Vegetable crop residues (e.g., cabbage, carrot tops) are converted into biomass for feed or fertilizer, supporting mixed farming systems and increasing yields by 10-20%. These applications promote zero-waste farms, diversify income, and strengthen soil ecosystems. These processes up-cycle horticultural byproducts, closing nutrient loops and reduce dependency on synthetic inputs.

Current Statistics and Market Insights in Horticultural Contexts

The BSF market, valued at \$0.44-1.01 billion in 2025, is increasingly horticulture-driven, with over 75 global facilities processing agro-wastes like manure and crop residues. In regions with intensive horticulture (e.g., Asia's palm plantations, Europe's orchards), adoption surges due to waste regulations. Horticultural operations produce thousands of tons of BSF biomass annually, supporting scalable systems that cut processing costs and generate revenue from frass sales.

Impact and Implications on Circular Economy and Environmental Impact in Horticulture

BSF advances circular economy in horticulture by transforming wastes into biofertilizers and feeds, conserving resources and enhancing soil biodiversity. Frass from horticultural substrates sequesters carbon, improves water retention, and boosts yields by 10-20%. Environmentally, it reduces water use by 70-90% compared to conventional methods and prevents nutrient runoff, safeguarding horticultural watersheds.

Green House Gas (GHG) impacts are significant- BSF cuts methane and nitrous oxide emissions by 50-97% versus composting or landfilling, with net negative CO₂ equivalents in horticultural setups. Processing 1 kg of horticultural waste avoids 0.5-1 kg CO₂ eq, aligning with SDGs and enabling carbon-neutral orchards. Implications include reduced pesticide needs through healthier soils and biodiversity gains in horticultural landscapes.

Opportunities in Horticulture with Examples

BSF unlocks vast opportunities in horticulture, converting byproducts into sustainable assets. For coffee grounds, bioconversion yields nitrogen-rich frass (2-3%), recycling nutrients directly into plantations and reducing fertilizer costs. Oil palm byproducts are degraded to produce lipids for biofuels and frass for soil amendment, minimizing waste in vast plantations. Sugarcane molasses enhances larval fat (up to 35%), while bagasse provides structure, enabling biorefineries that return nutrients to fields. Spent grains from fruit-based brewing are valorized into protein meal, diverting 80% of waste and generating \$500-1,000/ton revenue. Additional examples include tomato residues and vineyard prunings, where BSF frass increases yields and soil organic matter, promoting zero-waste horticulture and economic diversification.

Impact on Livestock Manure Conversions for Horticultural Benefits and GHG Emissions

While horticulture-focused, BSF's manure conversion complements integrated systems, such as agro-livestock-horticulture farms. Larvae reduce manure by 40-70%, extracting 50-60% nutrients into biomass for animal feed, with frass applied to horticultural soils. This enhances soil fertility in orchards or vegetable plots, with protein digestibility >85% supporting on-farm feed cycles.

GHG benefits amplify horticultural sustainability: Manure treatment reduces CH₄ by 72-99% and N₂O by 99%, with ammonia cuts of 82-90%, preventing emissions that affect crop health. In horticultural contexts, this translates to lower atmospheric pollution, enabling climate-resilient cultivation.

Future Scope and Utility in Horticulture

Horticulture stands to gain from BSF's projected market growth to \$5.6-52.7 billion by 2035 (CAGRs 29-34%), with automation reducing costs by 50-75%. Future utilities include chitin-derived biopesticides for crop protection and AI-integrated systems for substrate optimization in greenhouses. Expanding to urban horticulture and vertical farms, BSF will drive zero-emission models, overcoming challenges like regulatory hurdles through collaborative research.

Conclusion

Centering on horticulture, BSF's bioconversion fosters circular economies, mitigates environmental impacts, and unlocks innovative opportunities. By integrating BSF, horticulturists can achieve sustainable waste management, reduced GHG emissions, and enhanced productivity. Investment in BSF technologies is essential for a thriving, resilient horticultural sector.

Lead Lecture – 12

Agromet Advisories for Climate Resilient Horticulture

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Horticulture plays a vital role in boosting the economy. In India, it produces around 357 million tons of output, contributing about 35% to the gross value added (GVA). It supports nutritional security, provides rural employment, diversifies farm activities and increases farmers' incomes. Fruits and vegetables alone make up nearly 92% of horticulture production and are key sources of vitamins, minerals, carbohydrates, fats, and proteins. According to FAO 2022, India leads in producing okra, mangoes, bananas and guava. Over 55% of floriculture products are cultivated in Karnataka, Kerala, Andhra Pradesh, Tamil Nadu, and Madhya Pradesh. The National Horticulture Mission (NHM) has raised productivity by about 40% from 2005-06 to 2022-23. Growing demand due to health awareness, rising income, exports, and population, along with climate variability, pose challenges for increasing production and ensuring sustainability.

Challenges associated with horticulture crops in India

- **Pests and Diseases** – Horticultural crops in India suffer significant losses due to pests, fungal infections, and bacterial diseases, such as blight affecting potato exports and bacterial blights damaging pomegranate orchards.
- **Fragmented Land and Limited Irrigation** – Small landholdings and low irrigation coverage increase production costs and reduce competitiveness due to the lack of economies of scale.
- **High Post-Harvest Losses** – About 30–35% of fruits and vegetables are lost during harvesting, storage, transport, and distribution, with only 2% processed into value-added products.
- **Inadequate Infrastructure** – The sector lacks sufficient facilities like processing units, cold storage, grading, packaging, refrigerated transport, and phytosanitary services.
- **Small-Scale Processing Units** – Most units have capacities of 50–250 tons annually, while multinational companies process 5–30 tons per hour, limiting India's horticulture exports compared to countries like China, Brazil, and Italy.
- **Marketing and Export Barriers** – Small farmers depend on local markets and intermediaries, while exports face tariffs and sanitary regulations that restrict access.
- **Climate change impact** - Floods, drought, erratic rainfall and heat spells poses a major threat to horticulture, often reducing yields by shortening growing periods, lowering water availability and affecting crop suitability.

Effect of climate variability/change on growth and development of horticultural crops

- Climate change involves rising temperatures, altered rainfall, and more extreme weather.
- Higher temperatures speed up crop maturity (e.g., citrus, grapes, melons mature ~15 days earlier) but reduce yields.
- Heat stress affects pollination, causing flower/fruit drop and abortions.
- Quality issues arise: poor tuber initiation in potato, tomato disorders (tip burn, blossom end rot), bolting in crucifers, reduced anthocyanin in apples and capsicum.
- Heat and moisture stress cause sunburn, cracking in apples, apricot, cherries, and fruit damage in litchi.
- Tomatoes face reduced fruit set, smaller size, and lower quality.
- Low temperatures (<10°C) cause inflorescence problems, bunch malformations, and chilling injuries.
- Shifts in rainfall and humidity increase fungal and bacterial diseases, and affect soil moisture and irrigation.
- Major fruits like mango, banana, citrus, guava, grape, pineapple, and apple are impacted by delayed monsoon, dry spells, untimely rains, and heat during flowering and growth.
- Flower crops suffer due to poor flowering and development; chrysanthemum needs short days, while jasmine stops flowering below 19°C.
- Hailstorms damage crops through shredded leaves, bruised fruits, broken stems, and uprooting, reducing yield and quality.

Yield loss due to climate change/variability in horticultural crops in India

- Climate change is causing yield losses of up to 65 per cent in some major horticultural crops due to irregular rainfall and increasing temperatures.
- In onion, 36.6 per cent yield loss occurs by continuous six days water logging
- High temperature stress of more than 40°C during flowering stage in tomato causes 65 per cent yield loss.
- Rise in winter temperatures of 1.5-2°C leads to shifting of apple cultivation from low to high altitudes and results in 30 per cent yield reduction.
- Extreme weather—heavy rains, hailstorms, heat fluctuations, and droughts—severely disrupt horticulture, especially perishable crops like tomato, onion, brinjal, okra, leafy vegetables, and fruits such as mango, banana, grape, apple and pomegranate, with losses ranging from 5% to 80%.
- In 2023, Maharashtra lost ~60% of crops (91,429 ha) to unseasonal rain and hail, Telangana's Nizamabad saw 20–80% losses in mango, guava, tomato, and onion, and Karnataka reported 11% losses (18,093 ha) in vegetables due to erratic rainfall.

The major horticulture-producing states such as Maharashtra, Himachal Pradesh, Karnataka, Andhra Pradesh, and Telangana frequently face challenges like reduced yields, deterioration in crop quality, and consequent declines in farmer incomes due to the growing

impact of climate variability and extreme weather events. Erratic rainfall, prolonged dry spells, unexpected frosts, and rising temperatures often disrupt production cycles and increase vulnerability to pests and diseases. These risks not only threaten farm-level profitability but also undermine the stability of local markets and rural livelihoods. To address these challenges, a multi-pronged strategy is essential. Timely and accurate agromet advisories can provide farmers with early warnings on rainfall, temperature fluctuations, and pest outbreaks, allowing them to make informed decisions on irrigation, sowing, and crop protection. The adoption of climate-resilient and stress-tolerant crop varieties can further safeguard yields under unpredictable conditions. These measures can help build resilience, sustain productivity, and secure farmer incomes in the face of an increasingly uncertain climate.

Agromet advisory services for horticulture farmers

The horticulture sector contributes to food security, nutrition, economic growth and livelihoods by ensuring a steady supply of fruits, vegetables, spices and other products. It supports employment and income generation, strengthening rural households. However, climate change, especially altered weather patterns, poses significant risks to this sector.

To assist farmers, the India Meteorological Department (IMD) operates the Agrometeorological Advisory Services (AAS) under the Gramin Krishi Mausam Sewa (GKMS) scheme. It provides medium-range weather forecasts at district and block levels for the next five days. Based on these forecasts, 130 Agromet Field Units (AMFUs) at State Agricultural Universities (SAUs), ICAR institutes, IITs, and District Agromet Units (DAMUs) at Krishi Vigyan Kendras (KVKs) prepare advisories twice a week for farmers to guide day-to-day agricultural, horticultural, and allied activities.

The service, developed in partnership with ICAR and SAUs, aims to deliver location- and crop-specific weather information. With improved high-resolution models, the service has expanded to the block level. It helps the farmers to adopt weather-based crop and livestock management strategies, improving production, food security and reducing losses from extreme weather events. Daily forecasts, nowcasts and impact-based forecasts (IBFs) are also shared by IMD's Regional Meteorological Centres (RMCs) and Meteorological Centres (MCs), using warnings from the National Weather Forecasting Centre (NWFC), New Delhi.

Advisories are disseminated through multiple channels, including print and electronic media, Doordarshan, radio, the internet, SMS via the Kisan Portal, and private partners under the Public-Private Partnership (PPP) model. This ensures farmers receive timely and actionable information to better manage risks and enhance productivity.

Farmers access district-specific weather forecasts, alerts, and agromet advisories through the 'Meghdoot' app by the Ministry of Earth Sciences and the 'Kisan Suvidha' app by the Ministry of Agriculture & Farmers Welfare.

For faster communication, WhatsApp is widely used. AMFUs and DAMUs create WhatsApp groups of farmers, including District and Block-level Agriculture Department officials, to quickly share weather updates and agromet advisories.

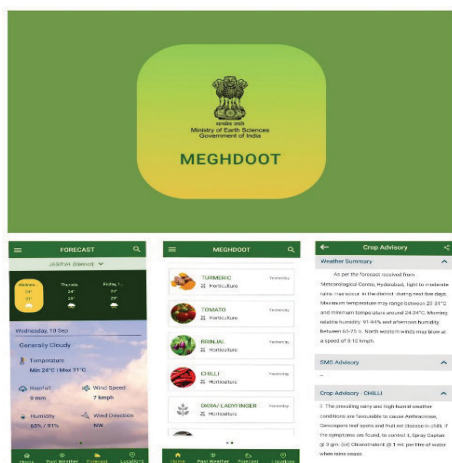


Figure : Meghdoot mobile app of IMD

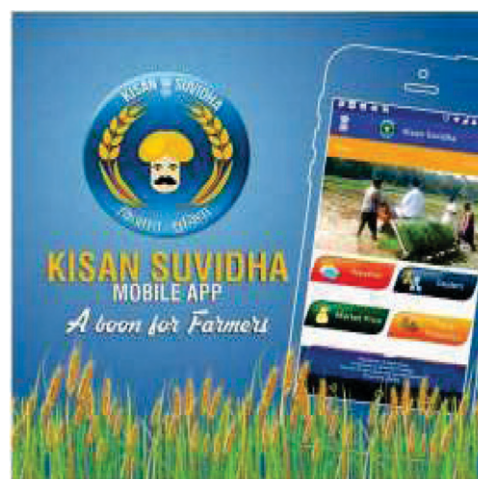


Figure : Kisan Suvidha mobile app

Case studies of successful climate-resilient horticulture in India

Across India, many successful case studies demonstrate how agromet advisories help to build climate-resilient horticulture.

In Tamil Nadu, banana growers used cyclone advisories to implement windbreaks, staking, and drainage management, reducing losses and maintaining marketable yields.

In Telangana, chilli farmers controlled *Thrips parvispinus* infestations by following advisory-based Integrated Pest Management (IPM) methods like neem oil sprays, sunflower intercropping, and border-trap cropping.

In drought-affected Maharashtra, pomegranate farmers earned ₹18–19 lakh per acre by adopting drip irrigation, mulching, and organic nutrient management as advised, with the ‘Bhagwa’ variety delivering high yields.

In Karnataka, farmers using polyhouses and shade-net structures, as recommended through localized advisories, stabilized vegetable and fruit production, shielded crops from heat, rain, and pests, and secured better profits.

These examples highlight how combining weather forecasts with adaptive farming practices helps farmers reduce risks, use resources efficiently, and achieve sustainable horticultural growth.

Integrating indigenous knowledge and capacity building for effective Agromet advisories

Indigenous knowledge, such as interpreting weather through bird movements, animal behaviour, or tree flowering, remains valuable for farmers. In Telangana, adjusting sowing dates based on seasonal cues, combined with scientific forecasts, enhances the reliability of agromet advisories. Capacity building through Agricultural Universities, KVKs, and farmer field schools provides training on climate-smart practices, protected cultivation, and water management, enabling farmers to better understand and apply advisories.

Cost savings from agromet advisories in Indian horticulture

Agromet advisories help the farmers to cut costs, optimize resources and boost profits. In Telangana, pest management advisories saved ₹5,000–7,000 per acre on pesticides for tomato and chilli. In Maharashtra, drip irrigation and mulching reduced water costs by ₹12,000 per acre, while pomegranate growers saved ₹15,000 per acre through water conservation. Mango and banana farmers cut fungicide costs by ₹10,000 per acre with timely disease-prevention advice. By guiding irrigation, pest control, and crop management, advisories also reduce losses from unseasonal rains, droughts, and heat waves, improving yields and incomes.

Policy support and future prospects of agromet advisories

Government policies and institutions play a key role in advisory dissemination. IMD, ICAR, State Universities, and KVKs provide localized guidance, while Telangana's robust extension network ensures it reaches farmers. Subsidies for micro-irrigation, protected cultivation, and digital tools promote climate-resilient practices. The future of advisories lies in personalization, using AI, remote sensing, and big data for more accurate, crop-specific, and real-time support.

Climate modelling and Next-Generation technologies in horticulture

Climate modelling, forecasts how rising temperatures, changing rainfall and extreme events affect horticultural crops, helping with risk assessment, crop planning and water management. GCMs and RCMs support region-specific strategies, while AI, remote sensing, drones and big data enhance precision horticulture through better pest detection, stress monitoring, irrigation planning, and market predictions. These advancements are transforming Indian horticulture into a climate-resilient and competitive industry.

Conclusion

Agromet advisories go beyond decision-making tools—they are key to climate-resilient farming. By combining AI, remote sensing, big data and climate modelling, they are becoming more accurate, accessible, and future-ready, supporting sustainable growth, higher productivity, and stronger resilience in horticulture.

Lead Lecture – 13

Accelerating a Climate-Resilient Horticultural Sector through Pioneering Innovations from Start Up Ecosystem

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1. Prelude

The Indian agricultural and allied sciences landscape is witnessing a major transformative wave driven by the technology driven startup ecosystem. Poised at the forefront of innovation, many of these startups are not only addressing longstanding structural challenges but are also laying the foundation for a more sustainable and prosperous future, by improving productivity, economic prosperity and ecological sustainability across the entire Agri- food value chain. Bringing a paradigm shift, dynamic Indian entrepreneurs are today leveraging cutting-edge technologies such as Artificial Intelligence (AI), Internet of Things (IoT), Machine learning, and Data analytics to address agricultural challenges.²

Currently, over 6,000 agriculture startups and 2,800 Agri-Tech startups were recognized by the Department for Promotion of Industry and Internal Trade (DPIIT), these startups are working across a myriad of domains including horticulture, postproduction, smart warehouse and storage technologies and building innovative solutions to long felt challenges³. Agri-tech start-ups empower farmers to make data-driven decisions, adopt modern practices in tandem with existing and traditional knowledge, and access real-time information through their innovative digital solutions. These solutions offer farmers higher profit margins, assistance in product grading and packaging, product traceability, market access, access to quality inputs, and science-based guidance. Technology-driven solutions also contribute to environmental conservation and climate change mitigation through ecologically sustainable practices such as organic and precision farming, agroforestry, crop rotation and water management solutions.

This paper will critically evaluate validated use cases of prominent startups and help fast track efforts of the national research and development system to build climate resilience into Horticulture sector as the part of its journey to become a Global Hub for Horticultural Goods. Further, it seeks to suggest a framework to synergize these discrete efforts and solve the concerns of all stakeholders including the researchers-farmer-consumer-business conundrum.

2. Indian Horticulture Sector

Indian horticulture sector contributes about 33% to the agriculture Gross Value Added (GVA) making very significant contribution to the Indian economy. India is the second-largest producer

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² <https://noida.stpi.in/en/blog/startups-agriculture-sector-are-pioneering-innovations>

³ <https://www.startupindia.gov.in/nsa2023results/innovators-for-agriculture-and-animal-husbandry.html>

of horticulture crops globally, accounting for approximately 12% of the world's production of fruits and vegetables. Apart from ensuring nutritional security of the nation, it provides alternate rural employment opportunities, diversification in farm activities, and enhanced income to farmers. India is currently producing about 320.48 million tons of horticulture produce which has surpassed the food grain production, that too from much less area (25.66 million Ha. for horticulture against 127.6 M. ha. for food grains). Productivity of horticulture crops is much higher compared to productivity of food grains (12.49 tones/ha against 2.23 tones/ha.)⁴. India has emerged as world leader in the production of a variety of fruits like mango, banana, guava, papaya, sapota, pomegranate, lime and aonla and is the second largest producer of fruits and vegetables. Besides, India has maintained its dominance in the production of spices, coconut and cashew. Among the new crops, kiwi, gherkins, kinnow, date palm and oil palm have been successfully introduced for commercial cultivation in the country.

3. Boosting Production through Government-led Interventions

The high remunerative capability of this sector has propelled it as one of the potential agriculture enterprises that can accelerate the growth of the Indian economy. The launch of National Horticulture Mission has spurred the production and productivity of horticultural crops. Horticulture production has increased from 280.70 million tonnes in 2013-14 to 367.72 million tonnes in 2024-25 (as per second advanced estimates). This includes fruit production of 114.51 million tonnes, vegetable production of 219.67 million tonnes, and 33.54 million tonnes from other horticulture crops. The productivity of horticulture crops has risen from 12.10 metric tonnes per hectare in 2019–20 to 12.56 metric tonnes per hectare in 2024–25, as per the second advance estimates⁵.

With a view to enhance the global competitiveness of the Indian horticulture sector, the Ministry of Agriculture and Farmers Welfare (MoA & FW), Government of India, has recently announced several programmes. Some of these include:

- i. Cluster Development Programme (CDP) for the horticulture sector. It is a Central Sector programme implemented by the National Horticulture Board (NHB).
- ii. As of July 2025, under MIDH, a total of 58 Centres of Excellence have been approved across various States in the country with 55 clusters identified by MoA & FW under Horticulture Cluster Development Programme (HCDP)⁶.
- iii. Setting up 9 centres for Clean the Clean Plant Programme is set to significantly boost India's horticultural sector while aligning with Mission Life and the One Health initiatives. It will promote sustainable and eco-friendly agricultural practices and reduces dependence on imported planting materials. This programme will be a crucial step toward establishing India as a leading global exporter of fruits and driving transformative change

⁴ <https://agriwelfare.gov.in/en/Horticulture>

⁵ <https://www.pib.gov.in/PressNoteDetails.aspx?id=155126&NoteId=155126&ModuleId=3>

⁶ Refer for details: Ministry of Agriculture & Farmers Welfare, Government of India. 2024. Horticulture Cluster Development Programme Strengthening the Horticulture Sector. At: <https://www.nhb.gov.in/pdf/CDPBrochure.pdf>

across the sector. This programme is implemented by the National Horticulture Board in association with Indian Council of Agricultural Research (ICAR)⁷.

- iv. A total of 55,748 post-harvest management facilities and 11,140 marketing infrastructures have been established under the MIDH scheme during past five years⁸.

3. Horticulture Startup Ecosystem in India.

In tandem with the launch of Start Up India programme in 2016, there has been an emergence of several startups in India are leveraging technology for precision farming, supply chain optimization, and sustainable practices in horticultural sector. Notable examples include ‘Fasal’ for AI-powered precision horticulture, ‘Ecozen Solutions’ for climate-smart cold chains, ‘Ninjacart’ and ‘WayCool’ for efficient farm-to-retail logistics, and ‘Farmtheory’ for innovative Agri-waste management solutions. Other key players focus on areas like precision farming using satellite data (Rootskart) and diverse farm diversification through technology (Aqgromalin). An illustrative brief about some of the innovative technologies of these startups is placed in Table 1. It may be noted that list is illustrative only and enumerates the major startups performing in this sector in India during last five years.

Table 1. Tabulation of Prominent Startups in Horticulture Sector.

Domain	Name of Start-up	Innovative Technology Offered
1.Precision Horticulture	Fasal	Uses on-farm sensors and AI to collect real-time data on growing conditions, providing farm-specific, crop-specific alerts for optimized irrigation, fertilization, and pest control to save costs and resources.
2.Climate-Smart Cold Chains	Ecozen Solutions	Develops deep-tech solutions for renewable energy and sustainable agriculture, including climate-smart cold chain solutions for perishables that improve supply chain efficiency and reduce food spoilage.
3.Supply Chain Optimization	Ninjacart & WayCool	B2B platforms that manage the entire agricultural supply chain from farm inputs to last-mile distribution, connecting farmers with various distribution channels and retailers, including other businesses
	Crofarm	Focuses on reducing agricultural waste by optimizing farm-to-business supply chains, partnering with major retailers to get fresh, high-quality produce to consumers.
4. Agritech Platforms & Services:	DeHaat	Offers end-to-end agricultural services, including access to inputs like seeds and fertilizers, personalized advisory, soil testing, and micro-finance
	AgroStar	An online marketplace providing farmers with essential agricultural inputs like seeds, crop protection, and nutrition.
	Rootskart	Utilizes satellite data to provide farmers with crop insights, yield information, and health index data through a subscription-based platform.

Table 1. Contd...

⁷ .:At: <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2043920>

⁸ <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2149705>

Domain	Name of Start-up	Innovative Technology Offered
5.Sustainable and Diverse Farming	Farmtheory	An Agri-waste management startup focused on reducing waste at the source, increasing farmer income, and mitigating climate change impacts.
	Aqgromalin	A farm diversification company that helps small landholding farmers supplement their income through integrated solutions in aquaculture, animal husbandry, and insect farming
	VMD Agro	Designs and operates Aquaponics food production systems to produce organic, chemical-free vegetables and herbs

*The tabulation is based on literature search through websites of startups and on personal interaction/experience of the authors during the last ten years as Incubator /Innovation Managers and mentors for Agri-food Startups.

It is interesting to note that horticulture sector is also attracting these young innovators with challenging problem statements and providing opportunities to ideate and innovate new approaches with emerging technologies. It is important that the incubation ecosystem nurtures these initiatives and catalyses the technology development and deployment at real-field sites for wider acceptance by the farmers and brings profitable business development into the ecosystem. Hence, the use of emerging technologies into horticultural systems presents another opportunity to elevate this sunrise sector from rural-survival level to rural livelihood-generating business enterprises, with transformational data-driven technologies and help reach SDG goals towards higher food and nutritional security, climate resilience and enhanced livelihoods for all.

The Indian National Research System including the horticultural-based research institutes, universities are endowed with dedicated repositories of large sets of historical data. which need to be part of developing emerging Agritech startup ecosystem. It is important to treat this as an “opportunity” and develop data policy and protocols of data sharing with Agri-tech start-ups and businesses. The launch of The Digital Agriculture Mission by Government of India (GOI) in September 2021 in partnership with leading industry and public sector players like Cisco, Ninjacart, Jio Platforms Limited, ITC Limited, and National Commodity and Derivatives Exchange (NCDEX) e-markets Limited (NeML) signifies new models to advance digital agriculture. More recently, the announcement of National Agri Stack and Sensor-based Smart Agriculture (SENSAGRI) launched during February 2023 enlarge the tool sets for accelerating data-driven agriculture initiatives⁹.

It is necessary to mainstream the data-driven technologies in the sector. This flow of technologies across various foci of Horti-value chains can be through combined efforts of all stakeholders - academic institutions, Agri-corporates, government departments, Farmer Producer Collectives and agritech start-ups Avoiding ‘valley of death’ scenario for data-driven technologies in agri-food sector is crucial so that the gap between early proof of concept and market feasibility, and break-even are fast-bridged¹⁰.

⁹ <https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=2051719>

¹⁰ V. Praveen Rao R. Kalpana Sastry, Vijay Nadiminti, Sayyeda Salima Asra. 2024. Transforming Agri-Food Systems Through Data-Driven Technologies: Lessons from India’s NAREES. T20 Policy Brief. T20

In the following section, two use case studies validated in real-farm situations are presented. Box 1 illustrates the use case 1 addresses problem statement of providing predictive advisories for disease detection through use of imagery technologies through indicator plants in the vicinity of crops grown in the main fields.

Box 1.

Use Case 1. BM eco-sustain:

Founded by Tushar Batham in 2024, Agri savant's mission is to democratize scientific farming. Agri savant is currently focusing on developing an early indication system for crop biotic stress. Tushar and his team bring blend of rich tech and agronomy experience and are actively working with a group of progressive farmers supplying for corporates like Kagome, Namdhari, Zetta farms, Kisan Mitr, SV Agro, etc and notable FPOs like Sahyadri farms in Maharashtra, Karnataka, Tamil Nadu, Madhya Pradesh, Telangana, Andhra Pradesh.

Problem statement:

Meeting supply demands of quality horticulture produce while meeting MRL requirements is getting increasingly challenging. One of the major contributors to this challenge is biotic stress management of horticulture crops. Unprecedented attacks and evolutions of pathogens & pest triggered by extreme climate events leads to indiscriminate application of synthetic inputs in fields. Repeated application of these inputs not only makes pests and pathogens develop resistance towards chemicals but also alters the ecosystem by affecting beneficial insects and deteriorates soil fertility.

Use case:

Agrisavant's extensive survey among farmer community reveal a common need, an early indication or alert for pest & disease attack to help farmers plan the controls actions appropriately in timely manner. The current markets solutions are mainly focussed on irrigation management and reactive Agri advisories, which fails to address this need reliably and comes with high capital expense.

Agri savant picked up this challenge and came up with a novel application of a traditionally used solution for pest indication on field, trap crops. Inspired by trap crop Agri savant built further over the idea and came up with Indicator crops extending trap crops capabilities to not only pests but also pathogens causing diseases. Further they use modern technologies like Ai/ML and spectral analyses to strengthen the reliability of crop biotic stress alerts provided by Indicator crop. Indicator crop is a plant which is more susceptible to pest and pathogen attacks than the cultivating crop stands across the various areas in the farm to provide farmers early indication of pest and pathogen attack. These indications analysed by ai/ML algorithms along with spectral images and field micro climatic conditions estimates ETL windows for control action and provides a concise advisory to farmer on their WhatsApp number. Advisory includes stress details, severity levels, control measure with clear briefing on when to apply, what to apply and how to apply. Early indication of biotic stress not only provide appropriate window for planning but also a fighting chance for controlling the stress with organic inputs itself.

The second use case defines use of drone based hyperspectral imagery technology for decision making for optimal use of crop inputs and for predictive prices for produce (Box 2).

Box 2.

Use Case 2. BharatRohan Airborne:

Two emerging aeronautical engineers, Amandeep Panwar and Rishabh Choudhary, stumbled upon farmers' plight while testing drones in farms of Barabanki, Uttar Pradesh. The idea of creating an end-to-end decision support system for farmers practising conventional farming sprouted in their curious minds. With research and expert guidance, they spotted a solution in drone-based hyperspectral imagery technology.

Problem statement:

BharatRohan conducts aerial surveys of agriculture farms every 10-15 days using UAV based Hyperspectral Remote Sensing. This enables to diagnose the problems of the farmer field with a non-destructive method and facilitates creation of prescription maps. This language of the farmers to enable the judicial/precise use of Agri inputs. The recommendations are duly validated by the agronomists/pathologist/entomologists whom BharatRohan has access to.

Use case:

BharatRohan has built spectral libraries in association with various agriculture research Institutes like CSIR-CIMAP handle the microscopic inoculation of pathogens in controlled conditions. The phonological/biochemical changes are then used to generate a comprehensive spectral library which is then correlated with and applied on Drone/UAV based Hyperspectral Data acquired from farmer's field using various proprietary unmixing models. These comprehensive proprietary libraries enable to predict the type of biotic/abiotic stress in the respective crop and suggest measure in the early stages to minimize losses of farmers. The team is highly dedicated to engaging with the crop specific ICAR institutes to build spectral libraries for the Perennial crops like Tea, Coffee, Pomegranate and Grapes. Also, for annual crops like Sugarcane and Rabi Crops like wheat, potato, tomato, mustard.

The use cases indicate the need to identify the potential and recognise the entry of startups into horticultural sector. Equally important is to catalyse the acceptance of technologies by the stakeholders in the sector. The myth that smallholder farmers and rural population are not technology savvy needs to be demystified. If technologies can mitigate the challenges faced and capacities to use technologies are in place, acceptance is faster.

4. Concluding Remarks

Based on the discussions and trends analysed as above, the innovative pathways triggered through the technologies developed by startups offer new opportunities and modes to brings in profitability, prosperity and people-led horticultural sector soon. It is essential that this is recognized, and policy-based interventions be put in place. The National Research System is in position to build an enabling ecosystem through the following policy interventions:

- i. Institutionalized collaboration to facilitate research, application of innovations across horticultural value chains, and to strengthen oversight cum regulatory concerns.

- ii. Build institutional Agri-innovation exchange in Universities/ICAR institutes to aid in capacity enhancement, encourage rural youth, build and share pool of use cases and best practices.
- iii. Build a sandbox facility for pilot testing of the technologies at real farm to stimulate SDG-aligned agribusiness investments, for sustainable and resilient SMEs/start ups

Build and nurture student-led innovation ecosystem in horticultural universities to inculcate university-led spin off and startups.

Lead Lecture – 14

Horticulture in Telangana: Combating Climate Induced Challenges

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Horticulture in Telangana

Telangana is the eleventh largest state, twelfth most populated state and ninth largest economy in India. Telangana is endowed with a subtropical climate and soils suitable for cultivation of a variety of sub-tropical and tropical horticultural crops. Horticulture sector has been identified as one of the focus sector for development of Telangana State. In 2023-24, the area under Horticulture crops in the state was 11.91 lakh acres producing 42.58 lakh MTs. Mango, sweet orange, acid Lime, guava, pomegranate, tomato, brinjal, oil Palm, chillies, and turmeric are the major horticulture crops cultivated in the state. Horticulture crops occupy 6% of the total agricultural land area in the state contributing 25 per cent to the state's Agricultural Gross Value Output (GVO) and is identified as key driver of growth in the Agriculture and Allied sectors in Telangana. In the financial year 2022-23, total agriculture GVO was ₹90,808 crore, with horticulture alone contributed ₹30,395 crore (Dept. of Horticulture, Govt. of Telangana).

Telangana ranks 12th in area and 16th in production of total horticultural crops at national level. Major horticultural crops grown in the state are mango, sweet orange, acid lime, guava, tomato, brinjal, chillies, oil palm and turmeric.

Among the fruit crops mango, sweet orange, acid lime, guava and pomegranate are the major crops occupying 73.73, 13.95, 3.37, 3.43 and 0.52 per cent of the area under fruit crops respectively. Among the vegetables tomato, potato, onion, okra and green chilli occupy 26.55, 4.79, 9.39, 4.88 and 8.50 per cent of vegetable area during 2023-24. Area under red chilli, turmeric and ginger account for 90.59, 8.08 and 0.45 per cent under spices during 2023-24. The fluctuations under spices is majorly contributed by the fluctuations in area of red chilli.

Climate change in Telangana

Telangana is a semi-arid zone and has a predominantly hot and dry climate. The areas covered by the Deccan Plateau are characterized by hot summers with relatively mild winters. Telangana has historically been prone to drought conditions especially in Rangareddy, Mahabubnagar and Nalgonda districts. Climate is projected to increase drought occurrence in the districts like Nalgonda and Mahabubnagar which would impact not only water resources but also have a cascading effect on other dependent sectors. Increased drought conditions can also severely affect agricultural and pastoral livelihoods and increase vulnerability and risks for farmers, and people depending on such livelihoods. The State is also prone to hailstorms in the month of April and May, occasionally rainfall. Major climate change issues for the State arise in the agriculture and forestry sectors and in relation to the droughts and heat waves. Agriculture

is severely affected by variability in rainfall and temperature patterns. In the recent years the state is witnessing extreme weather events like Increased frequency and intensity of droughts, floods, and heat waves disrupt crop yields . The state also witnessed very high intensity of rainfall in a day in the recent past causing significant challenges for water management and crop cultivation. Higher temperatures lead to reduced crop yields, increased pest and disease outbreaks, and water stress.

In the coming decades, climate change is expected to further exacerbate the risks of disasters. More frequent and intense storms and floods and long-lasting droughts can erode existing community coping capacities to prepare for, respond to and recover from successive hazard events. The hazard events often have a direct impact on people's agricultural production (crop farming, livestock keeping) and livelihood security. Other adverse impacts of climate change, such as reduced economic development and public health, degraded ecosystems, migration and conflict will increase the vulnerability of communities, especially in areas that are disaster-prone.

Climate change effect on horticultural crops

Fruit crops

The extreme weather events of hot and cold wave conditions and unseasonal rains have been reported to cause considerable damage to many fruit crops in Telangana. In perennial crops like mango and guava, temperature is reported to have influence on flowering, fruit set and ultimately yield. In mango, vegetative growth is favoured under increased temperatures and thus influenced the flowering phenology (Bhagwan *et al.*, 2013). The percentage of hermaphrodite flowers was greater in late emerging panicles, which coincided with higher temperatures (Balogoun *et al.* 2016). During peak bloom period, high temperature (35°C) accompanied by low relative humidity (49%) and long sunshine hours resulted in excessive transpiration and dehydration injury to panicles under Telangana conditions. Major observed effects of climate change on mango include early or delayed flowering, multiple reproductive flushes, variations in fruit maturity, abnormal fruit set and transformation of reproductive buds into vegetative ones (Rajan *et al* 2011). For monitoring of climate change, *Biologische Bundesanstalt Bundessortenamt und Chemische Industrie* (BBCH) scale for phonological studies in mango has been modified (Hernandez *et al* 2011, Rajan *et al* 2011).

In guava, there is severe increase in pests and diseases due to hot and humid conditions. Fruit fly in guava is becoming alarming due to hot and humid conditions. Untimely winter rains promote vegetative flushes in citrus instead of flowering flushes. Dry spell during flower emergence and fruit set affects flower initiation and aggravates incidence of pest (*Psylla*). In citrus severe water stress causes reduction in leaf initiation, leaf size gets reduced and leaves become leathery and thick. Root growth is adversely affected by water stress. It may lead to increased rooting depth and higher proportion of feeder roots in citrus. Water stress during flowering in banana causes poor filling of fingers and unmarketable bunches. Water stress reduces the bunch weight and other growth parameters. Micro irrigation techniques have proved boon for achieving high water use efficiency in various horticultural crops (Malhotra 2010).

Vegetable crops

Telangana climate is dominated by the monsoon, responsible for most of the region's precipitation, poses excess and limited water stress conditions. Vegetables being succulent are

generally sensitive to environmental extremes and high temperature, limited and excess moisture stresses are the major causes of low yields. In tomato, water stress accompanied by temperature above 28°C induced about 30-45% flower drop in different cultivars (Srinivasa Rao 1995). In tomato high temperatures can cause significant losses in productivity due to reduced fruit set, smaller size and low-quality fruits. Pre-anthesis temperature stress is associated with developmental changes in the anthers, particularly irregularities in the epidermis, lack of opening of stromium and poor pollen formation (Sato and Thomas 2002). Optimum daily mean temperature for fruit set in tomato has been reported to be 21-24°C. The pre-anthesis stage is more sensitive in tomato.

In cucumber sex expression is affected by temperature. Low temperatures favours female flower production, which is desirable and high temperatures lead to production of more male flowers. Cauliflower performs well in the temperature range of 15-25°C with high humidity. Though some varieties have adapted to temperatures over 30°C, most varieties are sensitive to higher temperatures and delayed curd initiation is observed (Singh 2010).

Combating climate induced challenges

Potential impacts of climate change depend not only on climate *per se*, but also on the system's ability to adapt to change. The potential depends on how well the crops adapt to the concomitant environmental stresses due to climate change. Crop based adaptation strategies have to be developed based on agro-ecological region, its susceptibility to climate change and combining all the available options to sustain the productivity. The scientists have already developed several technologies to cope with extreme events like high temperature, frost and limited and excess moisture stress conditions (Naresh Kumar *et al.* 2010). Integration of these technologies is the need of the hour to mitigate the impacts of climate change effect.

Importance should be given to the recommended production systems for improving water use efficiency which and to adapt to the hot and dry conditions. Strategies like changing sowing or planting dates in order to combat the likely increase in temperature and water stress periods during the crop-growing season should be adopted. Horticultural crops as amenable for integrated fertilizer application with beneficial microbiome to enhance nutrient availability and use of such soil amendments to improve soil fertility and enhance nutrient uptake (Malhotra and Srivastava 2015).

Horticultural crops have well demarcated critical stages for growth, flowering and fruit development and restricting irrigation or provided irrigation during these critical stages helps in conservation of soil moisture reserves thereby combating the extreme climate effects of drought. Management practices like mulching with crop residues and plastic mulches help in conserving soil moisture. In some instances, excessive soil moisture due to heavy rain becomes major problem and it could be overcome by growing crops on raised beds. Horticultural crops grown on raised beds offer an excellent method for both combating excessive heavy rainfall and drought. Production of vegetables could be taken up using clear plastic rain shelters, which can reduce the direct impact on developing fruits and also reduce the field water logging during rainy season. Planting of vegetables on raised beds during rainy season will increase the yield due to improved drainage and reduced anoxic stress to the root system.

Grafting of vegetables on tolerant rootstocks would provide the scion cultivars with tolerance to soil related environmental stresses such as drought, salinity, low soil temperature

and flooding. Efforts initiated by AVRDC in improving flood tolerance in tomato using eggplant rootstocks for grafting could be extended to impart water stress and temperature stress tolerance (AVRDC 1990).

MANGO

Sustainable climate resilient technology-Enhancing soil microbiome

Application of ½ RDF and 50kg FYM along with 250g *Azotobacter* in mango cv Banganapalli has reduced the recommended dose of fertilizer to half in recorded highest fruit no/tree (210), fruit weight (408 g) and yield (85.7 kg/tree) and also highest cumulative yield (767 kg/tree) from 2006-18 with a cost benefit ratio of 3.57 When compared to RDF (623 kgs/tree) an 23 per cent increase in yield under Telangana conditions at Fruit Research Station, Sangareddy.

Climate resilient technology for early flowering

Soil application of paclobutrazol 3 ml per meter of canopy diameter at during September) in mango cv Dashehari in Warangal district has increased production and advanced the crop by 15 days (Bhagwan *et al.*, 2013). Application of paclobutrazol @ 3 ml per canopy diameter during September, 2011 in mango cv Totapuri, Neelum advanced the harvesting dates by 59 and 40 days respectively. Application of paclobutrazol to multiple cropping variety Royal Special during the month of August, 2010 has advanced the fruit harvest by 45 days. Application of paclobutrazol @ 3 ml per canopy diameter during September, 2011 in mango cv Totapuri, Neelum advanced the harvesting dates by 59 and 40 days respectively. Application of paclobutrazol to multiple cropping variety Royal. (NAIP, 2014)

Spraying of combination of KH_2PO_4 (1%) and KNO_3 (1%) has initiated early flower bud differentiation and increased yield up to 39 % in mango cv Banganapalli under Telangana conditions at Fruit Research Station, Sangareddy.

Daily fertigation in mango for nutrient use efficiency

Application of daily fertigation with 100 % RDF of Nitrogen and Potassium along with micronutrient spray has recorded maximum yield and other quality parameters when compared with one time fertigation. (Ravikanth *et al.*, 2022). Daily fertigation has improved nutrient use efficiency which has the potential to reduce the nutrient resources in climate change scenario.

Precision farming in guava, grape and banana

Cultivation of guava cv Allahabad Safed in raised bed with drip irrigation of (80 per cent ER0 and 75 % fertigation along with mulching with 100 microns has recorded maximum number of fruits (251) and fruit yield (43.80kg/tree) under Telangana conditions at Fruit Research station, Sangareddy. Regulated deficit irrigation (RDI) to grape vines (cv. Thompson Seedless grafted on Dogridge) saved considerable amount of water (46 %) without affecting yield and quality under Telangana conditions at Grape Research Station.

Standardization of mulching and fertigation on growth, yield and quality parameters of Banana cv. Grand naine at Horticulture Research station, Aswaraopet revealed that organic mulch along with 100 percent RDF treatment 100 % N and K -300 gm N and 300 gm K_2O per plant) has recorded maximum yield (52.89 t/ha) by increasing the number of fruits per bunch

(118.45), bunch weight (21.42 kg) and also increased the fruit shelf life (11.56 days) compared to control and other combinations.

VEGETABLES

Mulching and Fertigation

In French bean, application of fertilizers in combination with 75 % NPK through inorganic source (38-45-38 N:P:K Kg/ha) + 25% N through Vermicompost (850 kg/ha) was found effective for getting higher marketable pod yield(142.15 q/ha), highest net return (Rs 4,47,000/ha) and maximum cost benefit ratio of 1: 3.68. Plastic mulch in potato has recorded highest yield of 23.7 t/ha compared to control of 17.99 t/ha. In chilies 100 % recommended dose of fertilizers through drip (120 kg N – 24 kg P₂O₅- 48 kg K₂O + 10 tons of farmyard manure /acre) + Water soluble fertilizers (19-19-19, 13-0-45 and 12-61-0) were applied in weekly intervals up to 100 days has given the maximum dry fruit yield of 20 quintal per acre in the Red Chilli variety LCA-625.

FLOWERS

Phenophase based fertigation scheduling

Studies in chrysanthemum at full bloom stage at Floriculture Research Station, Rajendranagar revealed that maximum number of flowers per plant was recorded in F₄ - 40:20:20% NPK at vegetative phase + 30:40:40% NPK at bud phase + 30:40:40% at flowering phase with 75% RDF (97.00) compared to other treatments with a yield of 9.75 t/ha. Studies in the tuberose indicated that F₂ (45:30:30 %) NPK at vegetative phase + 45:60:60% NPK at flowering phase + 10:10:10% NPK at dormancy) recorded maximum flower yield per plant (170.30 g) and hectare (9.44 t) compared to F₄ (Soil application of RDF 300:150:250 NPK/ha) (6.55 t).

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Proc. No. 202/Estt./SKLTGHU/2025,

Dt: 26-08-2025

Sub: SKLTGHU – Organization of National Conference on Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies from 18th to 19th September, 2025 at SKLTGHU Campus, Mulugu – Constitution of Committees – Orders – Issued.

Ref: Note orders of Hon'ble Vice Chancellor, SKLTGHU, dt: 26-08-2025.

In compliance to the orders vide reference cited, the following committees are constituted to organize National Conference on Climate Change and Horticulture: Impacts, Adaptation and Mitigation Strategies (CLIMAHort-2025) on 18th and 19th September 2025.

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