ICAR Sponsored Winter School

on

"Impact of Climate Change on Agriculture and Allied Sector: Adaptation, Mitigation Towards Sustainability and Livelihood Security"

February 14 – March 6, 2025

Training Manual

Organized by

Uttar Banga Krishi Viswavidyalaya

Pundibari, Cooch Behar, 736165, West Bengal

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Training Manual

Course Director

Dr. Prodyut Kumar Paul
Professor and Head
Department of Pomology and Post-Harvest Technology

Course Coordinators

Dr. Nonigopal Shit
Assistant Professor (Animal Science)
Regional Research Station - Terai Zone

Dr. Puspendu Dutta
Assistant Professor
Department of Seed Science and Technology

Organized by

Uttar Banga Krishi Viswavidyalaya
Pundibari, Cooch Behar 736 165, West Bengal, India

Compiled and Edited by

Prof. Prodyut Kumar Paul
Dr. Nonigopal Shit
Dr. Puspendu Dutta
Hosenur Rahaman

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Prof. Prodyut Kumar Paul
Course Director
ICAR Sponsored Winter School-2025
Uttar Banga Krishi Viswavidyalaya
Cooch Behar, West Bengal, India

PREFACE

Climate change is one of the most pressing challenges of our time, with far-reaching implications for agriculture and allied sectors. Rising temperatures, erratic rainfall patterns, increased frequency of extreme weather events, and shifts in pest and disease dynamics threaten global food security, rural livelihoods, and sustainable agricultural development.

This manual is a compilation of all deliberations during the 21 days ICAR sponsored winter school on "Impact of climate change on agriculture and allied sector: adaptation, mitigation towards sustainability and livelihood security". This will provide a comprehensive understanding of the impact of climate change on agriculture and allied sectors, including forestry, fisheries, and livestock. It aims to equip policymakers, researchers, extension workers, and farmers with the knowledge and tools necessary to adapt to changing climatic conditions and mitigate the adverse effects on agricultural productivity and sustainability.

The manual covers key aspects such as climate risk assessment, adaptation strategies, mitigation measures, and policy interventions. Special emphasis is placed on climate-smart agricultural practices, resource conservation techniques, and technological innovations that enhance resilience in farming systems. Case studies and practical examples have been incorporated to provide real-world insights into successful adaptation and mitigation efforts.

We hope this manual serves as a valuable resource for stakeholders at all levels, helping to build a more resilient and sustainable agricultural sector in the face of climate change. By integrating scientific knowledge with field-level practices, we can collectively work towards safeguarding food security, protecting natural resources, and ensuring the well-being of farming communities.

We express our gratitude to all experts whose contributions have made this manual possible. We also acknowledge the dedication of farmers and agricultural professionals who continue to adapt and innovate in the face of climate challenges.

Dated: 12th February, 2025

(Prodyut Kumar Paul)

Prof. Debabrata Basu
Vice -Chancellor
Uttar Banga Krishi Viswavidyalaya
Cooch Behar, West Bengal, India

MESSAGE

Agriculture and its allied sectors are the lifelines of global food security, rural livelihoods, and economic stability. Yet, they stand at the frontline of the escalating impacts of climate change. Rising temperatures, shifting precipitation patterns, and the increasing frequency of extreme weather events—such as droughts, floods, and cyclones—are already disrupting crop yields, livestock productivity, fisheries, and aquaculture systems. These disruptions pose significant challenges, particularly for smallholder farmers and vulnerable communities, who often lack the resources and infrastructure needed to adapt effectively.

Recognizing the urgency and complexity of these challenges, Uttar Banga Krishi Viswavidyalaya organized a Winter School on the theme: "Impact of Climate Change on Agriculture and Allied Sectors: Adaptation, Mitigation towards Sustainability and Livelihood Security", funded by the Indian Council of Agricultural Research (ICAR). This academic endeavor brought together a multidisciplinary cohort of experts, researchers, policymakers, and practitioners to deliberate on the multifaceted impacts of climate change and to explore innovative strategies for building resilient agricultural systems.

This resource book is a product of the rich discussions, scientific insights, and practical knowledge shared during the Winter School. It delves into the intricate dynamics of climate change and its far-reaching effects on crop production, livestock management, fisheries, aquaculture, and rural livelihoods. More importantly, it emphasizes a dual approach—adaptation and mitigation—as essential pathways toward achieving long-term sustainability and securing the livelihoods of millions who depend on these sectors.

The book offers a comprehensive analysis of climate-induced challenges affecting agriculture and allied sectors; adaptation strategies that empower farming communities to enhance resilience, including climate-smart agriculture, resource-efficient technologies, and ecosystem-based practices; mitigation approaches aimed at reducing greenhouse gas emissions, promoting carbon sequestration, and advancing regenerative agricultural practices and policy recommendations that bridge the gap between scientific research and ground-level implementation, fostering inclusive and sustainable development.

By synthesizing cutting-edge research, real-world case studies, and policy frameworks, this resource serves as a valuable reference for researchers, academicians, policymakers, extension professionals, and stakeholders committed to safeguarding agriculture in the face of climate uncertainty.

As we navigate the complex interplay between climate change, sustainability, and food security, this book underscores the importance of multidisciplinary collaboration, community participation, and forward-thinking policies. It is our hope that this compilation not only deepens understanding but also inspires tangible action toward creating climate-resilient agricultural landscapes and securing the livelihoods of rural communities.

We extend our gratitude to the contributors, participants, and organizing team whose dedication and expertise made this Winter School and the resulting resource book possible.

Dated: 13th February, 2025 **(Prof. Debabrata Basu)**

Prof. Prabhat Kumar Pal
Director of Extension Education
Uttar Banga Krishi Viswavidyalaya
Cooch Behar, West Bengal, India

MESSAGE

It is a matter of pleasure and pride that the Uttar Banga Krishi Viswavidyalaya is going to organise an ICAR sponsored 21-days refresher course on February 14 – March 6, 2025. Climate change is the most significant and challenging phenomenon of our time, and we should be equipped to develop resilience against its inevitable impacts. The present manual is covering those topics which will be delivered in this training; and as I perceive, these will certainly equip the participants with relevant knowledge and necessary tools and techniques to take appropriate decisions and actions towards their personal and professional life, especially to evolve a climate-smart agricultural production system.

I wish a grand success of the training programme and appeal the participants to be attentive enough towards taking some positive messages from the training.

Prabhat Kumar Pal

Dated: 12th February, 2025 **(Prabhat Kumar Pal)**

Dr. Ashok Choudhury
Director of Research
Uttar Banga Krishi Viswavidyalaya
Cooch Behar, West Bengal, India

MESSAGE

It is indeed a great pleasure for me to learn that a compendium is being published as a handbook for the participants of ICAR sponsored 21 days Winter School training programme on " Impact of climate change on agriculture and allied sector: Adaptation, mitigation strategies towards sustainability and livelihood security". This comprehensive resource is a testament to the dedication and expertise of our excellent resource persons and speakers. Over the course of 21 days, the complex relationships between climate change, agriculture, and mitigation strategies have extensively been explored. This compendium brings together the knowledge, experiences, and insights shared during the Winter School Program. It covers a range of topics, including climate change impacts on crop yields and quality, climate-resilient agricultural practices, agricultural insurance and risk management, policy and governance frameworks for climate-resilient agriculture.I extend my sincere thanks to all contribu well as to all members who made this publication possible. Your tireless efforts have resulted in a valuable resource that will benefit not only the participants but also researchers, policymakers, and practitioners working in the field of climate change and agriculture.

Dated: 13th February, 2025 **(Ashok Choudhury)**

Prof. Apurba Kumar Chowdhury
Dean
Post Graduate Studies
Uttar Banga Krishi Viswavidyalaya
Cooch Behar, West Bengal, India

MESSAGE

As we stand at the crossroads of climate change and its far-reaching effects on agriculture, it is increasingly clear that the need for actionable knowledge and sustainable solutions has never been more urgent. The impacts of a changing climate are already being felt across agricultural systems worldwide, influencing everything from crop yields to water availability, soil health, and biodiversity. In light of this, addressing climate change in the context of agriculture is not only essential for food security but also for the well-being of future generations.

The Winter School on Impact of Climate Change on Agriculture and Allied Sectors: Adaptation, Mitigation towards Sustainability and Livelihood Security will provide a unique platform for academics and practitioners to delve into the complexities of this challenge. Over the course of the program, participants will engage with cutting-edge research, explore innovative mitigation strategies, and discuss the sustainable practices necessary to adapt agriculture to a rapidly changing world.

This initiative brings together diverse perspectives, fostering collaboration among experts, policymakers, and the next generation of leaders in agriculture and environmental science. Through these dialogues and shared insights, we can identify pathways to mitigate the adverse effects of climate change on agriculture and build more resilient, sustainable systems.

At Uttar Banga Krishi Viswavidyalaya, we are proud to be part of this important conversation and to contribute to advancing the knowledge and solutions that will shape the future of agriculture in the face of climate change. I encourage all participants to take full advantage of the expertise and resources available during this Winter School, as we work together to ensure a sustainable future for agriculture and our planet.

Dated: 12th February, 2025

(Apurba Kumar Chowdhury)

Prof. Dibyendu Mukhopadhyay
Dean
Faculty of Agriculture
Uttar Banga Krishi Viswavidyalaya
Cooch Behar, West Bengal, India

MESSAGE

I am happy to know that, the ICAR-sponsored Winter School is being organised by Uttar Banga Krishi ViswaVidyalaya, Pundibari, West Bengal on "Impact of climate change on agriculture and allied sector-Adaptation and Mitigation towards Sustainability and Livelihood Security", during 14th Feb, to 6th March, 2025. The winter school is expected to focus on the burning concern of the global climate change affecting nutritional and livelihood security through the exchange of knowledge and ideas to bring out the strategic plans for sustainable development in agriculture.

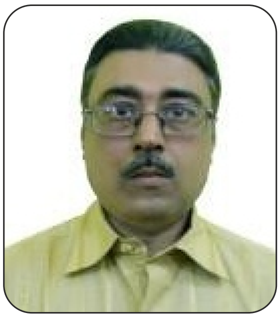
The food and nutritional security is ensured by the strong and sustainable foundation of agriculture of a country. There are challenges like climate change, degradation of soil, pollution in air and water and preservation of perishable products. It requires holistic and innovative approach to explore traditional knowledge, deliverable outcome of research and policy interventions in a collaborative way. The level of adoption of emerging technologies by the farming community is another challenge to meet the demand for food and nutrition in the long run.

I am also happy to learn that, the organizers are going to publish the compendium based on the discussions and deliberations in the Winter school which will definitely be a basic document to identify the possible options for mitigation of climate change and to attain sustainable development in agriculture at the global level. I am confident, that this Winter school will inspire all the participants and stakeholders to reshape and redefine their thoughts and ideas with the progress of agriculture under changing climatic conditions.

I wish the training programme a grand success.

Dated: 12th February, 2025 **(Dibyendu Mukhopadhyay)**

Prof. Soumen Maitra
Dean
Faculty of Horticulture
Uttar Banga Krishi Viswavidyalaya
Cooch Behar, West Bengal, India



MESSAGE

I feel very glad to know that the Course Compendium of the - ICAR sponsored 21 days Winter School on Impact of Climate Change on Agriculture and Allied Sector - Adaptation and Mitigation towards Sustainability and Livelihood Security, to be held at Uttar Banga Krishi Viswavidyalaya, Pundibari, CoochBehar, West Bengal, PIN – 736165, on and from 14.02.2025 to 06.03.2025, is going to be published, compiling the outline and essence of each and every lecture delivered by eminent speakers. Climate change is an ever-burning topic, which is now taking the front seat due to aggressive anthropogenic activity. Harnessing the impacts of climate change into favourable direction should be the need of the hour. The Winter School is also designed befitting to this necessity. A number of theory classes covering a wide array of subjects in this aspect will be arranged along with relevant practical classes, which may become instrumental to develop a comprehensive idea among the participants. I hope, this Course Compendium will become immensely helpful for the future academic and research activities of the participants of this Winter School.

Soumen Maitra

Dated: 12th February, 2025 **(Soumen Maitra)**

Dr. Ashis Kumar Das
Dean
Faculty of Technology
Uttar Banga Krishi Viswavidyalaya
Cooch Behar, West Bengal, India

MESSAGE

Dear Esteemed Participants, Distinguished Guests, and Colleagues,

It is with immense pleasure and pride that I extend a warm welcome to all of you to the ICAR-sponsored 21-day Winter School on "Impact of Climate Change on Agriculture and Allied Sectors: Adaptation, Mitigation towards Sustainability and Livelihood Security" at Uttar Banga Krishi Viswavidyalaya (UBKV).

Climate change is one of the most pressing challenges of our time, profoundly affecting agriculture and allied sectors, which are the backbone of our economy and food security. This Winter School is a timely initiative to address these critical issues, bringing together experts, researchers, and practitioners to share knowledge, foster innovation, and develop sustainable solutions for a resilient future.

As the Dean of the Faculty of Technology, I am confident that this program will provide a platform for meaningful discussions, collaborative research, and the exchange of ideas that will contribute to the global efforts in combating climate change. Your participation and insights will undoubtedly enrich the discourse and help pave the way for actionable strategies to ensure sustainability and livelihood security.

I extend my heartfelt gratitude to the Indian Council of Agricultural Research (ICAR) for their generous support and to all the organizers, experts, faculty members, and staff who have worked tirelessly to make this event a success. My special thanks to the participants for their enthusiasm and commitment to this vital cause.

Let us work together to create a sustainable and secure future for generations to come. I wish you all a productive and inspiring Winter School.

Dated: 12th February, 2025

(Ashis Kumar Das)

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CLIMATE CHANGE AS PERCEIVED AND CLIMATE ACTION TO ADDRESS SDGs IN AGRICULTURE PERSPECTIVE

Prof. Subhendu Bandyopadhyay
Department of Agronomy
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Climate change:

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. The Inter-governmental Panel on Climate Change (IPCC) defined Climate change as a "change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer".

Climate variability:

The temporal changes in weather phenomena, which is part of general circulation of atmosphere and occur on a yearly basis on a global scale. Climate change and climate variability are the concern of human kind in recent decades all over the world. The recurrent drought and desertification seriously threaten the livelihood of over 1-2 billion people who depend on the land for most of their needs. The weather-related disasters viz. drought and floods, ice storms, dust storms, landslides, thunder clouds associated with lightening and forest fires are uncommon over one or other region of the world.

Causes of climatic variability:

Causes for climate change can be categorized into two classes.

1) Natural causes of Global Warming

The accumulation of greenhouse gases in the atmosphere has warmed the planet and caused changes in the global climate. In 2001 the UN-sponsored Intergovernmental Panel on Climate Change (IPCC) reported that worldwide temperatures have increased by more than 0.6°C in the past century. The source of GHGs was both natural (for example, volcanic emissions and wildfires) and anthropogenic (human-influenced) sources (for example, burning of fossil fuels and deforestation).

All major global surface temperature reconstructions show that Earth has warmed since 1880. Most of this warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years. It is very much clear that the Earth's climate is changing in a manner unprecedented in the past 400,000 years. The IPCC (2007) report corroborated previous scenarios that by 2100 mean planet-wide surface temperatures will rise by 1.4 to 5.8°C, precipitation will decrease in the sub-tropics, and extreme events will become more frequent. However, changes in climate are already being observed—the last 60 years were the warmest in the last 1000 years and changes in precipitation patterns have brought greater incidence of floods or drought globally (Wassmann and Dobermann, 2007).

Causes of climatic variability:

External causes: Solar output: An increase in solar output by 0.3%when compared to 1650 -1700AD data.

Orbital variation: Earth orbit varies from almost a complete circle to marked ellipse (Eccentricity). Wobble of earth's axis (Precession of equinox), Tilt of the earth's axis of rotation relative to the plane of the orbit varies between 21.8^o and 24.4^o.

Internal causes Changes in the atmospheric composition.

i)Change in the greenhouse gases especially CO_2

ii)Land surface changes particularly the afforestation and deforestation iii)The internal dynamics of southern oscillation – changes in the sea surface temperature in western tropical Pacific (El-Nino/La-Nina) coupled with Southern Oscillation Index, leading to the ENSO phenomena.

Mechanisms of climate change:

Energy received from the sun is absorbed by the earth – atmosphere system and is used for heating land, water and air and for running atmospheric engine is derived from sun and is a part of this energy balance equation. Atmospheric circulation is determined by this energy balance at the earth surface. It is imperative that the change in energy balance brings about a change in atmospheric surface temperatures and circulation mainly and is basically responsible for any change in climate. Thus, the reason for climate change to be sought and interpreted through the energy balance of the earth-atmosphere system. Climatic changes occurred so for on different time scales have been attributed to the various factors responsible basically for energy balance and consequently changing surface temperature and circulation.

The factors are i) Change in intensity of the radiation at the top of the atmosphere, ii) Change in the reflectivity (albedo) of the atmosphere and earth's surface and iii) Change in intensity or absorption and emission of long waves radiations which depends upon the constituents of the atmosphere such as carbon dioxide, water vapour, dust etc.

Most of the gases in the atmosphere are transparent to the incoming shortwave radiation from the sun. The carbon dioxide and water vapour though present in smaller proportions block the outgoing long wave radiation emitted by the earth. Had the atmosphere not behaved thus, the earth's surface temperature would have been much lower(-18^{o}C), much below the freezing temperature. The surface temperature, in fact is around 15^{o}C representing the warning of 33^{o}C. This phenomenon of increasing temperature is called "greenhouse effect". The gases responsible for greenhouse effect are carbon dioxide (CO2), methane (CH4), nitrous oxides(N2O), chlorofluro carbons (CFC) and water vapour (H2O).

A. Carbon dioxide (CO2): This gas though in small proportion it is responsible for half of the total green-house effect. It absorbs short wavelengths of 2,3 and 4μ from the sun. It also absorbs 14-16 μ and 15μ IR long wave length emitted by the earth and emits still larger wave length producing warning on the earth. The increase in proportion of CO_2, will result in warming effect changing global climate. Its present proportion in atmosphere is 0.034% by volume or 340 ppm in 1860, its proportion was 290 ppm, in 1960 it was 310 ppm. It is now increasing at the rate of 1.5 ppm per year, and at this it should double by 2030 AD or so.

B. Methane (CH_4): The proportion of methane in air is about 1.3 to 1.6 ppm. Its concentration is rapidly increasing in this century. It is generated by the activities of microorganisms at swamps, paddy fields, marshs. Paddy fields and ruminants are the main sources of this gas. This gas absorbs in the infra-red region. This is mainly biogenic pollution.

C. Nitrous oxide (N_2O): Its proportion in air is 0.25 to 0.35 ppm. It is released through industry. It interacts with ozone decreasing its content ozone is destroyed. It has no important absorption peak. The main human-related sources of N_2O are agricultural soil management, mobile and stationary combustion of fossil fuel and nitric acid production. N_2O is also produced naturally from a wide variety of biological sources in soil and water. On a global basis, it is estimated that natural sources account for over 60% of the total N_2O emissions (IPCC, 2001).

D. Chlorofluro carbons (CFC): These chemicals (F12,F11,CCl3,F,CH3Cl) are largely used in cooling systems and in the walls of domestic and commercial refrigerators. CFC's are used in foam insulation, packing, aerosols, clearing, solvents and medical sterilizers. CFC's are released through industry, their content in atmosphere being less than 1 ppm. CFCs are mainly responsible for ozone (O_3) in the atmosphere.

Impact on Agriculture:

Increased carbon dioxide tends to suppress photo-respiration in these plants, making them more water-efficient. C_3 plants include such major mid-latitude food staples as wheat, rice, and soybean. The response of C_4 plants, on the other hand, would not be as dramatic (although at current CO2 levels these plants photosynthesize more efficiently than do C3 plants). C_4 plants include such low- latitude crops as maize, sorghum, sugar-cane, and millet, plus many pasture and forage grasses. Higher CO2 levels can increase yields. The yields for some crops, like wheat and soybeans, could increase by 30% or more under a doubling of CO2 concentrations. The yields for other crops, such as corn, exhibit a much smaller response (less than 10% increase). However, some factors may counteract these potential increases in yield. For example, if temperature exceeds a crop's optimal level or if sufficient water and nutrients are not available, yield increases may be reduced or reversed. More extreme temperature and precipitation can prevent crops from growing. Extreme events, especially floods and droughts, can harm crops and reduce yields. Dealing with drought could become a challenge in areas where summer temperatures are projected to increase and precipitation is projected to decrease. As water supplies are reduced, it may be more difficult to meet water demands. Many weeds, pests and fungi thrive under warmer temperatures, wetter climates, and increased CO2 levels. Currently, farmers spend more per year to fight weeds. The ranges of weeds and pests are likely to expand northward. This would cause new problems for farmers' crops previously unexposed to these species. Moreover, increased use of pesticides and fungicides may negatively affect human health.

Impacts on Livestock:

It is expected that increased air temperatures will cause more stress on livestock. Both humans and livestock are warm-blooded animals, so both are affected by increased heat and humidity. During stifling heat, livestock reproduction declines as well as their appetite. Decreased appetite will lengthen the time needed for the livestock to reach their target weight (most animals only eat about half of normal quantities when they are heat-stressed). Stress can also increase the incidence of sickness, decrease rates of reproduction, and increase fighting among animals in confinement. Drought may threaten pasture and feed supplies. Drought reduces the amount of quality forage available to grazing livestock. Climate change may increase the prevalence of parasites and diseases that affect livestock. Increase in carbon dioxide (CO2) may increase the productivity of pastures, but may also decrease their quality. Increase in atmospheric CO2 can increase the productivity of plants on which livestock feed.

Impacts on Fisheries:

Many marine species have certain temperature ranges at which they can survive. For example, cod in the North Atlantic require water temperatures below 54°F. Even sea-bottom temperatures above 47°F can reduce their ability to reproduce and for young cod to survive. In this century, temperatures in the region will likely exceed both thresholds. Many aquatic species can find colder areas of streams and lakes or move northward along the coast or in the ocean. However, moving into new areas may put these species into competition with other species over food and other resources. Changes in temperature and seasons could affect the timing of reproduction and migration. Many steps within an aquatic animal's lifecycle are controlled by temperature and the changing of the seasons.

Climate change in West Bengal:

According to the observations during this period of 1969-2005 (37 years), the maximum temperatures are decreasing across the state whereas the minimum temperatures are increasing. The maximum temperature has decreased by -0.5^{o}C with respect to starting of the observation period (1970s) in the New Alluvial zone, the laterite zone and the Saline coastal zone. In the Hilly, Terai and the old alluvial zone, the maximum temperature has also decreased but by only - 0.25^{o}C. Whereas the minimum temperatures are increasing all across the state. In the laterite zone, the minimum temperature has increased by 0.5oC, in the Hilly, Terai and the old Alluvial zone, the temperatures have increased by 1.5^{o}C and in the new alluvial zone and the coastal zone the minimum temperatures have increased by 1^{o}C. A decreasing trend in south-west monsoon rainfall has been observed over the Gangetic plains in India (IGP) between 1901-2012. The reasons for decreasing trend in south-west monsoon rainfall is attributed to the rapid increase in SST (Sea Surface Temperature) in the Western Indian Ocean, causing lesser contrast in land and sea temperature. For this state the maximum and minimum temperatures are projected to rise at different rates, which means the climate shall become warmer and diurnal differences shall reduce. The evapotranspiration rate shall also increase in warmer weather. These changes may impact the plant physiology and productivity. The rainfed agriculture is expected to receive less water from precipitation. Rain is likely to reduce in the summer months and in the winter months making crop rotation a difficult task. There can be drought and longer duration of heavy rains resulting in to prolong water logging in the same season. Selection of crop for sowing become a complex decision making process. Bhattacharyya and Panda (2013) shows that the grain yield increased an average of 0.35 kg/ha with per mm increase in rainfall and decreased by 156.2 kg/ha per degree rise in mean temperature at that region. Considering 10.99 million ha area for all types of rice production, there can be 5% reduction in the production of rice for every 1 degree rise in temperature and reduction of rainfall. Working in a hot and dry weather increases morbidity and prolong exposure in very hot weather can cause heat stress in farmers, who are working in the field. Heat waves cause livelihood problems in this sector.

The climatic change in *terai* agroclimatic region of West Bengal:

Here, the minimum temperature has increased by 1.5^{o}C in the Terai zone. Shorter winter period has been observed. There are distinctive changes in observed pattern of rainfall in terai zone of West Bengal. June rain fall has decreased by an amount of -3.1%. In July there is a increase in rainfall by 4.5%. In August there is an overall decrease by -0.1%. In September shows a decrease in rain fall by -1.1%. An analysis of total annual rain fall indicate that there is an overall decrease in the total rain. Decrease in total no of rainy days in *terai* zone has been observed which will drastically affect the distribution of rainfall and over all monsoon dependent agriculture. A general late onset coupled with early withdrawal suggests a shorter monsoon period.

Climate Change Adaptations:

It is the spontaneous or organized processes by which human beings and society adjust to changes in climate by making changes in production systems and social and economic organization in order to reduce vulnerability to changing climate conditions. For better adaptation in agriculture we have to improve the resilience of agriculture, we have to reduce the vulnerability of agriculture to changing climate and we have to enhance its capacity to deal with climate change conditions. There are four adaptation policy panels like, i) Diversity includes crop types and varieties, including crop substitution. ii) Development of new crop varieties, including hybrids to increase the tolerance, resistance and suitability (research), iii) Promotion of seed banks so as to help farmers diversity crops and crop varieties and iv) Increase the incentives to increase diversification through subsidies, taxes etc. Attention should be given on irrigation and water resource management. Emphasis on infrastructure for small-scale water capture, storage and use should be given. Then priority should be given on demand management and water allocation to encourage efficiency of use best timing and dose of irrigation. Then development of water management innovations should be done which includes irrigation, to address increase frequency of draught. Schemes to reduce distribution losses of irrigation water by maintaining canals should be adopted. And innovativeness on reuse wastewater for agriculture purpose and encouragement on the improved irrigation methods like drip and sprinkler irrigation etc. should be done. Research to develop crop varieties requiring little water should be undertaken. Disaster risk management on flood, drought etc. should be done by developing early warning systems, more water-efficient and/or drought tolerant crop varieties, infrastructure to protect against asset loss, community and municipality capacities in disaster management etc. Equip the areas from flood damage and maintain drainage outlets (source:https://www.fao.org/fileadmin/templates/ex_act/pdf/Climate_Change_and_Agricultural_Policies)

Climate Change Mitigation:

Mitigation is the actions to reduce and avoid GHG emissions and to increase the sequestration of atmospheric Carbon through absorption by carbon sinks. Reduction in emissions of CO_2 can be done by reducing in the rate of deforestation and in the rate of forest degradation. Side by side adoption of improved cropland management practices should be done. Reduction in emission of CH_4 and N_2O can be done by improved animal production, improved management of livestock waste and by more efficient management of irrigation water on rice. Sequestrating of carbon can be done in better way by adopting conservation farming practices, improved forest management practices, agroforestry and restoration of degraded land.

Four mitigation policy panels are there, i)Conservation agriculture, ii) reducing methane from rice field iii) Watershed and land management, and iv) Livestock management.Conservation Agriculture is based on three principles: i) Intercropping / crop rotation, I Minimum soil disturbance/Zero tillage, and Cover crops/ mulching. Under Water and land management we have to develop schemes to improve watershed resilience building at community level, We have to mobilize municipality/ Panchyet driven semi permanent labour intensive public works. And we also have to monitor carbon-fixing impact generation to allow Carbon Funding to support such action (source:https://www.fao.org/fileadmin/templates/ex_act/pdf/ppt/ Climate_Change_and _Agricultural_ Policies_ppt.pdf).

Role of Uttar Banga Krishi Viswavidyalaya in the aspect of Climate Change:

Project 1 : Sustainable Resilient Farming System Intensification in Eastern Gangetic Plains (SRFSI)

Collaborative research project on conservation agriculture was operative during 2014-2021 with Department of Agriculture, Government of West Bengal and UBKV as partners along with 22 national and international partners in India, Nepal and Bangladesh.

Significant benefits in West Bengal: Increased crop productivity (4-6 %), Increased profitability (15-40%), High water productivity, Better Nutrient Efficiency, Higher Energy Efficiency (1.2-3.2%), Low Fuel Consumption (70-80%), Low polluting technologies (9.2-31.7%)

Policy Changes: CA machineries in the compulsory list for establishment of a custom hiring centre (CHCs) utilizing subsidies of 40%. 50% subsidy to the women farmers groups to establish rice seedling hub and 50-80% subsidy on various machineries used under Crop Residue Management (CRM)

Project 2: "Transforming Smallholders Food Systems in the Eastern Gangetic Plain" (2022-2026)

The aim of the project is to define the processes and practices (technical options, scaling interventions, policy settings and implementation) that can be applied to achieve sustainable, efficient, diversified food systems at scale in the eastern Gangetic plains.

Works initiated: Reduced & Zero tillage in mustard cultivation in Rice-Rice crop rotation, Bed planting and poly-mulching in chili cultivation in irrigation constraint areas, Scientific goat rearing with hydroponics fodder production

Project 3: "Additive intercropping in wide-row crops for resilient crop production in Bangladesh, Bhutan and India" (2023-2028)

The aim of the project is to sustainably intensifying smallholder farmers' wide-row maize with vegetable production to improve productivity, food, nutrition & income security, and climate change resilience.

Expected Outcomes: 12-60% higher maize equivalent yield with 10 to 40% higher net return than sole maize

Project 4: Gramin Krishi Mausam Sewa (GKMS),

This is a central Govt. sponsored scheme in collaboration with India Meteorological Department, Ministry of Earth Science and State Agricultural Universities is running since the year 2005in this University. The main area is to i) issuing crop and location specific weather based agro advisories for the benefit of farming community, ii) Farmer's Awareness Programme to make farmers aware about weather based crop production, iii) and to record and conserve real time weather data through observatory.

Project 5: Forecasting of Agricultural Output on Space, Agrometeorology and Land based Observations (FASAL):This is a central Govt. sponsored scheme in collaboration with India Meteorological Department, Ministry of Earth Science and State Agricultural Universities. The main objectives of this project was to forecast the yield of different principal crops by running the established software models.

Sustainable Development Goals adopted in Paris Agreement and where are we standing now?

The Paris Agreement, established during COP 21 in Paris on December 12, 2015, represents a significant milestone in the global effort to address climate change. This accord, reached by the Parties to the UNFCCC, aims to accelerate and intensify necessary actions and investments for a sustainable, low-carbon future. By building upon the existing Convention, the Paris Agreement unites all nations in a collective endeavour to undertake ambitious measures to mitigate climate change and adapt to its consequences, particularly by providing enhanced support for developing countries. Consequently, it sets a transformative direction for international climate initiatives. The primary objective of the Paris Agreement is to bolster the global response to the climate change threat by limiting the increase in global temperatures this century to well below 2 degrees Celsius above pre-industrial levels, while striving to restrict the rise to 1.5 degrees Celsius. Furthermore, the agreement seeks to enhance the capacity of nations to manage the impacts of climate change and to align financial flows with a pathway that is both low in greenhouse gas emissions and resilient to climate effects. Achieving these ambitious targets necessitates the mobilization and provision of adequate financial resources, the establishment of a new technology framework, and the enhancement of capacity-building efforts, thereby supporting actions by developing and vulnerable countries in accordance with their national priorities. Additionally, the Agreement introduces an improved transparency framework for both action and support.

So far, there has been very limited progress in reducing the emissions gap for 2030 – the gap between the emissions reductions promised by countries and the emissions reductions needed to achieve the temperature goal of the Paris Agreement. Fossil fuel CO2 emissions increased 1% globally in 2022 compared to 2021 and preliminary estimates from January-June 2023 show a further 0.3% rise. To get on track to meet the Paris Agreement goals of limiting warming to well below 2 °C and preferably 1.5 °C, global greenhouse gas emissions must be reduced by 30% and 45%, respectively, by 2030, with carbon dioxide (CO_2) emissions getting close to net zero by 2050. This will require large-scale, rapid and systemic transformations. Some future changes in climate are unavoidable, and potentially irreversible, but every fraction of a degree and ton of CO_2 matters to limit global warming and achieve the SDGs, says the report. Inger Andersen, Executive Director of the UN Environment Programme said that, "The science continues to show that we are not doing enough to lower emissions and meet the goals of the Paris Agreement - as the world prepares for the first global stocktake at COP28, we must increase our ambition and action, and we must all do the real work to transform our economies through a just transition to a sustainable future for people and planet,". Only 15% of SDGs are on track (source: UNFCCC (2017) Informal notes and conclusions from the last session: Bonn, May 2017). Therefore, to save the earth and to save us everybody has to put a wholehearted effort to prevent global warming.

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Global climate change scenario and agriculture: Challenges and perspectives

Namita Das Saha[1,*] Partha Saha[1] and Anita Chaudhary[2]
[1]ICAR-National Institute for Research on Commercial Agriculture (ICAR-NIRCA), RS-Dinhata, Cooch Behar, West Bengal
[2]ICAR-Indian Agricultural Research Institute (IARI), Pusa, New Delhi
***Corresponding author**: soilnami@gmail.com

Introduction

Climate change can be defined as a change in the average weather conditions such as temperature and rainfall in a region over a longer period of time and global climate change refers to the average long-term changes over the entire 'Earth'. These include warming temperatures and changes in precipitation, rising sea level, more intense storms, increased flood incidence, protracted drought, shrinking mountain glaciers ice as melting at a faster rate than usual in Greenland, Antarctica etc. Earth's climate has constantly been changing even long before human came into the picture! However, scientists have observed unusual changes recently. For example, earth's average temperature has been increasing much more quickly than they would have been expected over the past 150 years. Changes observed in earth's climate since the mid 20th century and these changes are mainly driven by human activities, particularly fossil fuel burning, which increases heat trapping greenhouse gas levels in earth's atmosphere which raised earth's average surface temperature.

In fact, to describe about 'climate change', the most prominent phenomenon that comes to our mind is 'Global warming'. Many of us synonymously use global warming as climate change. But global warming is one of all the other triggers which are actually causing the 'Global climate change'. But, it's now proven that amongst different causes (Natural and anthropogenic), global warming is playing the great role in shaping our climate and the mechanism behind the warming process is termed as the greenhouse effect. The term 'green house effect' is described as 'the way certain atmospheric gases "trap" heat that would otherwise radiate back from planet's surface into the space. On the one hand, we have the greenhouse effect to thank for the presence of life on earth; without which, our planet would have been extreme cold (-18^{o}C) and unlivable!

Natural causes of climate change

Some amount of climate change can be attributed to natural phenomena. Over the course of Earth's existence, volcanic eruptions, fluctuations in solar radiation, tectonic shifts, and even small changes in our orbit have all had observable effects on planetary warming and cooling patterns. But climate records are able to show that today's global warming particularly what has occurred since the start of the industrial revolution is happening much faster than ever before. According to NASA, "these natural causes are still in play today, but their influence is too small or they occur too slowly to explain the rapid warming seen in recent decades."

Human driven causes of climate change

The unchecked burning of fossil fuels over the past 150 years has drastically increased the presence of atmospheric greenhouse gases, most notably carbon dioxide. Right now, atmospheric concentrations of greenhouse gases like carbon dioxide, methane, and nitrous oxide are the highest they've been in the last 800,000 years. Some greenhouse gases, like hydrochloro fluorocarbons (HFCs), do not even exist in nature. By continuously pumping these gases into the air, we helped raise the earth's average temperature by about 1.9 degrees Fahrenheit during the 20th century which has brought us to our current era of deadly and increasingly routine weather extremes.

Climate change and agriculture:

Climate change is posing serious risks to Indian agriculture as almost half of the agricultural land of India is rain fed. Climate change is in fact already affecting crop yield, soil biogeochemical cycles, water availability, and pest-pathogen dynamics. Several adaptation strategies such as heat and water stress-tolerant crop varieties, resilient crops, improved management practices, improved use efficiency (WUE and NUE), conservation agriculture, improved weather forecasts, and other climate services are in place to minimize the climatic risks. The agriculture sector contributes 14% of the greenhouse gas (GHG) in India. Mitigation aspect is another dimension and mitigation of GHG emission from agriculture can be achieved by changing land use management practices and enhancing input-use efficiency. Scientific findings in India showed that methane emission from lowland rice fields can be reduced by 40-50% by following simple alternate wetting and drying (AWD), growing shorter duration varieties, and using neem coated urea, application of Urea according to soil health card (SHC) and leaf color chart (LCC). Dry direct-seeding of rice, which does not require continuous soil submergence, can reduce methane emission by 70-75%. Sequestration of carbon (C) in agricultural soil can be promoted with the application of organic manure, incorporation of crop residues, and balanced nutrients. India has taken several proactive steps for addressing the issues of climate change in agriculture. Recently, it has also committed for reducing GHG emission intensity by 45% by 2030 and achieving net zero emission by 2070.

Agriculture plays a pivotal role in ensuring food and livelihood securities of India. About 46.5% of countries employment is from the agriculture sector, which contributes ~18% of the country's gross domestic product (GDP). In the last few decades, climatic extremes and risks have been continuously threatening global agricultural production and food security. According to the latest most IPCC report *i.e.*, the 6th Assessment Report (AR6) of the Inter-Governmental Panel on Climate Change (IPCC), released on August 9, 2021, observed that the climate change is wide spread, rapid and getting intensified. Over the last century, carbon dioxide (CO_2) concentration in the atmosphere has crossed 425 ppm. The global mean temperature has already risen by 1.1°C and may cross 1.5°C by 2040 and reach up to 3.5°C by 2100 as predicted from the scenario.

The last 7 years were the consecutive warmest years (2015 to 2021). WMO confirms that 2024 was the ever warmest year on record and 1.55^{o}C has risen above the pre-industrial level. In India, we are experiencing about the shifting of seasons; rainfall variability and intensity are increasing, sea level is rising, and the extreme events of weather such as cyclone, heat wave, heavy rain, flood, and drought are becoming fiercer and frequent. Ensuring food security while reducing emission of GHGs, *i.e.*, CO_2, methane (CH_4) and nitrous oxide (N_2O), is a challenge for Indian agriculture. As 85% of Indian farmers are marginal, cultivating agricultural land less than 1 ha. Land holding size being small, the task of achieving lesser emission from Indian agriculture is more challenging. The poor, small-holder farmers suffer more due to the risks of climate change as they are more dependent on climate-sensitive natural resources, although they contribute least to climate change.

The United Nation's 2030 Agenda for the Sustainable Development Goals (SDGs) targets to achieve 17 SDGs which address poverty, hunger, health, hygiene, climate and resource consumption to ensure global economic, social and environmental well-being. Agriculture is interdependently and multi-dimensionally connected to the SDGs, which can be both synergistic and antagonistic. Globally agriculture is the main sector for food production. However, agriculture and other land use changes (AFOLU) accounts for up to 24% of the GHG emission from about 22.2 million km^2 of agricultural area. Enhancing climate resilience of agriculture is therefore crucial for achieving the SDGs, particularly Goal No. 1 (No poverty), 2 (Zero hunger) and 13 (Climate action).

Impacts of climate change on Indian agriculture

India is diverse in terms of wide range of climatic conditions with extreme winters in the north and humid-tropical conditions in the South. The north-eastern regions of the country are humid whereas dry and arid conditions are in the North-western regions. Rainfall during June to September (southwest monsoon season) is the primary determinant of agricultural yields in India. Whereas the south states get monsoon twice in a year. Extreme weather events (flood, drought, heat and cold waves, flash flood, cyclone, and hail-storms) have become routine kind of event and are very severely affecting agricultural production.

The 6th Assessment Report of IPCC reaffirmed that climate change can affect agriculture with wide consequences (IPCC, 2021). Increase in atmospheric temperature can have direct impacts in reducing crop duration, photosynthesis, and ultimately crop yield. It can affect the survival and distributions of pest populations, increase soil nutrient mineralization, decrease nutrient use efficiency, and increase water loss resulting in increasing demand of irrigation water and plant nutrients. Climate change has significant indirect effects on agriculture with its effects on irrigation water availability, droughts and floods, soil fertility and erosion.

Climate affects all the plant processes including photosynthesis, respiration, water relations, nutrient uptake, and phenology affecting crop yield and quality. The major risk-prone crops with reduced productivity are rice and wheat in the Indo-Gangetic Plains (IGP) and maize in the mid-IGP and Southern Plateau. It is estimated that crop yield in India will be reduced due to climate change by 4.5–9.0% (Naresh Kumar et al., 2020). As agriculture currently contributes about 18% of the country's GDP, climate change will cost to GDP by about 1.0% from crop sector alone. Ironically, poor farmers are especially vulnerable due to climate change and they are more dependent on climate-sensitive resources, though they contribute the least to climate change.

Climate change and crop productivity

Climate change due to elevated level of carbon dioxide concentration in the atmosphere is likely to cause CO_2-fertilisation and by principle is expected to compensate the negative effects of increased temperature on yields. However, further increase in temperature would result in yield losses. Projections indicate losses of yield ranging from 9% in wheat to 18% in kharif maize by 2040 with the representative concentration pathways (RCP) 4.5 scenarios (Naresh Kumar et al., 2019, 2020). The representative concentration pathways, adopted in the IPCC 5th Assessment Report, are the possible changes in anthropogenic GHG emissions, and aim to represent their atmospheric concentration trajectory describing different climate futures. Four RCPs (2.6, 4.5, 6.0, and 8.5) were considered after a possible range of radiative forcing values (Wm^{-2}) in the year 2100. The climate suitability for rainfed rice is projected to decline in the range of 15–40% by year 2050.

Effects of elevated CO_2, temperature, and rainfall on the quality of produce of some horticultural crops are presented in Table 1. Shift in apple belt from 1250 to 2500 m above mean sea level is observed in Himachal Pradesh and Jammu and Kashmir (Aggarwal et al., 2021). Changes in rainfall pattern are affecting tea yield in Assam. The Arabica coffee is also projected to lose yield. Agro-biodiversity may be threatened due to climatic extremes. Climate change will adversely affect grain quality. For example, grain protein content would reduce by 1% with elevated CO_2 and low N availability in wheat (Aggarwal et al., 2021). Concentrations of minerals (Zn and Fe) in grains may reduce in many crops. Similarly, with stresses from increased temperature, heavy rainfall events and high CO_2, quality of horticultural crops is expected to be adversely affected.

Table1. Adverse effects of elevated CO_2, temperature and rainfall on some selective horticultural crops

Sl no.	Fruit	Quality parameters
1.	Apple	Exposure to direct sunlight and high temperatures causes accumulation of sugars; high temperatures increase tartaric acid in fruits, affects fruit firmness; causes sunburn, loss of texture and development of water core in fruits. In ripening apples, anthocyanins are synthesized at temperatures <10 °C. High temperatures affect biosynthesis of anthocyanin pigment and cause poor red peel
2.	Strawberry	Warmer day (25 °C) and night (18-22 °C) increase antioxidant components such as flavonoids. Fruits develop darker red color
3.	Vine grapes	High variation (15-20 °C) in day/night temperature promotes anthocyanin development
4.	Areca nut	Storage temperature >28 °C reduces myristic acid
5.	Cashew nut	High rainfall coinciding nut development causes nut germination, blackening of nuts
6.	Tomato	Temperature >27 °C inhibits red colour development

Conclusion:

In coming future, climate change is likely to further intensify the problems of food and livelihood security by increasing risks towards Indian agriculture. Yield of the major crops in India may be reduced by 9–18% due to climate change. Indian agriculture emits 14% of total GHG emission from all the sectors of Indian economy. Adopting Climate Smart Agriculture 'CSA' is an upcoming arena of focus which can help in adaptation and mitigation. However up scaling and implementation of those climates smart technologies to be implemented at field, farm and food system levels. A FARM-Building (Forecasting, Adapting, Responding, Mitigating and Building capacity) approach is required to address the risks of climate change in Indian agriculture. In this aspect, Govt. of India has already initiated several projects and policy changes to address the problems of climate change.

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Research Initiatives and future prospect on Commercial Agriculture for enhancing farmers' income in Terai region of West Bengal

Partha Saha* and Namita Das Saha
ICAR-National Institute for Research on Commercial Agriculture (NIRCA)
Research Station, Dinhata, Cooch Behar, West Bengal 736135
*hortparth@gmail.com

Introduction

ICAR-National Institute for Research on Commercial Agriculture (NIRCA), Research Station, Dinhata, the then ICAR-CTRI Research station originally known as Wrapper and Hookah Tobacco Research Station was established in 1952 under the aegis of the then Indian Central Tobacco Committee (ICTC) under the administrative control of Central Tobacco Research Institute, Rajahmundry (AP). In 1965 the function of the research station was taken over by the Indian Council of Agricultural Research (ICAR). On January 8, 2025 the institute has been renamed as ICAR-National Institute for Research on Commercial Agriculture with its headquarter in Rajahmundry, Andhra Pradesh, and six research stations at Guntur (AP) Kandukur (AP) Jeelugumilli (AP), Vedasandur (Tamil Nadu), Hunsur (Karnataka), and Dinhata (West Bengal) to address the research needs of farmers in various agro-climatic zones. West Bengal occupies an important place on tobacco map of India. Tobacco growing areas in the state are concentrated mainly in northern district of Cooch Behar, Jalpaiguri, Malda and Murshidabad. India is the leading producer of several high-value commercial crops in the world. The high-value commercial crops such as chilli, turmeric and tobacco have great potential to generate high returns, greater scope for post-harvest processing and value addition, and tremendous export potential to generate foreign exchange revenue to the national economy.

Research Accomplishments in tobacco and services by NIRCA

Varieties released

Since its inception, the station has developed 5 varieties in *Motihari* tobacco, 4 varieties in *Jati* tobacco and 2 varieties in wrapper tobacco. The released varieties have the average yield of 2200 kg in Motihari and 1500 kg in Jati tobacco.

Seed supply

The research station has been supplying quality seed of all the popular tobacco varieties to the farmers of this region.

Disease resistant variety development

Different accessions of *Motihari* tobacco were screened under artificial condition for resistance to Hollow stalk. White Pathar and Bengthuli (an accession from Assam) showed resistant reaction (< 2 cm) and were put under crossing program.

Crop production technology development

The studies on the long term (63 years) manurial trial indicated that application of 112 kg N/ha + 112 kg P_2O_5 + 112 kg K_2O/ha is the best for highest cured leaf, maximum first grade leaf yield and nicotine content of *Motihari* tobacco.

Plant protection technology development

Biocides (*Trichoderma viride* & *Pseudomonas solanacearum*) @ 5 g in talc formulation/1.5 kg Vermicompost was mixed for 7 days before their application in nursery beds. The best treatments for higher cured and first grade leaf yield, % quality leaf and lower incidence of brown spot in *Motihari* tobacco were *T. viride* + *.fluorescens* + SSP followed by *T.viride* + SSP.

Research initiatives and recent progress towards commercial agriculture

Bioactive compound rich chilli lines development

Chilli lines were characterized for different bioactive compounds. Total carotenoids rich line is Jalpaiguri Local. Capsaicin rich line is Tamenlong King Chilli. Three lines (Dinhata Local 1, Jum Chilli Local, Dinhata Local 6) were identified for black colour (anthocyanin rich). Wide range of variability has been created for black colour along with size of fruits. Five orange coloured lines were tested for Beta carotene content and highest was obtained in DinCh 210-2.

Dinhata Local 1

Jum Chilli Local

Dinhata Local 6

Variability in black coloured

Climate resilient technology development in turmeric

A new product has been developed (Rice husk ash-Potassium-Functional organic fertilizer: RHA-K-FOF) which has enhanced yield and quality of turmeric along with RDF. This RHA-K-FOF is a new fermented product which was developed from Rice Husk Ash (which is otherwise a huge and abundant waste from rice mill with disposal problem in West Bengal), K-Solubilising microbes and other ingredients. The FT-IR analysis of the product depicts about distinct functional groups of aromatic compounds which indicates about quality improvement possibilities in turmeric through application of RHA-K-FOF and RDF.

Climate resilient technology development in chilli

The fresh red chilli yield was significantly increased and by application of indigenous PGP treatments (PGP-2). In-vitro Antifungal assay of PGP-2 based formulation (NF-PGPT-Af) against Aflatoxin producing fungi *Aspergillus flavus* was observed with 48.88% of growth inhibition on plates. Also, in-vitro Antifungal assay of the same against Aflatoxin producing fungi *Aspergillus parasiticus* was observed with 67.2% growth inhibition.

Production technology development in turmeric

The rhizome yield was increased with application of 200 kg N, 80 kg phosphorus and 80 kg K_2O/ha. The highest rhizome yield was obtained when planting is done in 1st week of April. Among the organic treatment combinations, the highest yield was obtained in treatment FYM (40 t/ha) + microbial consortium.

Future scope

There is a potential scope to transform research sector into a more productive, sustainable, and profitable enterprise. The technological development of the research station will go a long way in enhancing income and profitability for the different stakeholders involved in the commercial agriculture sector.

Reference:

NIRCA Rajahmundry (icar.gov.in)

LINKING SOCIAL DIMENSIONS OF CLIMATE CHANGE: TRANSFORMING VULNERABLE SMALLHOLDER PRODUCERS FOR EMPOWERING AND RESILIENCY

Prof. Sumit Chakravorty
Department of Forestry,
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

ABSTRACT
Climate change (CC) is experienced across the globe; however, tropical developing countries are more vulnerable. Majority of the poor population in these countries are rural and smallholders with agriculture as primary occupation. These countries depend more on natural resources and weather dependent agriculture from marginal land holding. The smallholders have low adaptive capacity due to poverty, isolation, marginality, inaccessible to information, illiteracy, lack of institutions, investment, and services, neglect by policymakers and lower human development. CC will significantly reduce farm productivity declining net revenues from smallholder farming systems, adversely affecting economies and livelihoods of the communities in terms of food security and poverty. Unfortunately, agricultural policy is still not well defined and socially integrated with respect to CC mitigation in the developing countries. As a result, implementation of these policies is fraught with socio-economic and political difficulties. Social dimensions relate climate related policy and society. Policies must be developed and adopted considering social dimensions as adoption depend on people. This is possible by good governance that transforms and integrates social and economic interventions by empowering people through participation and decision making throughout the development process while, equally sharing the benefits. Institutions should be responsible to empower people through holistic approaches so that people can transform themselves for overall sustainable development.

KEYWORDS: Climate change, Social dimensions, Vulnerability, Adaptability, Resiliency,

INTRODUCTION

Climate change (CC) is already a reality and is one of the toughest challenges the humanity is facing today. Consequent of this drastic rise in temperature, extremities in weather are now more frequent and intense leading to vulnerable living conditions, insecure food supply and forcing displacement of people. The impact of CC is global but is posing a serious threat to poorer or developing or less developed countries as it will compound existing poverty. The poorer countries are most vulnerable because most of them are tropically located with its citizens subsistently agrarian depending mainly on their marginal land holdings and natural resources along with their limited capacity to adapt to CC (DID, 2004). Globally, over a billion people live in extreme poverty on US$ 1–2 a day (Summer, 2012$_{a, b}$). Poverty leads to vulnerability because of less accessibility to resources resulting inability to adapt to climatic changes (IPCC, 2001). Consequently, the livelihood of these nations is increasingly threatened and further widening the gap between the developing and developed worlds. The risk unfortunately is also collateral because current development strategies are mostly ignorant of CC risks.

IMPACTS OF CC

CC will influence sustainable development and effect livelihoods of people negatively, particularly the rural poor farmers living in the tropical countries. More than 200 million people are affected by climatic disasters every year (WFP, 2011). CC impacts on human systems and ecosystems is diverse and adverse negatively affecting livelihoods causing severe socio-economic stresses through decrease in farm productivity and yield, employment reduction and migration (Chakravarty *et al*., 2015). Impacts of CC depend on demography, economics, and governance (Dasgupta *et al*., 2014). Detection and attribution of impacts is challenging and involves issues using traditional knowledge and local people's perceptions through comparing with global climatic changes (Shukla *et al*., 2015; Dey *et al*., 2017$_{a,\,b}$).

Agriculture, Forestry, and Biodiversity

CC impacts on agriculture, forestry, and biodiversity are direct that lowers productivity which is due to rising temperature and changes in duration and intensity of precipitation and its associated extreme events (Chakravarty *et al*., 2015). Fluctuating crop prices due to CC will enforce the poor farmers to expand his farm land by clearing margin vegetation/deforestation which will modify natural habitat, resulting loss of topsoil and hence productivity (Lambin and Meyfroidt, 2011) which will adversely influence the smallholder activity and livelihood (Neely and Fynn, 2011).

Livestock and Fisheries

CC impact on livestock will be influenced by change in herd dynamics and carrying capacity of grazing lands through drought or heat stress, flood, and disease; changes in rangeland composition, decrease in fodder production or loss of rangeland productivity, demand for meat products, heterogeneity, and inequality between livestock keepers (Verner, 2012; Srikanthan, 2013).

Water Resources

The effect of CC on water resources will be through the size of the population dependent on these resources and will be universally experienced (Hoekstra and Mekonnen, 2012). Changes in water bodies either through drought/lower flow or inundation through flooding of water bodies and sea-level rise will cause temporary loss of land, land activities, sediment transport, damage to transportation, communication, and other infrastructures causing disruption in operations of water infrastructures, disruption in communication especially increasing the vulnerability of rural areas, change in storage capacity and failures of water allocation systems and conflicts among regions and nations (Meza *et al*., 2012; Das, 2015). Agriculture uses 70% of the available water by irrigation and is increasing due to increasing population (Nana *et al*., 2014). There will be shortage of water supply in the event of CC due to decrease in precipitation and melt water from glacial ice and snow, failure of ground water recharge and withering of water resources (Palazzoli *et al*., 2015). Amount and distribution of water available for agriculture will be reduced with increasing population due to its competing use in other sectors (Verner, 2012).

Recreation and Tourism

Recreation and tourism are also reported sensitive to CC affecting livelihood of rural communities close to forest and involved in tourism (Lal *et al.,* 2011).

Mining, Trade, and Investment

Mining enterprise may not remain economically viable due to CC, thus people dependent will become vulnerable (Backus *et al*., 2013). Apart from other economic and political factors, climatic condition like drought caused volatility and unpredictability in the trading environment (Nelson *et al*., 2013). The areas with high probability of climate extremes will repel investment.

Knowledge

CC will influence knowledge transfers, for example, use, dissemination, and transfer of traditional knowledge are believed to be threatened by CC-induced migration (Dasgupta *et al*., 2014).

Economic Loss

The value of losses due to CC is equivalent to at least 5–7% of global yearly GDP (Stern, 2007). CC is expected to decline 50% agricultural output by 2020 (Manyeruke *et al*., 2013). South Asian countries by 2080 will incur GDP reduction of 1.4 and 1.7%, respectively due to loss in agricultural productivity and welfare (Zhai and Zhuang, 2009). Asia will be annually spending US$ 4.2–5 billions more for mitigating the adverse effect of CC on agriculture (ADB & IFPR, 2009). Food grain production will reduce by 18% between 2030 and 2050 (Dasgupta *et al*., 2013) and up to 40% between 2080 and 2100 (Ninan and Bedamatta, 2012) in India.

VULNERABILITY

Vulnerability and CC impacts are related by exposure, sensitivity, and resiliency of people (Regmi and Adhikari, 2007). Agriculture particularly the rainfed is more vulnerable to CC (Bellon *et al*., 2011). Factors affecting vulnerability or resilience of in rural farmers depend on farm diversification, availability of irrigation facilities, farm management and market accessibility (Dasgupta *et al*., 2014). Vulnerability is location specific but its causes and solutions are not but have different social, geographic, and temporal occurrence (Ribot, 2010). Non-climatic factors like inaccessibility or absence to institutions (Romsdahl *et al*., 2013), lack of access to assets (McSweeney and Coomes, 2011), and market opened to international trade also renders the farmers vulnerable to CC (Rivera-Ferre *et al*., 2013_a). These factors make the farmers less accessible to technology, extension services and market (Brondizio and Moran, 2008).

LIVELIHOOD

Livelihood in the developing countries depends on farming (Manyeruke *et al*., 2013). About three-quarter of poor population is rural with agriculture as primary occupation for livelihood and income (IFAD, 2010). Agriculture creates employment opportunities for 1.3 billion smallholders (0.2–2 ha) and landless workers with low resource availability that too is ecologically vulnerable (Lal, 2016). Consequent of less available and vulnerable resource, smallholders are entrapped into a vicious cycle of poverty, hunger, and degradation (Lal, 2016). Unfortunately, CC impact in rural areas is more acute due to deficiency in inputs and infrastructure (Nelson *et al*., 2009). Poor developing nations will suffer more because they cannot afford to meet the cost of CC mitigation.

The access and availability of natural resources to these people will also be influenced by CC. Overall this will impact security and wellbeing of the rural people (Kumssa and Jones, 2010).

Rising food prices render rural people inaccessible to decent nutritious diet (Ruel *et al*., 2010). CC affects rural people through influencing their capabilities or farm heterogeneity (in terms of land rights/ownership, education, food price affecting decent diet, infrastructure) and social relationship (within and outside household); assets (stores, resources, claims, and access), health, and occupation (Claessens *et al*., 2012) that affect farm production.

FOOD SECURITY

World Food Summit (1996) has defined food security as “Food security exists when all people at all times have physical and economic access to safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life” (Manyeruke *et al*., 2013). Food to be secured needs both physical and economic access to food meeting dietary needs food preferences of the people. An individual is food secure only when he has enough income to procure the food he needs or is producing enough food to meet the household requirement at least through subsistence farming.

There is a strong link between poverty and food security as poor faces hunger. Thus, ensuring food security needs sufficient income.

CC is regarded as ‘hunger risk multiplier’ (WFP, 2011). Majority of people in the developing countries are inadequately accessed to food which gets more acute with increasing food prices due to frequent droughts resulting more and more people pushed to poverty and hunger (Nelson *et al*., 2009). More than 800 million people are food insecure and many more suffering from ‘hidden hunger’ (Khush *et al*., 2012). By 2050, hunger will increase by 10–20% solely due to productivity losses. This will significantly reduce calorie availability throughout the developing world causing 24 million more malnourished children (21% more than 2000 AD), majority of which will be from sub-Saharan Africa (WFP, 2009). Moreover, prices of staple crop will also increase up to 150% by 2060 (Bailey, 2011). India with 360 million undernourished and 300 million poor people has the largest number of hungry and deprived people in the world (Ninan and Bedamatta, 2012). The per capita availability of food grain in India declined from 510 grams in 1991 to 443 grams in 2007 (Ninan and Bedamatta, 2012).

SOCIAL DIMENSIONS

People are both victims and drivers of CC. Policy interventions for successful adoption of adaptations depends on people. Social dimensions of CC relate climate, related policy and society. Effective interventions rely on the transformation of socio-economic factors aiding vulnerability and empowering the victims for actions to adopt measures not only for climate-resiliency and sustainable economic future but also the essence of just and equitable societies. Recognizing social dimensions of CC in true sense is justified on these conditions:

• Social dimensions though recognized by climate agreements in vogue but unfortunately in most elemental sense and practice.

• Linking social dimensions with climate policy is fundamental respect human rights.

• CC policies need to be linked with social dimensions holistically in the strategies of action.

• Synergies between objectives and plan of action of CC strategies, sustainable development and human rights.

Social dimensions can easily be linked with CC policy:

• Assessing the issues, i.e., assessing initial impacts on social consequences.

• Processing policies for development, i.e., empowering decision making through transparency and involvement of stakeholders throughout the policy cycle.

• Monitoring and evaluation of results through assessing and restructuring the specific policies and strategies making it unbiased and efficient.

• Knowledge gaps are associated with social dimensions of CC.

Following approaches are recommended in response to knowledge gaps:

• Complementing scientific knowledge with traditional knowledge.

• More cooperation on institutional collaboration for research on social and climate issues.

• Strengthen climate science downscaling in health, disaster management and food and water security sectors.

• Integrating social dimensions in National Adaptation Programmes.

Integrating Social Dimension with CC Policies and Programmes

Policies must be developed and adopted considering social dimensions. Social policies and institutions should be holistic, responsible, and accountable to empower people so that they are transformed into duty bound citizens and become resilient to live

in a sustainably developed society in true sense (Mearns and Norton, 2010). Integrating good governance and social principles
with climate policy design will build up confidence in public spending and investments. Such holistic development can be achieved through the following principles.

Participation**:** Participation in policy formulation and implementation ensures opportunity
of sustainable development in true sense to all stakeholders creating equality and resiliency.

Accountability**:** Local, regional or national governments should be accountable and committed for efficient redressal and delivery system for ensuring human development.

Non-discrimination and equity**:** Status of marginalized, discriminated, and vulnerable groups should be focused during CC mitigation and adaptation policy-making in terms of their participation for involving them in decision-making process to ensure equitable outcomes.

Empowerment**:** Empowering local stakeholders in decision making right from policy planning to execution and then evaluation will avoid conflict of interest safeguarding entitled claims and rights. Empowering is involving the stakeholder in their own development process, i.e., right to decide for themselves. Empowerment is thus not only a stepping stone for good CC policies but forbearer of overall sustainable development.

Transparency**:** The success of CC policies depends on how transparently it is prepared by
giving honest access of information to all stakeholders.

Transformed Policies

Pro people CC policies will improve livelihood, resilience, adaptability and climate-smart farming practices.

General well-being**:** CC adaptation policies have strategies that consider all round personal development including health care and well-being against changing climate.

Balanced diet**:** Strategies encourage fund support for rural development and agriculture for adequate production, access to food, and balanced diet.

Carbon efficient energy generation and access**:** Strategies encourage development of carbon-efficient energy generation system like small-scale renewable energy units with guaranteed access.

Synergy with climate-induced displacement**:** Strategies are pro-poor and pro-development to prevent large scale climate-induced population displacement or develop community friendly small urban centers.

Livelihood opportunities**:** Creates opportunities for diversified income for sustainable livelihoods through encouraging green investments.

Involvement and participation**:** Policies are efficient enough to address and deliver through a system of transparency with involvement and participation of all stakeholders in decision making with equitable sharing of benefits and thus avoiding conflict of interests.

Transforming Smallholders

The way forward is now is transforming smallholders farming system into climate-smart farming system (IFAD, 2013) through practicing the sustainable agricultural management practices in reality by involving the small and marginal producers to manage trade-offs between farm productivity and overall sustainability, ease or withdraw policy barriers, access smallholders with information, and strengthening research and development with adequate flow of funds to identify research gaps and solution.

Research Gaps

The research gaps were identified (IFAD, 2013) are lesser understanding of biological communities i.e., their structure and ecosystem services they provide, relationship between below- and above-ground services with crop growth and development, land use management in relation to its environment that affects crop production, climate effect on agriculture production and management, valuation of ecosystem services associated with farming, diversification of farming methods, practices, and management, and low investments.

ADAPTATION

Adaptation is progressive, developed with experience on past stresses based on local and indigenous knowledge can reduces vulnerability to CC but in many cases was induced by non-climatic factors (Rivera-Ferre *et al*., 2013_b). Adaptation integrated with development process can reduce poverty and improve livelihood in rural areas (Nielsen *et al*., 2012). Farming initiatives for growth in the developing countries will develop resiliency in smallholders farming systems (Kotir, 2011). Holistic approach is required with a focus on socio-economic and environmental dimensions of adaptive capacity (Hammill *et al*., 2008). Poor households may adopt following three livelihood strategies i.e., hanging in (activities that maintain livelihood), stepping up (investment in existing activities for benefits), and stepping out (investment in existing activities for assets) to realize this transition with effective development interventions (Frank and Buckley, 2012).

Farming societies respond to CC impacts by adjusting/modifying/changing their farming/management practices like in planting, harvesting, irrigation, manuring/fertilizing, crop/fodder varieties, herd size and composition, grazing, and feeding patterns, diversifying crops and livelihoods and practicing rain water harvesting and conservation agriculture (Rivera-Ferre *et al*., 2013_b; Speranza, 2013). Agriculture in developing countries must transform to become 'climate-smart' to prevent further deterioration of natural resources ensuring food security amongst the rural poor. For this to achieve, smallholders should have access to either improved or existing technologies or extension services. The more the farmers/growers adopt or develop sustainable agricultural techniques, the more they become resilient to CC like achieving food security through "*Soil carbon 4 per mille*" goal (Minasny *et al*., 2017, 2018; Baveye *et al*., 2018; De Vries, 2018; Nath *et al*., 2018; White *et al*., 2018). The responsibility of achieving this aspiring goal depends on efficiently empowering smallholders through inclusive, responsive, and accountable institutions and good governance integrating holistic social policies and climate policy designs to mobilize and transform smallholder producer responsive and resilient for sustainable developed society.

CONCLUSION

Global CC is today's greatest challenges and it is crucial to act now and take decisive and immediate action against CC. The solution is adaptation and mitigation and fundamental is that it should be at the top of the political agenda in every country. Policies of developing countries to eradicate poverty, ensure food security, as well as to provide education and health services need to include adaptation strategies and implement it effectively considering social dimensions. Climate risk analysis can help to recommend appropriate adaptation strategy. Climate as resource needs efficient management or otherwise a risk to be faced which requires a portfolio of assets to be prepared. The assets are natural, physical, and biological including human, man-made, intellectual, policy, legislative, and service resources. Each asset should be value assessed for their integration into a holistic approach, transforming the actions into sustainable development for today and tomorrow.

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Livestock Technologies Suitable for Small Farming Situations to Mitigate the Impact of Climate Change for Better Livelihood Security

Dr Dilip Kumar Hajra
Department of Agronomy
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Livestock farming is a cornerstone of rural livelihoods, especially for smallholder farmers who depend on it for food, income, and sustenance. However, the accelerating impacts of climate change—including rising temperatures, erratic rainfall patterns, and increased incidence of livestock diseases—pose significant threats to these systems. Adopting climate-smart livestock technologies is essential for ensuring the resilience and sustainability of small farming systems. Below, we discuss various technologies and practices that can help mitigate these impacts and enhance livelihood security.

1. Heat-Resilient Breeds

Developing and promoting heat-tolerant livestock breeds is a critical step in adapting to rising temperatures. Indigenous breeds, which are often naturally adapted to local environmental conditions, can withstand heat stress better than exotic breeds. Breeding programs that focus on improving the productivity of these resilient breeds while retaining their adaptability are crucial for sustainable farming.

2. Improved Feeding Systems

The availability of fodder is one of the most significant challenges for smallholder farmers during periods of drought or erratic rainfall. Innovative feeding systems can help mitigate this issue:

- **Drought-Resistant Fodder Crops:** Cultivating crops that require minimal water ensures a steady supply of nutrition for livestock.
- **Silage and Hay-Making:** Preserving surplus fodder during abundant seasons can help farmers feed their livestock during lean periods.
- **Hydroponic Fodder Systems:** These systems enable farmers to grow nutrient-rich fodder using minimal water and space. Hydroponics is particularly beneficial in regions with limited arable land and water resources, providing a sustainable and reliable feed source year-round.

3. Water-Saving Techniques

Water scarcity is a growing concern in livestock farming. Employing water-saving techniques can significantly improve efficiency and resilience:

- **Rainwater Harvesting:** Capturing and storing rainwater for livestock use reduces dependency on external water sources.
- **Efficient Water Use:** Technologies like drip irrigation for fodder crops and optimized water distribution systems in livestock shelters can conserve water.

4. Livestock Housing

Proper housing can reduce the impact of heat stress on livestock. Climate-controlled shelters with adequate ventilation and shading can improve animal welfare and productivity. Simple and cost-effective designs, such as thatched roofs or reflective paints, can also mitigate heat.

5. Disease Management

The changing climate increases the risk of livestock diseases. Proactive disease management strategies include:

- **Early Warning Systems:** Monitoring and predicting disease outbreaks based on climatic conditions.
- **Vaccination Programs:** Implementing targeted vaccination schedules for climate-sensitive diseases.

- **Low-Cost Diagnostics:** Providing affordable diagnostic tools ensures early detection and treatment.

6. Sustainable Waste Management

Livestock waste, if managed effectively, can be transformed into valuable resources. Sustainable waste management techniques include:

- **Biogas Production:** Converting manure into biogas provides a renewable energy source while reducing methane emissions.
- **Composting:** Producing organic fertilizer from livestock waste improves soil health and reduces reliance on chemical fertilizers.

7. Case Studies

Real-world examples highlight the effectiveness of these technologies:

- Adoption of drought-resistant fodder in arid regions has improved livestock productivity.
- Farmers using biogas units have reduced energy costs and improved waste management.
- Hydroponic fodder systems have provided a reliable feed source in water-scarce areas, enhancing livestock health and yield.

8. Support Mechanisms

For widespread adoption of these technologies, support mechanisms are essential:

- **Government Subsidies:** Financial incentives for adopting climate-smart practices.
- **Training Programs:** Building the capacity of farmers through education and skill development.
- **Collaborative Efforts:** Partnerships with NGOs, research institutions, and private sector players can accelerate the dissemination of technologies.

Conclusion

Climate-smart livestock technologies offer practical and effective solutions for smallholder farmers facing the challenges of climate change. By integrating heat-resilient breeds, efficient feeding systems, water-saving practices, and sustainable waste management, farmers can build resilient livestock systems that ensure better productivity and livelihood security. Investments in education, policy support, and innovation are crucial for enabling these transformations at scale.

Climate Change Mitigation through Organic Farming in Vegetable Crops

Ranjit Chatterjee*, Raj Kumar and Mamoni Deori
Department of Vegetable and Spice Crops
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

ABSTRACT

Vegetable crops are short-duration herbaceous plants that provide essential nutrition to millions worldwide. However, climate change is a growing threat to global food security, significantly impacting vegetable crop development. Rising temperatures, erratic precipitation, excess UV radiation, and extreme weather events like droughts and floods disrupt flowering, pollination, and fruit development, ultimately reducing yields and economic returns. Organic farming offers a sustainable solution by lowering greenhouse gas emissions, enhancing carbon sequestration, and improving soil health through composting, crop rotation, and reduced tillage. It strengthens drought resilience by conserving water with organic mulches, supports climate-resilient crops, and prevents land degradation by restoring soil fertility. Additionally, organic practices promote biodiversity by encouraging pollinators and beneficial insects. Transitioning to organic vegetable farming is crucial for climate adaptation and sustainable agriculture. Policy support, financial incentives, and strong marketing can enhance food security, protect the environment, and improve farmers' livelihoods and rural economies.

Key words: Vegetable crops, Climate change, Organic farming, Soil fertility and Mitigation strategies.

Introduction

Vegetables are an essential part of our daily diet because they provide a cheap and natural source of essential nutrients. They are the powerful source of essential vitamins, minerals, fiber, and antioxidants, which protect the body from oxidative stress, slow aging, and reduce the risk of chronic diseases such as heart disease, diabetes, and obesity (Awuchi *et al*., 2020). Additionally, vegetables contain a high percentage of infused water, which helps keep the body hydrated and maintains optimal bodily functions. Their alkaline nature helps balance the body’s pH levels, reducing acidity and promoting better digestion. Moreover, vegetables are rich in natural bioactive compounds that support metabolism, enhance immunity, and prevent certain type of cancer. Including a variety of vegetables in our meals ensures a balanced and nutritious diet, contributing to a healthier and more active lifestyle. A diet rich in vegetables promotes better metabolism, enhances skin health, and aids in weight management. Most vegetables are low in saturated fat, which helps prevent the rise in blood cholesterol levels, thus supporting heart health. Additionally, vegetables like broccoli, spinach, and romaine lettuce have anti-inflammatory properties that protect the body from chronic inflammation. Since vegetables have a low glycemic index and are packed with dietary fiber, antioxidants, and phyto-chemicals, they help regulate blood sugar levels, minimizing the risk of Type 2 diabetes (Yadav *et al*., 2016). Furthermore, plant-based diets, particularly those rich in vegetables, have been associated with a lower risk of overall mortality, promoting longevity and overall well-being.

Climate change mitigation through organic farming in vegetable crops is a sustainable strategy that reduces environmental impact while enhancing soil health and crop resilience. Unlike conventional farming, which relies heavily on synthetic fertilizers and chemical pesticides that contribute to greenhouse gas emissions and soil degradation, organic farming focuses on natural methods that promote ecological balance. Organic practices such as composting, green manuring, and crop rotation help increase soil organic matter, enhancing carbon sequestration and reducing atmospheric CO_2 levels

(Nair *et al*., 2015). Additionally, intercropping and agroforestry systems in organic vegetable farming enhance biodiversity, supporting beneficial insects and pollinators that improve crop yields. Water conservation techniques like mulching, drip irrigation, and rainwater harvesting are integral to organic farming, reducing water wastage and improving drought resistance (El-Beltagi *et al*., 2022). The use of biofertilizers and natural pest control methods, such as neem extracts, pheromone traps, and microbial solutions, minimizes pollution while maintaining soil fertility. Furthermore, organic farming improves food quality by eliminating pesticide residues, leading to healthier produce with higher nutrient content. By promoting regenerative agricultural practices, organic vegetable farming not only reduces agriculture's carbon footprint but also strengthens food security, making it a vital tool in mitigating climate change and ensuring long-term environmental sustainability.

Climate Change and Vegetable Production

Climate change has emerged as a critical challenge for vegetable production, posing a significant threat to global food security. It refers to long-term shifts in temperature, precipitation patterns, and other atmospheric conditions, which directly impact agricultural productivity. Rising temperatures, unpredictable rainfall cycles, and an increase in extreme weather events such as floods and droughts disrupt the growth and yield of vegetable crops. Additionally, rising sea levels and saltwater infiltration negatively affect soil fertility, further endangering production (Battisti and Naylor, 2009; Lobell et al., 2008). According to the International Panel on Climate Change (IPCC), global agricultural output has declined by 1-5% per decade over the past 30 years due to climate change (IPCC, 2007). This decline highlights the urgent need for sustainable farming practices, improved irrigation systems, and climate-resilient crop varieties to mitigate the adverse effects of climate change on vegetable production.

Causes of Climate Change

Climate change is primarily driven by human activities that increase greenhouse gas (GHG) emissions and disrupt natural climate-regulating processes. One of the leading causes is the excessive release of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) due to industrialization, deforestation, and intensive agriculture, which trap heat in the atmosphere and contribute to global warming. The agricultural sector alone is responsible for 10–12% of direct emissions, excluding emissions from the production of inputs like synthetic fertilizers, pesticides, and fossil fuels (Bellarby *et al*., 2008). Deforestation further accelerates climate change by reducing the Earth's ability to absorb CO_2, with land conversion to agriculture accounting for an additional 12% of global emissions (Chatterjee and Thirumdasu, 2015). Intensive farming practices, including excessive use of chemical fertilizers, release nitrous oxide, a highly potent greenhouse gas. Additionally, industrial and transportation activities that rely on fossil fuels emit vast amounts of CO_2, further exacerbating the problem. Changes in land use, such as urban expansion and monocropping, degrade soil quality, diminishing its ability to store carbon and regulate climate. Overall, agricultural production practices contribute to at least one-quarter of global anthropogenic GHG emissions, and when food handling and processing are included, the agriculture and food sector accounts for nearly one-third of total emissions. Addressing these causes requires a shift towards sustainable practices, reduced fossil fuel dependence, and effective land management strategies to mitigate climate change.

Consequences of Climate change

Climate change has profound consequences on agriculture, biodiversity, and global ecosystems. The inevitable rise in temperature by approximately 2°C is already affecting weather patterns, leading to unpredictable precipitation and increased droughts. Seasonal patterns are shifting, disrupting traditional planting and harvesting cycles. Higher temperatures and erratic weather also contribute to the increased incidence of pests and diseases, further threatening crop yields (Muluneh, 2021). Soil degradation due to extreme weather events and unsustainable agricultural practices reduces land fertility, while declining pollination efficiency hampers fruit and vegetable production (Farooq *et al*., 2022). Rising sea levels pose a risk to coastal farmlands, leading to land loss and salinity intrusion. Additionally, established commercial crop varieties may perform unpredictably under changing conditions, resulting in lower yields and economic instability. The cumulative impact of these factors leads to a significant loss of biodiversity, threatening food security and ecosystem stability worldwide.

Climatic parameters affecting vegetable crop production

Environmental extremes have a profound impact on various developmental phases. The changing climatic patterns adversely affect the normal flowering, pollination and fruit development and subsequently the crop yield. High temperature can affect photosynthesis, respiration and membrane stability as well as levels of plant hormones, primary and secondary metabolites (Rehman *et al*., 2024). Abnormal changes in weather parameters will reduce the activity of pollinating agents posing a significant threat to pollination services (Ganie *et al*., 2024). Additionally, elevated temperatures accelerate the life cycles of many pathogenic fungi, increasing the spread and severity of soil-borne diseases.

Temperature is a crucial climatic parameter that significantly impacts vegetable crop production. Consistently high temperatures induce various morpho-anatomical changes in plants, affecting multiple growth and reproductive processes. Elevated temperatures can hinder seed germination, slow plant growth, and lead to excessive flower shedding, reducing overall yield (Bhattacharya, 2022). Moreover, heat stress negatively impacts pollen viability and gametic fertilization, further diminishing fruit set and production. The quality and marketability of vegetables are also compromised, as high temperatures can reduce fruit size, weight, and nutritional value. As global temperatures continue to rise due to climate change, heat stress poses a major challenge to sustainable vegetable production, necessitating adaptive farming strategies such as heat-tolerant crop varieties and improved irrigation techniques.

Rainfall is a critical climatic factor influencing vegetable crop production, as both excess and deficit rainfall can adversely impact plant growth and soil health (Bisbis *et al*., 2018). Irregular rainfall patterns, including prolonged droughts or heavy downpours, disrupt normal agricultural cycles and reduce crop yields. Insufficient rainfall weakens root growth, suppresses organic matter decomposition, and increases vulnerability to wind erosion, leading to poor soil structure and reduced nutrient availability. On the other hand, excessive rainfall causes soil erosion, leaches essential nutrients, and increases surface runoff, reducing water infiltration and making the land less productive. These unpredictable rainfall patterns, driven by climate change, pose significant challenges to vegetable farming, highlighting the need for water conservation practices, efficient irrigation systems, and soil management techniques to ensure sustainable crop production.

Drought is a major climatic challenge affecting vegetable crop production, leading to severe physiological stress in plants. When water availability decreases, the solute concentration in the soil increases, creating an osmotic imbalance that causes water to move out of plant cells (Farooq *et al*., 2022). This results in cell dehydration, reduced turgor pressure, and impaired metabolic activities. Drought stress negatively impacts seed germination, root development, and overall plant growth, leading to lower yields and poor-quality vegetables. Additionally, prolonged drought weakens plant defense mechanisms, making crops more susceptible to pests and diseases. The lack of adequate moisture also reduces nutrient uptake, further stunting growth and affecting fruit formation. To mitigate drought effects, farmers adopt strategies such as mulching, drip irrigation, and drought-resistant crop varieties to sustain vegetable production in water-scarce conditions.

Salinity is a significant climatic factor that negatively impacts vegetable crop production by hindering plant growth and development. High salt concentrations in the soil create osmotic stress, making it difficult for plants to absorb water and essential nutrients (Munns and Termaat, 1986; Jacoby, 1994). This results in reduced growth rates, smaller leaf size, shorter plant stature, and, in some cases, fewer leaves. Salinity also disrupts physiological processes such as photosynthesis and protein synthesis, leading to stunted growth and lower crop yields. Additionally, excessive salt accumulation in the root zone can cause ion toxicity, further weakening plant health. To mitigate the effects of salinity, farmers implement practices like soil amendments, proper irrigation management, and the cultivation of salt-tolerant vegetable varieties.

Flooding is a major climatic factor that adversely affects vegetable crop production by disrupting plant growth and physiological functions. When plants are submerged in water for extended periods, they accumulate endogenous ethylene, which leads to cellular damage and weakens overall plant health. Flooding reduces oxygen availability in the root zone, causing root suffocation and inhibiting nutrient uptake (Drew, 1981). This stress severely impacts both vegetative and reproductive growth, leading to stunted development, flower and fruit drop, and reduced yields. Additionally, prolonged waterlogging increases the risk of root rot and fungal diseases, further compromising crop productivity. To mitigate flooding effects, farmers adopt raised bed planting, improved drainage systems, and flood-resistant vegetable varieties.

Air pollution significantly affects vegetable crop production by exposing plants to harmful pollutants such as sulfur dioxide (SO_2), nitrous oxide (N_2O), hydrofluoride, ozone (O_3), and acid rain (Datta, 2013). These pollutants cause direct injuries to plant tissues, leading to physiological disturbances such as bronzing of leaves, leaf chlorosis, and premature senescence. High ozone levels can damage leaf surfaces, reducing photosynthesis and overall plant growth. Acid rain alters soil pH, affecting nutrient availability and microbial activity, further hindering crop productivity. As air pollution intensifies, it not only weakens plant resistance to diseases but also lowers vegetable yield and quality, impacting agricultural sustainability.

Problems of Conventionally grown vegetables

Conventionally grown vegetables pose several problems due to the excessive use of harmful fertilizers and pesticide residues. These chemicals not only remain in harvested vegetables but also alter their nutritional values, reducing essential vitamins and minerals. Leafy vegetables, in particular, accumulate toxic levels of nitrates, which can be harmful to human health (Du *et al*., 2007). Furthermore, the runoff of fertilizers and pesticides contaminates groundwater and nearby water bodies such as ponds, streams, and rivers, leading to soil and water pollution. This contamination affects ecosystems, harming aquatic life and biodiversity. Additionally, vegetable growers exposed to these chemicals suffer from skin issues, breathing difficulties, and other serious health problems, while livestock feeding on contaminated fodder also face severe health risks.

Choice of food production practices can be a problem or a solution in addressing climate change

The choice of food production practices plays a crucial role in either worsening or mitigating climate change. Conventional farming relies heavily on chemical fertilizers, synthetic pesticides, and intensive land use, leading to greenhouse gas emissions, soil degradation, and water pollution. Excessive use of synthetic inputs releases nitrous oxide, a potent greenhouse gas, while deforestation for large-scale farming further contributes to rising carbon dioxide levels (Snyder *et al*., 2004). In contrast, organic farming emphasizes natural fertilizers, crop rotation, and minimal chemical use, enhancing soil health and carbon sequestration. By improving biodiversity, reducing chemical runoff, and lowering emissions, organic farming serves as a sustainable alternative that helps combat climate change while ensuring long-term food security. Shifting from conventional to organic farming can transform agriculture from being a problem to a part of the solution in addressing climate change.

Conventional farming and organic farming differ significantly in their approach to crop cultivation, environmental impact, and sustainability. Conventional farming relies on synthetic fertilizers, chemical pesticides, and genetically modified organisms (GMOs) to maximize crop yield and efficiency (Gomiero *et al*., 2011). However, this method often leads to soil degradation, water pollution, and increased greenhouse gas emissions. In contrast, organic farming emphasizes natural processes, using compost, crop rotation, biological pest control, and organic fertilizers to maintain soil fertility and ecosystem balance. While conventional farming prioritizes high productivity, organic farming focuses on sustainability, biodiversity, and minimal environmental impact. Although organic farming may produce lower yields, it ensures healthier food, preserves soil health, and reduces pollution, making it a more eco-friendly alternative to conventional farming.

Benefits of Organic Farming

Organic farming offers numerous benefits that enhance both environmental sustainability and human health. It promotes carbon-rich soil, providing essential energy for microbes that support plant growth. The practice maintains healthy soil by supplying a balanced mix of primary, secondary, and micronutrients, which enhances soil physical, chemical, and biological properties, including water-holding capacity. Organic farming reduces dependence on synthetic fertilizers, minimizing the use of fossil fuels and cutting down environmental pollution (Siddique *et al*., 2014). By utilizing organic waste for cultivation, it fosters sustainable agricultural practices. The food produced is healthier and safer, as it is free from toxic chemical residues and pesticides. This not only ensures consumer well-being but also safeguards farmers, farm animals, and the overall environment. Additionally, crop diversification in organic farming provides farmers with a more secure income, making agriculture both profitable and sustainable in the long run.

Organic vegetables: Opportunity for promotion of local vegetables and endangered cultivars

Organic vegetables offer a great opportunity for promoting local vegetables and preserving endangered cultivars. Locally adapted vegetable varieties thrive under organic farming practices as they are naturally suited to the environment and require fewer chemical inputs. Additionally, local farmers possess traditional knowledge and expertise in large-scale cultivation, ensuring sustainable and efficient production. These farmers and communities also understand the nutritional and medicinal benefits of native crops, incorporating them into their diets through unique recipes. Moreover, organic farming helps conserve seeds and planting materials, maintaining biodiversity and ensuring the survival of indigenous cultivars for future generations. Encouraging organic practices not only supports local farmers but also enhances food security and promotes eco-friendly agriculture.

Basic steps of Organic Vegetable Production

Organic vegetable production follows a systematic approach to ensure sustainability and ecological balance. The process begins with the conversion period, during which the land transitions from conventional to organic farming, eliminating chemical residues. A field map is essential for proper planning and crop rotation, while a buffer zone is maintained to prevent contamination from neighboring conventional farms. Landscape design plays a crucial role in optimizing water use, soil health, and biodiversity. An organic system plan (OSP) outlines the farm's production methods, pest management, and compliance with organic standards. Biodiversity maintenance enhances soil fertility and pest control by integrating diverse plant species and natural habitats. Nutrient management relies on compost, green manure, and organic fertilizers to maintain soil health. Contamination control involves strict measures to prevent chemical exposure from water, air, or neighboring farms. Additionally, integrating **livestock** in organic farming contributes to nutrient recycling through manure, supports soil fertility, and provides an integrated farm ecosystem. By following these essential steps, organic vegetable production ensures sustainability, environmental health, and high-quality produce (Vitale, 2023).

Organic Farming to Combat Climate Change Effect

Organic Practices to Reduce GHG Emission

Organic farming plays a vital role in combating climate change by reducing greenhouse gas (GHG) emissions through sustainable agricultural practices. One of the key principles of organic farming is the prohibition of mineral fertilizers and chemical pesticides**,** which significantly lowers the carbon footprint associated with their production and application. Organic systems promote the reduced dependency on energy inputs, as they rely on natural fertilizers like compost, manure, and crop rotation instead of synthetic chemicals that require high-energy manufacturing processes. Additionally, the avoidance of nitrogen-based fertilizers helps mitigate the release of nitrous oxide (N_2O), a potent greenhouse gas that contributes to global warming. By fostering healthier soils, enhancing carbon sequestration, and reducing emissions, organic farming serves as a sustainable and climate-resilient alternative to conventional agricultural methods, ultimately helping to mitigate the adverse effects of climate change (Mader *et al*., 2002; Pimentel, 2005).

Enhance Carbon Sequestration

Organic farming is a powerful tool to combat climate change by enhancing carbon sequestration in the soil. Organic practices, such as composting, crop rotation, and reduced tillage, increase soil organic carbon levels**,** helping to store atmospheric carbon in the ground. This not only mitigates climate change but also improves soil fertility and resilience. Carbon-rich soil has a greater capacity to retain moisture, making it more resistant to extreme weather conditions such as high temperatures, droughts, and floods (Diacono and Montemurro, 2010). By promoting healthier soils that can absorb and store more carbon, organic farming helps create a sustainable agricultural system that supports long-term environmental stability and food security.

Soil Health Improvement

Organic farming plays a crucial role in improving soil health and combating the effects of climate change. By incorporating compost, farmyard manure, and green manure**,** organic farming enhances soil organic carbon levels, which improves soil fertility and structure. These natural inputs boost the physical, chemical, and biological health of the soil, leading to better water retention, aeration, and nutrient availability. Additionally, the increased microbial activity in organic soil promotes a balanced ecosystem, reducing the dependency on synthetic fertilizers and pesticides. Healthier soil not only supports higher crop productivity but also strengthens resilience against extreme weather conditions such as droughts and heavy rainfall, making organic farming a sustainable solution for climate change adaptation (Liang *et al*., 2008; Woolf *et al*., 2010).

Enhance Water Conservation and Drought Resilience

Organic farming enhances water conservation and strengthens drought resilience, making it an effective strategy to combat climate change. The use of **organic mulches** helps retain soil moisture by **storing more precipitation water**, increasing **water infiltration**, and significantly reducing **evaporation**. This ensures that plants have a consistent water supply, even during dry periods. Additionally, organic practices such as **cover cropping and minimal tillage** further improve soil structure, allowing it to hold water for longer durations. By maintaining higher soil moisture levels, organic farming reduces the impact of drought, supports plant health, and ensures **sustainable crop production** in changing climatic conditions.

Climate-resilient Crops and Varieties

Organic farming promotes climate-resilient crops and varieties, ensuring sustainable food production amid changing environmental conditions. Crop species and varieties are carefully **selected based on their adaptability** to local soil and climate, enabling them to thrive with minimal external inputs. By prioritizing **drought-tolerant, pest-resistant, and disease-resistant** varieties, organic farming reduces the need for synthetic chemicals, enhancing **eco-friendly agricultural practices**. Additionally, diverse crop rotations and polycultures further strengthen resilience, **minimizing the risks** of crop failure due to extreme weather events. This approach not only supports **food security** but also contributes to the overall **sustainability of farming systems** in the face of climate change.

Reducing Land Degradation

Organic farming plays a crucial role in reducing land degradation by restoring soil health and maintaining ecosystem balance. Through the use of **natural soil amendments** like compost, farmyard manure, and green manure, organic farming **enhances soil fertility** and promotes microbial activity. The adoption of **cover cropping, crop rotation, and agroforestry** prevents **soil erosion**, improves water retention, and reduces nutrient loss. By avoiding synthetic chemicals, organic farming **preserves soil biodiversity** and prevents chemical buildup that can degrade land quality. These practices help **rehabilitate degraded lands**, making them productive and resilient against climate change impacts, ensuring **long-term agricultural sustainability**.

Encouraging Pollinators and Beneficial Insects

Organic farming plays a vital role in encouraging pollinators and beneficial insects, which are essential for maintaining biodiversity and improving crop yields. By eliminating harmful pesticides and chemical fertilizers, organic farming creates a **safe habitat** for pollinators such as bees, butterflies, and other beneficial insects (Underwood *et al.*, 2011). The use of **flowering cover crops, hedgerows, and diverse crop rotations** provides essential food and shelter for these insects, enhancing their population and activity. With an increase in pollinators, **fruit and vegetable yields improve naturally**, leading to healthier and more resilient ecosystems. By fostering pollinator-friendly environments, organic farming helps sustain **agricultural productivity while combating climate change effects.**

Conclusion

The transition to organic farming in vegetable crops is a crucial step toward climate change mitigation and the creation of a more **sustainable and resilient agricultural system**. By eliminating synthetic fertilizers and pesticides, organic farming **reduces greenhouse gas emissions,** lowers energy consumption, and enhances soil health, contributing to a **climate-resilient food production model.** Additionally, it promotes **water conservation, biodiversity, and ecosystem balance**, ensuring long-term agricultural sustainability. In the post-COVID-19 era, the rising demand for **safe,**

chemical-free vegetables highlights the urgent need to **support farmers in adopting organic practices**. Encouraging organic farming through policy initiatives, financial incentives, and robust marketing strategies will not only strengthen **food security and environmental conservation** but also **uplift farmers' livelihoods and rural economies**.

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Impact of soil quality indicators affecting climate smart agriculture: A relook for sustainable livelihood security

Prof. Dibyendu Mukhopadhyay
Department of Soil Science and Agricultural Chemistry
Uttar Banga Krishi Viswavidyalaya, Pundibari, CoochBehar,

Abstract: The soil quality parameters like physical, chemical and biological parameters can affect the native fertility status of soil as well as growth and nutrition of the crops. The changing global climatic scenario has influenced the microenvironment in the soil biota leading to unbalanced mobilization of available nutrients of plants and carbon stock in soil. The emerging greenhouse gases from agricultural and allied sectors need to be controlled to ensure the nutritional security of the growing population. The integrated nutrient management could restrict the loss of nutrients from soils and judicious utilization of the applied nutrients for maximising crop yield. Hence, it requires constant monitoring of the soil quality indicators affecting the soil resilience to maintain sustainable livelihood security of the country.

Key words: Soil quality, Climate, Sustainable, Livelihood, Crop yield

Soils are considered as one of the land- components and dynamic systems that generate multiple functions. The soil supports the delivery of key ecosystem services, such as climate and water regulation, carbon sequestration, or nutrient cycling which are seriously affected in degraded ecosystems. Besides, the ecosystem restoration should aim not only to recover the soil's capacity to support vegetation establishment, but also to re-establish ecosystem functions and services. Most soil ecosystem- functions are difficult to assess directly and are therefore frequently inferred from measurable soil properties such as soil quality indicators, which can cover a broad range of soil physical, chemical and biological characteristics (Figure 1). In the context of global environmental change and increased land degradation, it is critical to understand the recovery of soil ecosystems as a fundamental and attached process in the resilience and restoration of degraded lands. It requires extensive review on the surrounding characteristics qualifying restoration, monitoring and assessment on resilience of degraded land. Hence, recognition of the soil quality in ecosystem management is essential for sustainable development in agriculture.

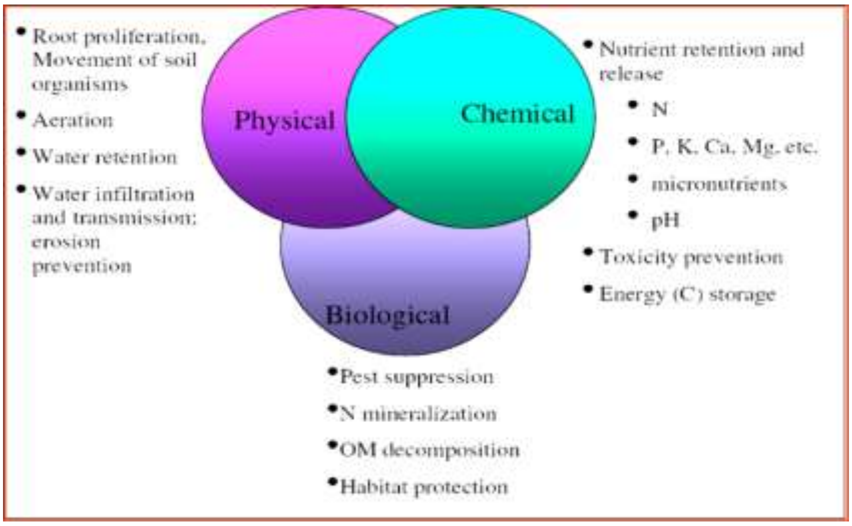

Figure 1: Soil quality parameters

Climate change and Sustainable Development Goals:

Understanding the Sustainable Development Goals (SDGs) is essential to transform the world. The SDGs envisage to end poverty and inequality, protect the planet, and ensure that everybody enjoy health, justice and prosperity. The seventeenth SDGs are structured around the five pillars: People, Planet, Prosperity, Peace, and Partnerships which highlight how the SDGs are an intertwined framework instead of a group of solo goals. There must be a balance and support among these pillars during development in the ecosystem . The Sustainable Development Goals work towards a world of peace and prosperity, eradicating major issues such as poverty and hunger which are related to changing climatic scenario. There is significant variation of average weather conditions over several decades or longer. It is the longer-term trend that differentiates climate change from natural weather variability. The global temperature is warming, weather patterns are changing, polar ice is melting, and sea level is rising in the ecosystem. The impacts of climate change threaten our health by affecting the food we eat, the water we drink, the air we breathe, and the weather we experience. The most common greenhouse gases are (in order of atmospheric concentration): water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and a suite of halogen- bearing gases (like fluorocarbons) that are derived from industrial activities.

There are different reasons for rising GHG emissions, which are:

I. Cutting down forests (deforestation).
II. Burning fossil fuels (coal, oil etc.)
III. Increasing livestock farming.
IV. Fertilisers containing nitrogen
V. Fluorinated gases emitted from equipment and products.

Climate Smart Agriculture:

It is because of the changing global climatic scenario, the concept of climate smart agriculture has come into focus. Climate-smart agriculture (CSA) is an integrated approach for managing landscapes, namely, the cropland, livestock, forests and fisheries addressing the interlinked challenges of food security and climate change. Climate-Smart Agriculture (CSA) could help the people who manage agricultural systems and respond effectively to climate change. The CSA approach pursues the triple objectives of sustainably by i) increasing productivity and incomes, ii) adapting to climate change and iii) reducing greenhouse gas(GHG) emissions whenever possible. Hence , major focus is given on mitigation of GHG emissions from agriculture, adaptation of agricultural practices to climate change, and sustainable maintenance or maximising agricultural productivity.

Sustainable agriculture:

Sustainable agriculture is a unified approach to address the challenges of climate change. Overall, regenerative agriculture systems are a type of sustainable agriculture that aims to increase soil quality and biodiversity (Muhie , 2022). The Climate Smart Agriculture (CSA) programme aims at building climate resilience by promoting regenerative agriculture practices in its value chains and implementing nature-based solutions. The collected data from various tools are converted into real source of information for strengthening and to make ease of agricultural work because CSA is trusted with food security, adaptation, and mitigation, where mitigation is linked with GHG emissions and analysing environmental sustainability. The overall GHG emission depends upon the water availability and quality, soil health and ecosystem services. Similarly, the concept of Smart farming, also known as smart agriculture, is the adoption of advanced technologies and data-driven farm operations to optimize and improve sustainability in agricultural production. The technologies which are now used for smart farming include artifical intelligence (AI), automation and the Internet of Things (IoT). The important aspects covering the Climate- smart practices for attaining the sustainable agriculture are:

I. Crop management
II. Livestock management
III. Soil and water management
IV. Agroforestry
V. Integrated food -energy systems

In this regard, the initiative aims to set a foundation for improving policy frameworks, analyze mineral resources and processing activities, explore decarbonization opportunities, identify challenges, and facilitate decision-making for sustainable development. The sustainable agriculture is again attached with livelihood security of the people in relation to their capabilities and their means of living, including food, income and assets which may be tangible or intangible assets. The household livelihood security covers adequate and sustainable access to income and resources to meet basic needs which should have adequate access to food, potable water, health facilities, educational opportunities, housing and time for community participation and social integration. The rural livelihoods in this regard are associated with , i. Farm labourers, ii. Farmers, iii. Farmers with other sources of income and
iv. Rich farmers and landowners.

Soil quality parameters affecting livelihood security:

The soil quality parameters greatly affect the production potential of the crop in a diversified ecosystem. There may be drastic reduction of yield for change in soil pH, available nitrogen, phosphorus, potassium, micro and secondary nutrients as well as soil microbial populations. The transformation of nutrients depends on climatic parameters that may lead to biototic and abiotic stress for crops. A livelihood is sustainable when it can withstand with and recover from the stresses and shocks and maintain or enhance its capabilities and assets both now and in the future without undermining the natural resource base. Livelihood refers to the full range of means that individuals, families and communities utilize to make a living, such as wage-based income, agriculture, fishing, foraging, other natural resource-based livelihoods. Based on the sustainable livelihood analysis framework, livelihood assets are the resource base of different households and are divided into five categories: nature, human, social, financial and material assets and the ultimate purpose of livelihood programmes lies in the creation of economic stability that works for the benefit of everyone in the community for long time. Again the livelihood security is related with the "Food and Nutrition Security'' which include availability, access, utilization, and stability. In addition, there are two more dimensions that are important: agency and sustainability. These six dimensions of food security are reinforced in conceptual and legal understandings of the right to food in terms of physical, social and economic access to people. The important factors affecting food security include population growth, poverty, global climate change, political instability, food waste, natural disasters, food production, food distribution networks, gender inequality, and malnutrition. Besides, the most important reasons of causing food insecurity are high food prices and disruptions in global food supplies, climate change, water scarcity, land degradation, agricultural diseases, pandemics and disease outbreaks in the environment , while the food insecurity is ensured when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life and thus qualifying the availability access ,utilization and stability of food security . In this regard, the soil health and resilience are important to cater the soil quality parameters influencing build up of N-P-K, micro and secondary nutrients as well as carbon stock. The agricultural management options are important for C-sequestration (Figure 2) over the progress of time.

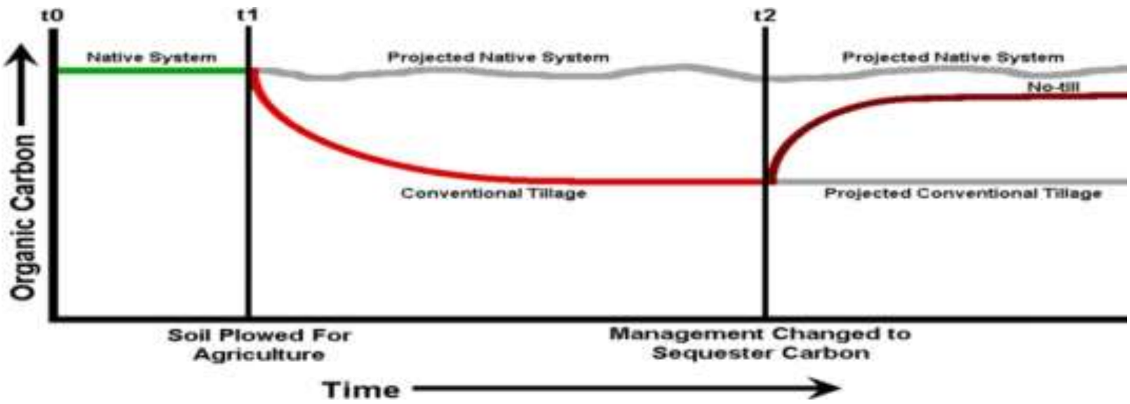

Figure 2: Changes of soil organic carbon under different management practices Eric C. Brevik (2013)

Furthermore, the available pools of nutrients are decreasing due to the gradual degradation of soils which are the physical, chemical and biological decline in soil quality leading to the loss of organic matter, decline in soil fertility, and structural condition, erosion, adverse changes in salinity, acidity or alkalinity, and build- up of toxic chemicals, pollutants or excessive flooding. Similarly, to harvest a good carbon yield from soils, the soils must have good carbon capturing or carbon emitting (to curb) capacity (NAAS,2025) to attain viability in carbon farming on long term basis. Hence, the need of adoption of smart agriculture was focussed to sustain agricultural production level. The food and nutritional security also depends on the soil quality indicators, which can determine the facility, status of soil for raising crops, still sometimes, the desired yield of crops may not be attainable due to the factors like,

I. Erosion
II. Compaction
III. Crusting and salinization
IV. Nutrient mining
V. Loss of soil organic matter As a result of which there is

Yield reduction

I. Reduction of efficiency of input
II. Micronutrient deficiency that leads to food insecurity in the long run.

Natural resource management: Natural resource management (NRM) deals with managing the way in which people and natural landscapes interact. It brings together land use planning, water management, bio-diversity conservation, and the future sustainability of industries like agriculture, mining, tourism, fisheries and forestry. There are various factors to maintain NRM in the environment, such as:

I. Water and nutrient management
II. Application of Nanotechnology/Nanofertilizers
III. Groundwater management
IV. Soil carbon build-up
V. Land Resource Inventerization (1:10000 scale, rainfed and irrigated)
VI. Soil fertility map-GIS approach

The gradual depletion of natural resources like water, nutrients and carbon with the growing population is creating stress in the environment. Hence, social awareness is very much essential to understand realities on sustainable development. Hence, in order to maintain proper balance in the ecosystem with respect to soil quality parameters and crop-yield potential, following policies may be considered.

1. Adoption of suitable crop rotation preferably legume-non-legume, remunerative crop diversification and intercropping for enhancing carbon sequestration.
2. Increasing cropping intensity by reducing the frequency of bare fallow to improve biomass production.
3. Adoption of system diversification by comprising diversification of income-generation activities at the farm level, value addition, changing market trends and exploring new opportunities.
4. Diversification of the cropping system under Conservation Agriculture to attain sustainability.
5. Implementation of technological development, government programmes and insurance products, farm production practices, and farm financial management as adaptation options.

Conclusion:

Thus, soil quality indicators could directly or indirectly affect the nutritional security of the people by improving proper management of the soil quality indicators. Agricultural practices, such as, conservation agriculture with zero tillage, residue management with diversified crop rotation could improve the soil quality parameters compared to conventional one. The soil organic carbon-stock may be improved which correspond to carbon farming. The climate smart agriculture (CSA) could increase the yield of the crop under resource conservation strategies ,where, lower GHG emissions may be observed from CSA than from conventional practices. These CSA practices provide an excellent alternative to conventional agriculture practices irrespective of location and size of the farm and improves soil organic carbon stock and also other soil properties to develop overall quality and resilience in the environment.

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Emerging Pest Problems in Horticultural Crops Under Changing Cropping Patterns and Climatic Conditions

Prof. Suprakash Pal
Agricultural Entomology, Regional Research Station (Terai Zone)
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

India is an important country to produce a wide array of horticultural crops like vegetables, spices, ornamentals, fruits and plantation crops. But successful cultivation of these high valued and commercial crops is often constrained by the attack of various insect pests and mites. In addition to causing direct damage by feeding some insect pests also cause the secondary damage by acting as vectors for transmitting viral diseases in a number of crops. Of late, the pest problem has been aggravated with the changes in cropping patterns and climatic conditions. Moreover, till recently the most common practices adopted by the growers to contain these pest infestation has been the application of calendar-based pesticides. As a result, many pests either have developed resistance to insecticides or expanded their horizon to invade new host plants. Many pests hitherto a minor one have attained the status of a major pest and the secondary outbreaks of pests have become a common phenomenon. Several pests got introduced and are now wide spread across the country due to inadequacy of plant quarantine measures. All these factors have resulted in an imminent shift in the status of pests. These emerging and invasive pests are one of the major concern for sustaining the food security of our country.

Emerging pests

The pest reported from a locality on a particular crop whose population has been increasing considerably over a period of time causing or likely to cause severe economic damage is termed as an emerging pest. The newly introduced invasive pests alien to any country which may cause a havoc in the absence of its native natural enemies is also designated as an emerging pest.

Reasons behind the exacerbation of insect pests

The main reasons behind the emergence of a pest are changes in climatic conditions, modification of cultivation practices like introduction of high yielding varieties, monoculture, increase in cropping intensity, excessive use of fertilizers, assured irrigation facilities, injudicious use of chemical pesticides and introduction of exotic insect pests due to quarantine failures. Among all these reasons, climate change is the most indubitable reason behind gradual change in the status of pests (Mukhtar *et al*., 2023). Ramamurthy *et al*. (2009) also opined that the climate change exerts a profound effect on the intensity of pest problems. There are several literature available that states the role of climate change behind the shift in status of pests and their outbreaks. In case of pests of horticultural crops, the probable reasons behind the upsurge of mealybug, *Phenacoccus solenopsis* in vegetables and ornamentals has been reported to be the hot and dry weather (Dhawan and Saini, 2009). In fact, mealybugs have become indicator insects for the current ecosystem alterations due to slow changes in climate during the period from 2002 to 2005 (Dhaliwal *et al*., 2010). Among these, *Paracoccus marginatus* on papaya have become quite serious. The hibiscus mealybug, *Maconellicoccus hirsutus* causes extensive damage to crops like *Hibiscus*, *Chrysanthemum*, Rose, cucumber, grape, guava, coconut coffee etc. (Tanwar *et al*., 2007; Rajendran, 2009). Earlier Palaniswami *et al*. (1995) opined that abnormal weather conditions were the reason behind the outbreaks of spiralling whitefly, *Aleurodicus disperses* in Tapioca.

Climate change: Species' distributions are strongly determined by climatic factors and are labile, expanding or contracting during long-term climatic fluctuations (Hewitt, 2000). Expansion of geographic range from tropics and subtropics to temperate regions will be resulting in increased abundance of tropical species in cooler regions (Das *et al*., 2011). The species at lowest latitudes or elevations must migrate to cooler environments to avoid extinction (Colwell *et al*., 2008). Due to elevated temperature regimes the multivoltine insects might have more number of generations. More sap feeding insects are emerging as major pests when plants are grown at elevated level of carbon dioxide (Hamilton *et al*., 2005). The intensity of *Spodoptera litura*, a polyphagous pest is likely to further increase under the potential climate change, as it has been found to consume more than 30 per cent cotton leaves at elevated carbon dioxide levels (Kranthi *et al*., 2009). Diamond back moth, *Plutella xylostella* may have two additional generations per year due to climatic changes in Japan (Cherim, 2007). Gupta *et al*. (2009) opined that the tea mosquito bug *Helopeltis antonii* may spread to new areas under current scenario of climate change and states like Andhra Pradesh, West Bengal and Orissa may come under this pest attack in the changed situation.

Modification of cultivation practices: Larger areas have been brought under monoculture of vegetables, spices, ornamentals and medicinal plants in recent times. Continuous cultivation of high yielding varieties of these crops under higher input use and expanded irrigation facilities have invited insect pest infestations in higher magnitude.

Injudicious use of chemical pesticides: It is a well-accepted fact that the pesticide umbrella played the pivotal role in safeguarding the yield potential of high yielding varieties and hybrids which was practically impossible to achieve in its absence. Inspite of increase in insecticide use, the losses due to insect pests have been increasing steadily, mainly due to the harmful effects the injudicious use of pesticides cause like elimination of natural enemies, resurgence of pests, development of insecticide resistance and outbreak of secondary pests.

Introduction of exotic insect pests: Plant quarantine measures both for imports/exports are critical to protect Indian agriculture from the ingress of exotic pests and to promote safe exports. However, in the past several pests got introduced and are now wide spread across the country due to inadequacy of plant quarantine measures. Among these the case history of Coffee berry borer (*Hypothenemus hampei*), a significant insect pest may be mentioned. It was first reported in 1990 at Wayanad, Kerala. It is believed that probably it got introduced accidentally either through coffee brought by refugees from Sri Lanka or through illegally imported coffee seeds in India (Singh and Ballal, 1991). It infests both arabica and robusta types of coffee. The coffee berry borer has spread to the major coffee growing areas (3,88,000 ha) in Southern states of India. Annually more than Rs. 20 crores is spent towards the control measures (Sathyanarayana and Satyagopal, 2013; Vijayalakshmi *et al*., 2013).

Emerging insect pests of horticultural crops in India

The insect and mite pests that have become much more serious and emerged as or are likely to emerge as key or serious pests mainly due to changing climatic conditions in the arena of horticultural crop ecosystems are tabulate in Table 1.

Table 1. Emerging insect and mite pests of horticultural crops in India

Common Name	Scientific Name	Crops
Serpentine leaf miner	*Liriomyza trifolii* (Burgress)	Tomato, Brinjal, Cowpea, Cucurbits etc.
Hadda beetle	*Henosepilachna vigintioctopunctata* Fab.	Brinjal, Bitter gourd, Cowpea
Fruit borer	*Helicoverpa armigera* (Hubner)	Tomato, Cabbage, Peas, Chilli, Brinjal, Okra
Gall midge	*Asphondylia capparis* Rubsaman	Brinjal, Chilli, Capsicum
Mealy bug	*Phenacoccus solenopsis* Tinsley	Brinjal, Tomato, Chilli, Okra, Cucurbits
Red spider mite	*Tetranychus urticae* Koch.	Okra, Brinjal, Cucumber, Cowpea
Plume moth	*Sphenarches caffer* Zeller	Bottle gourd
Peach potato aphid	*Myzus persice* (Sulzer)	Potato
Cotton aphid	*Aphis gossypii* (Glover)	Potato
Spotted pod borer	*Maruca vitrata Geyer*	Cowpea
Tomato leaf miner	*Tuta absoluta* (Meyrick)	Tomato, Potato
Diamond back moth	*Plutella xylostella* (Linn.)	Cabbage, Cauliflower, Knolkhol
Tobacco caterpillar	*Spodoptera litura* (Fab.)	Vegetables & Ornamentals
Fruit fly	*Bactrocera* spp.	Vegetables & Fruits
Thrips	*Thrips parvispinus* (Karny)	Chilli
Western flower thrips	*Frankliniella occidentalis* (Pergande)	Polyphagous
Silver leaf whitefly	*Bemisia argentifolii* Bellows & Perring	Wider range of crops
Spiralling whitefly	*Aleurodicus dispersus* Russel	Chilli, Groundnut, Papaya, Banana, Guava, Coconut
Litchi fruit borer	*Conopomorpha cramerella* Snellen	Litchi
Sapota seed borer	*Trymalitis margarias* Meyrick	Sapota
Papaya mealybug	*Paracoccus marginatus* Williams & Granara de Willink	Papaya, Brinjal, Potato, Tapioca/Cassava
Cassava mealybug	*Phenacoccus manihoti* Matile-Ferrero	Tapioca/Cassava
Banana skipper	*Erionota torus* Evans	Banana
Coconut leaf beetle	*Brontispa longissima* (Gestro)	Coconut
Coconut eriophyid mite	*Aceria guerreronis* Keifer	Coconut

Coffee berry borer	*Hypothenemus hampei* (Ferrari)	Coffee
Tea mosquito bug	*Helopeltis theivora* Waterhouse	Tea, Red cherry pepper (*Capsicum annum* var. *cerasiforme*), Large cardamom
Banana lace wing bug	*Stephanitis typica* (Distant)	Banana
Rugose spiralling whitefly	*Aleurodicus rugioperculatus* (Martin)	Coconut, Banana, Oilpalm, Arecanut, Guava, Mango
Woolly whitefly	*Aleurothrixus floccosus* (Maskell)	Guava

Sources: Dhaliwal *et al*. (2010); Rai *et al*. (2014); Sharma (2016); Rathee and Dalal (2018); Mukhtar *et al*. (2023); Kar *et al*. (2024)

Emerging insect pests of horticultural crops in Terai region of West Bengal

Hadda beetle, *Henosepilachna vigintioctopunctata* Fab. (Coleoptera: Coccinellidae) has been found in abundance on brinjal and other solanaceous crops at Pundibari, West Bengal *Henosepilachna septima* has been found to cause severe damage to ridgegourd and other cucurbitaceous crops. During rabi season *H. vigintioctopunctata* was significantly influenced by all the weather parameters (Jayashree, 2023). It has also been reported as an emerging pest in many parts of the country particularly eastern Uttar Pradesh and Bihar (Halder *et al*., 2011).

Lace bug, *Cochlochila bullita* (Stal) has been recorded as a major and severe pest of Tulsi or Basil causing significant damage in the terai region of West Bengal. The intensity of infestation may increase further in future due to climatic changes as the weather factors like temperature have been found to have significant association with this pest occurrence (Thathukannan, 2021).

Mealybug infestation is on the rise in the terai region of West Bengal particularly due to abnormal climatic conditions and erratic rainfall pattern during last few years. The invasive mealybug species like *Phenacoccus solenopsis* and *Paracoccus marginatus* have been recorded on number of ornamentals, fruits and medicinal plants.

Spider mites in ornamentals like the infestation of *Tetranychus macfarlanei* and *Tetranychus urticae* have been recorded in severe form in several crops like chrysanthemum, carnation, gerbera etc.

Spiralling whitefly, *Aleurodicus dispersus* and Rugose spiralling whitefly, *Aleurodicus rugioperculatus* infestation in severe form has been observed on coconut in terai region of West Bengal.

The melon thrips, *Thrips palmi* is causing devastating damage to watermelon crops in recent years under terai region of West Bengal.

Conclusion

The pest scenario of the country as well as this region has witnessed a drastic shift in status during the last few decades. Sucking pests like mealybugs, thrips, mites etc. which were earlier considered to be minor pests have now attained the status of major pests. Thus, there is an urgent need to conduct regular field scouting for judging the status of pests in various crop ecosystems so that timely interventions can be done for their sustainable management.

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Impact of climate change in varietal evaluation with special emphasis on wheat (*T. aestivum*)

Dr. Saikat Das
Associate Professor and In-Charge, AICW&BIP
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar 736165

Introduction

Long-term change in the weather pattern is affected by natural and human factors. Climate is changing every day due to several natural processes as well as by human acts. One of the biggest sources of climate change is the accumulation of carbon dioxide in our atmosphere. Carbon dioxide accumulates in the atmosphere by burning fossil fuel, automobile smoke, chlorofluorocarbons released from electric appliances (Air conditions or refrigerators), and volcanic eruptions. Accumulation of carbon dioxide in an atmosphere enhanced the greenhouse effect because carbon dioxide is considered one of the most important gases in greenhouse gases. It is observed that amount of carbon in the atmosphere is 80% increases today from the time when life on earth started. Other gases include Methane, Nitrous oxide, Ozone, Water vapour, Halocarbons. These gases create a sheet around the earth which causes a rise in temperature on earth which is also known as global warming. This temperature rise not only affects humans but also disturbs all the natural habitats and ecosystems on earth. Climate change effect not externally humans, plants, animals, and microbes but also internally by interrupting their genome and causing mutation and cause permanent change on a species level. It causes many animal and plants species endangered. This also interferes with the life cycle of insects and it makes pathogens resistant and cultivars fail to respond better which ultimately leads to food security issues.

Due to global warming agriculture faces serious threats like low crop productivity which leads to global hunger and this low production rise the cost of food commodities and makes it unaffordable for the poor population. Global warming affects the pattern of rainfall which contributes to other disasters. Rise in atmospheric carbon dioxide reduced crop production as well as downgrade its nutritional value, in some cases, due to change in the chemical composition some crops start producing toxins. Plant responses to climate change by altering their phenological characteristics. Flowering and fruiting or grain filling in the case of cereals is a very important stage that is particularly affected its pollination, root growth, seed formation, number of seed production, leaf expansion, and ripening of the crop. Time for flowering and fruit ripening is also affected by the environment, photoperiod, and vernalization.

Bread wheat (Triticum aestivum L.) accounts for 30% of the global cereal production and for 20% of the calories in human diets (FAO, 2014). After China, India is the world's second-largest wheat producer, accounting for roughly a quarter of global wheat output. Wheat output in India has grown by more than six times over the last four decades, from about 12 million tonnes in 1964-65 to around 112.92 million tonnes in 2023-24. Wheat acreage has risen from 13 million hectares to about 31.23 million hectares over this time, while productivity has improved from 9.13 q -ha to 36.15.0 q^{-1} ha. (Source: Project Directors Report, 2023-24, ICAR-IIWBR, Karnal, India). This was only possible due to the import of semi-dwarf genotypes from (CIMMYT) during the 1960s which was a crucial component in India's green revolution, which saw a quantum jump in wheat yield.

Effect of climate change on wheat growth and production

Climate change has a very different effect on crop productivity. It is estimated that a 1°C increase in temperature can cause a 10–20% decrease in crop yield globally. Wheat is also no exception to this. Among abiotic stresses heat stress is one of important abiotic stress which wheat faces today. The average global temperature is reported to be increasing at a rate of 0.18°C every decade (Hansen et al., 2012; Annual Climate Summary, 2010). Though, heat stress affects the metabolic pathways at every stage of life of wheat finally leading to yield reduction, the effect of high temperature is particularly severe during grain filling; these losses may be up to 40% under severe stress (Wollenweber et al., 2003, Hays et al., 2007). These, extreme temperature changes during sensitive stages like flowering, anthesis, and milking stage affect wheat yield, grain weight, and grain size at the end of season significantly. Other effects of high temperatures are decreased grain weight, early senescence, shrivelled grains, reduced starch accumulation, altered starch-lipid composition in grains, lower seed germination and loss of vigor (Balla et al., 2012). Wheat in rainfed areas is more affected with change in rainfall pattern, rainfall declines and it affects the production of wheat directly, yield decline 5–7 percent with the rise in each degree of temperature (Liu et al, 2016). To adapt new crop varieties to the future climate, we need to understand how crops respond to elevated temperatures and how tolerance to heat can be improved (Halford, 2009).

Carbon dioxide in the air is an important source of carbon for plants, unfortunately, this CO_2 level is increasing day by day due to human activities. This elevation not only results in ozone depletion but also affects the growth and yield of field crops. It is observed that an increase in carbon dioxide increases the rate of photosynthesis, it increases water efficiency and high nutrient availability (Long et al., 2004). In C_3 plants increase of CO_2 level up to 1 k ppm stimulates the rate of photosynthesis but this does not increase the yield or biomass of the plant as yield in the wheat crop depends not only on the rate of photosynthesis but also on the active phase of photosynthesis along with sink capacity of grain (Amthor, 2001).

Wheat is normally grown in the areas which received less than 550 mm to 325 mm of rainfall during the wheat growing season. In arid and semi-arid regions, elevated CO_2 and temperature change the pattern of rainfall which affect plant production very badly. In rainfed areas, the changing pattern of rainfall limits the plant growth in low rainfall areas while in high rainfall areas it avoids water logging conditions and helps plants to grow well. But according to rainfall prediction for 2070, it is expected that an increase of wheat yield globally due to reduction in the winter rain up to 10% in the rainfed areas (Ludwig *et al*., 2006).

Effect of climate change in diseases-pest outbreak

Climate change has a strong impact on the pathogen population. Temperature and water play important role in the germination and survival of pathogens. Among biotic stresses, diseases caused by fungal plant pathogens such as *Fusarium graminearum* Schwabe (teleomorph: Gibberella zeae), the main causal agent of Fusarium head blight (FHB), and *Puccinia graminis* Pers. f. sp. tritici Eriks & E. Hehn (Pgt), the causal agent of stem rust, are of global importance. FHB is one of the most serious problems in wheat cultivation in the upper Great Plains of North America, China, and Europe (McMullen et al. 2012). With climate change creating more conducive environments for FHB development, this disease could potentially impact wheat production areas outside of the current range where it is currently an issue (He et al., 2020). FHB causes shrivelled, lightweight, chalky coloured kernels (often regarded as Fusarium damaged kernels [FDK]), which affects yield, but also produces harmful mycotoxins such as deoxynivalenol (DON) and its acetylated derivatives. The presence of FDK results in downgrading of the grains because FHB destroys the starch granules, cell walls, and endosperm proteins. DON, also known as vomitoxin, causes feed refusal and poor weight gain in animals and may cause health problems in humans over a certain threshold (McMullen et al. 1997, 2012). Due to concerns over toxin accumulation in the grain, many countries have imposed limits on toxin levels present in food and feed items, which makes it a more practical problem associated with FHB (Gilbert and Haber, 2013).

Other than FHB, three wheat rusts, namely leaf rust (caused by *Puccinia triticina* Eriks.), stem rust (caused by *Puccinia graminis tritici*), and stripe rust (caused by *Puccinia striiformis* Westend f. sp. tritici Eriks.) are equally devastating in many parts of the world (Brar et al. 2019; R. P. Singh *et al*., 2011). Stem rust in particular has caused more economic damage than the other two rusts and in recent history, an outbreak of a group of stem rust races, regarded as Ug99 race group, caused significant yield losses in wheat-growing regions in Africa (Pretorius et al. 2000; R. P. Singh et al. 2011). The unique virulence combination on Sr31 and Sr38 of Ug99 races rendered a wide range of wheat cultivars susceptible to this disease and since then efforts were initiated to identify and breed for Ug99 resistance (R. P. Singh *et al*., 2016).

Another recent epidemic which shattered the South Asian wheat cultivation is the occurrence of Wheat blast disease in Bangladesh in districts close to West Bengal borders of India during early 2016 (Malakar et al, 2016). This disease is caused by *Magnaporthe oryzae* pathotype Triticum (MoT) B.C. Couch (Anamorph Pyricularia oryzae Triticum) which is originated in 1985 in Brazil and later reported from other countries like Bolivia, Uruguay, Paraguay and Argentina in South America (Iragashi et al., 1986; Prabhu et al., 1992; Perelló et al., 2015). Although, wheat blast is not yet reported in India, it can threaten wheat production as it is known to have devastating effects on yield losses of up to 100% (Duveiller et al., 2016; Cruz and Valent, 2017). The disease is categorized into most damaging diseases of wheat due to its multiple modes of survival (seed, secondary hosts, crop residue and airborne conidia), fast spread and damage to spikes thus causing losses ranging from 10-100%, development of resistance to fungicides, higher rate of mutation and lack of resistance in common wheat varieties.

Climate changes also affects insects population which survives on plants. It also contributed to increasing insect outbreaks. The increase in temperature and drought conditions causes wildfire and causes plant mortality which ultimately leads to carbon sinks and rising carbon levels in the air (Hicke et al., 2012). Major insects which threaten wheat yield are wheat stem borer, wheat aphids, which causes losses up to the economic threshold level. Change in carbon dioxide amount in the atmosphere causes a significant impact on plants, insects, and microorganisms. Xie et al, 2022 studied the effect of elevated CO_2 coupled with drought stress on aphid population in wheat where they observed both elevated CO_2 and drought promoted soluble sugar accumulation in wheat. However, opposite effects were found on amino acid content—it was decreased by elevated CO_2 and increased by drought. Further, elevated CO_2 down-regulated the jasmonic acid (JA) -dependent defense, but up-regulated the salicylic acid (SA)-dependent defense. Meanwhile, drought enhanced abscisic acid accumulation that promoted the JA-dependent defense. For aphids, their feeding always induced phytohormone resistance in wheat under either elevated CO_2 or drought conditions. Finally they concluded that the aphid damage suffered by wheat in the future under combined elevated CO_2 and drought conditions tends to maintain the status quo.

Insect population increases in this rising temperature and transmit virus very smoothly from infected to a healthy plant. These climate changes affect badly beneficial insects which cannot survive in dry weather with hot temperatures, it also affects their ability to kill harmful insects (Romo and Tylianakis,2013).

Management strategies

Global warming affects crop productivity throughout the world. Expensive food items are the first sign of a sudden food shortage in the world's crop yield which will be even more shortly if remain uncontrolled. For this reason, scientist needs to develop crop varieties that are resistant to drought, salinity, and major diseases which are the major threatening factors. So that wheat crop production increases to meet the demand of the human population. Adaptation includes agronomic practices like time of sowing, water management, nutrient availability, timely weeding, and resistant cultivars are helpful tools. Molecular breeding enhances the wheat productivity to fight with different abiotic and biotic stresses that crops have to face when cultivated in a field. Molecular markers help to identify the insertion and activity of various genes. Advancement in DNA sequencing helps in finding novel resistant genes and their insertion in different crops possible. Government should make management strategies for the minimization of global warming. New projects should be designed for the conservation of water loss, minimizing the use of pesticides in fields. Public awareness campaigns should be initiated at the individual level to stop activities that are changing our ecosystem. Pollution-free water should be used to irrigate agricultural land. There should be instruments for the assessment of Carbon concentration in air, and temperature monetization. Training sessions should be made to practice techniques that are helpful in conservation.

Conclusion

Climate changes cause an increase in carbon dioxide emission, which causes the greenhouse effect around the globe, it affects all agriculture ecosystems in different ways, sometimes one factor favours plant growth but in combination with other shifts the positive effect into a drastic negative effect. It has been found that global increase in carbon dioxide helps C_3 plants to increase growth, improve plant water uptake capacity and yield of crops. It also favors C_3 plants to compete with C_4 weed that is grown side by side with the main crop, plants become more resistant to diseases. But these benefits turn negative when the temperature of the area increases, suddenly plants lose the ability to uptake minerals from the soil, and reduction of grain size, grain weight, and crop resistance towards diseases, increase pest population and water holding capacity of plants. Temperature variation alters the rate of precipitation which ultimately increases drought conditions which is very crucial for wheat growing in rainfed regions of the world. This condition helps C_4 weeds instead of the wheat crop which increases the competition between crop and nutrient for food and water. It is also included as a topic of discussion that if these effects remain uncontrolled it will cause a major food shortage in coming years when food is already expected to be doubled as the world population increases day by day and industrialization increases all these risks. So, it is important to practice the management practice suggested above to conserve our ecosystem and make this planet a safe place to live.

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Implication of climate change on food security, food safety and agro-processing

Prodyut Kumar Paul
Professor and Head
Department of Pomology and Post-Harvest Technology
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

1. Introduction

Climate change has profound effects on food production, food safety, and agro-processing due to rising temperatures, erratic weather patterns, and increased frequency of extreme weather events. These impacts create challenges in raw material supply, processing efficiency, food safety, storage, and transportation. The food industry plays a crucial role in ensuring global food security, but it is also one of the largest contributors to carbon emissions, water use, and waste generation. To reduce its environmental footprint, the industry is increasingly adopting sustainable practices across production, processing, packaging, and distribution.

2. Global climate change trends

Over the year, the global surface temperature has risen to cause a significant cause of concern. Since the pre-industrial era (1850-1900), the Earth's average surface temperature has increased by approximately 1.1°C to 1.2°C due to greenhouse gas emissions. The last decade (2011-2020) was the warmest on record. The global average temperature in 2023 was about 1.45°C above pre-industrial levels. 2023 was recorded as the hottest year ever, surpassing previous records. Polar regions (especially the Arctic) are warming two to four times faster than the global average. Urban areas experience stronger warming due to the urban heat island effect.

2.1. Causes of Rising Surface Temperature:

- Increased Greenhouse Gases (CO_2, CH_4, N_2O) from burning fossil fuels, deforestation, and industrial activities.
- Deforestation reduces carbon absorption, increasing atmospheric CO_2.
- Changes in Land Use (agriculture, urbanization) affect heat absorption and reflection.
- Natural Variability (volcanic eruptions, ocean cycles like El Niño) influences short-term fluctuations.

2.2. Impacts of Rising Global Surface Temperature:

- More Extreme Weather: Heatwaves, droughts, heavy rainfall, and stronger storms.
- Rising Sea Levels: Due to melting glaciers and ice sheets.
- Ocean Warming & Acidification: Affecting marine ecosystems and fisheries.
- Threats to Agriculture & Food Security: Reduced crop yields due to heat stress.
- Health Impacts: Increased heat-related illnesses and disease spread.

2.3. Future Projections:

- If emissions continue unchecked, global temperatures could rise by 2.5°C to 4.5°C by 2100.
- The Paris Agreement aims to limit warming to below 2°C, preferably 1.5°C.
- Achieving this goal requires rapid reductions in CO_2 emissions and adoption of renewable energy.

3. Global Energy Needs and Sources

The world’s energy demand continues to rise due to population growth, economic development, and technological advancements. Meeting this demand while transitioning to sustainable energy sources is a key global challenge.

3.1. Global Energy Demand

- Current Energy Consumption:
  - The world consumed approximately 620 exajoules (EJ) of energy in 2023.
  - Global energy demand is expected to increase by 50% by 2050, driven by industrialization and urbanization.
- Sectoral Energy Consumption:
  - Industry (37%) – Manufacturing, mining, and construction.
  - Transport (28%) – Cars, planes, ships, and trains.
  - Buildings (30%) – Heating, cooling, and electricity for homes and offices.
  - Agriculture (5%) – Irrigation, machinery, and processing.
- Regional Energy Demand:
  - China, USA, and India are the top three energy consumers, accounting for over 50% of global demand.
  - Developing countries have rapidly increasing energy needs, particularly in Africa and Southeast Asia.

3.2. Global Energy Sources

Energy is derived from both renewable and non-renewable sources.

a) Non-Renewable Energy (Fossil Fuels) – 80% of Global Supply

Source	Share (2023)	Advantages	Challenges
Oil	31%	High energy density, transport fuel	Greenhouse gas emissions, depletion
Coal	26%	Cheap and abundant	High CO_2 emissions, air pollution
Natural Gas	23%	Lower emissions than coal	Methane leakage, price volatility
Nuclear	4%	Low-carbon, stable supply	Waste disposal, safety concerns

Fossil fuels dominate energy supply**,** but they contribute significantly to climate change and environmental degradation.

b) Renewable Energy – 20% of Global Supply

Source	Share (2023)	Advantages	Challenges
Hydropower	7%	Reliable, low emissions	Environmental impact on rivers
Wind	6%	No emissions, cost-effective	Intermittent, needs land space
Solar	5%	Unlimited source, scalable	Energy storage needed
Biomass	2%	Uses organic waste	Can cause deforestation
Geothermal	<1%	Constant power source	Limited to volcanic regions

Renewables are growing rapidly due to falling costs and government policies, but energy storage and grid integration remain key challenges**.**

3.3. Future Energy Trends & Transition

- Shift to Renewable Energy:
  - Renewables are projected to supply 60-70% of energy by 2050 to meet climate goals.
  - Countries are phasing out coal and investing in solar, wind, and hydrogen energy.

- Electrification & Energy Efficiency:
    - Growth in electric vehicles (EVs) and smart grids to reduce fossil fuel reliance.
    - Energy-efficient appliances and green buildings to lower consumption.
- Hydrogen & Battery Storage:
    - Green hydrogen is emerging as a clean alternative for industries and transport.
    - Advanced battery storage (e.g., lithium-ion, solid-state) will help store renewable energy.
- Carbon Capture & Nuclear Expansion:
    - Carbon capture technologies to reduce CO_2 emissions from fossil fuel plants.
    - Next-gen nuclear reactors (fusion, small modular reactors) are being explored for stable power.

4. Energy Needs in the Food Industry

The food industry is one of the most energy-intensive sectors, requiring energy for production, processing, packaging, storage, and distribution. The demand for energy continues to grow due to increasing food production, population growth, and technological advancements in food processing.

4.1. Energy Consumption in the Food Industry

- The global food sector consumes about 30% of the world's total energy.
- About 70% of this energy is used beyond the farm level, including processing, transportation, storage, and retail.
- The food industry also contributes to over 20% of global greenhouse gas emissions, mainly from fossil fuel use.

4.2. Key Energy-Consuming Processes in the Food Industry

Process	Energy Requirement	Key Energy Sources
Agricultural Production	Machinery, irrigation, fertilizers, transport	Diesel, electricity, solar
Food Processing	Heating, cooling, drying, milling, grinding	Electricity, natural gas, biomass
Refrigeration & Storage	Cold chain logistics, warehouses	Electricity, solar, geothermal
Packaging	Manufacturing, sealing, printing	Electricity, petroleum-based materials
Cooking & Preparation	Heat for cooking, baking, sterilization	Natural gas, electricity, bioenergy
Transportation & Distribution	Moving raw materials & finished goods	Diesel, biofuels, electricity

4.3. Major Energy Sources in the Food Industry

The food industry relies on a mix of fossil fuels and renewable energy sources for its operations:

(a) Fossil Fuels (Conventional Sources)

- Natural Gas – Used in heating, drying, and cooking.
- Electricity (Grid-based) – Powers refrigeration, processing equipment, and automation.

- Petroleum & Diesel – Used in transportation of raw materials and final products.
- Coal (Declining use) – Previously used in large-scale food processing plants.

(b) Renewable Energy (Sustainable Sources)

- Solar Power – Used for food drying, water heating, and solar refrigeration.
- Biogas & Biomass – Generated from food waste and agricultural residues for heating and power.
- Wind Energy – Powers some food production and processing facilities.
- Hydropower & Geothermal – Used in select food processing plants for energy needs.

4.4. Challenges in Energy Use for the Food Industry

- High Energy Costs – Rising energy prices impact food production and processing costs.
- Carbon Emissions – The industry is under pressure to reduce its environmental footprint.
- Energy Efficiency Gaps – Many food processing plants still rely on outdated, inefficient equipment.
- Cold Chain Dependence – Refrigeration and storage require constant electricity supply, leading to high energy demand.

5. Sustainability Options for the Food Industry

5.1. Renewable Energy Adoption

Switching to clean energy sources can significantly reduce carbon emissions and energy costs.

- Solar Power – Used for food processing, refrigeration, and drying.
- Wind Energy – Powering food manufacturing plants and supply chains.
- Biogas & Biomass – Converting food waste into energy for heating and electricity.
- Geothermal Energy – Used for heating greenhouses and food drying.

Example: Nestlé and Unilever have committed to using 100% renewable energy in their factories.

5.2. Energy Efficiency Improvements

Reducing energy waste in food processing and storage leads to cost savings and lower emissions.

- Smart Grids & AI Monitoring – Optimizing electricity use in production facilities.
- Heat Recovery Systems – Reusing waste heat from ovens and boilers for other processes.
- Energy-Efficient Equipment – Upgrading to low-energy ovens, refrigerators, and lighting.
- Adoption of nonthermal process – High pressure processing, Pulsed electric field, supercritical fluid extraction, microwave processing, high intensity light pulse processing, ultrasound processing

Example: Mondelez (Oreo & Cadbury) improved baking efficiency by 15% with energy-efficient ovens.

5.3. Sustainable Packaging

Reducing plastic waste and switching to **eco-friendly packaging** is a key sustainability goal.

- Biodegradable & Compostable Packaging – Made from plant-based materials.
- Edible Packaging – Using natural ingredients like seaweed-based wraps.
- Recyclable & Reusable Containers – Encouraging a circular economy for packaging.
- Lightweight Packaging – Reducing material use and transportation emissions.

Example: Coca-Cola aims to use 100% recycled or plant-based bottles by 2030.

5.4. Sustainable Agriculture & Sourcing

Using eco-friendly farming practices can reduce environmental impact at the source.

- Regenerative Agriculture – Improves soil health, absorbs CO_2, and increases biodiversity.
- Precision Farming – Uses AI and drones to optimize water and fertilizer use.
- Agroforestry – Integrates trees with crops to enhance carbon sequestration.
- Water-Smart Irrigation – Drip irrigation and rainwater harvesting reduce water waste.

Example: General Mills promotes regenerative agriculture to restore farmlands.

5.5. Reducing Food Waste

Food waste accounts for 8-10% of global carbon emissions, making reduction a top priority.

- Food Recovery Programs – Redirecting surplus food to charities instead of landfills.
- Byproduct Utilization – Using food scraps for animal feed, compost, or biofuel.
- Smart Inventory Management – AI-powered systems to prevent overproduction and waste.

Example: Tesco aims to cut food waste by 50% by 2030 through donation programs.

5.6. Sustainable Cold Chains & Logistics

The food supply chain relies on efficient transportation and refrigeration, which can be optimized for sustainability.

- Solar-Powered Cold Storage – Reduces dependency on fossil fuels.
- Electric & Hydrogen-Powered Trucks – Lower emissions for food distribution.
- Route Optimization & AI Logistics – Reducing fuel consumption in transport.
- Phase-Change Materials in Cold Storage – Energy-efficient cooling solutions.

Example: Unilever cut 30% of fuel consumption in ice cream transport with PCM technology.

5.7. Water Conservation & Management

The food industry is one of the largest water consumers, making efficient water use essential.

- Closed-Loop Water Recycling – Treating and reusing wastewater in processing.
- Low-Water Cleaning Systems – Reducing water use in factories.
- Desalination & Rainwater Harvesting – Alternative water sources for production.

Example: PepsiCo reduced water use by 26% through water recycling initiatives.

5.8. Sustainable Sourcing & Ethical Practices

Consumers demand responsibly sourced food with minimal environmental and social impact.

- Fair Trade & Ethical Supply Chains – Ensuring fair wages and responsible farming.
- Plant-Based & Alternative Proteins – Reducing reliance on resource-intensive meat production.
- Eco-Certifications (Organic, Rainforest Alliance, Carbon Neutral) – Supporting sustainable brands.

Example: Beyond Meat & Impossible Foods use plant-based proteins to cut emissions.

6. Conclusion

Climate change poses significant challenges to food production, food safety, and agro-processing, affecting raw material availability, processing efficiency, storage, and distribution**.** The world faces a dual challenge: meeting rising energy demand while transitioning to sustainable sources. A mix of renewables, nuclear, efficiency improvements, and emerging technologies will be key to a clean energy future. The food industry is a major energy consumer**,** with growing pressure to shift towards sustainable and energy-efficient practices**.** By integrating renewable energy, smart technologies, and energy-efficient systems**,** the industry can reduce costs, lower emissions, and improve sustainability**.** Thus through climate-resilient strategies, technological innovation, and sustainable practices**,** the agro-processing sector can adapt to climate change, reduce food losses, and ensure food security**.**

Impact of climate change on soil function and productivity

Dr. Ganesh Chandra Banik
Associate Professor
Department of Soil Science and Agricultural Chemistry
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Climate change is a complex and severe global issue characterized by long-term alteration of global and regional climatic patterns. Climate change presents a severe threat to our environment and significantly impacts soil functions including soil fertility, nutrient cycling, water retention, carbon sequestration, aggregation, soil erosion, microbial activity etc. which are critical in sustaining agriculture and ecosystem health. As global temperatures rise and weather patterns become increasingly erratic, the implications for soil quality and productivity are profound.

One major effect of climate change is the alteration in precipitation patterns. Regions previously characterized by predictable rainfall are experiencing increased frequency and intensity of droughts and floods. These changes can lead to soil erosion, nutrient leaching, reduced soil structure and porosity leading to diminished water infiltration and retention. Under this situation, crops may be more venerable to water stress in lean periods. These could increase the risk of topsoil erosion and nutrient loss. Erratic heavy rainfall can wash away the topsoil, which is vital for plant growth, while prolonged dry periods can cause soil compaction and a decline in organic matter. Furthermore, a major portion of cropped area especially in the developing countries are rainfed and are dependent on monsoon. Uncertainty of monsoon caused by climate change severely affects cultivation in these areas.

Higher temperatures exacerbate the rate of decomposition of organic matter in the soil by changing microbial population and activity. Increase in soil temperature due to climate change decreases the residence time of carbon in soil and increases the rate of carbon liberation from soil making the soil a source rather than a sink of carbon. Such carbon depletion strongly influences soil aggregate stability and makes the soil vulnerable for erosion. While this process can enhance nutrient availability in the short term, it ultimately leads to a decrease in soil organic carbon levels, undermining soil fertility and structure. This loss of organic matter not only affects soil productivity but also diminishes the soil's ability to store water, making it more susceptible to drought conditions.

Climate change significantly affects nutrient cycling in soil, disrupting the delicate balance of ecosystems. Rising temperatures can accelerate microbial activity, initially increasing the decomposition of organic matter and the release of nutrients. In short-term this could be beneficial but in long run it enhances nutrient mining from soil. Altered microbial decomposition rate sometimes increase nitrogen mineralization and deplete nitrogen stored in soil.

Prolonged heat and altered precipitation patterns may lead to reduced soil moisture in lean periods in some places which can diminish microbial populations and their functionality, ultimately hindering nutrient availability. Furthermore, extreme weather events, such as heavy rainfall, can cause nutrient leaching, resulting in the loss of essential elements like nitrogen and phosphorus, which are crucial for plant growth. This disruption not only affects soil health but also endangers agricultural productivity and threatens food security, as nutrient cycling is vital for sustaining crop yields. Overall, the interplay between climate change and nutrient cycling poses significant challenges for both natural and managed ecosystems.

Climate change also fosters the proliferation of pests and diseases that can further degrade soil functions. Warmer temperatures create more favorable conditions for harmful organisms, which may lead to increased pesticide use, affecting both soil biology and surrounding ecosystems. Soil functions relies heavily on a diverse array of microorganisms, and any disruption can compromise its functionality.

In addition to these direct effects, climate change impacts land use and agricultural practices, leading to shifts in crop production zones. Farmers may be forced to adapt by changing crop types or practices, which can sometimes result in practices that are detrimental to soil health.

To mitigate these impacts, sustainable soil management practices must be emphasized. Techniques such as precision farming, crop rotation, cover cropping, use of adaptive crops, and reduced tillage can help maintain soil integrity and enhance its resilience to climate fluctuations. Furthermore, embracing agroecological principles can foster a balance between agricultural productivity and ecological health.

In conclusion, the effects of climate change on soil function and productivity are complex and far-reaching. Addressing these challenges requires a concerted effort towards understanding soil processes, promoting sustainable practices, and implementing policies that prioritize long-term soil health. we safeguard this invaluable resource for future generations only through a holistic approach.

Livestock Production Dynamics: the concept and consequence of climate change

Dr. Nonigopal Shit
Assistant Professor (Animal Science)
RRS-TZ, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Abstract: Rise in ambient temperature due to climate change influencing livestock production system and its efficiency by impacting growth, milk production and reproduction of bovines under tropical conditions. Natural environments are much more complex, with far more environmental factors varying both spatially and temporally, so it is likely that global warming and climate variability will amplify the complexity of genotype environment interaction. Projected temperature rise is likely to impact livestock productivity (milk, meat, wool, and draught power), particularly in non-adapted livestock. The temperature rise will also cause a change in composition of species, breeds (quantity, quality) and their mix at farm level due to availability of resources. Inadequate resources and infrastructure make Indian farmers and their livestock highly susceptible to extreme weather events and climate change. Livestock production system is likely to suffer greater losses due to substantial increase (160%) in stressful days by the year 2100 due to global warming. The reduced availability of livestock products will increase risk of malnutrition, hunger and imbalance in vegetarian diets. The global imperative to achieve Sustainable Development Goals (SDGs) has intensified the need for innovative technological interventions in animal resource management. The innovations in technology can enhance sustainability in this sector, particularly under changing climatic scenarios and One Health approach, which links human, animal, and environmental health.

Introduction:

Livestock products and services play an important role for humans. Globally, livestock occupy about 26% of the ice-free land with one-third of the cropland being used for feed production (FAO, 2021). Livestock production generates nearly 40% of global agricultural gross domestic product (GDP). Livestock provide 33% of the global protein and 17% of the global calories consumed. Production creates substantial employment opportunities for rural households. Additionally, livestock are a major provider of food, nutritional security, livelihood, and income in developing countries (Swanepoel et al., 2010).

Driven by population and income growth plus urbanization, the demand for livestock products is growing rapidly. Simultaneously, livestock production is facing increasing pressure from climate change effects, such as increasing temperatures, more variable precipitation patterns, more frequent extreme events, and increasing carbon dioxide concentrations (IPCC, 2014). Such changes have been found to impact livestock performance across many regions and are projected to have growing impacts. Predictive models broadly indicate the impact will be negative (Escarcha et al., 2018). Meanwhile, livestock are a direct source of both methane and nitrous oxide and an indirect source of those gases and carbon through land use and feed production. Globally, the livestock emissions share is an estimated 14.5% of total anthropogenic emissions.

The interaction between on-going climate change and demands for increasing livestock production makes it challenging to increase production while lowering climate impacts and Greenhouse Gas (GHG) emissions. Addressing such challenges requires an understanding of climate change effects on livestock production, as well as the effect of both adaptation and mitigation action

Livestock production systems in India

Livestock is a rapidly growing sector that makes a key contribution to global food security. They produce 17% of calories consumed globally and 33% of protein and can increase the world's edible protein balance by transforming inedible protein found in forage. It accounts for 40 percent of the global agricultural gross domestic product (GDP) and is crucial for food security in all regions. Climate change has substantial impacts on ecosystems and the natural resources upon which the livestock sector depends.

Scientific endeavor has paid to characterize the farming systems in different agro-climatic zones in India.Livestock farming systems are mainly classified as-

1. Arid, semi-arid tropics and subtropics rain-fed system
2. Humid and sub-humid tropics and subtropics mixed system
3. Arid and semi-arid tropics and subtropics mixed system

The most popular method of rearing livestock is generally an arid rain-fed system, in which livestock do a number of tasks at once, such as producing meat and milk, producing manure, and serving as a currency reserve. The humid and sub-humid tropics and subtropics mixed system is characterized by intensive crop production, especially water-intensive crops such as

paddy twice a year due to increasing population pressure and demand for food crops (Amejo *et al.,* 2018).

Productivity trends

The livestock productivity per animal is much higher in multi-utility than that of single-utility livestock (meat or milk). However, milk productivity per indigenous cow is low in different agro-climatic regions of India. The indigenous cows maintained under sub-optimal stressful tropical conditions produce around 2-3 liters of milk whereas Murrah buffaloes kept in optimal managemental conditions produce between 6-8 liters of milk per day. The livestock of different states have large potential for milk production and have scope for increasing milk production not only in terms of yield (kg/ animal/day) but also productivity (kg/lactation) of cattle and buffaloes. India's milk production reached an estimated 230.58 million tons in 2022-23, marking a 22.81% growth over the last five years. Among states, in terms of annual growth rate (AGR), Karnataka saw the highest @ 8.76% followed by West Bengal 8.65% and Uttar Pradesh 6.99% over the previous year.

Climate change and milk production, its availability

A small rise in temperature towards climate change is not likely to impact the physiological functions of animals due to their adaptive capacity. The temperature changes are likely to affect the normal reproductive rhythm of animals. The reproductive cycles of seasonally breeding domestic animals are closely linked to the rhythmicity of the seasons; climatic changes are likely to cause de-synchronization of such events due to responses of pineal- hypothalamo-hypophysealgonadal axis that may lead to interdependent pairs of hormonal events. Alterations in temperature and photoperiodicity could lead to reproductive malfunctioning, affecting many other physiological functions, such as milk production and reproduction. Dairy is the largest agricultural commodity in India, accounting for 5% of the national economy and directly employing over 8 crore farmers. India ranks first globally in milk production, contributing 23% of the world's total milk output. The sector utilizes crop residues and agricultural by-products for animal feeding that are unfit for human consumption.

Climate change: growth and reproduction

The rise in temperature negatively impacts growth and time to attain puberty. The adverse effect of THI rise on animals growing at higher rates will be more than slow growing. The change in temperature with changes in photoperiodicity could lead to reproductive problems due to hormonal imbalance mediated through pineal-hypothalamo-hypophyseal-gonadal axis. Heat stress due to high ambient temperature with limited access to feed and water affect estrus expressions when these animals have relatively non-functional gonads with less number of sperms in the semen of males and poor expression of estrus in females- mainly due to animals are unable to dissipate the extra heat. ACTH is released from the anterior pituitary during heat stress, which triggers the release of cortisol and other glucocorticoids from the adrenal cortex, and ultimately, the secretion of luteinizing hormones is inhibited. Thermal stress also causes hyperprolactinaemia, which inhibits the secretion of both FSH and LH from the anterior pituitary (Singh et al., 2013). Heat stress impacts the endocrine system during the dry period, leading to shorter gestation lengths, higher rates of fetal abortions, reduced calf birth weights, and impaired follicle and oocyte maturation. It also reduces conception and pregnancy rates by 20-30% (Khan et al., 2013).

Table 1: Impact of climate change on livestock health, production and reproduction

Climate change factor	Direct and indirect effect	Reference
Rise in ambient temperature	• Decrease availability of water • Decrease feed intake and feed conversion efficiency • Age of puberty and maturity • Decrease milk and meat production • Decrease reproduction efficiency • Decrease semen quality • Increased mortality	Rojas-Downing *et al.*, 2017; Cheng *et al.*, 2022
Rise in relative humidity	• Increase diseases by: i. Increase of pathogens ii. Increase of parasites iii. Increase of disease spreading/transmission iv. Spreading of vector-born diseases faster • Following forage parameters will be affected: i. Forage quality ii. Forage growth • Biodiversity	Rojas-Downing *et al.*, 2017; Cheng *et al.*, 2022

Climate change and animal diseases

Elevated temperature and humidity will favour spread and growth of insects/vectors. Incidences of diseases affecting livestock species will spread in susceptible populations. The frequency of diseases like FMD, HS and tick fever are most likely to be higher because of climate change (Table 1).

Challenges and demands of the livestock sector

Lack of awareness among the farmers regarding the latest technological advancements related to improving productivity, breeding, and vaccination is the major reason for the low productivity of livestock. High incidence of animal disease also contributes to lower livestock production. Shortage of veterinary infrastructure, *i.e.* veterinary hospitals, polyclinics, veterinarians and other skilled staff in veterinary services, leads to a lack of health and welfare of animals. The rapid growth of the human population, together with economic and urban development, has a substantial impact on livestock production, particularly due to the increasing demand for animal products. The growing demand for affordable and high-quality meat, eggs, and dairy products has driven the rapid intensification and industrialization of animal production, with significant economic, social, and environmental implications on a global scale.

Technological interventions in animal resource management

a. *Precision livestock farming (PLF):* The term “PLF technology” describes the use of cutting-edge tools and data analytics in livestock production system management to enhance animal productivity, welfare, and health while reducing environmental impact and making the most use of available resources (Fig. 1). PLF usually refers to the application of technology that enables continuous, automated, real-time livestock monitoring. These technologies enable data collecting and analysis through the use of cameras, sensors, and acoustic devices that are increasingly combined with artificial intelligence (Hostiou *et al.*, 2017). With the help of this tactic, farmers may make informed decisions on the sustainability of agricultural techniques, animal welfare, and health (Papakonstantinou *et al.*, 2024).
b. *Automatic milking system, environmental control:* Automated systems control barn climate, enhancing animal comfort and reducing stress-related issues. These technologies not only improve animal welfare but also enhance productivity and sustainability by optimizing resource usage and reducing environmental impacts.

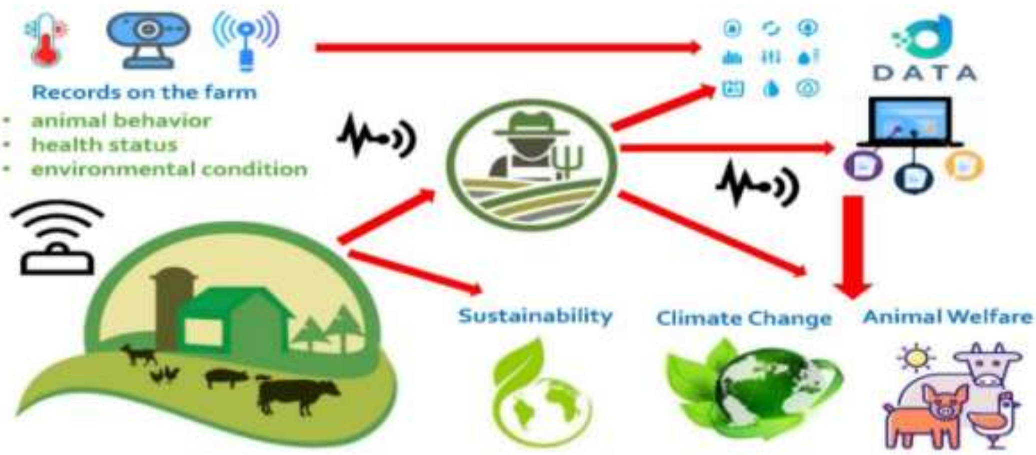

Figure 1: The concept of precision livestock farming in modern livestock production

Climate change adaptation and mitigation:

a. *Climateresilient breeds and species:* Developing and promoting breeds and species that are resilient to climate-related stressors, such as heat, drought, and disease, is crucial. Genetic research and breeding programs play a crucial role in this effort.
b. *Sustainable feed and resource use:* Alternative Feed Sources: Innovations in feed, such as insect-based proteins and algae, offer sustainable alternatives to traditional fishmeal and soybean meal.
c. *Resource-efficient practices:* Precision farming techniques optimize resource use, thereby reducing the carbon footprint and minimizing the environmental impact of animal production.
d. *Carbon footprint reduction:* Renewable energy: Incorporating renewable energy sources, such as solar and wind, into farm operations reduces reliance on fossil fuels.
e. *Methane mitigation:* Technological solutions for methane capture and reduction in livestock operations contribute to lower greenhouse gas emissions.

One Health Approach:

The One Health paradigm promotes equal, all-encompassing collaborations across various sectors of health, including animal, plant, environmental, and human health. This approach brings together a wide range of professionals, such as chemical, engineering, and social scientists, dentists, nurses, agricultural and horticultural experts, food producers, wildlife and environmental health specialists, among others.

According to the CDC and OHC, it is a collaborative, multi-sectoral, and trans-disciplinary approach working at local, regional, national, and global levels to achieve optimal health (and well-being) outcomes recognizing the interconnections between people, animals, plants and their shared environment.

Challenges and future directions

Technological adoption and accessibility:

1. Cost and scalability: High initial costs and scalability issues can hinder the widespread acceptance of advanced technologies. Strategies to reduce costs and enhance scalability are essential.
2. Training and education: Providing training and support to farmers is critical for effective technology implementation.

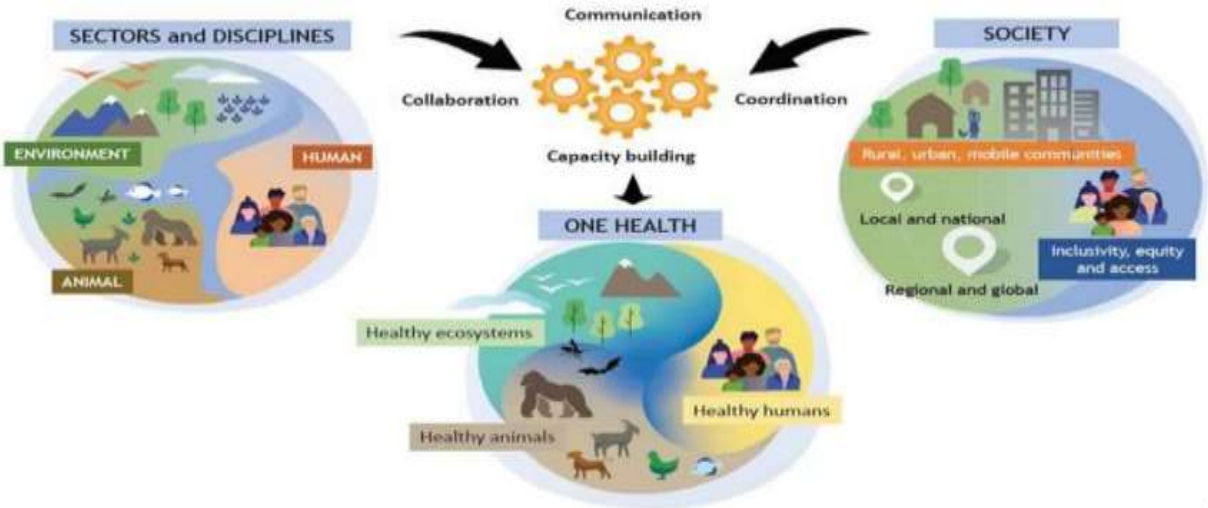

Figure 2: One heath approach for climate change mitigation

Policy and Regulatory Frameworks:

Supportive policies: Governments must develop policies that support innovation and the implementation of sustainable technologies. Regulatory standards: Establishing and enforcing standards for animal welfare, environmental protection, and food safety is crucial. Research and innovation: Continuous research and innovation are needed to develop new technologies and improve existing ones. Collaboration between academia industry, and government is essential to drive progress.

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Stress and secondary metabolite biosynthesis in medicinal plants - impact of climate change

Prof. Soumen Maitra
Department of Floriculture, Medicinal and Aromatic Plants
Uttar Banga Krishi Viswavidyalaya, Pundibari, CoochBehar

Medicinal plants are the altruistic aid from the end of the mother nature which are rich in secondary metabolites and are potential source of drugs. Each and every olden civilization of the world possessed rich tradition of using plant-based health care system. Though ancient India was reputed for its classical herbal formulations, the rich plant-based health care system had gone into oblivion, due to the upsurge of modern chemical medicinal based system of therapy as these were not dependent on nature and the effect was quick as well as bulk production became easier to serve the ever-increasing human population. Observing the morbid side effect of synthetic chemical based formulations, the developed world tried to use herbal formulations for their primary health care needs, which had been reflected through a worldwide survey conducted by the World Health Organization at the end of the last millennium, emphasized the need for revitalization of plant-based health care system, by identifying around twenty thousand plants across the globe for their miraculous healing properties, the number has been increased around thirty two thousand in present days. This landmark information spread rapidly creating the potential of multibillion dollar earning market utilizing the active principles, namely – the secondary metabolites of such plants.

India is considered as the birthplace of the most demanded plant-based health care system – "*The Ayurveda*", lies within the 17 megadiversity centres of the world as identified by Conservation International, possesses 4 biodiversity hot spots out of 36 biodiversity hot spots of the world, 8 phyto-geographic regions, 10 vegetation zones and 426 habitats for specific species having 47000 species of plants out of which 15000 are medicinal in nature. Indian medicinal plants are largely trees and root yielding, belong to 2200 genera under 386 plant families of which Asteraceae tops the list. Such a huge plant biodiversity including medicinal and other economic ones make the country highly liable to – Biopiracy, a significant menace to the rational utilization of natural resources.

Medicinal plants are classified into various manners, like – plant type basis, economic plant part basis, Agro-climatic requirement basis, propagation technique basis, cultivation technique basis etc., but the most contemporary and commercially utilizable one is chemotaxonomic classification based on the nature of available secondary metabolite, which is also having an industrial importance too. Secondary metabolite means the derivatives of secondary metabolic pathways which are not having any apparent function in plants primary metabolism and are active in minute quantities. The major classes include – Alkaloid, Glycoside, Tanin, Resin, Fixed Oil and Volatile Oil. Out of which Alkaloids and Glycosides predominate in the field of medicinal plants. Alkaloids are heterocyclic nitrogenous compounds derived from the breakdown of amino acids, which are basic in nature and useful in minute quantities. On the other hand, glycosides are having two components in the molecule, one part is a simple carbohydrate called as glycone and the other one is non-carbohydrate called as aglycone which are fused together through a hemiacetal or hemiketal bond. Biosynthesis and accumulation of alkaloids and glycosides depends greatly on the growing environment. Cinchona, a bark yielding medicinal plant, bearing quinine in bark, yields almost nil during the rainy season, whereas in other seasons the concentration becomes greater. Hence, stress in the form of climatological adversity is having immense importance in alkaloid and glycoside biosynthesis in medicinal plants.

Stress due to climatic change poses significant influence in alkaloid biosynthesis in medicinal plants through expression of specific genes at a particular agro-climatic combination, regulating enzymatic activity and alteration in metabolic pathways. As derivation as well as accumulation of this kind of secondary metabolite is highly associated to plant defence system, the stress in the form of both – abiotic, namely – salinity, drought, high temperature, temperature fluctuation etc., and biotic, namely – grazing animals, plant pathogens etc., can increase or decrease alkaloid biosynthesis as a protective measure. Drought stress increases ROS, ultimately enhances the production of Vincristine and Vinblastine in Periwinkle (Yahyazadeh *et, al*., 2021), total alkaloid content in Lupin (Christiansen *et, al*., 2008) and Anona (Honorio *et, al*., 2024). Salinity stress enhances alkaloid biosynthesis in *Atropa belladonna* (Stetsenko *et, al*., 2017; Ali, 2000), *Catharanthus roseus* (Isha, 2019; Huqail and Ali, 2021) and *Solanum nigram* (Bhat *et, al*., 2008). Temperature stress increases Morphine production in Opium Poppy (Isah, 2019). Increase in Nicotine biosynthesis in *Nicotiana tabacum* was found during insect attack (Holmstrup *et, al*., 2010). Quinine content in Cinchona plants enhances during fungal attack (Rahmawati *et, al*., 2021).

Glycoside development and accumulation in plants involves several biosynthetic pathways, but each having a common primary glycosylation process helped by the enzyme glycosyltransferases. Biosynthesis of Phenolic Glycosides involves Shikimate pathway, Flavonoids through Cinnamic acid, whereas, Cyanogenics involves amino acids and Saponins developed through Mevalonic acid (MVA) or Methylerythritol – 4 – phosphate (MEP) pathway. Drought stress increases phenolic and flavonoid glycosides as a result of oxidative stress and saponins to develop osmoprotectants. Cardiac glycoside production increases under heat stress to develop resilience or thermotolerance. Drought tolerance significantly increased the iridoid glycoside content in roots of *Scrophularia ningpoensis* (Wang *et, al*., 2010), cardenolide glycosides in *Digitalis lanata* (Stuhlfauth *et, al*., 1987), saponins in *Glycyrrhiza glabra* (Nasrollah *et, al*., 2014) and total glycosides in roots of *Panax ginseng* (Zhang *et, al*., 2024).

Now-a-days, medicinal plants are considered as a lucrative arena of agro-entrepreneurship, wherein, the role of secondary metabolite concentration is ever increasing. In majority of the cases, biotic and abiotic stresses enhance the secondary metabolite biosynthesis in medicinal plants. Such stress-induced greater biosynthesis of secondary metabolite may be due to active plant defence mechanism. As a result of climate change, occurrence of stress becomes common in different growth stages, as, this kind of plants are mostly grown under open field in rainfed condition. Enhanced biosynthesis of secondary metabolites in medicinal plants can be realized through artificial manipulation of microclimate under protected cultivation too, which have great significance in future agriculture, biotechnology and pharmaceuticals.

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Abiotic stress management for adaptation of different crops in different climatic conditions

Dr. Soumendra Chakraborty
Department of Genetics and Plant Breeding
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Introduction:
Given the growing influence of climate change on global food production, cultivating crops that are climate-resilient to cope with abiotic stress is a crucial task in agriculture. Abiotic stressors that negatively impact crop yields include salinity, drought, high temperatures, and nutrient shortages. According to recent reports, the production of ten major crops, including barley, rice, sorghum, wheat, sugarcane, and maize, has decreased globally by 1%. Severe droughts and flash floods are brought on by drastic changes in rainfall patterns, while the steady rise in temperature melts ice caps, raising the level of sea water. Due to the intrusion of salt water into agricultural lands brought on by the rise in sea levels, salt depositions occur. Scientists and farmers are working on creating climate resilient crops using a variety of techniques that combine conventional breeding, genetic engineering, improved agricultural practices, and cutting-edge technology in order to address these issues and guarantee food security.

Climate change stresses Climate-change related stresses:
Climate effects on the plant bio-system. The main abiotic stresses brought on by shifting climatic patterns are severe droughts, flash floods, temperature increases, extremely low temperatures, and salt water intrusion into agricultural areas. The change in rainfall patterns has a significant impact on agricultural areas that rely heavily on rainfall for irrigation and water sources, drying up the land and rendering it unusable for cultivation.

Drought stress: Drought is one of the most important water-related stresses that severely affect plant's growth and development. Drought is often defined as the absence of rainfall, specifically in arid and semi-arid agricultural areas. There are several factors triggering drought stress, such as high temperature, high light intensity and wind. These factors cause and increased evaporation rate from both the soil and the plant itself. Drought stress is experienced, when the soil is depleted with the sufficient amount of moisture needed by the plants. In terms of plant's physiology, water stress occurs when water loss is greater than water uptake.

Under water stress conditions, changes in carbon metabolism occurs due to diminished photosynthesis and active respiration. Plant's growth rate is determined by CO2 assimilation and the respiration ratio. Plants under drought conditions tends to use relatively greater amount of energy resources to uptake water from the soil, especially under severe conditions. Drought negatively affects the Kreb's Cycle and the synthesis of adenine triphosphate (ATP), leading in the reduction of respiration rate. Lower respiration results in too much containment of heat inside the plant system, causing enzymatic and biochemical processes to fail. When plants are exposed to drought stress, they produce reactive oxygen species (ROS) inflicting damage to cellular components.

Waterlogging or water stress: The simple definition of waterlogging is an area with an excessive amount of water, either temporarily or permanently saturating the soil. In anaerobic environments, waterlogging inhibits plant growth and productivity, which results in plant death. Approximately 12% of cultivated soil is impacted by excess water, making waterlogging a significant issue in agricultural areas worldwide. Under waterlogging conditions, yield loss is estimated to be between 39% and 40%. Because soil flooding lowers the endogenous levels of nutrients in the plant system, it has a negative effect on plant growth. Reduced potassium/sodium (K+/Na+) uptake and slowed K+ transport to the shoot system are the results of low oxygen levels in the root zone. Limited uptake of nitrogen (N) and the ensuing redistribution of nitrogen within the shoot cause early leaf senescence and stunted growth of shoots in flooded plants. Furthermore, insufficient micro and macronutrients cause the photosystem II (PS) to function poorly, which makes the process ineffective. It is widely accepted that nutrient deficiencies strongly correspond with the negative consequences of waterlogging. Plants that experience water logging switch to anaerobic respiration because it is more difficult for them to respire aerobically. The rhizosphere's reduced oxygen content produces hypoxic and anoxic conditions that change the cells' redox state. The intermediate electron carriers in the electron transport chain occur as a result of oxygen depletion.

High temperature: Excess solar radiation from global warming results in a sharp rise in temperature. These occurrences are frequently among the most restricting elements influencing plant development and yield. Elevated temperatures can result in significant harm to plants, including sunburned leaves, twigs, and branches; abscission and senescence of leaves; inhibition of root and shoot growth; discoloration and damage to fruit; and decreased yield. One of the main factors contributing to a notable decline in yield and dry matter production in practically all crops, including wheat, barley, rice, and maize, has been identified as heat stress. Elevated temperatures modify the physiological mechanisms and developmental growth patterns. These reactions may vary depending on the phenological stage. Extended heat stress during seed development can result in a reduction of seed viability by delaying germination or causing vigor loss. Coleoptile's growth in corn stops at 40 °C and reduces again at 45 °C. High temperatures reduce the net assimilation rate, shoot dry mass, and relative growth rate in plants; leaf expansion is only slightly impacted. Plants die too soon as a result of the reduction in the length of the first internode, which has a significant effect on shoot growth. Plants cultivated in high temperatures showed shorter internodes, more tillering, earlier senescence, and a decrease in total biomass in sugarcane. Heat stress has an impact on anthesis and grain filling in a variety of temperate cereal crops. It lengthens the grain filling period and slows down kernel growth, which can cause losses in wheat kernel density and weight of up to 7%.

High temperatures cause anatomical changes such as decreased cell size, stomata closure and reduced water loss, increased densities of stomata and trichomatous, and larger xylem vessels in both the root and the shoot. Photosynthetic processes are significantly altered as a result of substantial subcellular modifications in chloroplasts. Research findings indicate that certain effects of high temperatures on photosynthetic membranes lead to the swelling or loss of grana stacking. Grape plant mesophyll cells exhibited a number of physiological changes in response to heat stress, including swollen stroma lamellae, clumped vacuole contents, disrupted cristae, and empty mitochondria.

Saline stress: Salinity is one of the main agricultural hazards that results in enormous yearly losses exceeding USD 10 billion. Induced oxidative stress, high concentrations of sodium and chloride ions directly causing harm, osmotic stress, disruption of the cell membrane and ion transport, are some of the drastic effects of salt stress. Plant salinity tolerance is largely dependent on ion transport, which involves cation and anion transport across root cell plasma membranes, transport via vacuolar membranes, long-distance ion transport through xylem and phloem, and salt excretion and accumulation by specialized cells. Because salinity increases soil osmotic pressure and tampers with plant nutrition, it has an adverse effect on plant growth. Plants' capacity to absorb water is enhanced by high salinity concentrations. Due to the induced metabolic changes in the plant, which are the same as those brought on by water stress-induced wilting, extreme damage happens when the concentration reaches a point where crop growth is reduced.

Furthermore, deficiencies in nutrients and specific ion toxicities hinder the growth of plants.

Plants coping mechanism to abiotic stress: Since plants are multicellular, sessile creatures that need to withstand environmental stressors in order to adapt and live, they have evolved a variety of stress-tolerance mechanisms. Generally speaking, there are two primary mechanisms that allow plants to tolerate environmental stresses: avoidance and tolerance. A complex interplay of physiological, morphological, phonological, biochemical, and molecular responses characterizes plant adaptation to water stresses i) Escape mechanism, ii) Avoidance mechanism and iii) Tolerance mechanism and iv) Molecular mechanism.

i) **Escape mechanism**: Different escape mechanisms have evolved by plants to help them deal with abiotic stresses and improve their chances of surviving and procreating. These mechanisms are ways for plants to lessen or avoid the harmful effects of unfavorable environmental circumstances. Because plants can change their phenology, they can potentially escape from water stress.

ii) **Avoidance mechanism**: Plants experience morphological and anatomical changes as a result of environmental pressures. These modifications protect the plants' systems from disturbance and enhance their capacity to withstand stressful conditions. There are many different anatomical changes that plants have experienced at the organ and organizational levels. Variations have been observed in root, xylem, and leaf morphology in response to environmental pressures. Morphological changes can include slower internode growth, larger leaves with more surface area, altered branching patterns, and faster growth of shoots and roots in response to various stresses.

iii) **Tolerance mechanism**: According to several sources, plant tolerance is the capacity of a plant to continue growing and storing nutrients while continuing its vegetative stage. Physiological and biochemical modifications are a part of these processes. Mechanisms involved in plant tolerance to drought include the accumulation of compatible solute and osmotic adaptation, the induction of an antioxidant system, modifications to metabolic pathways, an increase in the root/shoot ratio, and stomata closure. A build-up of active compounds, such as sugars and amino acids, helps plants under water stress modify their osmotic conditions and lower their osmotic potential. With the help of osmotic adjustment, plants can survive in situations where there is a water shortage by effectively absorbing water and maintaining cell turgor pressure. The resilience of their cell membrane is another feature of plants that use tolerance as a mechanism for adaptation.

iv) **Molecular mechanism**: Plants have the ability to create molecular defenses against abiotic stressors through their genetic and sensory systems. Numerous compartments within cells, including the cell wall (CW), plasma membrane (PM), cytoplasm, mitochondria, chloroplasts, peroxisomes, endoplasmic reticulum, and nucleus, are susceptible to abiotic stress. This may set off chemical reactions. The downstream regulatory proteins and secondary messengers, such as Ca2+, ROS, and protein kinases, receive the signals from these stress sensors. Abiotic stress also sets off a range of reactions that entail multiple levels of control, signal transduction, and stress sensing.

Conclusion: Crop improvement for abiotic stress tolerance Plant breeders has tested various breeding techniques to improve abiotic stress tolerance in crop plants. The production of hybrid, mutants and transgenic plants are some of the well-known methods for this purpose. The wide range of drought related genes in the plant genome has opened amazing opportunities for crop improvement. Conventional breeding approach, Induced mutation approach, Genetic engineering, Molecular marker, Genome editing the problem of abiotic sress resistance can be developed in the crops. The development of acceptable and adoptable varieties in these environments that are tolerant of multiple stresses has been the focus of current plant breeding programs. Enhancing physiological efficiencies while simultaneously being exposed to abiotic stresses is one of the major goals of modern day crop improvement programme.

Vegetable Research Thrust Areas under Present Perspective and Important Achievements

Prof. Jagadish Chandra Jana
Department of Vegetable and Spice Crops
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

India's agriculture is a key driver of economic growth, with 66% of the population contributing 20-25% of GDP. The Green Revolution improved cereal production, ensuring food security, but nutrition security remains an issue. As a result, the focus has shifted from food grains to horticultural crops, particularly fruits and vegetables. Over the past decade, horticulture, especially vegetable cultivation, has become essential for sustainable agriculture. Out of 341.63 million tons of horticultural produce, vegetable production accounts for 200.45 million tons. Vegetable crops significantly enhance food, income, and nutritional security at both household and national levels. The nutrients in vegetables are essential chemical components that nourish humans. Vegetable production increased to 200.45 million tons in 2022 (ICAR, 2022). In the past decade, vegetable productivity has significantly increased more than fruit productivity, leading to a marked rise in per capita vegetable availability (IIVR, 2015). Despite this, 35.7% of the population is underweight, 38.4% is stunted, and 58.4% is anemic, with 53% of women (ages 15-49) also underweight and anemic. This underscores the need for continuous vegetable availability at the household level through year-round vegetable kitchen gardening.

Constraints

India is second largest producer of vegetable in world after China. Vegetable production is the major driver of sustainable agriculture. Although, India has produced more than its requirement but at household level, still there is nutritional deficiency. There is wide gap exist between the farm yield and potential yield. There are a number of constraints which discourage the vegetable growers. The adoption the improved varieties and technologies might increase the production and productivity but there are constraints being faced by the farmers. Lack of knowledge about improved varieties and techniques of vegetable production have been ranked first. The stray cattle, monkey and wild animals are also discouraging vegetable grower's especially male youth. Most of the farms are fragmented and posing problem in vegetable production at household level. The distant market, non-availability of storage facility, low price of produce during cropping season and high transportation cost discouraging farmers for adoption of new technologies and consequently reduce the yield and income. The irrigation facilities are also affecting the vegetable cultivation. The farmers are of the opinion that chemical cost is very high; besides few of the market chemicals are spurious. Generally, the vegetables are sensitive to climate change. A little change in temperature and soil moisture might alter physiological and biochemical process in plant and reduces the yield (Dastagiri *et al*. ,2013). Varieties and non- monetary inputs affect the production and productivity of vegetables. Empowerment of farmers including farm women will create awareness and market information to increase yield and income of vegetable growers even at household level.

Vegetable nutraceuticals

Vegetables are essential protective diet ingredients that supply ample amounts of minerals, vitamins, carbohydrates, proteins, dietary fibre, and various nutraceutical compounds for protection against various disease conditions. The coloured vegetables contain functional compounds like chlorophylls, carotenoids, betalains, anthocyanins, etc. well recognized for their antioxidant, antimicrobial, hypolipidemic, neuroprotective, antiaging, diuretic, and antidiabetic properties. Lycopene from tomatoes, lutein from kale, carotenoids from carrots, etc. are some popular photo nutraceuticals. Most nutraceuticals derived from vegetables are claimed to have a variety of therapeutic advantages. For instance, lutein and zeaxanthin prevent cataracts and macular degeneration; beta-carotene and lycopene safeguard the skin from UV damage; and lutein and lycopene may improve cardiovascular health. The significance of different phytochemicals in the prevention of chronic degenerative diseases needs to be further studied. Efforts should also be directed to breed colour rich cultivars or to improve the existing varieties through conventional and molecular breeding approaches. Recently, there has been a shift in food consumption patterns from processed to semi-processed or fresh fruits and vegetables to ensure a healthy disease-free life.

Farm mechanization

Multiple cropping systems has been one of main features of Indian agriculture and it is attributed to rainfed agriculture and prevailing socio-economic situations of farming community. Mechanization of vegetable crops involves the use of various machinery and equipment to streamline the planting, cultivating, harvesting, and processing of vegetables. This modern farming approach offers numerous benefits, including increased efficiency, higher productivity, and reduced labour costs. For planting, seeders and transplanters are employed to achieve precise spacing and depth. Tractors equipped with tillers and plows help prepare the soil, while mechanical weeders and cultivators eliminate weeds without damaging the crops. Drip irrigation systems efficiently provide water, minimizing wastage. During harvesting, specialized machinery such as vegetable harvesters or pickers facilitate the collection of produce at optimal ripeness. Additionally, sorting and packaging machines enhance post-harvest handling and reduce damage. Mechanization also aids in pest and disease control through automated monitoring and application of pesticides, minimizing chemical usage and environmental impact. Overall, mechanization enhances the sustainability and profitability of vegetable farming by reducing labour demands, improving crop quality, and increasing yields. The suitable varieties of vegetable crops are to be selected and the cultivation practices are to be standardized for mechanization. The transplanters for vegetable seedlings developed at IIHR, PAU and CIAE needs adoption. For healthy seedling production, the vegetable nurseries need the adoption of media siever, media mixer and plastic bag filler developed at IIHR, Bangalore. By using this machinery containerized seedling production under protected structures has become commercial venture in India to produce healthy seedlings of tomato, capsicums, cauliflower, cabbage, chillies, brinjal hybrids at large scale.

Stress management

In a changing climate scenario, plants are exposed to extreme environmental stresses like high temperatures, low temperatures, drought, flood, salinity, wind, solar radiation, and nutrient deficiency. Plant growth and development are severely affected by these biotic stresses. The various types of abiotic stresses caused by regional and global climate change pose significant challenges to increasing vegetable crop productivity. Heat, cold, drought, and salinity are the critical abiotic stresses that harm development and production and can cause a series of morphological, biochemical, physiological, and molecular alterations in various vegetable crops (Bhardwaj *et al*., 2025). Plants develop or adopt several mechanisms to cope with different abiotic stresses in nature. Adaptation and acclimatization to environmental stresses are the consequence of coordinated activities at all levels of an organization, from the morphological and anatomical to the biochemical, cellular, and molecular levels. Studying plant responses and the physiological changes during these conditions is essential for improving current cultivars and releasing new cultivars with increased resilience to such stresses.

Water use efficiency

Agricultural water consumption accounts for 70% of total freshwater use. The competition for this precious resource is increasing tremendously. Therefore, it is becoming critically important to optimize agricultural water use efficiency (WUE) defined as the ratio of crop yield over the applied water. This requires a shift from maximizing productivity per unit of land area to maximizing productivity per unit of water consumed. To maximize WUE it is necessary to conserve water and to promote maximal crop growth. The former requires minimizing losses through runoff, seepage, evaporation, and transpiration by weeds. The latter objective may be accomplished by planting high-yielding crops/cultivars well adapted to local soil and climatic conditions. Optimizing growing conditions by proper timing of planting and harvesting, tillage, fertilization, and pest control also contribute to improve crop growth.

F1 hybrids and Vegetable seed industry

Accessibility of profitable method to deliver huge scope F1 hybrid seeds chosen parental lines is a significant factor, which in the long run decides the trading viability of the hybrid genotypes. In Vegetable crops, albeit hybrid varieties can be produced through various methods like hand emasculation for hermaphrodite crops, accompanied by pollination of emasculated flowers and various other breeding methods, viz, male sterility, self-incompatibility, Chemical Hybridizing Agent (CHA). Commercial hybrid seed production based on these mechanisms is economically viable almost in all vegetables especially in tomato, brinjal, cucurbits, sweet pepper, etc in which a huge number of F1 generation seeds are produced from a single cross-pollinated fruit (Kalloo, 2013). Biotechnology has become a boom in today's fast-growing world since it has the ability to efficiently speed up the crop improvement programmes. Genetic modification in vegetable crops has lead to the development of resistant (insect pest and diseases) varieties, high in nutrition, cultivars having high storage life. Recombinant DNA technologies, cell and tissue culture for improvement of vegetable crops forms the basis of genetic engineering of microbs, plants and animals. Similarly, quantitative trait loci (QTL) mapping and tissue culture techniques are utilized to improve vegetable crops at the molecular level (Gruda, 2025). India has a unique opportunity in terms of breeding a range of vegetables. Competent breeders capable of developing superior hybrids, backed by strong production capabilities can galvanize the industry towards development of hybrids not only for the Indian subcontinent but also for other Asian and middle-eastern countries.

Precision farming

A truly comprehensive approach to precision agriculture begins with crop planning and includes tillage, planting, chemical applications, harvesting and post-harvest processing of the crop. A more holistic agricultural approach uses information technology to bring data from multiple sources to bear on decisions associated with agricultural production, logistics, marketing, finance and personnel. Technological interventions in precision horticulture include genetic conservation, genetic engineering, integrated nutrient management, protected cultivation, post- harvest technology, micro irrigation and fertigation etc. Modified crop geometry further improved B:C ratio to 3.26 without subsidy and 4.0 with subsidy. Precision farming is a comprehensive system designed to optimise production. This can increase production efficiency, improve product quality, improve the efficiency of crop chemical use, conserve energy and protect environment with the use of key elements of information, technology and management. Technology and management practices such as field scouting, field mapping, variable rate control, yield mapping and post- harvest processing can be readily adopted to vegetable crop production. However, the technology related to precision farming needs refinement to realize benefits.

Protected cultivation

Due to ever-increasing population, massive urbanization and rapid industrialization, it is becoming challenging to feed the millions in our country. though, population is increasing at a faster pace; agricultural land capacity can increase by 2% only. As per an estimate, 342 million tonnes of vegetables will be required to cater the demand of consumers by the year 2050. Therefore, to improve the productivity and cropping intensity, protected cultivation of vegetables seems a promising proposition. Protected cultivation is taken up in special structures known as greenhouses. depending on the covering material, different terminologies have been used in the context of greenhouse structures for instances, glasshouse, polyhouse, shade house, net house, etc.

Biofortification

Hunger and malnutrition can be overcome through nutrient-rich biofortified vegetables with long-term benefits. It is both environmentally beneficial and eco nomically viable. Many health problems can be prevented and controlled by increasing awareness about the benefits of many vegetables. Agronomic biofortification, conventional breeding methodologies, and transgenic techniques are the most feasible means to improve the nutritional quality of vegetable crops. Conventional breeding is one of the most acceptable approach because the improved cultivars could be utilised in the long term, and do not have any health issues than of agronomic and transgenic approaches (Kumar, 2015). Enhancing the biofortification of nutrients and other quality traits in vegetable crops require strengthening of germplasm pool (Meena and Meena, 2014). A close collaboration between nutritionists and breeders is required to initiate crop specific breeding program including indigenous vegetables.

Nanotechnology

Modern technology is developing steadily and swiftly. Because of smaller molecules and changing molecular interactions, matter exhibits altered properties at the nanoscale. Because of their reduced drug-loading capacity, increased surface area to volume ratio (which keeps only the important fraction of atoms on the surface), high reactivity, high mobility, and improved nutrient uptake by the plants, nano formulations allow for the highly effective use of smaller quantities of fertilisers, fungicides, and pesticides. The main advantage of employing nano formulations over traditional formulations is this. Numerous uses of nanotechnology exist in the production of vegetables, such as improved seed germination and seedling development.

Biological control

The utilisation of synthetic pesticides has been the predominant control processor for diseases brought about by phytopathogenic microorganisms. Notwithstanding, their open and improper application in intensive agriculture has realised issues that have prompted ecological contamination, considerable residues in agricultural products and phytopathogen resistance. They are likewise disrupting the quantity of beneficial microorganism which is available in the soil and capable of expanding soil fertility. Along these lines, there is a need to look through the option of synthetic pesticides that are safe, environmental and monetarily feasible to confront this problem. Biocontrol agent's utilisation is the best alternative method to control the different kinds of diseases, such as nematode infestation, fungal pathogen and bacterial pathogen. Nowadays, biocontrol agents assume a significant role in the field of agriculture. It is a financially savvy, environment-friendly and inhibits the advancement of pathogenic microorganism sustainably.

Organic and natural farming

Organic farming has the potential to provide benefits in terms of environmental protection, conservation of non-renewable resources and improved food quality. Organic farming is a societal need; it is not only from the consumer's perspective but also from a farmer point of view. Natural Farming (NF) refers to the indigenous traditional farming totally based on low cost, naturally available inputs like desi cow dung-urine and other plant-based formulations. In this system no externally purchased inputs namely synthetic, chemical, or organic fertilizers are used, thus, it reduces the input cost of farming and improves economic benefits of farmers.

Vegetable processing

Vegetable processing is a lucrative industry in India because of the crops' nutritional value. In order to improve their level of life and generate more income than they would from the direct sale of fresh food, the Indian government is also pushing farmers to become farmer-entrepreneurs. The Indian government wants to increase the percentage of vegetables processed to over 10% by 2025. Additionally, there is a clear market for processed veggies in various consumable forms for all customer demographics. Tomato is an important vegetable crop in the world for both fresh consumption and making processing products such as ketchup, sauce, paste, etc.

Environmental contamination

Environmental contamination and climate change can modify food quality; generally, they have a negative impact on and imply risks to human health. Industrial emissions and human activities produce airborne contaminants, particulate matter, heavy metals, and volatile organic compounds, which can deposit on vegetal crop surfaces, waterways, and soil, thus increasing the contamination. Intensive agricultural methods have resulted in soil erosion and diminished soil fertility, primarily due to the spread of numerous fertilizers and pesticides into the soil and water systems. Improper waste management practices, coupled with the depletion of local water resources, have resulted in environmental contamination and bioaccumulation in food plants. Heavy metals, like lead, arsenic, cadmium, and chromium, can be present at various environmental levels (soil, water, and atmosphere), and they are widely distributed in the world. Food plants can carry out heavy metal bioaccumulation, a defence pathway for plants, which is different for every plant species. Accumulation is frequent in the roots and the leaves, and heavy metals can be present in fruits and seeds; As and Cd are always present. In addition, other contaminants can bioaccumulate in food plants, including emerging contaminants, like persistent organic pollutants (POPs), pesticides, and microplastics. In food plants, these are present in the roots but also in the leaves and fruits, depending on their chemical structure. Climate changes and their impact on agriculture require new approaches to food production, implementing sustainable agricultural practices, precision agriculture, pest management, and food security (Bhardwaj et al., 2025). The vegetable productivity can be improved by decreasing the number of pesticides used and by looking for new varieties resistant to different biotic and abiotic stresses.

Use of Artificial Intelligence

Role of Artificial Intelligence (AI) in vegetable production, emphasizing its potential to address critical challenges such as climate change, population growth, and resource scarcity. AI technologies, including machine learning, computer vision, and robotics, are revolutionizing agricultural practices. AI-driven innovations in crop management, pest control, and soil analysis enhance productivity, reduce labour costs, and ensure sustainable farming practices. Notable advancements include precision spraying by Blue River Technology, significantly reducing herbicide use, and deploying autonomous tractors and drones for efficient farm management. AI applications, such as

PEAT's Plantix and Trace Genomics, provide accurate diagnostics for soil health and pest management. Satellite-based solutions like Farm Shots and aWhere offer real-time crop monitoring and weather prediction, optimizing resource use and mitigating risks.

Crop modelling

New agricultural research is needed to supply information to farmers, policy makers and other decision makers on how to accomplish sustainable agriculture over the wide variations in climate around the world. In this direction the use of crop models in research is being encouraged. Modeling techniques applied to agriculture can be useful to define research priorities and understanding the basic interactions of the soil-plant-atmosphere system. As a research tool, model development and application can contribute to identify gaps in our knowledge, thus enabling more efficient and targeted research planning (Kumar and Singh, 2004). Using a model to estimate the importance and the effect of certain parameters, a researcher can notice which factors can be most useful. An intensely calibrated and evaluated model can be used to effectively conduct research that would in the end save time and money and significantly contribute to developing sustainable agriculture that meets the world's needs for vegetable food.

Conclusion

With approximately 340 million tonnes the horticulture sector has surpassed cereals in food production and diversified food basket. This has played in important role in ensuring food security and decreasing malnutrition in the country. With seasonal to perennials, vegetables have also played an important role in developing multiple cropping systems models to increase production and productivity in a given area, providing periodic income and increasing the income at various levels in addition to making agriculture more sustainable. The diversified vegetable-based cropping systems play a significant role in reducing the carbon sequestration, mitigating the greenhouse gasses and foot print and increasing the sustainability of the food production systems. With state of art technologies like high density planting, precision horticulture, urban horticulture, vertical farming, protected cultivation, multilevel cultivation, micro irrigation, aqua and aeroponics, drone technology, remote sensing, nanotechnology, smart farming etc are revolutionizing horticulture with vegetable crops globally and so also in India.

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Conservation Agriculture for Sustainable Intensification: A Package Bringing Sustainability

Prof. Biplab Mitra
Head, Department of Agronomy
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Agriculture in India has achieved self-sufficiency in foodgrain production but the production is cereal centric and resource-intensive. The country is facing a number of challenges like exploding population, shrinking harvested area, increasing price of inputs, resource fatigue, groundwater depletion, increasing problems of land degradation, etc leading to limited scope for area expansion under agriculture; the greatest challenge is to make the agricultural systems sustainable and climate resilient for achieving food security of the nation. Conservation agriculture (CA) is perceived as the system which could meet the ever increasing food demand worldwide with sustainable intensification of crops and various resources. CA is a farming system which is designed to hasten sustainability of the agricultural systems through its three basic principles: minimum traffic on agricultural operations, making a permanent soil cover by managing crop residues, and crop diversification through temporal or spatial means. In one hand, CA considers the sustained agricultural production and on the other hand, it is addressing the environmental security.

The CASI (Conservation Agriculture for Sustainable Intensification) technology has been tried to reach our farming community and attempts have been made in the form of conduction of station and on farm trials, observing farmers' field days, arranging exposure visits, conducting capacity building programmes, refinement of technology and so on. These are having noticeable impact on productivity, profitability as well as resource use efficiency. The CIMMYT-led project 'Sustainable and Resilient Farming System Intensification' (SRFSI) is instrumental in bringing CASI technologies and many positive changes happened through our direct intervention. These includes machinery using (farm mechanization), diversified and intensive cropping, varietal replacement in various field crops, judicious use of fertilizers and herbicides, bringing back rural youths into farming avocation, residue keeping habit, etc. Multi-criteria assessments of conventional tillage (CT) (rice) followed by conventional tillage (Maize; Wheat; Lentil) and CASI technology, i.e., unpuddled transplanted rice followed by zero tillage (ZT) (maize;wheat;lentil) showed the clear patterns on the positive impacts of the CASI over CT. CASI technology on average reduced irrigation water, energy, labour, and production costs by significant extent, while it increased system productivity, net returns, and net energy production. CASI also reduced the CO2 equivalent emissions in rice-maize, rice-wheat and rice-lentil systems and thus showed potential to mitigate the potential impact of climate change. Proper integration of institutional-technological-policy related issues is the need of the hour to make it a sustained viable option. Building partnership amongst farmers, scientists, extension agents, policy makers, private players is very important for developing and promoting CA technologies.

Extension Advancement in Climate Change Scenario

Prof. Kausik Pradhan
Department of Agricultural Extension
Uttar Banga Krishi Viswavidyalya, Pundibari, Cooch Behar

Prologue

The impacts of climate change on agriculture are multifaceted and far-reaching, posing significant challenges for farmers and the agricultural sector as a whole. As the climate continues to shift, with changes in rainfall patterns, temperature fluctuations, and the increased frequency and severity of extreme weather events, traditional agricultural practices and systems may no longer be adequate. In this context, the role of agricultural extension science has become increasingly critical in developing and disseminating innovative strategies and technologies to help farmers adapt to these changing conditions. Agricultural extension systems have traditionally played a vital role in bridging the gap between research and practice, providing farmers with the necessary information, technologies, and support to enhance agricultural productivity and sustainability. However, in the face of climate change, these systems must evolve and adapt to meet the new and complex challenges faced by farmers. Recognizing the urgent need to support farmers in adapting to climate change, agricultural extension systems have been exploring and implementing a range of innovative approaches. One such approach is the advancements in precision agriculture and smart farming technologies.

Precision agriculture and smart farming technologies have emerged as powerful tools in the arsenal of agricultural extension science to help farmers navigate the complexities of climate change. These technologies, which utilize data-driven decision-making, remote sensing, and precision application of inputs, enable farmers to optimize resource use, enhance resilience, and adapt to changing climatic conditions. For instance, the use of advanced weather forecasting and monitoring systems, coupled with site-specific recommendations for irrigation, fertilizer application, and crop management, can help farmers make more informed decisions and adapt to fluctuations in weather patterns. Alongside these technological advancements, agricultural extension science has also been actively promoting the adoption of sustainable agricultural practices that can enhance the resilience of farming systems to the impacts of climate change. In addition to precision agriculture and smart farming, agricultural extension science has also been actively promoting the adoption of sustainable agricultural practices that can enhance the resilience of farming systems to the impacts of climate change.

Climate change directly affects agricultural production as this sector is inherently sensitive to climatic conditions and is one of the most vulnerable sectors at the risk and impact of global climate change. The Inter-Governmental Panel on Climate Change (IPCC), in its third assessment report published in 2001, concluded that the poorest countries would be hardest hit, with reductions in crop yields in most tropical and sub-tropical regions due to decreased water availability, and new or changed insect pest incidence. In Asia, agricultural crop yield is expected to decline by 5-30% by 2050s due to rising temperature in Himalayas and this decline in agricultural yield will lead to food insecurity, which becomes a serious future problem for human beings.

In areas where temperatures are already close to the physiological maxima for crops, warming will impact yields more immediately. Overall, agricultural productivity for the entire world is projected to decline between 3 and 16 % by 2080s. According to the International Food Policy Research Institute (IFPRI), it will cause an increase of between

8.5 and 10.3% in the number of malnourished children in all developing countries, relative to scenarios without climate change.
Agriculture contributes to approximately 16% to India's GDP. In India, significant negative impacts have been implied with medium-term (2010-2039) climate change, predicted to reduce yields by 4.5-9%, depending on the magnitude and distribution of warming. Individual developing countries face even larger declines. India, for example, could see a drop of 30 to 40% decline in agricultural productivity by 2080s. There will be a projected loss of 10-40% in crop production by 2100 if no adaptation measures are taken. A 1 degree Celsius increase in temperature may reduce yields of major food crops by 3-7%.
To alleviate some of the complex challenges posed by climate change, agriculture (including forestry and fisheries) has to become "climate smart", that is, sustainably increase agricultural productivity and incomes, adapt and build resilience to climate change, and reduce and/or remove greenhouse gases emissions, where possible.
Here,

- Productivity
- adaptation and
- Mitigation

are three interrelating pillars in achieving goal of food security and development in CSA.
Rural Advisory Services (RAS) contribute to achieving climate-smart agriculture (CSA) by disseminating climate information and technologies and information on production practices for climate adaption through innovative approaches. Keeping this in view, the present article tries to explore the advancements of extension in climate change scenario.

Methodology

The entire content was prepared with the help of the learning experiences gained by the author from different climate change related extension strategy based projects implemented at the field level and the knowledge gained through some extension literatures available in the field of climate change adaptations.

Content

Extension advisory services (EAS) play a crucial role in helping farmers and rural communities adapt to climate change. These services provide essential information, support, and training to enhance resilience and sustainability in agricultural practices. Key roles include:

1. **Knowledge Dissemination**: EAS facilitate the transfer of climate-smart agricultural practices and technologies to farmers, helping them understand and implement strategies to cope with changing climatic conditions.
2. **Capacity Building**: By organizing workshops, training sessions, and field demonstrations, EAS empower farmers with the skills and knowledge needed to adopt innovative practices and improve their adaptive capacity.
3. **Community Engagement**: EAS promote collective action and collaboration among farmers, researchers, and other stakeholders, fostering a supportive environment for sharing experiences and solutions.
4. **Access to Resources**: EAS help farmers access financial, technical, and material resources, such as improved seeds, pest management tools, and irrigation systems, which are essential for adapting to climate change.
5. **Monitoring and Evaluation**: EAS continuously assess the effectiveness of adaptation strategies and provide feedback to farmers, ensuring that practices are refined and optimized over time.

By bridging the gap between research and practice, extension advisory services are instrumental in building resilient agricultural systems that can withstand the challenges posed by climate change.

These advancements of EAS are transforming the landscape of agricultural extension services, making them more efficient, accessible, and impactful. Here are some recent advancements in Extension Advisory Services (EAS):

1. **Technological Integration**: The use of digital platforms, mobile applications, and data analytics has revolutionized EAS. Farmers now have access to real-time information on weather forecasts, market prices, and best agricultural practices. Technologies like drones, satellite imagery, and sensors are enhancing precision farming and resource management.
2. **Public-Private Partnerships**: There has been a growing trend of collaboration between public and private entities. These partnerships are helping to bridge gaps in knowledge dissemination and resource allocation, ensuring that farmers receive comprehensive support.
3. **Customization and Personalization**: EAS are increasingly focusing on tailoring their services to meet the specific needs of individual farmers. This approach ensures that farmers receive relevant and actionable advice, improving their decision-making and productivity.
4. **Entrepreneurial Models**: Private extension services are adopting entrepreneurial approaches to engage with farmers. These models emphasize innovation, sustainability, and long-term capacity building, empowering farmers for future challenges.
5. **Focus on Sustainable Practices**: There is a heightened emphasis on promoting sustainable agricultural practices. EAS are encouraging the adoption of climate-smart agriculture, conservation techniques, and organic farming to ensure environmental sustainability and resilience.
6. **Capacity Building and Training**: EAS are investing in capacity building and training programs to enhance farmers' skills and knowledge. Workshops, field demonstrations, and educational campaigns are helping farmers adopt new technologies and practices.

The innovative extension methods for climate change adaptation are mostly used for socialisation of climate knowledge, learning and capacity development.

The extension approaches for socialisation of climate knowledge are:

- SMS or Short Messaging Services
- Climate Wallpapers
- Climate Voice Messages
- Folk media
- Use of Public Addressing System
- Climate Group meetings
- Exposure visits
- Climate Workshops

The extension approaches for learning are:

- Climate Field Group Visits
- Farmer Interest Groups (FIGs)
- Climate Trainings
- Informative Crop Calendar
- Livestock Calendar
- Block Contingency Planning

- Information & Communication Tools

The extension approaches for capacity development are:

- Climate Trainings
- Climate Workshops
- Field Demonstration
- Climate-Smart Farmers Field Schools (CFFS)
- Weather-Based Insurance
- Community Based Disaster Management (CBDM) approach
- Village Level Custom Hiring Centre (CHCs)
- Agro-meteorological Advisory Service

The extension methodologies can help farmers and rural communities better adapt to the challenges posed by climate change, ensuring sustainable agricultural practices and improved livelihoods. Here are some effective extension methodologies for climate change adaptation.

Participatory and Community-Based Approaches

Farmer Field Schools (FFS): These are group-based learning approaches where farmers learn through observation and experimentation in the field. FFS focus on building farmers' capacity to adapt to climate change by promoting sustainable agricultural practices. FFS on climate-smart rice cultivation in Andhra Pradesh.

Climate-Smart Village (CSV): CSV integrates climate change adaptation and mitigation into agricultural development strategies. It includes practices such as crop diversification, conservation tillage, and agroforestry to enhance resilience and reduce greenhouse gas emissions. Example: ICRISAT's Climate-Smart Village model in India

ICT and Digital Extension Approaches

Mobile-Based Advisory Services: SMS, WhatsApp groups, and interactive voice response (IVR) services for climate alerts. Example: Kisan Mobile Sandesh, mKisan, Kisan Sarathi, and Plantix for pest and weather advisories

GIS and RS based Advisory Services: Weather forecasting, soil moisture mapping, and climate risk assessment. Example: RISAT satellite-based weather and soil moisture monitoring.

AI and Big Data analytics based Services: Predictive analytics for climate risk assessment and decision-making. Example: Microsoft AI for sowing advisories in India

Policy & Institutional Approaches

Public-Private Partnerships (PPP): Collaboration with agribusinesses, research institutions, and NGOs to enhance climate advisory. Example: ICAR-Amazon Kisan Store initiative.

Policy Advocacy & Governance Mechanisms: Strengthening extension personnel capacity through training in climate resilience. Example: DAESI (Diploma in Agricultural Extension Services for Input Dealers) for local climate advisories.

Climate Insurance & Risk Management Services: Promotes Weather-Based Crop Insurance Scheme (WBCIS) and PMFBY for risk reduction.

Capacity Building & Knowledge Co-Creation

Experiential Learning Approaches: Hands-on training through demonstration plots and field days. Example: KVK-led on-farm demonstrations for climate-smart practices.

Multi-Stakeholder Platforms: Brings together scientists, policymakers, private sector, and farmers to co-develop solutions. Example: MANAGE-hosted National Dialogue on Climate Resilience in Agriculture.

Epilogue

Extension advisory services (EAS) are pivotal in empowering farmers and rural communities to face the challenges posed by climate change. The advancement of EAS, through technological integration, public-private partnerships, and tailored support, has significantly enhanced their capacity to disseminate climate-smart agricultural practices. By adopting innovative methodologies such as participatory rural appraisal, farmer field schools, and digital platforms, EAS have bridged the gap between research and practice, ensuring that farmers receive timely, relevant, and actionable advice. Furthermore, the emphasis on sustainable practices, capacity building, and community engagement has fostered resilience and self-reliance among farmers. As climate change continues to impact agriculture, the role of EAS becomes ever more critical. By facilitating knowledge transfer, promoting collaboration, and advocating for supportive policies, EAS are instrumental in building resilient agricultural systems that can adapt to the changing climatic conditions. In conclusion, the advancements in extension advisory services represent a beacon of hope and innovation, driving the agricultural sector towards a more sustainable and resilient future in the face of climate change.

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Abiotic stress management of fruit crops under the climate change scenario

Prof. Nilesh Bhowmick
Dept of Pomology & Post-Harvest Technology
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Introduction

Climate change poses a significant challenge to global agricultural systems, particularly fruit crop production, which is highly sensitive to environmental fluctuations. Abiotic stresses, such as extreme temperatures, drought, salinity as well as nutrient imbalances, have intensified due to shifting climatic patterns, leading to severe reductions in fruit yield and quality. Unlike annual crops, fruit crops are perennial in nature, making them more vulnerable to prolonged exposure to adverse climatic conditions. Their inability to adapt quickly to sudden environmental changes further exacerbates production losses, threatening food security, economic stability, and biodiversity.

Among the various abiotic stresses, temperature extremes have emerged as a major concern for fruit production. High temperatures accelerate transpiration, cause sunburn in fruits, and disrupt flowering and fruit-setting processes, ultimately reducing marketable yield. Conversely, low temperatures and frost can induce chilling injuries, affecting post-harvest quality and storage potential. Similarly, drought stress limits water availability, leading to reduced photosynthetic efficiency, poor fruit development, and increased susceptibility to diseases. With erratic rainfall patterns and prolonged dry spells becoming more frequent, water scarcity has become a critical constraint in fruit cultivation, particularly in arid and semi-arid regions. Salinity stress is another growing concern, especially in coastal and irrigated agricultural regions. Excessive salt accumulation in the root zone impairs water uptake, disrupts ionic balance, and induces physiological disorders in fruit crops. Crops such as strawberry, mango, apple, citrus etc. exhibit significant sensitivity to saline conditions, resulting in stunted growth and yield reductions. Additionally, nutrient stress, including deficiencies and toxicities of essential elements, hampers metabolic functions and compromises fruit quality. Heavy metal contamination, often linked to industrialization and excessive agrochemical use, further threatens fruit crop health by inducing oxidative stress and impairing cellular functions.

Given these challenges, sustainable and resilient management strategies are imperative for ensuring stable fruit production under changing climatic conditions. The integration of advanced agronomic practices, breeding approaches, biotechnological innovations, and climate-smart agricultural techniques offers promising solutions to mitigate abiotic stress effects. Understanding the physiological and biochemical responses of fruit crops to various stress factors is crucial for developing effective mitigation strategies.

Major Abiotic Stresses in Fruit Crops

Fruit crops, being perennial in nature, are particularly vulnerable to various abiotic stresses that significantly impact their growth, yield, and quality. Climate change has exacerbated the frequency and intensity of these stresses, making it imperative to understand their effects and develop effective mitigation strategies. The major abiotic stresses affecting fruit crops include temperature stress, drought, salinity, nutrient imbalance, and heavy metal toxicity.

1. Temperature Stress

Temperature extremes, both high and low, adversely affect fruit crops by disrupting physiological processes such as photosynthesis, respiration, and hormone regulation.

1.1 Heat Stress

Rising global temperatures pose a severe threat to fruit production, particularly in tropical and subtropical regions. Heat stress accelerates transpiration, leading to excessive water loss, dehydration, and reduced photosynthetic efficiency. In crops such as mango, citrus, and apple prolonged exposure to high temperatures can cause fruit sunburn, cracking, and reduced sugar accumulation, which negatively impact marketability. High temperatures also disrupt pollination and fruit set, as seen in crops like litchi, where elevated temperatures impair pollen viability and fertilization.

1.2 Cold and Frost Stress

Conversely, low temperatures and frost pose a significant challenge in temperate fruit crops such as apple, peach and cherry. Cold stress disrupts membrane stability, leading to cell damage and physiological disorders such as chilling injury and delayed bud break. In citrus crops, frost exposure can cause severe leaf drop and fruit damage, significantly reducing yield and fruit quality. Late spring frosts are particularly harmful to early-flowering fruit crops like apricot, often leading to complete yield loss due to flower and fruitlet abortion.

2. Drought Stress

Water scarcity is one of the most critical abiotic stresses affecting fruit crops worldwide. Drought stress limits water availability, leading to stomatal closure, reduced photosynthesis, and impaired nutrient uptake. Water-deficient conditions also enhance oxidative stress, causing cellular damage and reduced fruit quality.

Drought-sensitive crops such as banana, papaya, and avocado exhibit severe growth reduction and yield losses under prolonged dry conditions. In grapes, drought stress affects berry development, reducing fruit size and altering sugar-acid balance, which significantly impacts wine quality. Deep-rooted fruit crops such as pomegranate and date palm exhibit higher drought tolerance due to their ability to extract water from deeper soil layers. However, even these crops suffer yield reductions under prolonged drought conditions.

3. Salinity Stress

Salinity stress is a growing concern in fruit production, particularly in coastal and irrigated regions where excessive salt accumulation in the soil and water leads to osmotic stress and ion toxicity. High soil salinity reduces water uptake by creating an osmotic imbalance, while excessive sodium (Na^+) and chloride (Cl^-) ions disrupt nutrient absorption, causing toxicity symptoms. Citrus crops are highly sensitive to salinity stress, with symptoms such as leaf chlorosis, reduced growth, and poor fruit quality. Mango and banana also exhibit significant salt sensitivity, experiencing reduced fruit yield and premature leaf senescence under high salinity conditions. In contrast, pomegranate and fig demonstrate moderate tolerance to salinity, making them suitable for cultivation in saline-prone areas. However, excessive salt accumulation still reduces their productivity over time. The use of salt-tolerant rootstocks in citrus and grape production has shown promise in mitigating salinity stress effects.

4. Nutrient Deficiency and Toxicity

Nutrient imbalances, including deficiencies and toxicities, impair physiological and metabolic functions in fruit crops, affecting overall growth and productivity.

4.1 Nutrient Deficiencies

Deficiencies of essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) lead to stunted growth, poor flowering, and reduced fruit set. For example, nitrogen deficiency in citrus results in pale green leaves, poor fruit enlargement, and reduced yield. Potassium deficiency in banana causes leaf edge necrosis and poor fruit filling, impacting market quality. Micronutrient deficiencies, particularly zinc (Zn), iron

(Fe), and boron (B), are also prevalent in fruit crops. Zinc deficiency in mango leads to a disorder known as "little leaf," characterized by reduced leaf size and poor flowering. Iron deficiency, common in calcareous soils, causes chlorosis in crops like apple and peach, leading to reduced photosynthesis and fruit yield. Boron deficiency affects pollen viability and fruit set in crops such as almond and grape, leading to lower production.

4.2 Nutrient Toxicities

Excessive nutrient levels, particularly of heavy metals such as aluminum (Al), cadmium (Cd), and lead (Pb), pose a significant threat to fruit crops. Heavy metal toxicity disrupts metabolic processes, induces oxidative stress, and reduces crop productivity. For instance, cadmium accumulation in citrus and grapevine can lead to reduced root growth and impaired nutrient uptake, affecting overall plant health and fruit quality. The application of organic amendments and biochar has shown potential in mitigating heavy metal toxicity in fruit orchards.

5. Heavy Metal Stress

Heavy metal contamination in soil and water, often resulting from industrial pollution, mining activities, and excessive agrochemical use, has become a major concern for fruit crop production. Heavy metals such as cadmium, lead, and mercury (Hg) interfere with cellular functions, leading to oxidative stress, enzyme inhibition, and DNA damage. Grapevines, citrus, and apple orchards located near industrial areas are particularly vulnerable to heavy metal accumulation, which not only affects plant health but also poses risks to human consumption. Phytoremediation using hyperaccumulator plants and soil amendments such as biochar and organic matter has shown potential in mitigating heavy metal toxicity in fruit orchards.

Physiological and Biochemical Responses of Fruit Crops to Abiotic Stresses

Fruit crops, being perennial in nature, exhibit a wide range of physiological and biochemical responses to abiotic stresses. These responses are primarily aimed at enhancing stress tolerance, maintaining cellular homeostasis, and ensuring survival under unfavorable environmental conditions. The ability of fruit crops to withstand abiotic stress is largely dependent on their capacity to regulate water balance, maintain photosynthetic efficiency, activate antioxidant defence mechanisms, and modulate hormonal signaling pathways. Understanding these physiological and biochemical adaptations is essential for developing effective stress mitigation strategies to sustain fruit crop productivity under climate change scenarios.

1. Physiological Responses of Fruit Crops to Abiotic Stresses

1.1 Stomatal Regulation and Water Balance

One of the primary physiological responses of fruit crops to abiotic stress, particularly drought and high temperatures, is stomatal regulation. Stomata play a crucial role in controlling gas exchange and transpiration. Under water-deficient conditions, fruit crops such as grapes, mango, and citrus close their stomata to reduce water loss. However, prolonged stomatal closure leads to reduced CO_2 uptake, thereby limiting photosynthesis and affecting fruit yield. Some drought-tolerant fruit crops, such as pomegranate and date palm, exhibit partial stomatal closure, allowing limited gas exchange while minimizing water loss.

1.2 Photosynthetic Adjustments

Abiotic stresses significantly impact the photosynthetic machinery of fruit crops, affecting their growth and productivity. Heat stress leads to the inactivation of photosystem II (PSII) and reduced chlorophyll content, thereby decreasing photosynthetic efficiency. In crops like apple and banana prolonged exposure to high temperatures results in photoinhibition, leading to leaf scorching and poor fruit set.

Similarly, drought stress induces oxidative damage to chloroplasts, reducing photosynthetic activity in citrus and grapevines. Some fruit crops, such as fig, exhibit osmotic adjustment mechanisms to maintain leaf turgor and sustain photosynthesis under drought conditions.

1.3 Root System Modifications

The root system plays a critical role in water and nutrient uptake, and fruit crops exhibit adaptive root modifications in response to abiotic stress. Under drought and salinity stress, deep-rooted fruit crops such as pomegranate and guava develop extensive root systems to access water from deeper soil layers. In contrast, fruit crops with shallow root systems, such as strawberry, are highly susceptible to drought stress due to limited water absorption capacity. Additionally, root exudation of organic acids and secondary metabolites enhances nutrient uptake and mitigates heavy metal toxicity in fruit crops like grape and citrus.

1.4 Osmotic Adjustment and Turgor Maintenance

Osmotic adjustment is a key physiological response in fruit crops exposed to drought and salinity stress. This mechanism involves the accumulation of compatible solutes such as proline, glycine betaine, and soluble sugars to maintain cellular turgor and osmotic balance. In mango and papaya (*Carica papaya*), increased proline accumulation under water-deficient conditions enhances drought tolerance by stabilizing cellular membranes and proteins. Similarly, citrus and grapevines accumulate osmolytes to mitigate salt-induced osmotic stress, maintaining cell hydration and metabolic functions.

2. Biochemical Responses of Fruit Crops to Abiotic Stresses

2.1 Antioxidant Defence Mechanisms

Abiotic stresses generate excessive reactive oxygen species (ROS), such as superoxide radicals (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH^-), which cause oxidative damage to cellular structures. Fruit crops activate antioxidant defence systems to counteract ROS-induced damage and maintain cellular homeostasis. Enzymatic antioxidants, including superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), play a crucial role in scavenging ROS and protecting fruit crops from oxidative stress. In citrus and grapevines, increased activity of SOD and CAT under drought and salinity stress enhances stress tolerance by neutralizing ROS. Additionally, non-enzymatic antioxidants such as ascorbic acid (vitamin C), glutathione, and phenolic compounds contribute to oxidative stress mitigation in apple, banana, and pomegranate.

2.2 Accumulation of Secondary Metabolites

Fruit crops synthesize and accumulate secondary metabolites such as flavonoids, phenolics, and terpenoids in response to abiotic stress. These compounds act as protective molecules by scavenging ROS, regulating stress-responsive signalling pathways, and enhancing defence mechanisms. For instance, in grapevines, drought stress leads to an increase in flavonoid and anthocyanin content, which not only enhances stress tolerance but also improves fruit quality. Similarly, mango and guava accumulate phenolic compounds under salinity and heavy metal stress, providing protection against oxidative damage and enhancing stress adaptation. The biosynthesis of these secondary metabolites is often regulated by stress-responsive transcription factors and metabolic pathways.

2.3 Hormonal Regulation and Signal Transduction

Phytohormones play a crucial role in mediating stress responses in fruit crops by regulating growth, development, and metabolic processes. The key stress-responsive hormones include abscisic acid (ABA), salicylic acid (SA), jasmonic acid (JA), and ethylene. ABA is a central regulator of abiotic stress responses, particularly in drought and salinity stress. Under water-deficient conditions, fruit crops such as citrus and apple exhibit increased ABA accumulation, leading to stomatal closure and activation of stress-responsive genes.

Salicylic Acid (SA) enhances antioxidant defence mechanisms and mitigates oxidative stress in fruit crops. In banana and grapevine, SA application improves drought and heat tolerance by enhancing ROS scavenging activity. Jasmone Acid (JA) and Ethylene play a role in stress signalling and defence responses in fruit crops. JA enhances resistance to abiotic stress in crops like strawberry and papaya, while ethylene regulates fruit ripening and stress adaptation under unfavourable conditions.

2.4 Ion Homeostasis and Detoxification Mechanisms

Salinity and heavy metal stress disrupt ion homeostasis, leading to nutrient imbalances and toxicity in fruit crops. To counteract these effects, fruit crops activate ion transporters and compartmentalization mechanisms to regulate ion uptake and distribution. In salt-sensitive crops such as citrus and banana, the Na^+/H^+ antiporter system helps in maintaining cellular ion balance by sequestering excess sodium ions into vacuoles, thereby preventing toxicity. Similarly, grapevine and pomegranate activate metal chelation mechanisms using phytochelatins and metallothioneins to detoxify heavy metals and prevent cellular damage.

Strategies for Abiotic Stress Management in Fruit Crops

The increasing impact of climate change on fruit crops necessitates the development of effective strategies to mitigate abiotic stresses such as drought, temperature extremes, salinity, and nutrient imbalances. Various agronomic, physiological, genetic, and biotechnological approaches have been explored to enhance stress tolerance in fruit crops. The integration of these strategies into sustainable agricultural practices can improve fruit production, maintain quality, and ensure long-term productivity under changing climatic conditions.

1. Efficient Irrigation Management

Water scarcity is a major limiting factor for fruit production, necessitating the adoption of efficient irrigation strategies. Drip Irrigation method provides water directly to the root zone, reducing water wastage and improving water-use efficiency. Drip irrigation has been successfully implemented in various crops like citrus, grapevine, pomegranate resulting in improved growth and yield under drought conditions. Regulated deficit irrigation (RDI) and partial root-zone drying (PRD) techniques optimize water use without compromising fruit yield. These approaches are widely used in grape and citrus orchards to enhance drought resilience.

2. Soil Management and Nutrient Optimization

Proper soil management improves fruit crop resilience to abiotic stresses. The application of organic amendments like compost, farmyard manure, and biochar enhances soil structure, water retention, and microbial activity, promoting stress tolerance in fruit crops. The use of gypsum and organic amendments reduces soil salinity and improves nutrient uptake in salt-sensitive crops like mango and strawberry. Organic and synthetic mulches help conserve soil moisture, reduce soil temperature fluctuations, and suppress weed growth. In guava, mulching has been shown to enhance soil water retention and improve fruit quality. Besides, balanced fertilization with macronutrients (N, P, K) and micronutrients (Zn, Fe, B) improves stress tolerance. For example, potassium application enhances drought resistance in apple (Malus domestica), while zinc supplementation prevents stress-induced fruit drop in citrus.

3. Genetic and Breeding Approaches

Developing and utilizing stress-tolerant fruit crop varieties is a sustainable approach to mitigating abiotic stress. Pomegranate and date palm naturally exhibit high drought tolerance, making them suitable for arid regions. Breeding programs in mango and guava have identified genotypes with improved water-use efficiency. The use of salt-tolerant rootstocks in citrus and grapevine enhances plant survival in saline conditions by regulating ion uptake and preventing sodium toxicity. In temperate regions, cold-resistant apple and peach cultivars have been developed to withstand frost damage. Advancements in molecular breeding enable the identification of stress-resilient traits in fruit crops. Technique like Marker-Assisted Selection (MAS) helps to identify and incorporate genes responsible for drought, heat, and salinity tolerance. Besides, transgenic approaches involving the introduction of stress-related genes (e.g., DREB, HSPs) have been explored to improve abiotic stress tolerance in fruit crops. For instance, overexpression of stress-responsive genes in citrus enhances drought and heat resistance.

Many fruit crops are endowed with physiological and morphological adaptations and have capacity to withstand adverse effects of water stress. Leaf hairiness, hypostomatous distribution and sunken stomata are all characteristic features of species that exist in drought-prone regions (Clifford *et al.*, 2002). In salt-affected lands where cultivation of annual field crops is limited, adopting relatively tolerant crops like ber, aonla, guava, grape, karonda, jamun and phalsa would help in utilization of such lands for horticulture. These crops could be considered as candidate crops to face the challenges of abiotic stresses under climate change conditions. Varieties for drought conditions should be short in duration. Some of the drought tolerant varieties in fruit crop *viz.* -Ruby (Pomegranate), Arka Sahan (Annona), Deanna and Excel (Fig), Karpuravalli andKanthali, (banana), har Neelkanth (Mulberry) and Goma Aiswarya (Aonla). The varieties like Rajapuri, Poovan, Tahiti Lime, Fuerte and Duke are cold tolerant whereas, New Castle,

Early Shipley in apricot and Tropical Beauty, Michel and Anna are low chilling varieties of apple. The grape cultivars Thomson Seedless, Perlette, Cardinal, Black Rose and strawberry varieties Lassan and Shasta are found to be salt tolerant innature (Nimbolkar *et al.*, 2016)

4. Integration of propagation techniques

Grafting is a widely used horticultural technique that has shown significant potential in enhancing abiotic stress tolerance in fruit crops. Rootstocks that are selected for their drought tolerance can significantly enhance the scion's ability to cope with water scarcity. For instance, *Citrus sinensis* demonstrated that grafting onto drought-resistant rootstocks, such as *Poncirus trifoliata*, improved the drought tolerance of the scion. The role of grafting in improving salt tolerance in citrus trees is also prominent. Grafting onto *Citrus volkameriana*, a salt-tolerant rootstock, significantly reduced the uptake of toxic sodium ions in the scion and improved overall growth and fruit production in saline soils. The grafted trees exhibited lower leaf chloride concentrations, better leaf chlorophyll content, and higher fruit yield compared to ungrafted trees grown in high salinity conditions.

5. Microbial Approaches

Beneficial microorganisms play a crucial role in enhancing stress tolerance in fruit crops. Rhizobacteria such as *Azospirillum*, *Pseudomonas*, and *Bacillus* improve root growth, water uptake, and nutrient acquisition in banana and papaya under drought conditions. Arbuscular mycorrhizal (AM) fungi establish symbiotic associations with plant roots, enhancing water and nutrient absorption. In mango and citrus, AM fungi improve salinity tolerance by regulating ion balance and osmotic adjustment.

6. Exogenous Application of Bio-stimulants

The application of bio-stimulants such as seaweed extracts, humic acids, and plant-derived hormones improves fruit crop resilience to abiotic stress. Salicylic Acid (SA) and Jasmonic Acid (JA) enhance antioxidant defence mechanisms and mitigate oxidative damage in grapevine and apple under drought and heat stress. Osmoprotectants like proline and glycine protect cellular structures and improve water retention in salinity-stressed citrus and banana plants.

7. Agroforestry and Intercropping Systems

Integrating fruit crops with agroforestry and intercropping systems enhances microclimatic conditions and reduces abiotic stress. Planting fruit trees alongside nitrogen-fixing species (e.g., legumes) improves soil fertility and water retention. Growing fruit crops with low stature crops enhances soil health and reduces evapotranspiration.

8. Climate-Smart and Protective Cultivation Practices

Controlled environment cultivation reduces the impact of extreme temperatures and water scarcity on fruit crops. In cold-sensitive crops like papaya and banana, greenhouse cultivation protects plants from frost damage and temperature fluctuations. In high-temperature regions, shade nets reduce heat stress and sunburn damage to the low canopy crops.

9. Smart Technology and Precision Agriculture

Technological advancements in remote sensing and Geographic Information Systems (GIS) help monitor abiotic stress in fruit crops. Satellite imaging and drone-based thermal sensors detect water stress and heat stress in orchards. GIS-based soil surveys identify saline-affected areas, aiding in targeted soil management strategies for fruit crops. Smart irrigation technologies improve water management in fruit crop production. Automated irrigation systems with the help of soil moisture sensor can optimize water use by monitoring soil moisture levels in real-time. AI-driven irrigation models adjust water supply based on weather forecasts, reducing drought impact in fruit orchards.

Challenges and Future Perspective

The management of abiotic stress in fruit crops presents significant challenges due to the increasing impact of climate change. While various mitigation strategies have been developed, their effectiveness is often limited by factors such as economic constraints, lack of awareness among growers, and the complexity of stress responses in fruit crops. Addressing these challenges requires a multidisciplinary approach, integrating scientific advancements with practical applications to ensure sustainable fruit production. Fruit crops often face a combination of abiotic stresses, including drought, salinity, temperature extremes, and nutrient imbalances. These stresses interact in complex ways, making it difficult to develop a one-size-fits-all solution. For instance, high temperatures can exacerbate drought stress by increasing evapotranspiration, while salinity can further restrict water uptake, leading to compounding negative effects on plant growth and fruit yield. Understanding these interactions is crucial for designing effective stress management strategies. Despite advances in breeding and biotechnology, the development and adoption of stress-tolerant fruit crop varieties remain limited. Traditional breeding methods are time-consuming, and while genetic engineering and marker-assisted breeding offer promising alternatives, regulatory constraints and public perception issues often hinder their widespread implementation. Additionally, many fruit crops have long reproductive cycles, making genetic improvements a slow and complex process. Precision agriculture technologies, such as remote sensing, automated irrigation, and climate-controlled cultivation, have shown great potential in mitigating abiotic stress. However, the high cost of these technologies limits their adoption, particularly among small-scale fruit growers. Furthermore, the lack of technical expertise and infrastructure in many regions further restricts their accessibility and effectiveness. Managing abiotic stress in fruit crops remains a significant challenge, requiring an integrated approach that combines genetic, agronomic, and technological innovations. While several solutions have been developed, economic and logistical constraints hinder their large-scale implementation. Future research should focus on developing climate-resilient varieties, advancing microbial-based stress management techniques, and promoting smart agriculture to ensure sustainable fruit production in the face of climate change. Collaborative efforts between researchers, policymakers, and farmers will be essential in overcoming these challenges and securing the future of global fruit cultivation.

List of physiological disorders of fruit crops due to abiotic stress

Sl No	**Name of the Physiological Disorder**	**Affected Crops**	**Symptoms Associated**	**Mitigation**
A. Stress Associated with Temperature				
1	Sunburn	Apple, Mango, Grape, Citrus etc.	Yellowing, browning, necrotic patches on fruit skin, reduced fruit quality	Use shading nets, increase canopy cover, apply kaolin-based sprays, and maintain proper irrigation
2	Chilling Injury	Banana, Mango, Citrus, Avocado, Papaya etc.	Browning of peel, uneven ripening, water-soaked lesions, poor fruit texture	Store at optimal temperature, avoid prolonged exposure to low temperatures, use protective coverings
3	Freezing Injury	Apple, Peach, Grape, Citrus etc.	Water-soaked appearance, softening of tissues, cell damage, fruit decay	Use frost protection techniques (mulching, windbreaks, sprinklers), select cold-hardy rootstocks
4	Heat Stress-Induced Fruit Drop	Mango, Citrus, Apple, Pear etc.	Premature fruit drop due to high temperatures and water deficit	Maintain adequate soil moisture, use mulching, regulate canopy temperature through pruning
5	Lenticel Breakdown	Apple, Mango, Avocado etc.	Dark, sunken spots on the fruit skin, reducing market value	Avoid excessive rainfall or humidity, improve post-harvest handling, regulate irrigation
B. Stress Associated with Moisture				
1	Blossom End Rot	Tomato, Pepper, Watermelon, Eggplant etc.	Dark, sunken, leathery patches at the blossom end of fruit due to calcium deficiency linked to irregular water supply	Maintain consistent soil moisture, avoid over-irrigation, apply calcium-rich fertilizers

2	Fruit Cracking (Splitting)	Cherry, Pomegranate, Tomato, Citrus etc.	Fruit cracks due to sudden changes in water availability (heavy rain after drought)	Maintain uniform soil moisture, use mulching, regulate irrigation frequency
3	Water core	Apple, Pear etc.	Water-soaked, glassy appearance of fruit flesh due to excessive water uptake	Regulate irrigation, avoid excessive nitrogen fertilization, select resistant cultivars
4	Edema (Oedema)	Grapes, Tomato, Citrus, Cucumber etc.	Small, water-soaked blisters on fruit/leaf surface due to excessive water uptake and poor transpiration	Improve drainage, avoid over-irrigation, enhance air circulation
5	Drought-Induced Wilting & Fruit Drop	Mango, Citrus, Apple, Papaya etc.	Wilting, reduced fruit size, premature fruit drop due to prolonged water scarcity	Apply mulching, use drought-tolerant rootstocks, optimize irrigation scheduling
C. Stress Associated with Soil Edaphic Condition				
1	Salt Injury	Citrus, Grape, Mango, Banana etc.	Leaf burn, marginal necrosis, reduced fruit size, poor growth due to high salt accumulation in soil	Use salt-tolerant rootstocks, improve drainage, apply gypsum to leach salts, adopt proper irrigation practices
2	Aluminium Toxicity (Acid Soil Stress)	Pineapple, Citrus, Papaya, Banana etc.	Root stunting, yellowing of leaves, poor fruit set, reduced growth due to high aluminum availability in acidic soils	Apply lime (calcium carbonate) to raise soil pH, use aluminum-tolerant cultivars, maintain proper fertilization
3	Chlorosis (due to Iron deficiency (High pH Induced)	Citrus, Grape, Pear, Apple etc.	Interveinal chlorosis (yellowing between leaf veins), poor fruit development due to iron unavailability in alkaline soils	Apply iron chelates or foliar sprays, use acidifying fertilizers (sulfur), select tolerant rootstocks
4	Sodium Toxicity	Pomegranate, Citrus, Banana, Guava etc.	Leaf scorching, stunted growth, premature leaf drop, reduced fruit yield due to excess sodium in the soil	Improve soil drainage, leach excess sodium with good-quality irrigation water, use gypsum to displace sodium

5	Magnesium Deficiency (Linked to soil acidity and high salinity)	Banana, Apple, Citrus, Mango etc.	Yellowing of older leaves, poor fruit development, weak plant structure due to magnesium leaching in acidic or saline soils	Apply dolomite lime (for acidic soils), use magnesium sulfate or Epsom salt foliar sprays
D. Stress Associated with Essential nutrients				
1	Nitrogen Deficiency	Apple, Mango, Citrus, Banana etc.	Pale green to yellow leaves, reduced leaf size, poor fruit development, early leaf drop	Apply nitrogen-rich fertilizers (urea, ammonium nitrate), use organic manures, maintain balanced fertilization
2	Phosphorus Deficiency	Grape, Papaya, Apple, Guava etc.	Dark green to purplish leaves, stunted growth, delayed flowering, poor fruit quality	Apply phosphorus fertilizers (DAP, superphosphate), use mycorrhizal inoculants to enhance P uptake
3	Potassium Deficiency	Banana, Citrus, Mango, Pineapple etc.	Leaf edge scorching, weak plant structure, small-sized fruits, poor resistance to stress	Apply potassium sulfate or muriate of potash (MOP), use organic sources like wood ash
4	Calcium Deficiency (Bitter Pit, Cork Spot)	Apple, Pear, Tomato, Citrus etc.	Sunken, corky spots on fruit, poor fruit texture, premature fruit drop	Apply calcium sprays (calcium chloride), maintain consistent soil moisture, use gypsum
5	Magnesium Deficiency	Banana, Citrus, Mango, Apple etc.	Interveinal chlorosis (yellowing between veins), premature leaf drop, weak fruit development	Apply magnesium sulfate (Epsom salt), use dolomite lime in acidic soils
6	Iron Deficiency (Chlorosis)	Citrus, Grape, Apple, Pear etc.	Interveinal chlorosis in young leaves, reduced photosynthesis, poor fruit yield	Apply iron chelates or foliar iron sprays, use acidifying fertilizers in alkaline soils
7	Zinc Deficiency (Little leaf disease)	Citrus, Apple, Grape, Mango etc.	Small, narrow leaves, poor shoot elongation, reduced fruit set	Apply zinc sulfate, use foliar zinc sprays, improve soil pH management
8	Boron Deficiency (Internal browning, cracked fruit)	Apple, Mango, Pomegranate, Grape etc.	Fruit cracking, internal browning, stunted root growth, hollow fruit formation	Apply borax or boric acid, use foliar boron sprays, avoid excessive liming
9	Copper Toxicity	Citrus, Mango, Grape, Apple etc.	Dark green leaves with stunted growth, root damage, leaf tip burn due to excess Cu accumulation	Avoid excessive copper-based fungicide application, improve soil drainage, use organic amendments
10	Manganese Toxicity	Citrus, Pineapple, Grape, Banana etc.	Brown spotting on leaves, poor root development, toxicity symptoms in acidic soils	Apply lime to neutralize acidic soils, avoid excessive Mn fertilization
D. Stress Associated with Heavy Metals				

1	Cadmium (Cd) Toxicity	Grape, Apple, Citrus, Strawberry etc.	Stunted growth, chlorosis, leaf necrosis, reduced fruit yield due to cadmium accumulation	Use organic amendments (biochar, compost), apply phosphate fertilizers to reduce Cd uptake, select Cd-excluder rootstocks
2	Lead (Pb) Toxicity	Mango, Banana, Citrus, Guava etc.	Leaf discoloration, root damage, reduced fruit quality, heavy metal accumulation in edible parts	Improve soil aeration, use phytoremediation (plants like mustard), apply organic matter to immobilize Pb
3	Arsenic (As) Toxicity	Pomegranate, Apple, Grape, Papaya etc.	Leaf necrosis, poor root growth, fruit deformities, arsenic contamination in fruits	Use arsenic-tolerant rootstocks, avoid contaminated irrigation water, apply sulfur-containing amendments
4	Mercury (Hg) Toxicity	Citrus, Strawberry, Pineapple, Banana etc.	Growth retardation, leaf chlorosis, fruit malformation, cellular damage due to mercury accumulation	Avoid industrial wastewater irrigation, apply organic amendments, use sulfur-containing compounds to bind Hg
5	Nickel (Ni) Toxicity	Pear, Apple, Grape, Avocado etc.	Leaf tip necrosis, root stunting, reduced fruit set, toxicity symptoms at high Ni concentrations	Apply lime to reduce soil acidity, use organic matter to bind Ni, select Ni-tolerant rootstocks

Conclusion

Abiotic stress poses a significant threat to fruit crop production, with climate change exacerbating challenges such as drought, salinity, temperature extremes, and nutrient imbalances. These stresses not only affect plant growth and development but also compromise fruit yield, quality, and market value. Effective management strategies are essential to sustain fruit production and ensure food security in the face of increasing environmental uncertainties. A comprehensive approach integrating genetic, physiological, agronomic, and technological solutions is crucial for mitigating abiotic stress in fruit crops. The development of climate-resilient cultivars through conventional breeding, molecular techniques, and biotechnological interventions offers a promising pathway to enhance crop tolerance. Additionally, microbial inoculants, bio-stimulants, and organic amendments have shown potential in improving plant resilience by enhancing root growth, nutrient uptake, and stress tolerance mechanisms. Adopting precision agriculture technologies, such as remote sensing, automated irrigation, and artificial intelligence-based decision-support systems, can significantly improve stress management by enabling real-time monitoring and resource-efficient interventions. Furthermore, sustainable soil and water management practices, including conservation tillage, mulching, and integrated nutrient management, are essential for maintaining long-term productivity and environmental sustainability. Despite these advancements, challenges such as high implementation costs, limited farmer awareness, and regulatory barriers remain obstacles to widespread adoption. Future research should focus on interdisciplinary approaches that combine genetics, microbiology, agronomy, and data-driven solutions to develop holistic strategies for stress mitigation. Strengthening collaboration between researchers, policymakers, and farmers is critical to overcoming these challenges and ensuring the resilience of fruit crops against abiotic stress. By embracing innovative technologies, sustainable practices, and scientific advancements, the fruit industry can adapt to the changing climate and continue to meet the growing global demand for high-quality fruits.

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Successful scaling approaches leading to autonomous adoption of Conservation Agriculture in West Bengal

A.K. Chowdhury
Professor in Plant Pathology & Dean, Post Graduate Studies (Actg.)
Uttar Banga Krishi Viswavidyalya, Pundibari, Cooch Behar

Introduction

In West Bengal, India, the agricultural sector needs options that can address labour scarcity, reduce production costs and improve productivity. Conservation agriculture (CA) based technologies offer potential solutions for these issues and have been tested in the north of the state since 2012, with promising results. Through research for development project, a network of actors comprised of research (local university, international research organisations), extension (Department of Agriculture) and farmers groups have been working together through participatory field trials, capacity development, supply chain and policy interactions to undertake research and development activities with the unified aim to take CA to scale across the state of West Bengal. As a result of this, more than 100,000 farmers in the state are now using CA practices, while opening the new window opportunity to intact the youth in agriculture with several important factors identified that have contributed to the scaling success.

Approach to scaling

Scaling is a crucial approach for agricultural technology (agtech) because it ensures that innovative solutions are effectively extended from small, localized applications to larger, more widespread use.: Scaling ensures that agricultural innovations can reach more farmers, regions, or even countries. This maximizes the positive impact of the technology, whether it's in increasing yields, improving resource efficiency, or enhancing food security.

Proof of concept

A coordinated set of over 200 participatory, on-farm field trials in five nodes over several seasons provided proof of concept of the benefits of CA systems. The results showed that CA based systems improve profitability, maintain productivity, and reduce the emissions footprint, water and energy inputs, and labour requirements of food production systems *(Dutta et al., 2020; Gathala et al., 2021; Gathala et al., 2020; Gathala et al., 2020; Islam et al.,* 2019). These more productive and sustainable farming techniques offer the potential for significant impact if widely adopted

Strengthened networks

Innovation platforms are instrumental in ensuring the successful development, adoption, and scaling of sustainable agricultural technologies by fostering collaboration, co-creation, and a multi-stakeholder approach. They provide the necessary environment for creating solutions that are environmentally, economically, and socially sustainable.

A network of key actors in the agricultural system were engaged in the project, including research (local university UBKV, international and Australian research organisations), extension (Department of Agriculture) and farmers groups. The opportunity to strengthen links and build networks that were limited before was a key element of the project and scaling success. For example agricultural universities worked very closely with the state extension department, which was integral to fostering trust in academic results. These strong networks helped develop trust with communities, and coupled with the participatory trials and ongoing technical backing from international research organisations, resulted in greater buy-in from multiple actors in the system and gave confidence to partners to channel demand to higher levels.

Farmers' Groups

An important part of this network was the farmers' groups (i.e. state sanctioned Farmers Clubs/ Farmers Groups and Farmer Producer Organisations). These groups played a crucial role in machinery provision, access to quality inputs and as an information channel for farmers. As emerging entrepreneurs, they have been linked to partner networks, and had access to technical expertise and act as a single window service mechanism that has reduced risk and allowed them to capitalise on an opportunity to use more profitable and inclusive enterprises.

As an example, the Satmile Satish Club O' Pathagar (SSCOP) in Coochbehar, West Bengal has demonstrated exemplary success in providing CA services, identifying suitable farmers for key activities such as participatory adaptive on-farm trials, and facilitating training and demonstrations. They have been nominated by the Indian National Bank for Agriculture and Rural Development (NABARD) as a Producer Organization Promoting Institution (POPI) which trains other farmer organisations developing as commercial organisations. They have acquired dealership of agricultural machineries (Zero-till multi-crop planters, mechanical rice transplanters, mini combine harvesters, threshers etc.) from the producer companies (National Agro Industries, Mahindra and Mahindra, Yanmar and more). About 60 such farmers' organisations in North Bengal of different sizes have filled a critical gap in both knowledge transfer and making the conservation agriculture based sustainable intensification (CASI) machines and servicing and repair available to a large number of farmers in the northern part of the state. Their current portfolio includes paid trainings; agri-advisory services; input sales (linked to agribusiness company Mahindra Samriddhi); farm equipment rental and sales (with Yanmar Coromandel, Mahindra, Vijay Villiers, National Agro); market linkage and product aggregation and processing for providing better prices to farmers; soil testing; financial services (with strong linkages with financial institutions such as NABARD). SSCOP is also supporting the DoA-WB to promote CASI technologies in other districts of the state. Government agencies have sent their lead farmers for CASI training to SSCOP, which receives visitors from across India, but also from Nepal and Bangladesh.

The private sector

The private sector is a key part of CA systems in South Asia, both through direct provision of machinery, supporting mechanisation service provision, and input and output markets. Large private players like National Agro and Yanmar provided dealership and services on soft terms, after continuous negotiation with research partners, which saw several Farmers' Associations even in the poorest settings become dealers of CA machinery with the support of these companies. Farmers' Cooperatives who had previously focused on agro-input business added CA service provision to their portfolio of services, expanding the number of people who could access the services. Other agro-input dealers made new generation herbicides available, which was a key factor for agronomic success of CA in some areas. Corporate Social Responsibility funds from companies like Godrej and Mahindra were used to train more people in the region in best practice implementation of CA.

CA systems have resulted in business opportunities in rural communities, including for individual service providers. Service Providers are a critical part of the wider CA system in a region where farms are small and fragmented, access to finance is low, and the opportunity for individual farmers to own machines and tractors is limited. Service

Providers fill the gap by taking on the mechanisation services as a business, and selling their services for crop establishment, harvest and post-harvest processes to farmers. CA mechanisation adds an additional income stream in a portfolio of services. Timely and quality service provision is a key enabler in successful CA systems.

Enagement of women and rural youth makes the new system attractive to communities and government alike. Time saved and removed drudgery during crop establishment has been demonstrated to equitably allow the pursuit of alternative income generating activities.

Engaging at all levels

A combination of proof of concept and increasing demand from farmers meant policy makers had something to see in the field that was also supported by locally produced, international standard science. Engagement with government officials and policy makers on issues of CASI, agriculture mechanization and sustainable irrigation were delivered through multiple channels such as workshops, policy dialogues and high-level meetings. To promote scaling in West Bengal, the project team conducted policy and orientation meetings for DoA-WB extension officials at all levels. Having dedicated, focal staff at every level from local (block and subdivision) and higher allowed for coordinated lobbying from different levels within the government system. Engaging high-level officials including the Minister for Agriculture, Chief Secretary of Agriculture and the Adviser on Agriculture to the Chief Minister has given credence to research results and project aims.

Demonstrating convergence

Convergence with government schemes was the ultimate aim for scaling and sustainability of CA use in West Bengal, and these outcomes are demonstrated in several ways.

- In West Bengal, the government has made CA machineries a compulsory part in new Custom Hiring Centres (CHC) that receive government subsidies, which means that every new CHC has at least two CA machineries in their portfolio of five machines (minimum), in an attempt to promote CA technologies and avoid environmental hazards associated with straw and stubble management.
- Government of West Bengal, Department of Agriculture agreed and endorsed the CASI evidenced based recommendation from the project.
- To support this mandate, a Centre of Excellence for Conservation Agriculture (CECA) has been approved by the GoWB to be located at UBKV. Given the rate of adoption within the state, and aligned with government subsidies for machinery purchase, it is necessary to ensure that at the same time there are enough people trained in CASI principles and practical elements, to ensure good quality operations for farmers. The CECA will increase the number of people professionally trained in CASI across the state and improve the quality of information available to farmers and service providers. This centre will establish the infrastructure to further promote CASI beyond the life of the project, a great development for CASI training infrastructure for long term capacity impact. The GoWB has provided the operating funds for this center to ensure sustainability outside of SRFSI. In 2019-20, UBKV sponsored three state level and six district level policy dialogues to finalize the CASI related policies described here.
- At the local (block) level, extension staff are able to commit resources from state extension schemes to activities of their choosing (e.g. ATMA, NFSM), allowing these schemes to promote CA. This promotion of CA is supported by government

research and extension staff assigned at district levels who have a commitment of both time and funds for technical backstopping, troubleshooting and adaptation as adoption spreads in both time and space.

Conclusion

The approaches used here have contributed to scaling and long term sustainability of CA use in West Bengal, and provide key learnings more broadly for successful scaling approaches that can be used elsewhere. Experience highlights the need for proof of concept that incorporates equitable and multi-dimensional assessment of CA approaches; this generates interest at multiple levels and needs to be coupled with technical backstopping. A strong network of actors that includes farmers, research and extension, and the private sector is critical to promote local ownership and fill gaps that can otherwise inhibit scaling.

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Climate Change and Its Impact on Stored Grain Pests

Tapan Kumar Hath[1*] and Tumma Mounika[2]
Department of Agricultural Entomology
Uttar Banga Krishi Vishwavidyalaya, Pundibari, Cooch Behar

Climate change is the most challenging issue in the developed as well as developing and underdeveloped countries in the world. It is an admitted fact that the temperature of the Earth was on the rise over the past 100 years, presumably after the start of industrial revolution and there will be an increase in atmospheric temperature by 1.4- 5.8 degree C by 2100. The CO_2 will also increase and reach between 540 and 970 ppm during the same period.

As agriculture is fully dependent on weather, any change in the climate affects the growth and development, distribution and abundance of all living plants or crops. The important abiotic factors of the climate include the temperature, rainfall and CO_2. Any notable change in these parameters obviously affects agricultural production system and in turn, the life of human being and all other animals on this planet including the insect pests.

Temperature is the most dominant abiotic factor that directly affects the insects in different ways. The physiology of insects responds quickly to the changes in temperature and the rate of metabolism enhances doubly as a result of temperature increase by 10˚ C. Several studies demonstrated that due to the increase in temperature the distribution and migration of insect pests were changed. Temperature directly affected the growth and development of the insects, their population, reproduction and dispersal which will result into variation in pest intensity and abundance. Higher temperature influenced the larval development of different insects and there were a greater number of generations per year, that is to say, more infestation and damage to crops. Insects living in cold regions might proliferate and start migration to warmer areas much earlier than usual causing early infestation to crops and newer arears of pest invasion besides disruption in pollination due to asynchrony in the occurrence of insects and blooming period.

Increased $CO_{2,}$ more accurately to be stated, the elevated carbon dioxide i.e. eCO_2 in nature will directly impact the plant growth. There will be much higher carbon content in the plant tissues that will alter the food quality for the insects. Besides, eCO_2 will change the phenolic compounds in the leaves, water content, the carbohydrates and leaf thickness. These changes in the leaf quality will have differential effect on the growth and development of the insects that feed on eCO_2. Recent studies showed that the susceptibility level of insects to different pesticides were altered due to consumption of plants grown under eCO_2 compared to ambient $CO_{2.}$

Rain or drought regulates the growth and development of different crops during different seasons. Heavy rainfall leads to flooding and inundation of water that threatens survival of insects and affects the diapausing insects. Heavy rainfall can wash away tiny and soft bodied insects and mites. Drought also affects herbivorous insects in different ways viz. dry climate may create favourable conditions for some phytophagous insects and plants grown under drought- stress conditions attract some insects.

Likewise, climate change will also have impacts on the stored grain pests. Stored grain pests are not confined to storages only under protected environments. These insects can be considered as the open-area insects that were co-evolved with mankind from the onset of agriculture (Hagstrum and Phillips, 2017). They became the stored product insects since humans started storing agricultural commodities (Plarre, 2013). Majority of the studies focused on the impacts of climate change on the potential of crop yields (i.e. pre-harvest implications). Comparatively little focus has been made on the impacts of climate change on the post-harvest agriculture. Sudden change in the humidity during post-harvest operations and storing will lead to enhanced activities of the stored grain pests causing greater loss of food grains. As a result of climate change due to global warming, many of the stored grain insects have been recorded in the agricultural fields in different parts of the world. Moreover, some insects have been reported to be invading new areas. Thus, changes in the distribution and abundance of stored grain pests are taking place as a result of climate change.

In the above background it is necessary to pay a serious look at the impact of climate change on stored grain insects especially on the distribution, abundance, biology, growth and development and susceptibility to pesticides and management strategies in the changing scenario. Cereals and pulses are the major food grains which are stored for long periods in the storages either at domestic or commercial level or in government establishments. Grain losses in storage vary from 12-16 million metric tons every year in the country (Singh, 2010) and loss of food production due to insect pests in the storage may be 20-25% (Nattudurai *et al.*, 2015). The World Bank estimated that out of the total production, losses of pulses in our country accounting for 9.5% can suitably feed 1/3rd of the Indian population lying below the poverty level (Rajasekhar *et al.*, 2014). The above clearly suggests that besides giving major emphasis on production and productivity of crops, due attention are also required for protecting the grains after harvest in the storage to lessen the loss of huge quantity of food grains for ensuring food security of the country.

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Externality vs Sustainability: An agroeconomic assessment

Prof. Ashutosh Sarkar
Department of Agricultural Economics
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Externality

In case of economic system externality is a situation where freeness of activity of individual A will be affected by action of B with- out any relation between them. The former may be defined as receiver and the later as generator. The receiver of externality will have no control over it but to face. Externality is an obvious part of our life dynamics which cannot be denied. Each individual person participates in dual role both as receiver vis-à-vis generator.

Forms of externality and their mode of appearance

Forms	Mode of operation
Positive/Negative	Positive externality will be beneficial for the receiver and it will be a free gift. Negative externality will create problem and the sufferer needs to incur additional cost to get out of that.
Producer/ Consumer	When it is created as a by- product of production process then such externality is called producer externality. On the other hand if it is created by the consumption process then it is called consumer externality.
Local/Regional/National/ Global	According to area of generation or occurrence the externality can be classified so. This information is required for better understanding about solution.
Inter- generational/intra-generational	In case of Inter-generational externality the creator will act at present and the receiver will face the effect in future. But in case of intra generational, externality will be created and confronted at present time only.
Society/ Individual	Externality created by a private person may be called as individual externality. But when it is created by a large number of people together then it is regarded as social externality.

Present discussion will be on impact and mitigation of Negative Externality. In case of agricultural production system externality is a process out- come that may destabilize the natural resource stock along with dumping of wastes in environment.

Beneficiaries of externality outcome: Usually the individual producer can produce in lower cost (better explained through Marginal Social Cost vs Marginal Private Cost) by avoiding abetment cost. The benefit of this lower cost is given to consumer through lowering the price of the product. At the same time the producer also enjoy the scope of increasing supply along with additional profit. In such case benefit will be enjoyed both by producer and consumer of concerned product.

Strategic option to impose desired level of externality: Though the externality cannot be avoided, it can be optimised. For this, a techno-economic study will be required to find the optimum level of acceptance (by Marginal Abatement Cost vs Marginal Damage

Cost). Now the said level will be maintained by the Govt. regulatory through **Command & Control** or **Polluter's Pay Principle** or Liability **Law Principle**.

Natural Capital

Natural capital is considered as a fifth factor of production for which no payment is usually made. At the cost of exploitation of natural capital we make reproducible capital which is directly used as input support of production process and subsequently increase income. Natural resource can be regarded as stock of natural capital of a country at any point of time. Environment plays major role in this domain by assimilating waste and maintaining cleanliness through her own mechanism. Capacity of natural capital to provide safe guard to human population is considered as a basic parameter for sustenance.

Classification of Natural resource

Type	Example	Remark
In exhaustible resource	Air, sunlight light, tide	Stock will never reduce
Exhaustible resource	Forest , mine, ground water	Stock will reduce by current use
Renewable resource	Fishery, animal herd, fertility of soil	Stock will increase by reproduction

Consumption of Natural Resource: Exploitation dynamics

Exhaustible Resource

Optimum extraction path: $(P_t – C) = (P_0 – C) (1+r)$

Where P_t = price per unit at future time t
P_0 = price per unit at present time
C= cost for extraction per unit
r= rate of discount

Recardian Scarcity hypothesis of exhaustible resource: Any sorts of use of exhaustible resource at present will reduce the stock and finally reduce the opportunity of use the same in future. Hence the said resource will become scarce over time. As a result the real Price of exhaustible resource will rise (Strong hypothesis). If not so be established, at least Price of exhaustible resource will rise in comparison to non - exhaustible one (Weak hypothesis).

Criticism of Recardian scarcity hypothesis:

- As highgrade resource exhausts the lower grade resource will come under active use.
- When one resource becomes scarce people will switch over to alternatives.
- Increase of scarcity will encourage recycling
- Technical efficacy of search and use will increase.
- Resource use will not be preferable if it adds environmental pollution.

How can we buy time to extend life of existing stock of natural resource?

- Increasing efficiency of primary use
- Increasing efficiency in recycling
- Increasing Efficiency in extraction
- Switching over to renewable alternatives

Consumption of Renewable Resource:

In case of Renewable resource (eg. natural fish pond) the stock will increase through natural regeneration process. On the other hand by maintaining stock at a given level constant amount of harvesting can also be possible. The yield has a positive relation with stock until the later attain certain level of optimality. After that with the increase of stock, yield will decrease due to overcrowding of stock. However, it is advised to keep stock at higher level (dynamically stable zone). In that case any reduction of stock will increase the yield. The same can be better understood with the help of sustainable yield curve.

Sustainability

The word Sustainability may be conceptualised as to maintain the activity pathway along the time horizon keeping due parity between present and future.

Propositions to get sustainability of natural capital.

Weak proposition of sustainability: Natural capital (eg. coal) should only be consumed so far as it is compensated for by increase in the stock of reproducible capital (eg. electricity from coal)

Strong proposition of sustainability: The quantity of natural capital should be maintained at constant. Depletion of one sort of natural capital should be compensated for by increase in other sorts.

Approaches for attaining sustainability

Standard approach of sustainability:

- To achieve sustainability this approach advices for maintenance of standards in different forms. If the said standards are followed, the sustainability will be maintained in return.
- Basic three standards are Discharge standard, Stock Standards and Flow Standards.

Discharge standard: Here the Economically efficient level of emission will be drawn (by using Marginal Abatement Cost and Marginal Damage Cost) first. Then policy will be imposed to keep the discharge at any given level.

Stock standard: Stock standard is maintained where conservation is needed for irreplaceable asset which is vital for sustainability. A portion or whole asset is reserved. The enhanced cost for this restoration will be the value of sustainability standard.

Flow standard: Re-allocating activity from its existing site. Destruction at Location A will be allowed with a committed rebuilt of the same at location B. Emission of CO_2 is allowed with a promise of equivalent green plantation elsewhere (carbon trading) .

Issues of sustainable development:

Sustainable development is defined as Development that meets the needs of the present without compromising the ability of future generation to meet their own needs.

Under Naturogenic back ground: If the damage is caused by naturogenic process, it is very tough to confront with. In that case resiliency is the way to face the challenge. Here we have to search alternative ways to coup with the nature. Priority needs to be given on Integrity of atmosphere, Restoration of Bio-diversity, Restoration of stock of exhaustible resource, Exploration of renewable resource and Conservation of cultural practice.

Under Anthropogenic back ground: When the externality is caused by individual person, the issue will harness over Property right. In that case mere technical solution (even with awareness) may not be able to resolve the matter. There will be the question of Inter-generational equity (Present vs Future) and Intra generational equity (between countries: Global North vs Global South and within country: (Rich vs Poor, Farm sector vs Industrial sector) that needs to be resolved by negotiation (explained in Coase theory).

<u>Sustainability in Agriculture</u>

Long term Impact of green revolution:

- Degrading top soil
- Declining ground water level
- Contaminating water bodies
- Reducing biodiversity

Mitigation through Resiliency

Sustainable agricultural Practice and systems: Environment friendly approach to coup with change of natural resource (both qualitative and quantitative). Each practice has economic viability (though needs initial 2-3 years gestation for establishment) over conventional practice.

❖ **Practices: Focused on single aspect of agriculture.**

Vermicomposting, Drip irrigation/ sprinkler, Crop rotaion, Intercroping, Mulching, Rainwater harvesting/ artificial recharge of ground water, Floating farming, Plastic Mulching, Shade net house, Alternative wetting and drying technique, Foar pond lined with plastic film, Direct seeding of Rice, Canopy management, Mangrove and non-mangrove bio shields.

❖ **Systems: A holistic focus comprising multiple aspects.**

Permaculture, Organic farming, Natural farming, System of Rice Intensification (SRI), Biodynamic agriculture, Conservation agriculture, Integrated farming system (IFS), Agroforestry, Integrated Pest Management (IPM), Precision farming, Silvipastoral system, Vertical farming, Hydroponics/ Aeroponics, Crop-livestock-fisheries system**.**

❖ **Mitigation through property right settlement:**

Selling of farm products with residual toxicity of insecticide (ignoring health issue of customer) for higher price.

Issue of Rice Stubble burning in North Western part of India: Farmers in role of polluter is facing cash penalty to the tune of Rs.5000 to Rs.30, 000 for single burning case. Govt. of India along with ICAR and State Govt.s is trying to resolve the issue with the way of resiliency mechanism (convincing farmers through awareness and incentives) but still the practice is increasing like wild fire. It is an emerging issue of property right may need to be resolved by Negotiation.

Impact of climate change on the dynamics of insect-pests including invasive alien species and their management strategies.

S.K. Sahoo
Professor and Head
Department of Agricultural Entomology
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

In the current times, climate change has become the serious global issues for existence of life on the earth. The term "climate change" is used to denote the gradual increase of the temperature of the earth's atmosphere and its ocean. Over the past hundred years, the global temperature has increased by 0.8^0 C and is expected to reach $1.1\text{-}5.4^0$ C by the end of next century. On the other hand, CO_2 concentration in the atmosphere has increased drastically from 280 ppm to 370 ppm and is likely to be doubled by 2100 (IPCC, 2007). These changes happening due to the overexploitation and misuses of natural resources. Insect-pests of different crop plants are the real candidate most affected by the ongoing climate change. Increased temperatures will increase the pest population, and at the same time water stressed plants may result in increased insect populations and pest outbreaks. This will affect the crop yield and availability of food grains and threaten food security of the nation. The climatic change impacts on pests may include:

- Changes in diversity and abundance of insect pests
- Changes in geographical distribution of insect pests
- Increased overwintering insects
- Rapid population growth and no. of generations
- Changes in synchrony between insect pests and their host crops
- Introduction of alternative hosts plants
- Changes in host plant resistance
- Changes in insect biotypes
- Changes in tritrophic interactions
- Impact on extinction of species
- Changes in activity and relative abundance of natural enemies
- Increased risk of invasive pest species
- Reduced efficacy of crop protection technologies.

Thus, it is expected that growers will face new and intense problem of different insect-pests in the coming years. Therefore, now it is an urgent need to intervene the challenging issue for modification of the plant protection measure with changed climate in order to attain the goal of food security of the nation.

The insect diversity in any habitat indicates the health status of the ecosystem as they are very good indicator of environmental changes, play an important role in food chains, are excellent pollinator of many economically important plants and contribute directly to the human economics through valuable products like honey, silk, lac and wax etc. India is the inhabitant of about 6.83% world insect species (Alfred, 1998). The Western Ghats is the only habitat to many rare, endemic and exotic species of colourful butterflies in the world (Anand and Pereira, 2008). However, in present day climate changing scenario, many butterfly species are under a real threat due to depletion of natural vegetation. The negative effects of climate change are accelerating the rate of biodiversity loss, worldwide.

The geographic distribution and abundance of plants and animals in nature is determined by the species-specific climatic requirements essential for their growth, survival and reproduction. With rise in temperature, the insect-pests are expected to extend their geographic range from tropics and subtropics to temperate regions at higher altitudes along with shifts in cultivation areas of their host plants. This may lead to increased abundance of tropical insect species and at the same time in the temperate region relative abundance of temperature sensitive insect population may decrease (Sharma *et al*., 2010).

Insects are poikilothermic or clod blooded animals and therefore have a limited capacity of homeostasis with external temperature changes. They have evolved a variety of strategies to survive under thermally stressful environmental conditions such as behavioural avoidance through migration and physiological adaptations like diapause (aestivation and hibernation to sustain life under high and low temperature extremes, respectively). It has been reported that global warming is most pronounced in winter at high altitudes. Thus, insects undergoing winter diapause are likely to experience the most significant changes in their thermal environment (Bale and Hayward, 2010). Accelerated metabolic rates at higher temperature shorten the duration of insect diapause due to faster depletion of stored nutrient resources.

Under a global worming scenario this makes it possible to accelerate the reproductive rates and shorten the life cycle leading to an increase in the number of generations per year of many insect species and ultimately it will result in more crop damage.

The effect of increased temperatures is greater for above ground insects than for those spending most of their life cycle in the soil, because soil is a thermally insulating medium. Under warmer condition, aphids are less induced by the alarm pheromone they normally release when threatened by predators and parasitoids.

A common feature of plants grown under elevated CO_2 levels is a change in the chemical composition of leaves, which would affect the nutrient quality of the foliage (change in the C: N ratio) and palatability to leaf feeding insects. Nitrogen is the key element in the insect's body for its development and therefore, increased CO_2 concentration leads to increased plant consumption rate in some pest groups. This can lead to increased level of plant damage, as pests must consume more plant tissue to obtain an equivalent level of food.

Globalization and liberalization of world agricultural trade leads to increase chances of exotic introduction followed by invasion of alien species. Climate changes is predicted to be largely beneficial to invasive insects (Bale *et al*., 2002). For example, the distribution of the invasive hemlock woolly adelgid in the Eastern United States is currently limited by clod winter temperature but predicted future worming could allow hemlock woolly adelgid to spread unchecked throughout the rage of hemlock in North America. It is expected that global worming may exacerbate ecological consequences like introduction of new pests by altering phenological events like flowering times especially in temperate plant species as several tropical plants can withstand the phenological changes (Corlett and LaFrankie, 1998).

Climate change resultant abiotic environment (increased temperature, elevated CO_2 and depleted soil moisture) will affect significantly the diversity and abundance of insect-pests through geographic range expansion, increased overwintering survival and a greater number of generations per year, thereby increasing the extent of crop losses. It may result in upsetting ecological balance because of unpredictable changes in the population of insect-pests along with their existing and potential natural enemies (IPCC, 2007). Host plant resistance is greatly influenced by environmental factors like temperature, sunlight, soil moisture, air pollution, etc. Under stressful environment, plant becomes more susceptible to attack by insect-pests because of weakening of their own defensive system resulting in pest outbreaks and more crop damage (Rhoades 1985).

In India, pest damage varies in different agro-climatic regions across the country mainly due to differential impacts of abiotic factors such as temperature, humidity and rainfall. In order to tackle the impact of climate change on population dynamics of insect-pests some of the strategies need to be followed.

- Sensitization of Stakeholders about Climate Change and its Impacts
- Farmers' Participatory Research for Enhancing Adaptive Capacity
- Promotion of Resource Conservation Technologies (RCTs)

In addition to these, the future line of research for combating the pest problems under climate change regimes may also be decided as follows.

- Breeding Climate-Resilient Varieties
- Rescheduling of Crop Calendars
- GIS Based Risk Mapping of Crop Pests
- Screening of Pesticides with Novel Mode of Actions

Although there are still many unknowns related to climate change, it is widely accepted that it greatly affects the cultivation of agricultural plants as well as the insect pests associated with them. Dealing with the climate change is really tedious task owing to its complexity, uncertainty, unpredictability and differential impacts over time and place. If climate change factors lead to favourable conditions for pest infestation and crop damage, then we face a high risk of significant economic losses and a challenge to human food security. A proactive and scientific approach will be required to deal with this problem. Therefore, there is a great need for planning and formulating adaptation and mitigation strategies in the form of modified IPM tactics, climate and pest monitoring, and the use of modelling tools.

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NUTRIENT MANAGEMENT IN CONSERVATION AGRICULTURE

Prof. Abhas Kumar Sinha and Jayshree Dey Sarkar,
Department of Soil Science and Agricultural Chemistry
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Conservation agriculture (CA) according to FAO 'is a farming system that maintains a permanent soil cover to assure its protection, avoids soil tillage, and cultivates a diverse range of plant species to improve soil conditions, reduce land degradation and increase water and nutrient use efficiency'. CA as a modern agricultural practice enables farmers to achieve the goal of sustainable agricultural production. CA based system aims at sustainable productive capacity along with maintenance of health of agroecosystem in the long run. The benefits of the CA lie in the fact that it improves soil health and its functions which are generally managed by the farmers.

Derpsch (2007) said that: "One has to remember that it takes about 5 years of continuous no-tillage [CA] to get positive effects on soil quality, and it takes about 20 years to reap the full benefits of the system."

Therefore, three core principles have been generally accepted as defining CA:

1) minimum soil disturbance,
2) permanent soil cover, and
3) diversified crop rotations.

Acreage under conservation tillage, especially no-till, is steadily increasing throughout the India. Conservation tillage provides many benefits, including increases in soil organic matter, increased water infiltration rate, plant-available water content, and soil biota, while also reducing soil compaction, soil erosion, nutrient loss and and production costs. The transition to no-till system poses many challenges (Figure-1) for the farmers compared to conventional tillage system because of the difference in soil properties, crop growth and climatic conditions. One of the producers' concerns about adopting no-till may be the lack of clear guidelines for nutrient management for those systems.

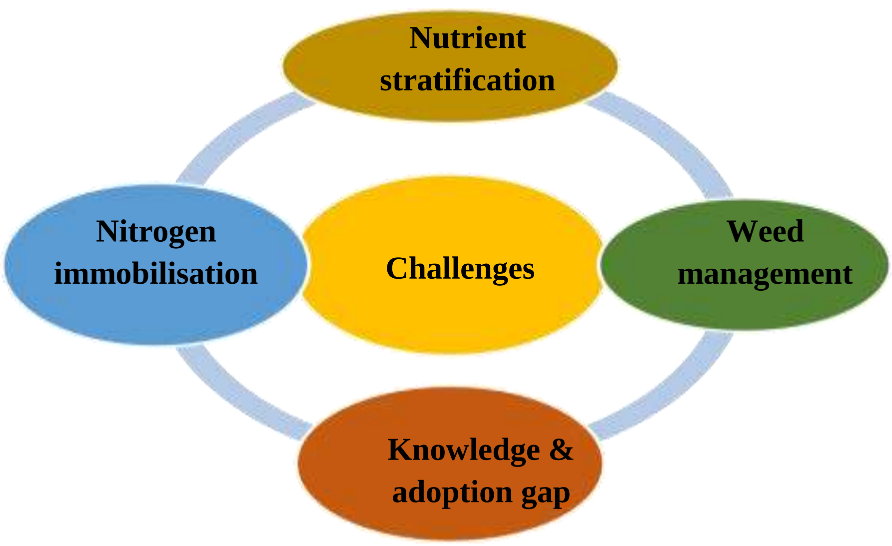

Figure: 1

The successful implementation of CA also depends upon many other agronomic practices, such as appropriate time of seeding, seed depth, seed rate, variety selection, nutrient management, and weed, disease and pest management. In addition, in no-till systems, minimal disturbance of soil alters soil properties, such as soil organic matter, microbial biomass and water infiltration rate, which, in turn, affect nutrient cycling, crop growth and yield. Therefore, compared to conventional tillage, no-till may alter the availability of plant nutrients and may necessitate adjusting fertilizer rate, time and placement.

Nutrient management in CA systems is different from conventional systems because of stratification of nutrients in the soil layer. It is common to have nutrients accumulate and concentrate in the top few inches of soil in no-till systems as a result of surface-broadcasting fertilizers, surface accumulation of crop residue and low movement of nutrients into the soil. Stratification and accumulation of more nutrients within the top 2 inches of soil can limit the crop nutrient availability, including the major nutrients nitrogen, phosphorus and potassium. Although nutrient availability in the surface layers in no-till systems may be enhanced by increased soil moisture because of residue cover, lower temperatures and lower moisture during dry spells may limit availability.

Applying starter fertilizer in no-till systems helps in overcoming slow growth because of low soil temperatures at the early growth stages. Applying the starter to the side of the row below the soil surface, known as side banding, is desired because applying fertilizer close to the seed in the planter row can cause injury to seedlings.

In no-till systems, surface-applied nitrogen fertilizers, especially urea as a top- dressing lead to higher denitrification and volatilization losses than in systems where fertilizer is incorporated into the soil. In addition, surface application in no-till systems can lead to short- term nitrogen immobilization because of more residue application in soils. Because of this, during the first few years of no-till, applying up to 20 percent more nitrogen than recommended may help supply sufficient nitrogen to the crop to compensate for some of the nitrogen that is immobilized by the increased organic matter on the surface. After a few years, however, the increase in the amount of organic matter compensates for the lower mineralization rate and increases the nitrogen supply to the crop. Subsurface application of nitrogen fertilizers in no-till systems helps in overcoming excessive nitrogen volatilization and immobilization.

Application of N fertilizer as urea in alkaline soils in the presence of surface residue, N may be lost by ammonia volatilization into the atmosphere. Similarly, high residue load under No till along with N source and presence of increased macro-aggregates under CA than in CT system also contribute to N loss through denitrification. If nitrogen fertilizers will be broadcasted, it is desirable to decrease excessive losses by using non-urea-based sources – such as ammonium nitrate or ammonium sulfate – coated urea or nitrogen stabilizer-coated fertilizers.

In no-till systems higher crop residues limit urea applied as broadcast in top dressing to interacting with surface soil. Applying urea as shallow bands rather than surface broadcasting minimizes nitrogen loss as ammonia by up to 50 percent; however, the cost of the application has to be considered. Similar to inorganic nitrogen fertilizers, shallow banding of animal wastes helps in significantly minimizing nitrogen losses compared to surface application.

No-till can increase leaching losses of nitrogen fertilizers because of increased infiltration rates. The development of continuous pores between the surface and subsurface under No till may lead to more rapid passage of soluble nutrients deeper into the soil profile than when soil is tilled. This can be overcome by split applications, which are a recommended practice for all tillage types because of the high potential of nitrogen loss. One way to minimize nitrogen fertilizer use is with fall legume cover crops, such as cow pea, lentil, mung bean.

No till system increases the concentration of phosphorus (P) and potassium (K) in surface layer of soil. The surface placement of residues and fertilizers are responsible for improved P and K availability. Fertilizer placement studies that compared broadcast, shallow placement and deep placement of phosphate and potash showed inconsistent results but possible benefits to grain yield from both shallow and deep placements.

The residue recycling along with fertilizer application in each season has tremendous impact on soil nutrient availability. The residue addition has also impact on soil microbiome impacting the nutrient cycling. Reduced disturbance in soil also increases macro aggregates in soil which also support the microbial diversity in soil. Mycorrhizae population is also increased due to increase in glomalin content in soil helps in P nutrient bioavailability.

Monitoring soil pH in no-till systems is important, especially for acidic soils, because the increased organic matter and surface application of ammoniacal nitrogen fertilizers lower soil pH in the soil surface layer. Applying lime as needed is important to optimize the availability of nutrients to the crop. On the other hand, decreasing soil pH will improve nutrient availability in alkaline and calcareous soils. However, continuous application of residues in soil supplies different ions like Ca2+ and Mg2+, which slowly neutralises the acidity in soil in the long run.

The synergy between the organic residues and fertilizers have managed to change the total nutrient management concept for CA based crop production system. Therefore, recommendations for no-till systems include: legume cover crops, starter fertilizers containing both nitrogen and phosphate along with needed micronutrients, split application of nitrogen fertilizers, and shallow-to-deep banding of other nutrients.

Socioeconomic Development of Targeted Farming Communities in the Terai and Dooars Region of West Bengal in changing climate scenario

Somnath Mandal*[1], Sayonton Mondal[2], Nandita Sahana[1], Gobinda Mula
[1]Department of Bio-Chemistry & [2]Department of Agril. Economics,
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Introduction

The Terai and Dooars regions of West Bengal, situated in the sub-Himalayan plains, are characterised by rich biodiversity and diverse agricultural practices. This region, spanning approximately 8,567 square kilometres, experiences an annual rainfall ranging from 2,000 mm to 3,600 mm, supporting crops like rice, tea, jute, and turmeric. However, the area's demographic makeup, with a high concentration of Scheduled Caste communities, heavily depends on traditional, vulnerable agricultural methods. In response, the Science, Technology & Innovation (STI) Hub was established to tackle socioeconomic challenges through technology-driven interventions to strengthen resilience and promote sustainable livelihoods amidst the increasing impacts of climate change.

Climate Change Impact on Terai and Dooars

Climate change has exacerbated environmental challenges in the Terai and Dooars regions, leading to frequent floods, erratic rainfall, and severe soil erosion. These environmental disruptions have directly impacted agricultural productivity, reducing crop yields, reducing biodiversity, and increasing pest infestations. Marginalised communities, especially those from Scheduled Castes, face heightened socioeconomic vulnerabilities due to food insecurity and economic instability. This scenario necessitates urgent climate-resilient interventions to safeguard livelihoods and promote sustainable agricultural practices.

STI Hub Interventions

The STI Hub, with project duration from April 2021 to September 2024 has initiated various interventions. These include sustainable agricultural practices, skill development programs, and the adoption of innovative technologies. Key components of the intervention focus on mushroom cultivation, improved seed production, turmeric cultivation with essential oil extraction, flower cultivation, post-harvest processing, tissue culture, and enhanced fruit cultivation. These initiatives are designed to support secondary or off-farm income generation, promote climate-resilient livelihood practices, and foster self-sustainability among the local communities.

Key Interventions and Success Stories

1. **Turmeric Cultivation in the Buxa Range:** Before the intervention, agricultural labourers in Buxa faced poverty and frequent crop destruction due to elephant intrusions. The STI Hub introduced commercial turmeric farming using high-curcumin varieties and the Single Bud Technique (SBT). Capacity-building initiatives included training in processing, packaging, and value addition, as well as the formation of cooperatives. The outcomes were significant: enhanced income, improved agricultural practices, and reduced wildlife-related crop damage.
2. **Empowering Women through Mushroom Cultivation:** The introduction of mushroom cultivation benefited women previously engaged in hazardous bidi-making jobs with low incomes and poor health outcomes. The STI Hub facilitated the formation of Self-Help Groups (SHGs), provided training in value-added

products (nuggets, pickles, powders), and secured FSSAI certification to ensure market access. This intervention led to notable successes, including participation in the G20 summit, increased income, and women's empowerment as entrepreneurs.

3. **Reviving Kalonunia Aromatic Rice:** Kalonunia rice, once favoured by royalty, had declined due to seed impurity and reduced cultivation. The STI Hub's intervention involved distributing pure seeds, providing sustainable farming training, and establishing market linkages. These efforts resulted in the GI tagging of Kalonunia rice, improved packaging, and access to national markets. The impact was profound, restoring cultural heritage, increasing farmer income, and boosting market demand.

Climate-Resilient Practices Introduced

The STI Hub introduced various climate-resilient agricultural practices, including diversification of turmeric, mushrooms, aromatic rice, and gladiolus crops. Intercropping strategies optimised land use, such as turmeric and banana intercropping in Samuktala. Using bio-based nano-formulations from turmeric extracts as plant immunity boosters and implementing soil conservation techniques contributed to sustainable land management and efficient resource utilisation.

Socioeconomic Impact Analysis

The interventions had a measurable socioeconomic impact. Household incomes increased by approximately 7% due to adopting modern agricultural practices. Technology adoption rates were high in seed production (63%), turmeric processing (61%), and mushroom cultivation (56%). Local employment opportunities reduced migration from 16% to around 9%. Women's empowerment saw a significant boost, with 34% of stakeholders being women who actively participated in farming and household decision-making.

Conclusion

The STI Hub has been pivotal in fostering community resilience, technological innovation, and sustainable livelihoods in the Terai and Dooars regions. The Hub has facilitated long-term socioeconomic growth by focusing on education, skill development, and self-reliance. Its success serves as a model for replication in other climate-affected regions, offering a blueprint for sustainable agricultural development and community empowerment.

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Promotion of Conservation Agriculture practices through Government Mechanism in West Bengal

Rajat Chatterjee
Joint Director of Agriculture (P.), (Admn), Alipurduar.

History of the field always helps us to feel the change. I am here only to share our experience from the Government system, how the promotion of Conservation agriculture practices happened being facilitated by Government Mechanism. We have took a path, amongst many active paths, to reach the Goal for Promotion of Conservation Agriculture We basically based on 4T approach -TECHNOLOGY-We do have validated technology from the SRFSI project.The Sustainable & Resilient Farming System Intensification Project has been rolled from 2024-2019 .This project was officially collaborated by UBKV,DoAGoWB,CYMMIT and was funded by ACIAR.

Team-A strong team with close liaison consisted of Scientists from UBKV, CYMMIT, Extension functionaries from DoA,GoWB,Presence of farmers organization like Farmers club/FPC etc across the geography in the form of CHC promoted by DoA,GoWB helped in building a strong and vibrant Team with reversible communications.

Training- Designed & implemented for the Extension Functionries, The Service Providers and the farmers.

Time: Time scale is one of the important factors to help the techno quake be absorbed and accepted within the social framework.

Department of Agriculture, Government of West Bengal has been promoting Conservation Agriculture Practices through its related Guidelines, Fund allocation & programme implementation through its extension system:

Guidelines:

1) Anti Stubble Burning activity under RKVY with following components
    a) Publicity and awareness creation
    b) Farmers training
    c) Demonstration with Crop Residue Management Machinery
    d) Assistance for adoption of Conservation Agriculture Practices
    e) Providing Eighty Percent (80%) subsidy for purchasing Crop Residue Management Machinery like Multi Crop Planter,Happy Seerder, Super Seeder etc.

Sufficient fund has been allocated for these activities and the Government Extension System has executed these project components with all sincerity

Department of Agriculture, Government of West Bengal has been promoting Conservation Agriculture Practices through opportunities harvested with local initiatives under ATMA scheme.

In Coochbehar, Alipurduar District the technology and the benefits of conservation agriculture practices in the crops like Maize, Jute, Mustard, Wheat, Pulses etc were and are being demonstrated & hand holded to the farmers through Farmers Training, Demonstration in cluster mode, Conduction of Farm School, Convergence with other schemes like NFSM, TRFA, SDS etc.

The opportunity for conduction of demonstration with Mechanization has been designed to be implemented with Conservation Agriculture Machinery

DIVERSIFIED POULTRY PRODUCTION *VERSUS* COMMERCIAL CHICKEN UNDER CLIMATE CHANGE SCENARIO[1]

D. Sapcota[2], Dimpi Choudhury[3] and Rajsekhar Sapcota[4]
[2]Department of Poultry Science, College of Veterinary Science
AAU, Khanapara, Guwahati-22
[3]Livestock Research Station, AAU, Mondira, Kamrup, Assam
[4]KVC, Department of AH & Veterinary, Dibrugarh, Assam.

Introduction.

Poultry farming is one of the most significant sectors in global agriculture, providing a substantial portion of the world's protein supply. However, the poultry industry faces multiple challenges, particularly under the pressures of climate change. Using modern intensive farming techniques, global poultry production has been showing a steady growth, each year. Such intensive growth however lead to a significant environmental footprint. Waste materials such as poultry litter and manure can pose a serious threat to environmental and human health, and need to be managed properly. Poultry production and waste by-products are linked to NH_3, $N_2O$and CH_4 emissions, and have an impact on global greenhouse gas emissions, as well as animal and human health. Litter and manure can contain pesticide residues, microorganisms, pathogens, pharmaceuticals (antibiotics), hormones, metals, macronutrients (at improper ratios) and other pollutants which can lead to air, soil and water contamination as well as formation of antimicrobial/multidrug resistant strains of pathogens. Dust emitted from commercial poultry production operations contains feather and skin fragments, faeces, feed particles, microorganisms and other pollutants, which can adversely impact poultry health as well as the health of farm workers and nearby inhabitants. Fastidious odours are another problem that can have an adverse impact on health and quality of life of workers and surrounding population. This study discusses the current knowledge on the impact of intensive poultry farming on environmental and human health, as well as taking a look at solutions for a sustainable future.

Under climate change scenarios, diversified poultry system and commercial poultry system play different, but complementary roles in ensuring sustainable poultry production. Diversifying poultry species beyond commercial chicken farming can play a significant role in climate change mitigation and adaptation. Species like ducks, quail, turkey, geese, and pigeons contribute to sustainability, biodiversity, and resource efficiency.

1. <u>Resilience and Adaptation to Climate Change.</u>

Traditional and indigenous poultry breeds are more resilient to heat stress, variable feed availability, and disease challenges. They can adapt to changing environmental conditions and require fewer external inputs. Ducks, geese, and turkeys are more tolerant to extreme weather conditions (heat, cold, and humidity) compared to commercial broilers and layers.

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[1] A lecture to be delivered in the ICAR sponsored Winter School at Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal on 27-02-2025.
[2] Former Prof. and Head.
[3]Scientist.
[4]Veterinary Officer

Quails and pigeons require minimal space and adapt well to various environments, making them suitable for small-scale urban and rural farming. Ducks thrive in flooded areas, making them ideal for flood-prone regions affected by climate change. Ducks and geese help control pests in agricultural fields, reducing the need for chemical pesticides that contribute to soil and water pollution. Pigeons and quails play a role in seed dispersal and maintaining ecological balance in natural habitats. Integrated poultry systems with ducks and turkeys reduce reliance on synthetic inputs, improving farm sustainability. While high-yielding broilers and layers are sensitive to heat stress, requiring controlled environments, precision feeding, and healthcare management to sustain productivity.

2. <u>Genetic Diversity and Disease Resistance.</u>

Local and indigenous breeds have a broader genetic base, increasing disease resistance and adaptability to new climatic conditions. While selectively bred for high production, commercial breeds often lack genetic diversity, making them more vulnerable to emerging diseases and environmental stressors. Commercial poultry relies on a few high-yielding breeds, making the system vulnerable to diseases and climate-induced stress. Including ducks, geese, quail, and turkeys enhances genetic diversity, increasing resilience to diseases and environmental fluctuations. Diverse poultry farming encourages polyculture systems, integrating multiple species that coexist and utilize different ecological niches.

3. <u>Feed Efficiency and Sustainability.</u>

Most diversified poultry breeds can thrive on locally available feeds, including insects, kitchen waste, and agricultural by-products, reducing dependency on expensive commercial feed. While commercial poultry requires high-energy, protein-rich feeds that depend on industrial production, making them more susceptible to feed price fluctuations and supply chain disruptions due to climate change. Ducks and geese can be raised in wetlands, rice fields, and waterlogged areas, maximizing land use without competing with terrestrial livestock. Quail and pigeon farming require very little land, making them ideal for urban and peri-urban settings. Integrated rice-duck farming improves rice yields, reduces pests, and minimizes the need for chemical fertilizers and pesticides, lowering environmental impact.

4. <u>Environmental Impact and Resource Use.</u>

Small-scale, free-range, or semi-intensive systems have lower greenhouse gas (GHG) emissions, better manure recycling, and contribute to sustainable agriculture. But intensive systems generate higher GHG emissions per unit area, require significant energy for climate-controlled housing, and pose challenges in manure and waste management.

Diversified poultry farming helps mitigate climate change through:

4.1. <u>Lower methane emissions</u>: Unlike ruminant livestock (e.g., cattle), poultry species produce negligible methane emissions, reducing overall GHG contributions.

4.2. <u>Efficient protein conversion</u>: Ducks, quail, and pigeons efficiently convert natural feed resources into protein, minimizing dependency on commercial feed that contributes to deforestation and carbon emissions.

4.3. <u>Manure utilization</u>: Poultry manure from diversified species is an excellent organic fertilizer, promoting regenerative agriculture and reducing reliance on synthetic fertilizers.

Diversified poultry provides sustainable protein options, reducing pressure on industrial chicken and livestock farming. Species like quail and pigeon mature quickly, ensuring fast protein production with minimal environmental impact. Turkey and goose meat offer larger yields per bird, contributing to food security without excessive resource use.

5. <u>Livelihoods and Socio-Economic Contributions.</u>

Diversified Poultry can support smallholder farmers, enhances food security, and provides income diversification in rural areas. Commercial Poultry ensures large-scale production and consistent supply of poultry products but may not be as accessible to small-scale farmers without significant investment.

6. <u>Market and Consumer Demand.</u>

Diversified Poultry breeds can offers niche products (e.g., organic, free-range, indigenous chicken) that appeal to consumers seeking sustainable and ethically produced meat and eggs and provide economic opportunities while promoting climate-friendly farming practices.. Encouraging diversified poultry farming supports smallholder farmers and rural economies by reducing dependence on expensive, industrialized chicken production. Lower input costs (feed, housing, veterinary care) make diversified poultry an accessible and sustainable option for farmers in developing regions. While the commercial poultry dominates mass markets due to lower cost and efficiency but is increasingly pressured to adopt sustainable practices.

Conclusion

A balanced approach integrating diversified poultry systems with commercial poultry can enhance climate resilience, ensure food security, and promote sustainable poultry production. Diversified poultry helps buffer risks associated with climate change, while commercial poultry ensures high production efficiency. Encouraging multi-species poultry farming can help mitigate climate change by reducing carbon footprint, improving feed and land efficiency, supporting small-scale, climate-smart agriculture and enhancing biodiversity and ecological balance. Promoting climate-smart poultry practices, such as improving housing, enhancing feed sustainability, and maintaining genetic diversity, will be crucial for the future of poultry farming.

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Free-living life cycle of Enterobacterales under light of climate change

Dr Kapudeep Karmakar,
Assistant Professor in Soil Microbiology
RRS-TZ, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Abstract

Enterobacterales is the name of an order of bacteria that contain enteric bacteria (living in the intestine or digestive tract of animals). They may be pathogenic or commensal. The members of this group are facultative anaerobes. Since these bacteria are adapted to the environment of the digestive tract, they have a higher tolerance to acidic, alkaline pH and bile salt. The acidic soil of Coochbehar and its high rainfall create a partial anaerobic condition in soil, making a competition-free micro-environment for these microbes to dwell. With increasing global temperature, the soil temperature also rises during the hot summer months. The erratic behavior of rainfall adds fuel to the fire and increases the osmolarity of the soil solution. This leads to drought and salinity. The Enterobacterales are well-adapted to the human body temperature i.e. 37^{o}C. Thus, increasing soil temperature makes the environment more favorable for these microbes.

Pathogen biology in soil

Members of Enterobacterales are common in the soil. Some pathogenic ones are known to colonize various hosts like humans, plants, etc. A well-known member of this order is *Salmonella* which causes typhoid and gastroenteritis in humans. Soil-dwelling *Salmonella* is transmitted by fresh produce like tomato, spinach, onion, cabbage, etc. They migrate towards the plants via the fliC-derived flagella and enter the plants via the lateral root junction point. In one of the case studies, we examined if the morphotype based on the attachment factors (like cellulose and curli fimbriae) of *Salmonella* was important for its colonization of roots. We classified the Rdar morphotypes as good plant colonists.

Risk factor due to extreme environment

These Enterobacterles could migrate from the soil to the edible parts of the plants. When consumed, they cause food-borne illness. However, plants face various environmental extremes that can alter their colonization by beneficial or pathogenic bacteria. In one of the case studies, we have recently shown that the deletion of the gene *lgl*, encoding lactoyl glutathione lyase, reduces the colonization of *Salmonella* on plants specifically under salinity stress. Such bacteria died on plants pre-exposed to salinity stress. The exogenous methylglyoxal (MG) produced by the plants under salinity stress was found responsible for the cell death and not the *de novo* MG produced by the bacteria.

Pathogen control

In one of the case studies, a screening of competitive rhizospheric bacteria was performed. One isolate identified as, *Lysinibacillus macroides*, was able to inhibit the biofilm of *Salmonella* and subsequently reduced its colonization on roots. In another case study, a wide variety of crops were screened and biocontrol crops were identified. One such crop is beetroot, whose exudates can kill the soil-dwelling *Salmonella*.

Ecological functions of Enterobacterales

There are members of Enterobacterales, which also perform some ecological functions and can be engineered to use them in agriculture. One such bacterium is *Phytobacter*, which is known to promote the canopy growth of tomato plants and buffer the thermal fluctuations in soil. *Phytobacter* also prevents electrolyte leakage from the seeds of

Solanaceous plants. Others like *Enterobacter* and *Serratia*, were able to prevent the leeching loss of nutrients. They are also important for the aggregation of soil.

Enterobacterales for mitigation of stress

All these beneficial activities can counteract the negative effects of extreme climate. For example, the promotion of aggregates in soil improves the soil structure by sequestering the carbon in the soil. The nutrient retention properties also show their potential to prevent excess application of fertilizers, which is very common in Coochbehar, as the dissolved nutrients are lost due to excessive rainfall. The thermal buffering of soil by these microbes suggests that they can resist the heat loss/gained by the soil which is an essential step in using soil as a sink of heat from the atmosphere. Our case study showed that the low temperature in soil during January is detrimental for seeds. The thermal buffering of soil by these microbes improved the vigor of seeds.

Innovation Platform - concept, relevance and application

Prof. Kalyan Kanti Das
Department of Agricultural Economics
Uttar Banga Krishi Viswavidyalay, Pundibari, Coochbehar

Technology dissemination plays an important role in research for development(R4D), especially, in agrarian economy of most part of the globe. A rough estimate shows that about 26.7% of the world population (about 2 billion people) derive their livelihoods from agriculture (https://www.ncesc.com/geographic-faq/ visited on 30.01.2025). Any improvement, therefore, in this sector could make a huge difference in the lives of millions of people. However, the sector faces manifold challenges that relate to production, post-harvest handling, marketing, policy frameworks and the information/knowledge exchange/flow between the stakeholders (Makini et al, 2013). It becomes much more complex in the sub-Saharan or South Asian farming and similar context where 'marginality' is evidenced not only in land holding but in investment capacity & mindset & attitude (risk aversive, basically) too. For example, as per Situation Assessment Survey (SAS) of Agricultural Households during NSS 77th round (January 2019- December 2019), the percentage distribution of agricultural households owning less than two hectares of land in India is **89.4%** (https://pib.gov.in/ visited on 31.01.2025). There is need to boost be-fitting 'approachs' towards transforming agriculture with a view to reducing poverty, increasing food and nutrition security and reduced environmental degradation (Makini et al, 2013).

There has been a shift from linear approaches (during 1950s) to technology and knowledge transfer where, scientists were considered as the innovators and farmers were the target audience with the goal always being to improve productivity of a single commodity, to farmer participatory approaches (FPR) in 1990s recognizing the importance of farmers' engagement in the knowledge development process. But, it (the FPR) failed to recognize institutional constraints, and the usefulness of multiple actors besides the necessity to engage all key stakeholders. Towards the end of the 1990s, the innovation Systems Approach and its actualization through Innovation Platforms was introduced (Makini et al, 2013). This approach unlike FPR includes institutions and policies which are regarded as major obstacles to adoption of improved methods (Hounkonnou et al., 2012 in Makini et. al.).

An Innovation Platform is a space or forum for learning, action, and change. It is a group of individuals (who often represent organizations) with different back grounds, expertise, and interests: farmers, traders, food processors, researchers, government officials, and so forth. As the name indicates, Innovation Platforms have an innovation objective, that is, the introduction and utilization of any new knowledge (technological or other) in an economic or social process (OECD, 1999). The members come together to diagnose problems, identify opportunities, and find ways to achieve their goals. They may design and implement activities as a platform or coordinate activities by individual members (Homann-Kee Tui et al., 2013). Innovation Platforms are an increasingly popular approach to enhancing multi-stakeholder collaboration in agricultural research for development (AR4D) programmes.

Innovation Platforms encourage creativity and learning, and provide a safe environment for multiple actors to experiment and explore solutions to their joint problems (Homann-Kee Tui et al., 2015). Innovation Platform (InP) may indeed be established at village level, district level, regional level or national level. The objective of the InP might be to

tackle a specific technological, organizational, or institutional challenge in a value chain (e.g. access to high quality potato seeds) or a more generic problem that needs to be addressed across value chains (e.g. farmers' access to agricultural credit). Once the Innovation Platform has achieved its objective, its members may (or may not) decide to take up new challenges. Innovation Platforms can start as informal networks and be forged into more formalized structures, such as public-private partnerships, with the ultimate goal of becoming self-sustaining entities.
In the face of agrarian set up in India and the current situation of public extension network in the country, we need to think and foster alternative ways and means for effective outscaling and upscaling of technologies. The concept of Innovation Platform (InP) may be one of the effective solutions and it is required to understand the applicability of InP in agrarian economy like India. The question may be raised about the tenability, formation (who to form), level of formation (village, district, regional or national), facilitation/functioning and sustainability of Innovation Platform. Attempt has been made to clarify/narrate all these aspects by sharing practical examples and experiences.

Potential Aquaculture for Agri-Business Development with Respect to Climate Change and Resilience

Professor (Mrs) Debapriya Sarkar
Fishery Science, Regional Research Station, Terai Zone
Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar

Aquaculture refers to the farming of aquatic organisms such as finfish, shellfish and different algae in controlled water resources and it is popular as a growing and demanding allied component in the field of Agriculture to leverage food production, economic growth, and rural development of our country to gain momentum in the Global Aquaculture Market. Unfortunately, rising temperatures, changing rainfall patterns, sea level rise and extreme weather exposure are posing threat to several existing aquaculture system and practice due to inaccessibility of resources, reduced crop yield, altered growing seasons. In spite of all adverse impact, aquaculture presents significant potential for agribusiness development through innovation and diversification of adaptive and sustainable aquaculture alternatives as Climate-Resilient strategies particularly in the context of climate change affecting traditional farming. Here's how:

1. Innovation and adoption of Climate-Resilient Aquaculture Systems:

1.1. Recirculating Aquaculture Systems (RAS) and Biofloc (BFT): Uses minimum water and operates in controlled environments, reducing vulnerability to extreme weather condition.

1.2. Integrated Multi-Trophic Aquaculture (IMTA): Combines different species (e.g., finfish, shellfish and seaweed) to optimize resource use and reduce wastes.

1.3. Aquaponics: Integrates fish farming with hydroponic crop production, particularly vegetables and fruits, reducing water use and improving food security from the same land and water area.

1.4. Climate Change Mitigation: Reducing greenhouse gas emission through sustainable aquaculture practices.

2. Species Selection for Climate Adaptation

2.1. Farming of heat-tolerant species (e.g., tilapia, catfish and shrimp) ensures sustained productivity in warming waters.

2.2. Promotion of Indigenous and native species adapted to local environments to reduce disease risk and increase resilience.

2.3. Cultivating seaweed and shellfish mitigates ocean acidification and provides carbon sequestration benefits.

3.. Sustainable Feed and Resource Management

3.1. Using alternative feeds (e.g. Insect-based proteins like larvae of Black soldier fly, Meal worm, algae etc.) reduce reliance on wild fish stocks used in the form of dry fish meal in the commercially marketed fish feed.

3.2. Promoting low-carbon aquaculture practices (e.g., solar-powered aeration systems) minimizes environmental impact and electricity charge.

3.3. Implementing water-efficiency enhancing technologies (e.g. use of bio-filters, ozone, artificial wetlands etc.) ensures sustainability of aquaculture system.

4. Economic and Social Opportunities

4.1. Climate-resilient aquaculture can diversify income streams for farmers affected by crop failures due to altered climate.

4.2. It provides employment opportunities in coastal and rural areas, enhancing food security and livelihoods.

4.3. Aquaculture can strengthen public-private partnerships to support investment in research and training for long-term success.

5. Policy and Infrastructure Support from Apex level

5.1. Governments can promote climate-smart aquaculture through subsidies, research grants and technology transfer programs.

5.2. Developing early warning systems for climate risks help farmers to prepare for against extreme weather events.

5.3. Strengthening regulations on sustainable practices to ensure long-term environmental and economic viability.

5.4. Strong network for implementation and monitoring on different issues of technology adoption by the stakeholders at regional, state and national level to draw successful case studies for further technology promotion.

6. Challenges and Barriers

6.1. Environmental Risks: Overfishing, habitat destruction, disease management.

6.2. Economic Barriers: Initial investment costs, market access, policy support.

6.3. Regulatory Frameworks: The need for appropriate policies, regulations, and management practices.

7. Case Studies for success of Aquaculture towards Agribusiness development:

Aquaculture has strong potential for agribusiness development in West Bengal, Odisha, and Bihar, especially under the situation of climate change. Here's how it can be leveraged:

7.1. West Bengal

7.1.1. Key Species: Carp (Rohu, Catla, Mrigal), Prawn (Scampi), Tilapia

7.1.2. Opportunities:

- Vast freshwater resources (rivers, ponds, and wetlands) support fish farming.
- Integration with rice farming (paddy-cum-fish culture) improves water use efficiency.
- Coastal aquaculture (shrimp and crab farming) is growing, but needs climate adaptation strategies.

7.1.3. Climate Challenges & Solutions:

- Cyclones & Salinity Intrusion: Promoting saline-tolerant species like mud crab and brackish water fish.
- Water Pollution: Biofloc and recirculating aquaculture systems (RAS) reduce dependency on freshwater.

7.2. Odisha

7.2.1. Key Species: Shrimp (Vannamei, Black Tiger), Carp, Catfish

7.2.2. Opportunities:

- A long coastline with brackish water resources ideal for shrimp and crab farming.
- Government support for inland aquaculture expansion.
- IMTA (Integrated Multi-Trophic Aquaculture) to enhance sustainability.

7.2.3. Climate Challenges & Solutions:

- Cyclones & Flooding: Strengthening coastal embankments, insurance schemes for fish farmers.
- Rising Temperatures: Promoting deep-water pond aquaculture to maintain optimal water temperatures.

7.3. Bihar

7.3.1. Key Species: Carp, Catfish, Pangasius, Tilapia

7.3.2. Opportunities:

- Large floodplain and oxbow lakes (chaur areas) suitable for aquaculture.
- Government incentives for fish farming and hatchery development.
- Potential for aquaponics and small-scale biofloc farming to reduce water usage.

7.3.3. Climate Challenges & Solutions:

- Flooding in monsoon, drought in summer: Adaptive fish species selection and seasonal pond management.
- Cold winters impacting growth: Promotion of greenhouse-based aquaculture (RAS, biofloc).

8. Business and Policy Support to promote Aquaculture :

- Government schemes like PM Matsya Sampada Yojana (PMMSY) offer financial support.
- Public-private partnerships can enhance technological adoption and market linkages.
- Export potential for shrimp and processed fish can boost rural income.

9. **Funding Opportunities**

Aquaculture in West Bengal, Odisha, and Bihar offers significant opportunities for agribusiness development, especially in the context of climate change. Various funding opportunities and successful case studies in these states highlight the sector's potential.

9.1. Pradhan Mantri Matsya Sampada Yojana (PMMSY): A central government scheme aimed at enhancing fish production and productivity through various interventions, including financial assistance for infrastructure development and technological adoption.

9.2. State-Specific Initiatives:

9.2.1. West Bengal:

Biofloc Technology Promotion: The state government is encouraging fish farming through biofloc technology, which is efficient and sustainable. The West Bengal Comprehensive Area Development Corporation (CADC) has initiated projects to train self-help groups (SHGs) in this method.

9.2.2. Odisha:

Biofloc-Based Farming: The Odisha government has introduced biofloc-based farming to promote sustainable intensification of freshwater fish and brackish water shrimp farming. The program aims to develop 5,000 biofloc tanks with subsidy support.

9.2.3. Bihar:

Project ERADA (Enhancing Rural Resilience through Appropriate Development Actions): This initiative focuses on improving livelihoods through aquaculture by providing training and resources to rural communities. The project has significantly contributed to the socio-economic upliftment of local populations in Bihar.

10. Successful Case Studies

10.1. West Bengal:

Sustainable Aquaculture Practices in Bhangar Block: A project aimed at improving the socio-economic status of small and marginal fish producers by providing training on sustainable aquaculture practices, disease diagnosis, and access to quality seed stock and markets.

10.2. Odisha:

Brackish Water Aquaculture Development: The state has leveraged its extensive brackish water resources to develop shrimp farming, contributing significantly to the local economy. The Fisheries & Animal Resources Development Department offers various schemes to support this sector.

10.3. Bihar:

Aquaculture for Rural Resilience: Through Project ERADA, communities in Bihar have adopted aquaculture practices, leading to improved livelihoods and economic stability. The project emphasizes sustainable practices and community involvement.

These initiatives and success stories demonstrate the potential of aquaculture as a climate-resilient strategy for agribusiness development in these states.

Extension Intervention for Climate Resilient Agriculture for Small holder Farmers: Strategy and Steps

Prof. Prabhat Kumar Pal
Head, Dept. of Agril. Extension; and Director of Extension Education (Actg.)
Uttar Bnga Krishi Viswavidyalaya Pundibari, Cooch Behar

Introduction

The agriculture sector contributes only about one-sixth of the gross domestic product (GDP) but employs around 50% of the country's workforce, highlighting its critical importance. Among this workforce, nearly 80% of farming families belong to the category of small and marginal farmers. The Agricultural census of India shows that in 1960-61, this percentage was 62%, whereas, it increases to 83% in 2005-06 (Chand *et al*., 2011) as the average size of holdings showed a decreasing trend. It was 2.28 ha in 1970-71 which is reduced to 1.32 ha in 2000-01. In India, a farmer having an operational area of less than 1 ha is denominated as marginal farmer, and with an operational area of 1-2 ha falls under small farmer category.

Small and marginal farmers in India face multiple challenges despite increased access to micro- irrigation system. They pay higher irrigation costs due to limited access to cheaper sources like canals. Market imperfections result in lower returns, while restricted access to credit, extension services, public irrigation, and electricity further hampers their progress. Indiscriminate fertilizer use raises production costs, and socially disadvantaged groups among them struggle with limited access to information, credit, and markets. Lower education levels restrict knowledge dissemination, forcing them to rely on informal credit sources, leading to chronic debt. The feminization of agriculture is rising as men migrate to non-farm jobs, and these farmers are also the most vulnerable to climate change, health risks, underemployment, and market fluctuations (NCEUS, 2008; Dev, 2012; Jagadeeshbabu, 2015; Macharla and Lal, 2017).

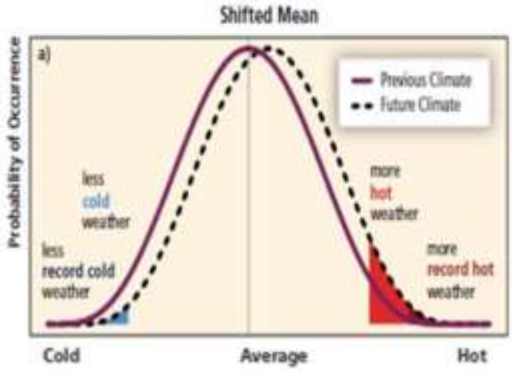
Climate change, climate disaster, climate vulnerability and resilience

Simply, change in regular trend of climatic parameters in relation to time is called climate change. This change may create a facet of climate variability under changing climate conditions. They are defined as the deviation of value of weather or climate variable above (or below) a threshold value near the upper (or lower) ends (‘tails’) of the range of observed values of the variable in relation to time (Fig-2a, 2b & 2c).

Climate change may change the normal trend of production cycle causing low production, can create a physiological stress to plant causing low production, may create resurgence of unknown/fewer known pests causing low yield and many others.

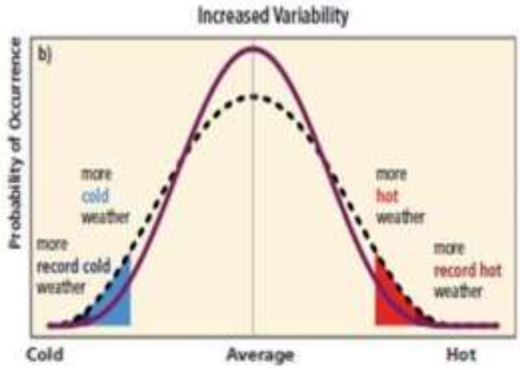
Intense negative impact due to climate change causing wide spread devastation to life and property are called climatic disaster. It completely disturbs the normal day to day life, negatively influences the emergency systems, deteriorates the normal life process, affects fundamental needs like food, shelter, health etc. These are floods, cyclone, earthquake, forest-fire due to extreme dryness etc.

In physical science, resilience is the ability of a substance or object to spring back into shape viz. elasticity. In respect of human livelihood, it is the ability to withstand adversity and capacity to recover quickly from difficulties, aberrations, extremities and such other negative forces.



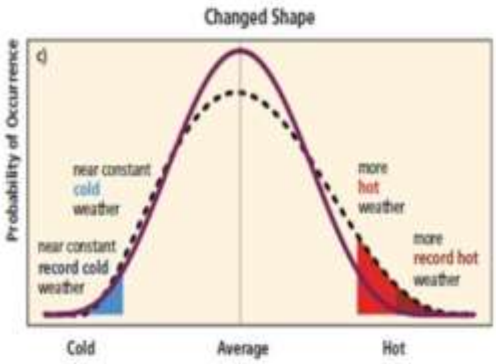
A positive deviation causes longer spell of hot weather or a greater number of extreme hot days than cold weather; and a reverse deviation causes reverse effect viz. longer spell of cool weather or a greater number of extreme cold days.

Adopted from IPCC (2012)



A flattened curve causes both longer spell of hot and cold weather and also greater number of extreme hot and cold days.

Adopted from IPCC (2012)



A skewed curve can cause extreme hot or extreme cold weather. Skew towards right shall cause prolonged and extreme hot; and left- skew shall cause prolonged and extreme cold.

Adopted from IPCC (2012)

Fig.-1: Forms of Climate Change

Small holder farmers and climate risks

Climate Risk is the resultant outcome of interplay among variability in weather and climate events, exposure to negative livelihood sustaining factors and vulnerability of a community or household.

Smallholder farmers are considered the worst hit by climate change because they typically rely heavily on rain-fed agriculture, have limited resources to adapt to changing weather patterns, and are often located in regions particularly vulnerable to extreme weather events like droughts and floods, making them highly susceptible to crop losses and income disruptions when climate conditions shift drastically; their limited financial capacity further hinders their ability to recover from such impacts.

If we take a glance on the risk paradigm (Fig.-2) forwarded by IPCC (2012), It will be seen that a livelihood which has more vulnerability and exposure will face more risk of climate change.

Fig.-2: Risk paradigm
(Adapted from special report of Working Groups-I & II of IPCC, 2012)

Strategies to cope up with the climate risks in small-holder farmers

The risk paradigm (IPCC, 2012) postulates that the magnitude of risk may increase if the magnitude of system vulnerability, system exposure and negative climate trend and event increase. Considering the diversity in geographical, social, cultural or agro-economic perspectives in India, this section presents a methodology for a micro-level (down to farm level) assessment of these risk factors due to climate vulnerability parameters; and suggests the micro level strategies to cope with climate change.

A farm-level planning for extension intervention shall be thought of with the following steps (Fig.- 3).

1. Assessment of farm level climate risk / vulnerability
2. Advocating appropriate technology to cope up with the risk
3. Evaluation and assessment of technology effectiveness

Upscaling of effective technology and / or reconsideration for further assessment

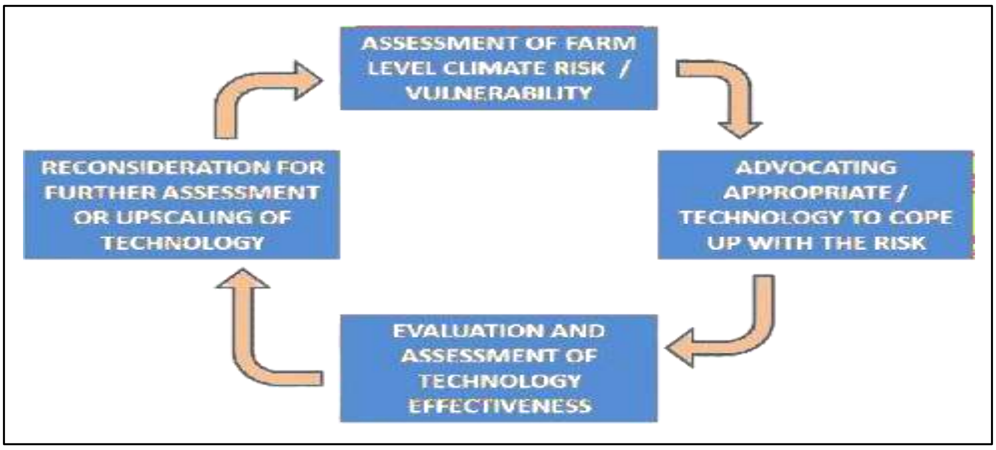


Fig.-3: Steps in farm level strategy to reduce climate change effects

Step-1: Assessment of farm level climate vulnerability

Among all these steps, assessment of farm level climate vulnerability is the most complex one. Numerous authors have postulated vulnerability assessment methodology (Deressa *et al*., 2009; Gbetibouo and Ringler, 2009; Eriyagama *et al*., 2010; Islam *et al*., 2013; Etwire *et al*., 2013). Among all those, methodology advocated by Intergovernmental Panel on Climate Change (IPCC) are widely used.

As per the analysis of Intergovernmental Panel on Climate Change (2007), which is an amalgamated form of the risk paradigm of Lavell et al. (In: IPCC, 2012), the system vulnerability can be assessed from the interplay of different factors and is defined as LV=f (Exposure, sensitivity and Adaptive capacity) in relation to a system e.g. Livelihood system of a farming family.

System vulnerability can be assessed by Livelihood vulnerability Index (LVI) with the help of the method advocated by Hahn et al., (2009).

Livelihood Vulnerability Index (LVI)

LVI = (E−AC) × S; where, E = Exposure, AC = Adaptive Capacity, and S = Sensitivity

An LVI value 0, indicates subsistence system, whereas, negative value indicates stable system, and positive value indicates vulnerable system.

Exposure and Sensitivity

Exposure means the chance that assets and livelihoods will be impacted by different risks like climate change, whereas, sensitivity is the extent to which a system is negatively affected, directly or indirectly by different changes and variability. Whether, exposure is the external negative forces, sensitivity is the internally produced or inherent negative forces.

Adaptive capacity

Adaptive capacity is the least understood concept. However, according to IPCC (2007), it is the ability to deploy social risk management strategies for reduction of risk and human vulnerability associated with climate change. Operationally, it is the ability of a system to reduce to moderate levels, the potential effects of climate change and variability by either taking advantage of existing opportunities or undertaking measures to deal with its consequences. It is unequally distributed.

According to Cinner and Barnes (2019), adaptive capacity is the aggregation or resultant force of interplay of assets, flexibility, social organization, learning, socio-cognitive constructs and agency.

Fig.-4: Components of Adaptive Capacity

Assets: An asset is a resource that has value to a person or organization. It can be a physical item like a car or a financial asset like a stock. Assets can be tangible or intangible. People are generally more resilient to social-ecological changes when they can access a diversity of financial, technological, service-related (i.e., health care), and other types of assets.

Flexibility: Flexibility reflects the capacity of both individuals and institutions to deal with change by being able to switch between strategies. Flexibility is closely related to the idea of having diversity and redundancy in a system to provide a sort of "insurance" that can prevent shocks from having catastrophic consequences.

Social Organization: The way that society is organized can enable or inhibit resilience by influencing whether and how people share knowledge, cooperate, and access resources beyond their immediate domain. The formal and informal relationships that support these key social processes include both social networks and institutions, which can operate at different scales.

Learning: Learning reflects people's capacity to recognize change, attribute this change to causal factors, and assess potential response strategies. Importantly, learning is not solely about access to information but rather captures the experiential and experimental processes that enable people to frame or reframe problems.

Socio-cognitive Constructs: Resilience is also shaped by subjective socio-cognitive dimensions, such as risk attitudes, personal experience, perceived social norms, and cognitive biases. Risk attitudes include perceptions about the probability and severity of risk associated with change as well as the costs and benefits associated with adapting. Personal experience, cognitive biases, and perceived social norms can profoundly affect risk attitudes and whether they help to build or erode resilience.

Agency: Agency reflects people's free choice in responding to social-ecological changes and encompasses aspects of empowerment and self-efficacy. Agency also captures people's belief in their own ability to manage prospective situations and control the events that affect them, which is closely linked to the cognitive dimensions of resilience discussed above.

However, in case of measuring farm level system vulnerability, only farm-level indicators to be taken which will reduce the complexity of measurement to a great extent; and in such case, LVI may be considered as FVI viz. Farm vulnerability Index.

Step-2: Advocating appropriate technology based on previous analysis

Based on the vulnerability in the farm level, appropriate technologies to be advocated. As for example, in a water-vulnerable farm, water-saving crops and varieties should be advocated, whereas, in a water-logged farm, flood tolerant varieties can be advocated.

Step-3: Assessment and evaluation for technology effectiveness

Assessment of technology can be done in many ways, e.g. (i) economic impact of technology (increase in income, increase in cropping intensity), (ii) Up scaling potential of the technology, and most importantly (iii) Reduce of climate vulnerability (increase in water holding capacity of farm, increase of crop area in dry season, crop success in water logged area etc.)

Step-4: Reconsideration for upscaling of technology or further assessment

If the technology is found working well, the technology should be advocated in extensive areas.

The following strategies can be utilised for doing this:

(i) Extension approaches like skill training and demonstration
(ii) Use of ICT tools
(iii) Utilisation of grass root extension organisations like SHG, FC, FPO, FPC, FIG etc.
(iv) Creating pluralistic support for upscaling

Further assessment of technology effectiveness should consider the system perspective

Indicators to be considered to measure effectiveness

(i) Fit with the situation
(ii) Cost of the technology
(iii) Income enhancement from the technology
(iv) Compatible with existing knowledge and skill
(v) Technology is available in time

Challenges in measuring vulnerability for a farm family

In measuring vulnerability, the sub-variables under main variable especially for adaptive capacity and sensitivity for constructing LVI are many times non-physical in nature and also having complex inter-relationship among themselves and intermingled, and also not linear. The contribution of the variables on livelihood vulnerably is also not universal on spatial and temporal frame. So, selection of variables and their weightage in computation of sub-constructs is a challenging job and require usage of robust methodology with the utilisation of appropriate statistical and computational tools. Moreover, in assessing climate exposure, it requires micro-level data which is not available down the level than a district still date.

The possible way out may be (i) to utilise the data generated from District Agro-Meteorological Units (GKMS), wherever possible, (ii) in case of non-physical variables, perceptual and psychological dummy variables may be a possible way out. However, appropriate scaling technique with proper statistical treatment should be done. (iii) to reduce the complexity, variables for both adaptive capacity and sensitivity should be considered in the same bracket, however, with opposite direction.

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Environmental Life Cycle Assessment (E-LCA), Carbon Trading; and European Union Deforestation Regulation (EUDR) shaping the current sustainable natural rubber (NR) industry

Dr. Jayanta Sarkar
RRS, Rubber Research Institute of India
Rubber Board, Nagrakata, Jalpaiguri, West Bengal

Life cycle assessment (LCA), also known as life cycle analysis, is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service. For instance, in the case of a manufactured product, environmental impacts are assessed from raw material extraction (cradle) and processing, through the product's manufacture, distribution and use, to reuse, recycling or final disposal of the materials and composing it (grave). Hence, it is sometimes referred to as "cradle-to-grave analysis". An E-LCA study involves a thorough inventory of the energy and materials that are required across the supply chain and value chain of a product, process or service, and calculates the corresponding emissions to the environment (Fig. 1).

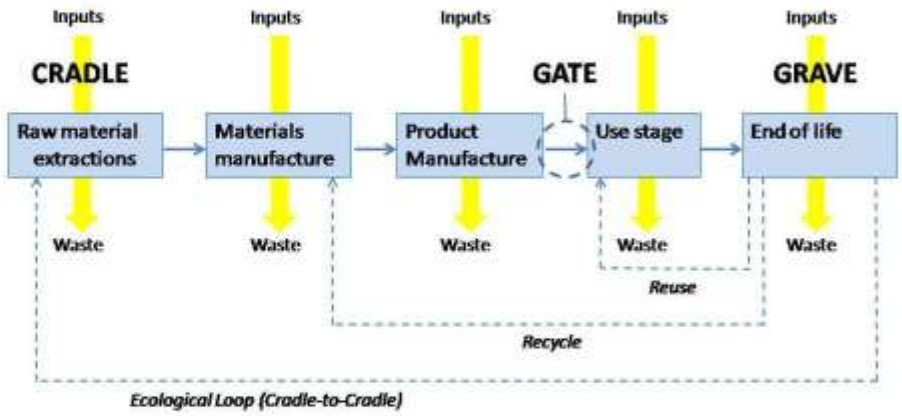

Fig. 1: Life cycle assessment (LCA) stages diagram

An LCA study begins with a goal and scope definition phase, which includes the product function, functional unit, product system and its boundaries, assumptions, data categories, allocation procedures, and review method to be employed in the analysis. The ISO LCA Standard requires a series of parameters to be quantitatively and qualitatively expressed, which are occasionally referred to as study design parameters (SPDs). The two main SPDs for an LCA are the goal and scope, both which must be explicitly stated.

Carbon footprint of products and processes that contribute to economic growth is a major indicator of their environmental sustainability. At a time when the world is seriously concerned about rising carbon dioxide (CO_2) emissions and global warming, this assumes much significance. The rubber industry, which consumes both natural rubber (NR) and synthetic rubber (SR), is a major driver of economic growth. Globally, about 65% of the total amount of rubber consumed by the industry is SR and the balance is NR. In India, the share of SR is about 30%, and NR is 70%. Increasing demand and rising deficit in domestic NR production may lead to more consumption of SR by the Indian rubber industry in the coming years. Since SR is produced from petroleum stocks, a rise in its consumption will invariably increase the global CO_2 emissions of the rubber industry, which is against reduction of the carbon intensity of the economy and attain ‘net zero’ emission.

Assessing the carbon footprint of NR even as there exists a substantial amount of data on the high carbon sequestration capacity of NR plantations. Lifecycle analysis of carbon emissions from one ha NR plantation in India with an estimated productivity of 1.5 tonnes/ha/yr and an economic lifecycle of 27 years, including an immaturity period of seven years. Potential emissions from each cultural practice from nursery preparation to felling of old trees at the end of the plantation cycle and processing of latex into different marketable forms of NR, need to be estimated. NR has a net negative carbon footprint after incorporating CO_2 sequestration potential of rubber plantations of 25 MT CO_2/ha/yr (from the seventh year onwards using Eddy covariance analysis) was used in the calculation of LCA.

Sources of emissions associated with the production of latex and processing it into marketable forms of NR, namely ribbed smoked sheet rubber (RSS), technically specified rubber (TSR) and centrifuged latex (cenex), can be grouped into direct and indirect emissions. These are calculated using the IPCC emission factors and global warming potential of various greenhouse gases (GHGs). Direct emissions are those generated within the physical boundaries of the one ha plantation as a result of agronomic activities related to latex production and converting it into marketable forms of NR in processing factories and these are directly measurable and monitorable from the plantation and processing factory. Indirect emissions are those associated with the production of various inputs such as chemical fertilizers used in the plantations, their transportation, use of fuels and electricity to run any farm machinery, processing factories, etc.

Carbon footprint of natural rubber: The LCA showed that for a lifecycle yield of 30 MT dry rubber (productivity @1.5 MT/ha/yr for 20 years), the total emission from farming operations and primary processing of latex was 27.8–41.7, 13.3–22.9 and 2.67–3.93 MT CO2 for making RSS, TSR and cenex respectively. From earlier studies using eddy covariance analysis18, we have shown that rubber plantations in Kerala, on average fix, about 25 MT CO2/ha/yr, which amounts to 500 MT CO2 during the 20-year mature phase of the plantation (tapping period). Since much more CO2 is removed from the atmosphere than what is released into it when NR is produced, the carbon footprint of NR is highly negative. Thus, based on the lifecycle estimates of emissions and carbon sequestration, it can be observed that the carbon footprints of RSS, TSR and cenex are similar: –14.4 to –14.9, –15.0 to –15.4 and –15.4 to –15.6 respectively. To summarize, irrespective of the forms of processed rubber, the carbon footprint of NR is around –15 MT. In other words, about 15 MT of net CO2 is sequestered for every tonne of RSS, TSR or cenex produced.

The negative carbon footprint of NR is in stark contrast with the high carbon footprint of SR, which is about 10 to 15 tonnes of CO_2 per tonne. This should make NR a unique and preferred raw material over SR, which is increasingly being used in the Indian rubber products manufacturing industry due to the deficit in the production of NR in the country.

Carbon trading

Rapid expansion of natural rubber plantations in South and South-East Asia and other regions has greatly altered ecosystem based carbon (C) stocks with potential impacts on climate change mitigation and future C trading opportunities. Therefore, reliable estimated of carbon sequestration and emission at the landscape level after land cover transition from forest and other land use types along with study on C sequestration in above and below ground biomass production and raw material produced from latex after primary processing.

Unlike SR, which is produced in factories most often associated with large oil refineries, NR is produced by several million small and marginal growers from some of the most populous, poor and developing countries. In India alone, there are nearly 1.2 million small and marginal NR-growers, including some of the most socially and economically marginalized indigenous people in the North East, even as SR is manufactured by a couple of large industry houses in the country. The highly favourable environmental and social credentials of NR over SR should make the former a more preferred raw material for the global rubber industry. The glaring contrast in the carbon footprints of NR and SR makes a compelling argument in favour of charging a Pigouvian carbon tax on SR. The proceeds from such a tax on SR could support small NR-growers and help the rubber products manufacturing industry offset its emissions by promoting more NR consumption, thus creating a circular rubber economy with reduced carbon intensity.

India has established an emission trading scheme called the Carbon Credit and Trading Scheme (CCTS). The CCTS incentivizes industrial entities to reduce emissions and is an important policy instrument in India's path to reach net zero by 2070. India's carbon trading market is growing rapidly, with nearly 850 projects in the pipeline and carbon credits being traded on the multi commodity exchange. The government has passed an amendment to the Energy Conservation Act. 2001 to establish a legal framework for a carbon market and incentivize emission reduction actions. India has issued a significant number of carbon credits globally, but now intends to focus on the domestic market and internal trade.

European Union Deforestation Regulation (EUDR)

The European Union Deforestation Regulation (EUDR) aims to reduce the EU's impact on global deforestation by ensuring that products consumed in the EU do not contribute to deforestation or forest degradation. The regulation applies to seven key commodities: timber, cattle, cocoa, coffee, palm oil, rubber and soybean along with products derived from these commodities. Adopted in 2023, the EUDR establishes strict due diligence requirements for companies placing these products on the EU market, with obligations set to take effect from 20th December 2024. The regulation is expected to promote sustainable practices in global supply chains and help combat biodiversity loss.

The EUDR relies on the definition of 'forest' of the Food and Agricultural Organization (FAO) of the United Nations (UN). Rubber cultivation falls within the definition of 'agricultural plantation' under the Regulation which means 'land with tree stands in agricultural production systems, such as fruit tree plantation, oil palm plantations, olive orchards and agroforestry systems where crops are grown under tree cover'. This definition includes all plantations of relevant commodities other than wood. Agricultural plantations are excluded from the definition of 'forest'. This means that the replacement of a forest with a rubber plantation would be considered as deforestation under the Regulation. As each of the other EUDR-regulated commodities, rubber has its own complexity in view of the standard procedures. The status of rubber plantations and agroforestry as 'agriculture' or 'forests' is ambiguous (between FAO and EU), with consequences for the key concepts.

In the above circumstances, under EUDR it has become difficult to export NR from the South and SE-Asian countries to the European countries in the recent years as the Regulation guarantee that the products EU citizens consume do not contribute to deforestation or forest degradation worldwide.

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Entrepreneurship development through Bee keeping

Nripendra Laskar, Samrat Saha, Riju Nath and Adrish Dey
Department of Agricultural Entomology
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Bees are insects that have wings closely related to ants and wasps belonging to order Hymenoptera and well known for their role in pollination. In the superfamily Apoidea there is description of around 20,000 species of bees. A no. of common traits are shared between them this traits are unique to bees and separating them from the rest of the Hymenoptera. Bees are completely herbivorous and derive all of their nutrition from nectar and pollen of flowers (but there is an exception in which when bees face nutritional stress, worker bees can kill and consume larval stage, thus they conserve the protein), but incase of ants and wasps at least in some stage(s) of their life cycle they are carnivorous. For the collection of food from flowers their anatomy and morphology is highly modified.

Besides being producers of honey, all the honey bee species are very efficient pollinators. In addition to honey bees, more than 20000 species of other bees are also there which help in pollination. It needs to be clear that all bees are not comes under honey bees. Batra (1992) has separated a group for non- *Apis* bees called'pollen bees' which includes all bees that help in pollination except honey bees.

Role of bee and honey bee in pollination:-

Pollination is the most important activity that bees perform. For plants to reproduction pollination is important, and a number of plants depend on bees or some other insect pollinators. During collection of nectar for their hives, bees move from one plant to another plant and thereby they spread pollen which is collected on their furry bodies and legs. Bees can pollinate a near about 85% of food crops which is used for human consumption. Bees are important pollinators because-

- They have furry legs and bodies which able them to collect pollen easily and thereby facilitating the transfer of pollen from male parts (anther) to female parts (stigma). That is how pollination occurs.
- Thousands of bee species are present worldwide which are highly adapted for entering into and pollinating many millions of different flower shapes that include very tiny bees which enter into small, delicate flowers.
- There are certain flowers which do not release pollen easily. Bees have evolved different methods to deal these flowers, for example by techniques like buzz pollination.
- It is necessary for bees to visit flowers as because they require nectar for honey production and pollen
- The time of emergence is different for different bee species in a year which will suit varying periods of flowering.
- The pollination service provided by bees is absolutely free! (*Honey Bee Pollination - 3 Reasons Honey Bees Are Important Pollinators*, n.d.)
- There is no injury of plants caused by bees.
- They can forage even in extreme weather condition also.

A wide range of agricultural crops are pollinated by western honey bee (*Apis mellifera* L.) which provides highly valued pollination services (Calderone, 2012), and as a single species it is the most frequent pollinator for different crops worldwide (Garibaldi et al., 2013). Fruit crops like strawberry, almond, apple, guava, jamun, date palm, coconut, cashew, phalsa, plum, apricot, litchi, peach; field crops like maize, millet, lentil, buckwheat, pigeonpea, Cambodia cotton; vegetables like cabbage, cauliflower, onion, cucumber, radish, pumpkin, turnip, peas, brinjal, beans, okra, sweet potato, coriander; oil seed crops like mustard, rapeseed, sunflower, gingelly, safflower, niger; timber trees like soapnut, arjun, sal, neem, eucalyptus, mahua, wild cherry, sandal wood, tun, house chestnut, *Acacia,* semele, kachnar; ornamental flowers like cosmos, wild rose, hydrangea, golden rod, poctulaca, dandelion, poinsettia and fodder crop like lucerne, clover are benefited by bee pollination (Ragumoorthi et al., 2016). Bee pollination helps in improvement of quality of crops and increase the yield in terms of fruit yield or seed yield. Bee pollination is must required for some incompatible crops. Some plants such as peas, figs, chrysanthemum, seasonal flowers and many ornamental crops would nor produce any fruit untile they are get pollinated by bees. Particularly in oilseed crops bee pollination increase the oil content and yield to great extent.

Crop	Percentage yield increased due to bee pollination
Rapeseed	128.8-139.3
Mustard	128.1-159.8
Niger	38.5-260.7
Sunflower	48.2-155.0
Soybean	18.1
Sesame	22.0-33.0
Safflower	4.2-114.3
Linseed	1.7-40.0
Castor	30.6

(*Role of Honey Bees in Pollination of Oilseed Crops — Vikaspedia,* n.d.)

Management of honey bees for pollination:-

- Bee hives needs to be placed close to the field to save honey bee's energy
- At the time of 10% flowering colonies need to migrate near the field
- In case of *A. mellifera* 3 colonies/ha and incase of *A. cerana* 5 colonies/ha has to be placed
- Colonies has to be provided with 5-6 frame of bee strength along with young mated queen and sealed brood
- In hive sufficient space should be kept for honey and pollen storage. (Ragumoorthi et al., 2016)

Scope of bee keeping in India:-

In India a total of 50 million hectare area contain crops which are dependent on bees for pollination. To meet this requirement near about 150 million bee colonies are required at the rate of 3 colonies/ hectare. At present in India there is only existence of only 1.2 million bee colonies. Hence there is a great scope for expanding bee keeping for pollination purpose in India (Ragumoorthi et al., 2016).

According to the United Nation it has projected that around 2024 India's population could cross China's population and by 2030 the projected population is 1.5 billion. Because of this great rise in population two major challenges will be faced by India, i.e. generating employment for youth and providing nutritive food to people in adequate quantity. To tackle these problems beekeeping industry can perform an important role. As per the National Commission on Agriculture, India require minimum of 200 million colonies of honeybee only for pollinating and increasing productivity of 12 major selfsterile crops which are completely dependent on insect pollination. A total of 215 lakh people can get employment through this and it will produce about 10 million tons of honey (Nath et al., 2019). Recently it is estimated that, based on the current inputs price status, an apiary unit containing 100 colonies that are kept under diversification plan can provide a profit of Rs. 3, 19,150 per year.

In India if international standards are met then honey industry can be a major earner of foreign exchange. Honey industry is a lucrative business and it provides employment. In Indian market about 70% of the honey & bees wax is provided by this informal sector. Honey produced in India has a good market for export. By using modern collection, storage processes, beekeeping equipments, bottling technologies and honey processing plants the potential export market can be captured (Jain Agrawal, 2014).

Brief perspectives of beekeeping in India:-

In our country beekeeping has been mainly based on forest. So, the raw material required for the production of honey is freely available in nature. In India beekeeping is a tradition carried out from a very old age, but in most areas it is considered as a no-investment profit giving venture. Later it has been found that beekeeping has the potentiality to develop as a major agri-horticultural and forest-based industry (Jain Agrawal, 2014). During 1882 in Bengal first attempt of rearing honey bees in movable frame hives was made and then attempt was made in Punjab during 1883-84. Over centuries, beekeeping techniques have developed by farmers who lived in inaccessible and remote areas of the Himalayan region for benefiting from the indigenous bee *A. cerana*. By using simple resources these Indian bees can be maintained in hives and they can be kept at higher altitudes up to 3000 m as they are well adapted to tolerate the harsh conditions of the present in high mountain areas. *A. cerana* suites well to the climatic conditions of the region as well as the farming practices which are typical for these marginal areas.

In India initiation of beekeeping industry take place after 1910 when Rev. Father Newton a small hive suitable for rearing of *Apis cerana* and the hive was named as 'Newton Hive'. Father Newton also trained a number of people from southern part of India and helped them to develop beekeeping as an economically profitable business. Mahatma Gandhi also realized that beekeeping had a significant importance in human life and included beekeeping in his development programs of rural areas and inspired freedom fighters of these areas to choose beekeeping for their livelihood (Srivastava & Dhaliwal, 2017). In 1962 *A. mellifera* was introduced to India which has 4-5 times higher honey producing potentiality compared to other bees. At modern bee keeping both the hive species are utilized and lot of honey is also collected from the wild bees (*A. Dorsata* and *A. Florea*). An estimated amount of 85000 metric tons of honey is annual production in India and substantial quantity of this production is being exported to other countries (Nath et al., 2019).

Bee keeping:-

Beekeeping or apiculture is a method of artificial rearing of honey bee colonies mainly in hives. For some people beekeeping is a hobby where many people has chosen beekeeping to maintain their livelihood in order to collect different hive products such as honey, bee wax, propolis, bee venom; for pollination purpose or to produce bees for selling to other beekeepers. A site where bee hives are kept is called apiary site.

Major aim of commercial beekeeping is production of honey. But modern beekeeping technique also include production of propolis, beeswax, pollen collected by bees, royal jelly, bee venom, as also of queen bees, package bees and nucleus colonies. For these proper management practices for bees are required by utilizing the locally available plant resources and adopting the climatic conditions (Prasad, 2019).

Benefits of bee keeping:-

a) Beekeeping is neither expensive nor require any expensive tool for management
b) No requirement of any sophisticated technologies
c) Helps in generating self-reliance
d) Provide honey, beeswax, bee venom, propolis and other valuable products
e) A good way of generating employment
f) Beekeeping provides business opportunities for non-beekeepers and those who are willing to choose an alternative way of earning
g) In the integrated agricultural system beekeeping suits well as an allied activity for increasing the economic condition of farming community.
h) As honey bees feed only on pollen and nectars of flowers, so there is generally no requirement of providing any special food supply. So chance of competition with other crops is not there
i) It is easy to learn the basic techniques of beekeeping
j) No competition with crops for land. Wasteland areas and wild cultivated areas also have value for beekeeping as bees collect pollen and nectar from any where
k) Bees are major pollinator of wild and cultivated plants
l) People f all ages can be engaged in bee keeping regardless of gender. Daily care is not required for bee keeping and people can engaged themselves in other works also
m) Beekeeping generate income without destroying habitats (*Beekeeping Benefits to Farmer & Ecosystem - Aziza Goodnews*, n.d.).

Activities in beekeeping:-

There are five tiers of activities in beekeeping. A person can perform any activity for earning a livelihood. These five tiers of activities are:-

i) Production from hive activities
ii) Multiplication activities
iii) Fabrication and construction activities
iv) Processing activities
v) Service activities

i) <u>Production from hive activities:-</u>

Main objective of beekeeping is to obtain various bee products that honey bee yield, such as honey, beeswax, propolis, bee venom, royal jelly, bee collected pollen etc. All of these products has a impact on human life and fetch a good market worldwide. A lot of revenue come from these products as well as it generates employment.

a) Honey:-

Honey is a very sweet and viscous fluid which is produced by honey bees by using the nectars that they have collected from different flower nectaries. Sometimes they collect nectars which is secreted from different plant parts other than flowers, called as extra floral nectaries.

Honey bee particularly field bees collect nectar by using their modified lapping tongue which is known as proboscis. This nectar is carried in their crop which is also called as honey stomach. Then the field bees regurgitate this collected nectar and collected by the hive bees which later on deposited in the honey cells of comb. The enzyme invertase play its role and convert nectar into honey. Nectar generally contain 20-40 percent sucrose. This sucrose is converted into glucose (dextrose) and fructose (levulose) by the action of the enzyme invertase. Invertase is present in saliva of honey bee as well as in nectar also. Once the honey is deposited in the honey cells, the worker bees fan their wings at a very high speed at the rate of 11,000 times per minute above the honey cells which results in evaporation of water from the honey and finally it reaches only 18% moisture content.

As a result sugar content increases which is important for preventing fermentation in the honey. Then the honeycomb cells are capped with wax (McHugh, 2017).

- Honey is hygroscopic in nature, so it will absorb moisture if exposed to air.
- Honey has high viscosity. If honey is heated it will reduce its viscosity.
- Pure honey has a specific gravity of 1.35-1.44 grams/cc.
- Refractometer is used to measure the refractive index of honey which helps to measure the moisture content.

Purity test of honey:-

Purity of honey can be judged by measuring the specific gravity of honey with the help of hydrometer. If the specific gravity is found between 1.35-1.44 grams/cc, then the honey will be considered as pure.

Aroma and flavor of honey:-

- Aroma and flavor depends on nectar of the flower.
- If honey is heated or exposed to air then aroma and flavor will decrease.

Colour of honey:-

- It depends on the species of flower plant from which nectar is obtained.
- Darker honey has a stronger flavor.
- Lighter honey has a pleasant smell.

Fermentation of honey:-

High moisture containing honey can undergo fermentation because of the presence of sugar tolerant yeast. When the temperature is 11-21^{o} C more fermentation occur. Alcohol and carbon-di-oxide are formed because of fermentation. Later acetic acid is formed by conversion of alcohol. Due to acidity fermented honey is sour in taste. Fermentation can be prevented by heating honey for 30 minutes at 64^{o} C at which yeast is destroyed.

Crystallization or granulation of honey:-

At lower temperature honey undergo crystallization. Dextrose in honey form granules and settles down. At top levulose and water remains. High levulose:dextrose (L/D ratio) results less granulation and high dextrose:water (D/W ratio) results more granulation.

Benefits honey:-

- Honey is a good source of antioxidants. An array of plant chemicals contained in raw honey which act as antioxidants.
- Honey is a source of carbohydrate having high energy. Honey is a good source of heat and energy providing over 5,500 calories per kg. Estimated energy value of honey equal to 65 eggs, 13 kg of milk, 19 kg green peas, 8 kg plums, 20 kg carrots and 12 kg apples.
- Compared to other foods, honey provides wholesome nourishment.
- Ayurveda and Unani system of medicine use honey extensively. Ayurvedic and Sidha system of medicines use honey as a carrier for enhancing the properties of drugs.
- Honey is used for purifying blood; cold, coughs and fever preventing agent; curative for eye sores, tongue ulcer, throat ulcers and burns; used as laxative.
- Traditionally, for the treatment of eye diseases, bronchial asthma, tuberculosis, fatigue, constipation, thirst, hiccups, hepatitis, worm infestation, dizziness, piles, eczema, and wounds honey is used.
- Honey is used as tonic for both athletes and infants.
- Honey is useful in weight management.
- Honey nourishes both skin and face and boost the memory power.
- Since ancient time honey is acclaimed as a health giver and restorative healer.
- Honey has antibacterial and antifungal properties.

b) Beeswax:-

Beeswax is natural wax that is produced by the worker honey bees. Wax glands are located on the ventral side of the last four visible abdominal segments in 8 numbers. When the worker bees are about 14-18 days old they starts secreting wax. They secret wax in liquid form, but when exposed to air it get solidified and form scales. Hive bees collect these scales and use it for comb building. It is estimated that a honey bee need to consume about 10-15 kg of honey for producing 1kg of wax. In India most of the beeswax is collected the comb of wild bees (*Apis dorsata*). It is estimated that for every 100kg of honey production is corresponding with 1-2 kg of wax production. It is evident that wax costs more than honey. 22kg of honey can be supported by 1 kg of wax, which is 20 times of its own weight.

Composition of beeswax:-

Beeswax of traditional *Apis mellifera* is composed of near about 300 fractions of compounds. It consists of monoesters 35%, diesters 14%, hydrocarbons 10.5%, Hydroxy polyesters 8%, free acids 8%, hydroxyl monoesters 4%, acid esters and polyesters 3%, trimesters 3% and 13% unspecified compounds. It also contain vitamin A 4096 IU.

Uses of beeswax:-

- Near about 75% of total produced beeswax worldwide is utilized in cosmetic industries for production of lotions, creams, eyebrow pencils, hair creams, lipsticks, pomades, cold creams, rouges etc.
- Beeswax is also used in pharmaceutical industries for preparation of ointments, capsules, pill coatings etc.
- Beeswax is used for preparation of candles.
- Used in preparation of comb foundation sheets.
- In perfume industry for manufacturing deodorants it is also used.
- Used for production of polishes for floor, leather, furniture, shoe etc.
- Used for preparation of crayons, carbon paper, sealing wax, lubricants, ink, varnishes and paints.
- Also used in telescopic lenses.
- Used as ingredient if production of chewing gum, adhesives, basketball moldings and archer’s bow string.
- A large amount of beeswax is used in ammunition factories.

c) Bee venom:-

Bee venom is obtained from the poison glands of worker honey bees. Their sting is connected with the poison sac. Incase of newly emerged individual the sting is not fully chitinized, so they can’t sting. Also in their venom sac a little amount of venom is stored. A bee contains maximum venom in their poison sac when they are two weeks old.

Properties and composition of bee venom:-

Bee venom is a clear liquid. It has a aromatic odour, bitter taste, and acidic reaction. Bee venom composed of apamine, histamine, hydrochloric acid, tryptophan, lecithinase, acithinase, formic acid, phospholipase, hyaluronidase, orthophosphoric acid, calcium, copper, magnesium and sulpher.

Use of bee venom:-

- Apitherapy is used to cure rheumatism in which patients are sting with bees.
- Bee venom is also used as a sub-cutaneous injection to treat rheumatism.
- Ointment is prepared by mixing apitoxin with vasaline and salicylic acid at the rate of 1:10:1 and applied on affected areas.
- Bee venom lower the blood pressure, decrease the cholesterol level and stimulate the heart muscles.

- Bee venom can cure endoarteriosis, endoarthritis, neurosis and neuroglia
- It can neutralize alcohol poison.

d) Propolis:-

Propolis is a solid dark substance which bees collect from the gums and resin that plants and tree secrets. Propolis is used by bees for the construction and repairing of combs in a combination with beeswax. It protects colonies from unpleasant odour, bacteria. Propolis is collected by scrapping it from frames.

Composition of propolis:-

Propolis contain balsam and resin at the rate of 55%, scented oil and ethanol 10%, wax 30% and pollen 5%.

Use of propolis:-

- Propolis is used for preparation of ointments to treat cuts, wounds and abscesses of cattle.
- Combined with vasaline to treat burns.
- It has antiallergic and antibacterial properties.
- Effective against herpes virus and useful for tissue regenaration.
- Propolis extracts are useful to cure many dermatological disorders.
- It also posses antituberculosis properties.

ii) <u>Multiplication activities:-</u>

Multiplication activities includes queen bee production and package bee production. For establishing a new honey bee colony in require a healthy good quality queen with few drone and a number of worker bees. This multiplication activities is an efficient way of generating employment.

Queen bee production:-

Doolittle (1889) method of rearing queen is employed for production of large number of queen cells. In this method young larvae from worker cells are transferred to artificial queen cups by grafting. For selection of breeder colony the best performing colony in the apiary is selected and broods of this colony is used for the raising of better quality queens. Selected broods are taken in a queen cap containing sufficient amount of royal jelly and transferred to a frame. These frames are placed to a queen less colony containing sufficient brood cells and destroy the queen cells produced by the honey bees. After some days new queen will emerge. Upon emergence the queen can be used for marketing and the colony is united with strong colony (Valley & Wt, 2007).

Package bee production:-

Persons who want to adopt bee keeping require bee colony containing a healthy good quality mated queen and a number of worker bees along with the hive. This packaged bee production is an efficient way of income generation.

iii) <u>Fabrication and construction activities:-</u>

Beekeeping require a lot of equipments such as hive, hive stands, brood and super frames, queen cage, queen gate, queen cell protector, synthetic comb, comb foundation sheet, hive tool, dummy division board, pollen collector, bee veil, smoker, honey extractor etc. For harvesting of honey from *A. dorsata* need specialized tools. Production unit of these equipments required for beekeeping can be an efficient venture for rural people. Production of different packaging materials required for marketing of honey and other bee products is also a good way of generating employment in rural area. Manufacturing of processing plant is another way of income generation.

iv) <u>Processing activities:-</u>

Different hive products need to be processed before consumption or use. As honey, beeswax contain a number of impurities, raw honey is prone to crystallization and this need to be undergo through certain processing activities before release it for marketing.

So the processing activities of honey, beeswax and other valuable products generate employment.

Processing of honey:-

After collecting frames from the hives, decapping of honey cells is carried out manually or by using uncapping machine. Then the frames are taken into a honey extractor which uses centrifugal force to extract honey. The honey drains out the bottom and collected in a vessel. In a screw press the remaining wax can be pressed to extract the remaining honey.

Raw honey is sticky and viscous, so difficulties will be faced during filtering. Honey is heated at a temperature of 66°–77°C to decrease its viscosity before filtration. Some honey is pasteurized at 72°C or higher. The heating process delays crystallization, destroys yeast cells and enhance shelf life of honey. During heating process the brown color of the honey increases. Heating can be carried out in tanks or by using an infrared heater or using heat lamp above the honey product.

After heating process filtration is carried out. The primary objective of filtration is to reduce crystallization of honey and produce a clear product. There are various types of filtration processes are available for different types of honey, in which most frequently used is membrane filters. The membrane permits some of the compounds to pass through the pores and others to compounds to remain behind which depends on the pore size and pore distribution of the membrane. Macro-filtration (10–1,000 µm) is used to remove dust, bubbles, insect parts and crystals. For this cheesecloth or nylon or metallic screens are used. If this process is used without applying heat, then the honey is considered as raw honey. Microfiltration (0.1–10 µm) removes coal dust, yeast cells, and some bacteria (McHugh, 2017).

Processing of beeswax:-

Beeswax is collected from cappings that is retained during honey extraction. It is also collected from older combs which are not suitable for use and also from the combs which get damage during honey extraction. Cappings where recovery percentage is higher give the best grade wax. In India major amount of beeswax is collected from combs of *Apis dorsata*.

For processing collected cappings are first washed by rinsing in water and then air dried, otherwise it will be converted into a big fermented mess. This cappings are then melted and passed through sieves to remove different impurities.

Processing of bee venom:-

Commercially bee venom is produced by use of electric shock. Copper wires are used through which electric shock passes. Below the copper wires a thin nylon cloth is provided. As the bees get shock, they irritated and release the venom by inserting the sting into the nylon cloth. Below the nylon cloth a glass plate is provided in which venom is collected. After this the venom is dried and scrapped from the glass plate. Near about 1mg of bee venom is obtained from an *Apis mellifera* colony.

Processing of value added products from honey and other bee products:-

Different value added products can be obtained from the honey. This value added products include different foods and liquids such as honey gums, nougat, torrone, caramels, honey candies, honey beer, honey liqueurs, honey milk, honey spreads, honey jelly, syrups, rose honey, gingerbread, marzipan, honey bakery products; cosmetics such as lotions, creams etc. Except honey value added products from beeswax like candle, comb foundation sheets can be obtained. Processing of this value added products can be an efficient way of earning.

v) Service activities:-

In beekeeping various kinds of service activities such as can be provided. It will generate employment for those who are not directly associated with beekeeping. These activities include-

- Pollination activities: Transportation of bee hives to the fields at the flowering period of crop to enhance the chances of pollination for increasing yield of crop.
- Bee colony migration and transport: Incase of migratory beekeeping bee hives need to be transported to long distance and proper packaging of bee hives. Sometimes it requires more than a day. Transportation services of colonies can provide employment.
- Consultancy services to small beekeepers and cooperatives: Small bee keepers are unaware about the modern and improved management strategies of beekeeping. So they need to educate about the improved practices. Cooperatives which want to initiate beekeeping need knowledge regarding the beekeeping. So consultancy service to them can be provided by the educated unemployed persons.
- Transport of produce and manufactured equipments: Transfer of bee products from processing unit to the market and equipments from market to processing units require well transportation facilities. So, transportation service can be an efficient way of employment.

Beekeeping and conservation of nature:-

Above all beekeeping is a process of conserving nature.

- Direct production of honey and other bee products
- Pollination and increasing farm production
- Creation of jobs in maintenance, manufacture and value added products and marketing
- Utilising nature's gift which is hitherto going waste
- Production without any suffering to nature
- Productive job to millions and protection of nature
- No other production process helps conserve the nature to the extend as beekeeping does
- Protection of vegetation and forests and for more honey
- Grow more crops full of nectar for more honey as well as for increased crop yield
- Protect environment against pollution for better and productive beekeeping industry

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CLIMATE CHANGE MITIGATION THROUGH CLIMATE RESILIENT PRODUCTION TECHNOLOGIES

Dr. Partha Sarathi Patra
Agronomy, Regional Research Station, Terai Zone,
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Introduction:

Climate change is one of the most pressing challenges of the 21st century, impacting ecosystems, economics and societies on a global scale. As temperatures rise, extreme weather events become more frequent and ecosystems face unprecedented stresses, there is an urgent need for innovative approaches to mitigate these impacts. Among the various strategies, climate-resilient production technologies have emerged as a promising solution to address the dual challenges of reducing greenhouse gas (GHG) emissions and adapting to the impacts of climate change. Climate-resilient production technologies encompass a wide range of innovations and strategies designed to reduce vulnerability to climate change while simultaneously decreasing emissions. These technologies are particularly crucial in sectors such as agriculture, energy, manufacturing and infrastructure. The integration of climate resilience into production systems can enhance sustainability, improve resource efficiency and ensure economic stability in the face of climate uncertainties. The development and deployment of climate-resilient technologies are guided by principles such as efficiency, sustainability and minimal environmental degradation. These technologies often leverage advancements in science and engineering, digital tools, and traditional knowledge to create sustainable solutions that are tailored to specific climatic and geographic conditions.

1. Climate Change: Climate change refers to long term alterations in temperature, precipitation patterns and other climatic variables over decades to millions of years. While natural factors like volcanic activity and variations in solar radiation have historically driven climatic shifts, current climate change is predominantly influenced by human activities. According to the Intergovernmental Panel on Climate Change (IPCC), the primary driver of contemporary climate change is the increase in atmospheric concentrations of greenhouse gases—such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)—resulting from fossil fuel combustion, deforestation, industrial processes, and agricultural practices. These emissions trap heat in the Earth's atmosphere, causing a warming effect known as the greenhouse effect.

1.1 Agricultural operations responsible for climate change: Agriculture plays a dual role in the climate change narrative: it is both a victim of and a contributor to the changing climate. Agricultural operations are responsible for a significant portion of global greenhouse gas emissions with various practices impairing the problem. Below are key agricultural operations that contribute to climate change.

i) Land use change and deforestation: Land use change, including deforestation for agricultural expansion, is a major driver of carbon dioxide emissions. When forests are cleared to create farmland, the carbon stored in trees and soil is released into the atmosphere. Deforestation also reduces the planet's capacity to sequester carbon, further accelerating climate change. Agricultural activities, such as the establishment of plantations and livestock grazing are leading causes of deforestation in tropical regions.

ii) Methane emissions from livestock: Livestock farming, particularly ruminants such as cattle, sheep and goats, produces large quantities of methane through enteric fermentation. Methane is a potent greenhouse gas, with a global warming potential many times greater than that of carbon dioxide over a 20-year period. Manure management systems, especially those involving liquid storage, also emit methane, contributing significantly to agricultural emissions.

iii) Submerged rice cultivation: Flooded rice create anaerobic conditions that facilitate the production of methane. Rice cultivation accounts for a substantial share of global methane emissions. The continuous flooding of fields not only generates methane but also depletes water resources, making it a critical area for mitigation efforts. Alternate wetting and drying methods can significantly reduce methane emissions from rice fields while maintaining crop yields.

iv) Nitrous oxide emissions from fertilizers: The application of synthetic and organic fertilizers contributes to the release of nitrous oxide (N_2O), another potent greenhouse gas. When fertilizers are applied to agricultural soils, a portion of the nitrogen undergoes microbial processes that release nitrous oxide. Over-application of fertilizers exacerbates this issue, highlighting the need for precision in fertilizer use. Strategies like the use of nitrification inhibitors and slow-release fertilizers can mitigate nitrous oxide emissions.

v) Soil degradation and carbon loss: Conventional tillage practices disturb soil structure, leading to the release of stored carbon as CO_2. Soil degradation through erosion, overgrazing and unsustainable land management further reduces the soil's ability to act as a carbon sink. Unsustainable practices also result in the loss of organic matter, diminishing soil fertility and resilience. Practices such as reduced tillage, cover cropping, and organic matter addition can improve soil health and sequester carbon.

vi) Burning of agricultural residues: In many regions, farmers burn agricultural residues, such as straw and stubble, to clear fields for the next planting season. This practice releases large amounts of carbon dioxide, methane, and other pollutants into the atmosphere, contributing to both global warming and air pollution. Alternative approaches, such as incorporating residues into the soil or using them as feedstock for bioenergy, can mitigate these emissions.

vii) Use of fossil fuels in agricultural machinery: The operation of tractors, harvesters, and other agricultural machinery relies heavily on fossil fuels, contributing to carbon dioxide emissions. From ploughing and planting to harvesting and transportation, fossil fuel combustion is an integral part of conventional agriculture, adding to the sector's carbon footprint. Transitioning to renewable energy-powered machinery can significantly reduce emissions from this source.

viii) Intensive water use and energy consumption: Irrigation-intensive farming depletes freshwater resources and requires significant energy inputs for pumping and distribution. In regions where energy is sourced from fossil fuels, this further increases greenhouse gas emissions. Additionally, inefficient water management can lead to waterlogging and associated emissions. Innovations such as solar-powered irrigation systems and drip irrigation can address these challenges.

2. Mitigation: In the context of climate change, it refers to efforts to reduce or prevent the emission of greenhouse gases to limit the magnitude of global warming and its associated impacts. Mitigation strategies aim to enhance carbon sinks, improve energy efficiency, promote renewable energy sources, and adopt sustainable practices across various sectors, including agriculture, industry, and transportation. By addressing the root causes of climate change, mitigation plays a critical role in stabilizing global temperatures and preventing catastrophic consequences for ecosystems and human societies.

3. Climate Resilience: Climate resilience refers to the ability of systems, communities and economies to anticipate, prepare for, respond to, and recover from the adverse effects of climate change. It involves building adaptive capacity to withstand climate shocks and stresses while maintaining or improving functionality. Climate-resilient production technologies are specifically designed to enhance the resilience of agricultural, industrial and energy systems, enabling them to sustain productivity under changing climatic conditions.

3.1 The role of climate resilient technologies in climate change mitigation

Climate change mitigation involves reducing or preventing the emission of greenhouse gases into the atmosphere. Climate-resilient production technologies contribute to mitigation in several ways:

a) **Reducing Greenhouse Gas Emissions:** Many climate-resilient technologies focus on minimizing carbon emissions by improving energy efficiency, reducing waste, and adopting cleaner production methods. For example, in agriculture, conservation tillage and precision farming can reduce emissions from soil disturbance and fertilizer use.
b) **Enhancing Carbon Sequestration:** Some production technologies enhance the ability of natural systems to absorb and store carbon dioxide. Agroforestry, reforestation, and soil carbon management practices help sequester carbon while maintaining agricultural productivity.
c) **Promoting Renewable Energy Use:** Transitioning to renewable energy sources, such as solar, wind, and bioenergy, reduces dependence on fossil fuels and lowers overall carbon emissions. In industrial sectors, integrating renewable energy into manufacturing processes can significantly reduce the carbon footprint.
d) **Improving Resource Efficiency:** Climate-resilient technologies optimize resource use, reducing waste and improving overall efficiency. Water-efficient irrigation systems, energy-efficient appliances, and circular economy approaches help minimize resource depletion while maintaining productivity.
e) **Developing Resilient Infrastructure:** Climate-resilient infrastructure, such as flood-resistant buildings, green roofs, and smart transportation systems, reduces vulnerability to climate-related disasters and supports long-term sustainability.

3.2 Mitigation strategies through climate resilient production technologies

3.2.1. Climate resilient agricultural practices:

Agriculture is both a major contributor to greenhouse gas emissions and one of the most vulnerable sectors to climate change. Climate-resilient production technologies in agriculture focus on reducing emissions while ensuring sustainable productivity. Key strategies includes

a. Conservation Agriculture: Conservation agriculture involves minimal soil disturbance, permanent soil cover and maximum residue retention to enhance soil health, reduce emissions, and improve water retention. Practices like zero tillage and residue management contribute to carbon sequestration while maintaining yields.

b. Precision Agriculture: Precision agriculture uses technologies such as GPS, sensors, and drones to optimize resource use, reduce input wastage, and lower emissions. For instance, precise application of fertilizers minimizes nitrous oxide emissions, while targeted irrigation conserves water.

c. Agroforestry: Agroforestry integrates trees and shrubs into agricultural landscapes, enhancing carbon sequestration, improving soil fertility, and providing shade and windbreaks to protect crops from climate extremes.

d. Drought-Resistant Crop Varieties: Developing and adopting crop varieties that are tolerant to drought, heat, and salinity can help farmers maintain productivity in regions experiencing climatic stresses.

3. 2. 2 Climate smart water management

Water resources are highly sensitive to climate change, with impacts on availability and quality. Climate-resilient technologies for water management include:

a. Smart irrigation systems: Technologies like drip irrigation and automated irrigation scheduling reduce water wastage and improve agricultural productivity under water-scarce conditions.
b. Water recycling and reuse: Implementing wastewater treatment and recycling systems ensures sustainable water use in industries and urban areas.
c. Desalination with renewable energy: Powered by solar or wind energy, desalination plants provide freshwater in arid regions while minimizing environmental impacts.
4. Challenges and Opportunities: While climate-resilient production technologies offer immense potential for mitigation, their adoption faces several challenges, including high initial costs, limited technical expertise and resistance to change. However, advancements in technology, supportive policies and international cooperation provide opportunities to overcome these barriers. Increased investment in research and development, capacity building, and public awareness can accelerate the deployment of these technologies.
5. Conclusion: Climate-resilient production technologies represent a key way to mitigate climate change while ensuring sustainable development. By integrating innovative practices in agriculture, energy, industry, water management and urban planning, these technologies address the dual imperatives of reducing emissions and adapting to climate impacts. As global efforts to combat climate change intensify, the widespread adoption of climate-resilient production technologies will be instrumental in achieving a sustainable and resilient future.

Trends, intensification, attribution and uncertainty of projected heatwaves in India

Dr. Bratati Chowdhury
Assistant Professor, Soil and Water Conservation Engineering,
Uttar Banga Krishi Viswavidyalaya Pundibari Cooch Behar

The rising incidence of extreme climatic events, encompassing incremental geographies, has been attributed to anthropogenic climate change in multiple studies (Guldberg et al. 2018). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming (IPCC, 2021) states that a warming of 1.5°C (over pre-industrial levels) would further increase the intensity and frequency of extreme events across different regions. Heat waves stand out as one of the most impactful extreme events (BBC 2019; Carbon Brief 2018), with multiple instances globally in the last decade (Chandrasekara et al. 2021). For example, official records of the India Meteorological Department (IMD) indicate that there have been approximately 223 severe heat wave incidents between 1978 and 1999 (Chaudhury et al. 2000). The heat waves in 1998, 2003, 2013, and 2015 are identified by researchers as the more severe heat waves in India (Ratnam et al. 2016; Mazdiyasni et al. 2017). Besides, it is projected that the mean temperatures in India will see a rise between 2.2° C and 5.5° C by the end of 2100 (Kumar et al. 2013; Dholakia et al. 2015) and will be accompanied by the intensification of heat waves in India, increasing the heat stress and mortality rate (Murari et al. 2014). In order to facilitate adaptive planning for such inclement events, it is imperative that a detailed quantitative analysis of projected heat waves is carried out for India while accounting for spatial variation, associated uncertainties, risk attribution and finally, the cost of climate inaction. In this context, we take up the study of heat waves over the Indian geographic extent under various scenarios of projected climate change.

The definition of heat waves has morphed from non-flexible duration indices and counting days above a particular threshold (Perkins 2015) to multi-definition and characteristic frameworks (Perkins and Alexander 2013). Essentially a heat wave is defined as the period of successive hot days above normal temperature (Perkins et al. 2012; Perkins and Alexander 2013), thereby including seasonally extreme (i.e., summertime) events or seasonally anomalous warm spells (i.e., annual). The current study has characterised the spatio-temporal behaviour of projected (2016-2100) heat waves in India at 0.25° × 0.25° grids using data from six scenarios of CMIP-5 and CMIP-6 ensembles. The heat wave characteristics were represented by four variables – accumulated heat wave intensity (ahwc), annual heat wave days (ahwd), mean heat wave days (mhwd) and heat wave days (hwd). Our analysis began with the study of reference temperature data (1961-2005) and deciding on the threshold for demarcation of an event as a heat wave. Based on this analysis, we decided to use a threshold of 85 percentile of the daily summer mean temperature (Mazdiyani et al., 2017). To capture the effect of climate change, we used the median of the threshold values between 1961-2005 to calculate the projected variables. We were able to demarcate eight zones that broadly represented the country's different physiographic divisions through optimisation (Fuzzy C-mean clustering technique). Further, we used the PR-FAR methodology to study the intensification of extreme heat waves with the increase in temperature and be able to attribute this intensification to the temperature anomalies. Finally, we defined and computed the metric intensification ratio to establish the degree of severity of heat waves in the absence of any climate action. We concluded our study with the non-parametric PDFs to capture the spatial signature of the said intensification ratio.

The common theme in the results was the differential behaviour of the variable annual heat wave count. While for the other variables, the homogeneity analysis showed shifts in the time series, mostly in the decade of 2045-2055, for ahwc the years ranged from the 2030s to 2060s. When we look at the PDFs of the variables during the pre and post break years, we see distinctive changes (shift of means to higher value and increased variance) in all variables except ahwc. This points to the fact that on an all-India basis the number of heat waves is not increasing while their duration and consequently intensity are getting amplified. When we zoom into the zonal results of trend analysis, we see that across the zones there are negative trends for ahwc for all scenarios. However, for the other variables we find a preponderance of positive trend especially as we move towards the higher emission scenarios. It can also be established from the above observations that in regards to trends and percentage changes there is spatial homogeneity rather than heterogeneity. Similar trends of spatial homogeneity and intensification of heat waves are observed in the analysis of 1in 100-year events (using PR-FAR). We see that while in the case of ahwc the 1 in 100-year events recur every 15-25 years, for the rest the frequency is as low as 3-4 years in the projected scenario. Consequently, the changes in ahwd, mhwd and hwd can be attributed to temperature increases with a high degree of certainty (95%) while for ahwc it is only 60-70%. These results once again make it clear that the footprint of increase in temperature is evident in heat wave intensities rather than count.

The analysis of uncertainty reflects the results of homogeneity (temporal) analysis where we see that around 2050 the scenario uncertainty exceeds the internal climatic variability. The consequent, analysis also shows a high degree of spatial homogeneity in the most probable values of the variables while the associated uncertainty is mostly below 0.5, thus establishing confidence in the results. In the case of most probable value and uncertainty analysis, we some a weak footprint of the zones demarcated in clustering. The extremes of higher (the Western Ghats and Northern Himalayas) and lower (mashes of western coast) elevations have relatively higher values of the most probable values and the associated uncertainty. It can be concluded that areas that lie at extremities of the distribution of temperature in India have higher variance in their response to different climate scenarios. Finally, our analysis of the intensification ratio established that majority of the Indian landmass would see heat waves of higher intensities in case of climate inaction as compared to climate action.

Future researchers studying projected heat waves in India can use the major takeaways, viz- heat wave intensity has a more clear footprint of temperature increases than heat wave count; even though India can be classified into different zones based on their climatic characteristics, there majorly a degree of spatial homogeneity when it comes to analysis of heat waves; the effects of different climate actions become prominent post 2050, which is also the time around which the heat wave variables (expect ahwc) show a break in temporal homogeneity; the cost of climate inaction on heat waves in India is going to widespread and massive. This study can be extended to project human mortality, analysis on effects on energy consumption for cooling, administrative steps necessary for mitigation and change in work hours to reduce chances of heatstroke and many others.

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Impact of climate change on ornamental bio-diversity and its mitigation

Dr. Arpita Mandal Khan
Assistant Professor
Department of Floriculture, Medicinal and Aromatic Plants
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Introduction

Ornamental plants have been integral to human culture for centuries, serving as sources of beauty, cultural symbolism, and even therapeutic value. Whether in domestic gardens, public parks, or large-scale landscapes, ornamental species offer more than visual appeal—they enrich the ecosystems they inhabit and provide essential services such as air purification, carbon sequestration, and support for pollinators. However, the accelerating pace of climate change presents a profound challenge to the conservation of ornamental biodiversity.

Climate change, driven by rising temperatures, shifting precipitation patterns, and increasing extreme weather events, poses significant threats to plant species. For ornamental plants, the changing climate may result in altered growth patterns, the introduction of new pests and diseases, and shifts in suitable habitats. As a result, there is an urgent need to adapt conservation practices to safeguard ornamental biodiversity for future generations.

Climate Change and Its Impact on Ornamental Biodiversity

Climate change affects ornamental plant species in numerous ways:

1. **Temperature Shifts**: Rising temperatures can cause shifts in the flowering and growth cycles of ornamental plants, potentially leading to mismatches between plant life stages and pollinator activity. Hutchings (2010) reported that peak flowering of *Ophyrus sphegodes* Mill. advanced by half a day per year in last 32 years. Some species may become vulnerable to heat stress, reduced water availability, and prolonged growing seasons, which could outpace their adaptive capacity. Upward shift to higher altitude is already evident in *Aconitum heterophyllum, Lilium polyphyllum, Sorbus lanata* etc. Distribution of some alpine species such as *Hippophae spp, Betula utilis, Cotoneaster spp., Nordostychus grandiflora* is gradually narrowed with loss of diversity. Telwala et al., (2013) observed natural migration of alpine plants in Sikkim by 29-998m elevation in last century including rhododendrons and other woody ornamentals.
2. **Precipitation Changes**: Climate change can alter rainfall patterns, leading to more frequent droughts or flooding. Ornamental plants often require specific water regimes, and fluctuations in precipitation can result in plant mortality or a reduction in ornamental value due to poor growth. Rise in cloud-base of the cloud-forests of Costa Rice and Yachen Reserve of China has made the orchids prone to desiccation (Nadkarni and Solano, 2002 and Lui, *et al*., 2010).
3. **Pests and Diseases**: Warmer temperatures and erratic weather conditions may expand the ranges of pests and pathogens that threaten ornamental plants. Warmer climate tend to lessen the requirement of overwintering of pathogens and vectors, resulting in prolonged activity periods and expanding their geographic distribution (El-Sayed and Kamel, 2020). On the other hand, scientists also predict extinction of certain pathogens due to altered climate. Like, in certain areas of Europe, when summer temperatures rose steadily over a 30-year span, the rust pathogen *Triphragmium ulmarie*, which infest *Filipendula ulmaria* (meadowsweet), was going extinct (Zhan et al., 2018). Moreover, invasive species, both plant and animal, may exploit new habitats, further stressing native ornamental species and disrupting

ecosystem services. The shrub lantana (*Lantana camara*) is now considered invasive in over 60 countries, and has invaded large geographies in several countries prompting aggressive federal efforts at attempting to control it (Bhagwat et al, 2012)

4. **Habitat Loss**: Climate change may lead to habitat fragmentation, particularly in regions already facing high levels of urbanization or deforestation. The loss of natural habitats, including wetlands, forests, and grasslands, reduces the diversity of ornamental species available for cultivation and restoration.

Strategies for Conservation of Ornamental Biodiversity

1. **Ex Situ Conservation**:
   - **Seed Banks and Genetic Resources**: One of the most effective ways to safeguard ornamental species is through *ex-situ* conservation methods like seed banking. By collecting and storing seeds from a wide range of ornamental plants, conservationists can preserve genetic material for future restoration efforts. Advances in cryopreservation and tissue culture techniques also offer promising options for long-term storage.
   - **Botanic Gardens**: Botanic gardens serve as living repositories for ornamental plants, offering a space for research, education, and public engagement. These gardens can be instrumental in conserving threatened ornamental species while also providing a platform for studying their responses to changing climates.
2. **In Situ Conservation**:
   - **Habitat Restoration**: Rehabilitating ecosystems where ornamental plants thrive is essential for maintaining biodiversity. Restoration projects can focus on native plant species that are more resilient to climate change and help restore ecosystem functions, such as soil health, water regulation, and carbon sequestration. In many cases, restoring native plant populations ensures the survival of ornamental species that are part of larger ecological communities.
   - **Landscape Adaptation**: Incorporating climate-resilient ornamental species into public landscapes and urban planning is vital. Municipalities and landscape designers can prioritize plant varieties that are more tolerant to extreme temperatures, drought, and flooding, while also reducing reliance on water-intensive species.
3. **Policy and Advocacy**:
   - **Climate-Smart Policies**: Governments can implement policies that promote the conservation of ornamental biodiversity. These may include incentives for the cultivation of native and climate-resilient plants, regulations to control invasive species, and financial support for conservation programs.
   - **Public Awareness and Education**: Raising awareness about the importance of ornamental biodiversity and climate change is essential. Public education campaigns can encourage homeowners and gardeners to plant resilient species, support conservation efforts, and engage in sustainable horticultural practices.
4. **Research and Monitoring**:
   - **Climate Impact Assessments**: Ongoing research into the effects of climate change on ornamental plants is crucial for understanding potential risks. Climate modelling, long-term monitoring, and field studies can provide insights into which species are most vulnerable and which have the potential for adaptation.
   - **Genetic Studies and Breeding**: Genetic research can help identify traits associated with climate resilience in ornamental plants. Through selective breeding or genetic engineering, it may be possible to develop ornamental plants that are better equipped to cope with environmental stressors, such as heat, drought, and disease.

Opportunities in the Era of Climate Change

While climate change poses significant challenges to ornamental biodiversity, it also presents opportunities for innovation and adaptation in horticulture:

1. **Development of Climate-Resilient Varieties**: Advances in plant breeding and biotechnology may lead to the creation of new ornamental varieties that are better suited to changing environmental conditions. For example, drought-tolerant ornamental grasses or heat-resistant flowering plants could be developed, enhancing the resilience of gardens and landscapes.
2. **Utilizing Local Ecotypes**: Native ornamental species and local ecotypes may be better adapted to the changing climate than non-native or cultivated varieties. Focusing on the cultivation and promotion of native ornamental plants can help preserve genetic diversity, reduce the risk of invasive species, and support local ecosystems.
3. **Green Infrastructure**: The increasing emphasis on green infrastructure, including green roofs, urban gardens, and sustainable landscaping, offers a unique opportunity to incorporate ornamental biodiversity into urban environments. By prioritizing sustainable plant choices, cities can become more resilient to climate change while enhancing their aesthetic value.

Conclusion

In the era of climate change, the conservation of ornamental biodiversity is both a challenge and an opportunity. While climate change threatens ornamental plants with altered growing conditions, pests, diseases, and habitat loss, there are numerous strategies that can be employed to preserve and enhance ornamental biodiversity. Ex situ and in situ conservation efforts, innovative research, and public awareness initiatives can all play crucial roles in safeguarding ornamental species for future generations. By embracing climate-smart approaches and prioritizing resilience, we can ensure that ornamental plants continue to contribute to the beauty, ecology, and well-being of our societies, even in the face of a changing climate.

Statistical methodology for applied research using statistical package

Dr. Manoj Kanti Debnath,
Assistant Professor, Department of Agricultural Statistics
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Statistical methodology plays a crucial role in applied research across various fields, including social sciences, business, healthcare, and engineering. It involves the systematic collection, analysis, interpretation, and presentation of data to make informed decisions and draw valid conclusions.

Key Aspects of Statistical Methodology:

1. Data Collection & Preparation – Involves sampling techniques, survey design, and data cleaning.
2. Descriptive Statistics – Summarizing data using measures like mean, median, standard deviation, and visualizations such as histograms and boxplots.
3. Inferential Statistics – Hypothesis testing, confidence intervals, regression analysis, and ANOVA to make predictions and assess relationships.
4. Modelling & Advanced Analysis – Includes machine learning, time-series forecasting, and multivariate techniques.
5. Interpretation & Reporting – Translating statistical findings into meaningful insights for decision-making.

Use of Statistical Packages:

Popular statistical software like **SPSS, R, SAS, Stata, and Python** facilitate efficient data analysis by providing built-in functions for statistical modelling, visualization, and hypothesis testing. These tools help researchers automate complex computations and ensure accuracy in data-driven research. By integrating statistical methodology with powerful statistical packages, researchers can enhance the reliability and validity of their findings, ultimately contributing to evidence-based decision-making.

Challenges in Statistical Methodology and Software Use

Despite their advantages, statistical methodologies and packages present certain challenges:

- **Data Quality Issues**: Inaccurate or missing data can lead to misleading conclusions.
- **Software Learning Curve**: Some statistical packages require advanced programming knowledge.
- **Misinterpretation of Results**: Incorrect application of statistical techniques can lead to erroneous inferences.

Statistical methodology is essential for applied research, providing a structured approach to data collection, analysis, and interpretation. The use of statistical packages such as SPSS, R, SAS, Stata, and Python enhances the efficiency, accuracy, and reproducibility of statistical analyses. By leveraging these tools, researchers can draw meaningful conclusions, make informed decisions, and contribute to knowledge advancement in their respective fields. However, understanding statistical concepts and ensuring high-quality data remain critical for producing reliable research outcomes.

Agricultural Field Experimental Design

Agricultural field experiments are essential for studying the effects of various factors—such as fertilizers, irrigation, crop varieties, and pest control—on crop yield and soil health. A well-planned experimental design ensures accurate, reliable, and unbiased results by minimizing variability and controlling external factors. The use of statistical methods in experimental design helps researchers analyse data effectively, leading to evidence-based agricultural recommendations.

Common Experimental Designs in Agriculture

1. Completely Randomized Design (CRD)

- Treatments are assigned randomly to plots without restrictions.
- Suitable for small, uniform fields with minimal environmental variation.
- Advantages: Simple and easy to implement.
- Disadvantages: Less effective if soil fertility varies significantly.

2. Randomized Complete Block Design (RCBD)

- The field is divided into blocks based on natural variations (e.g., soil type), and treatments are randomly assigned within each block.
- Advantages: Controls variability within blocks, improving accuracy.
- Disadvantages**:** Requires proper identification of blocking factors.

3. Latin Square Design (LSD)

- Treatments are arranged in rows and columns to control two sources of variation (e.g., soil fertility and moisture levels).
- Advantages: Effective when two major factors influence crop growth.
- **Disadvantages:** Complex to implement, requires equal replications of treatments.

4. Factorial Design

- Examines the interaction between two or more factors (e.g., fertilizer type × planting density).
- Advantages: Provides insights into how factors interact and affect crop yield.
- Disadvantages: Can become complex with multiple factors and levels.

5. Split-Plot Design

- Used when studying two levels of treatments:
  - **Main plot factor** (e.g., irrigation method).
  - **Sub-plot factor** (e.g., fertilizer application).
- **Advantages:** Efficient when certain treatments are difficult to change (e.g., large-scale irrigation systems).
- **Disadvantages:** Requires careful analysis due to different error structures.

Pooled (Combined) Analysis of Variance (ANOVA)

Pooled or Combined Analysis of Variance (ANOVA) is a statistical method used to analyze data from experiments conducted across multiple locations, years, or environments. This method helps in assessing the overall effect of treatments while considering variations due to different experimental conditions. It is commonly used in agricultural research, clinical trials, and industrial experiments to evaluate the stability and consistency of treatments under varying conditions.

A well-designed agricultural field experiment minimizes errors, maximizes efficiency, and provides reliable results for improving farming practices. By selecting appropriate experimental designs and using statistical tools for analysis, researchers can make data-driven recommendations to enhance crop productivity and sustainability.

```
rm(list = ls(all = TRUE))#clear all the objects or values in global environment
graphics.off()#clear all the plots
shell("cls") #clear everything in console
```

R Code for CRD ANALYSIS

```
a <- read.csv(file.choose(),header = T)
#a<-read.table("clipboard",h=T)
attach(a)
str(a)
a$TRT=as.factor(TRT)# Make as Factor
model=aov(YIELD~TRT, data=a) # General Linear Model
```

```
print(anova(model)) # Anova
# Multiple Comparison Tests
library(agricolae)# Packages-----
LSD <- LSD.test(model,"TRT",group=TRUE); LSD      # Least Significant Difference
DUNCAN <- duncan.test(model,"TRT",group=TRUE);DUNCAN # DUNCUN Test
Tukey <- HSD.test(model,"TRT",group=TRUE);Tukey     # Tukey Test
```

Output

```
>
> a <- read.csv(file.choose(),header = T)
> #a<-read.table("clipboard",h=T)
> attach(a)
> str(a)
'data.frame':	25 obs. of  3 variables:
 $ TRT  : chr  "T1" "T1" "T1" "T1" ...
 $ YIELD: num  89.2 89.4 82.4 83.7 86.7 85.1 85.4 87.9 79.7 83.4 ...
 $ PH   : num  33.6 35.6 36.4 35.4 33.8 ...
> a$TRT=as.factor(TRT)# Make as Factor
> model=aov(YIELD~TRT, data=a) # General Linear Model
> print(anova(model)) # Anova
Analysis of Variance Table
Response: YIELD
          Df Sum Sq Mean Sq F value    Pr(>F)
TRT        4 8778.4 2194.61   201.1 7.597e-16 ***
Residuals 20  218.3   10.91
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> # Multiple Comparison Tests
> library(agricolae)# Packages-----
> LSD <- LSD.test(model,"TRT",group=TRUE); LSD      # Least Significant Difference
$statistics
  MSerror Df   Mean       CV  t.value      LSD
   10.913 20 83.936 3.935717 2.085963 4.358216
$parameters
        test p.ajusted name.t ntr alpha
  Fisher-LSD      none    TRT   5  0.05
$means
    YIELD      std r       se       LCL       UCL   Min   Max
T1  86.28 3.168122 5 1.477363  83.19828  89.36172  82.4  89.4
T2  84.30 3.032326 5 1.477363  81.21828  87.38172  79.7  87.9
T3 115.96 4.051296 5 1.477363 112.87828 119.04172 111.2 121.9
T4  74.36 3.289073 5 1.477363  71.27828  77.44172  70.9  78.1
T5  58.78 2.846401 5 1.477363  55.69828  61.86172  55.1  62.2
     Q25   Q50   Q75
T1  83.7  86.7  89.2
T2  83.4  85.1  85.4
T3 113.6 115.7 117.4
T4  71.0  75.1  76.7
T5  57.4  58.2  61.0
$comparison
NULL
```

```
$groups
   YIELD groups
T3 115.96      a
T1  86.28      b
T2  84.30      b
T4  74.36      c
T5  58.78      d

attr(,"class")
[1] "group"
NULL
```

R Code for RBD ANALYSIS

```
a <- read.csv(file.choose(),header = T)
#a=read.table("clipboard",h=T)
attach(a)
str(a)
a$TRT=as.factor(TRT)# Make as Factor
a$REP=as.factor(REP)# Make as Factor

model=aov(FW~TRT+REP, data=a) # General Linear Model
print(anova(model)) # Anova
# Multiple Comparison Tests
library(agricolae)# Packages-----
LSD <- LSD.test(model,"TRT",group=TRUE);LSD # Least Significant Difference
DUNCAN <- duncan.test(model,"TRT",group=TRUE);DUNCAN # DUNCUN
Tukey <- HSD.test(model,"TRT",group=TRUE);Tukey # Tukey
```

OUTPUT:

```
> a <- read.csv(file.choose(),header = T)
> #a=read.table("clipboard",h=T)
> attach(a)
> str(a)
'data.frame':	36 obs. of  3 variables:
 $ TRT: int  1 2 3 4 5 6 7 8 9 10 ...
 $ REP: int  1 1 1 1 1 1 1 1 1 1 ...
 $ FW : num  33.6 35.6 36.4 35.4 33.8 ...
> a$TRT=as.factor(TRT)# Make as Factor
> a$REP=as.factor(REP)# Make as Factor
> model=aov(FW~TRT+REP, data=a) # General Linear Model
> print(anova(model)) # Anova
Analysis of Variance Table

Response: FW
          Df  Sum Sq Mean Sq  F value    Pr(>F)
```

```
TRT       11 1286.51 116.956 2205.080 < 2.2e-16 ***
REP        2    1.70   0.851   16.039 5.051e-05 ***
Residuals 22    1.17   0.053
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> # Multiple Comparison Tests
> library(agricolae)# Packages-----
> LSD <- LSD.test(model,"TRT",group=TRUE);LSD # Least Significant Difference
$statistics
     MSerror Df     Mean       CV  t.value       LSD
  0.05303914 22 39.85972 0.577782 2.073873 0.3899732

$parameters
        test p.ajusted name.t ntr alpha
  Fisher-LSD      none    TRT  12  0.05

$means
         FW       std r        se      LCL      UCL   Min   Max    Q25   Q50    Q75
1  33.31667 0.3350124 3 0.1329651 33.04091 33.59242 32.98 33.65 33.150 33.32 33.485
10 42.81667 0.3350124 3 0.1329651 42.54091 43.09242 42.48 43.15 42.650 42.82 42.985
11 42.18000 0.3300000 3 0.1329651 41.90425 42.45575 41.85 42.51 42.015 42.18 42.345
12 42.53667 0.3350124 3 0.1329651 42.26091 42.81242 42.20 42.87 42.370 42.54 42.705
2  35.31000 0.3300000 3 0.1329651 35.03425 35.58575 34.98 35.64 35.145 35.31 35.475
3  36.11000 0.3300000 3 0.1329651 35.83425 36.38575 35.78 36.44 35.945 36.11 36.275
4  35.09667 0.3350124 3 0.1329651 34.82091 35.37242 34.76 35.43 34.930 35.10 35.265
5  33.47000 0.3300000 3 0.1329651 33.19425 33.74575 33.14 33.80 33.305 33.47 33.635
6  34.91000 0.3300000 3 0.1329651 34.63425 35.18575 34.58 35.24 34.745 34.91 35.075
7  41.98667 0.3350124 3 0.1329651 41.71091 42.26242 41.65 42.32 41.820 41.99 42.155
8  47.14667 0.3350124 3 0.1329651 46.87091 47.42242 46.81 47.48 46.980 47.15 47.315
9  53.43667 0.4650090 3 0.1329651 53.16091 53.71242 52.97 53.90 53.205 53.44 53.670

$comparison
NULL

$groups
         FW groups
9  53.43667      a
8  47.14667      b
10 42.81667      c
12 42.53667     cd
11 42.18000     de
7  41.98667      e
3  36.11000      f
2  35.31000      g
4  35.09667     gh
6  34.91000      h
5  33.47000      i
1  33.31667      i

attr(,"class")
```

```
[1] "group"
```

R Code for LSD ANALYSIS

```
a <- read.csv(file.choose(),header = T)
#a=read.table("clipboard",h=T)
attach(a)
str(a)
a$TRT=as.factor(TRT)# Make as Factor
a$ROW=as.factor(ROW)# Make as Factor
a$COL=as.factor(COL)# Make as Factor
library(agricolae)# Packages-----
model=aov(YIELD~TRT+ROW+COL, data=a) # General Linear Model
print(anova(model)) # Anova
# Multiple Comparison Tests
LSD <- LSD.test(model,"TRT",group=TRUE);LSD # Least Significant Difference
DUNCAN <- duncan.test(model,"TRT",group=TRUE);DUNCAN # DUNCUN
Tukey <- HSD.test(model,"TRT",group=TRUE);Tukey # Tukey
```

OUTPUT:

```
> a <- read.csv(file.choose(),header = T)
> #a=read.table("clipboard",h=T)
> attach(a)
> str(a)
'data.frame':	36 obs. of  4 variables:
 $ ROW  : int  1 1 1 1 1 1 2 2 2 2 ...
 $ COL  : int  1 2 3 4 5 6 1 2 3 4 ...
 $ TRT  : int  3 6 1 5 2 4 2 1 3 6 ...
 $ YIELD: num  3.1 5.95 1.75 6.4 3.85 5.3 4.8 2.7 3.3 5.95 ...
> a$TRT=as.factor(TRT)# Make as Factor
> a$ROW=as.factor(ROW)# Make as Factor
> a$COL=as.factor(COL)# Make as Factor
> library(agricolae)# Packages-----
> model=aov(YIELD~TRT+ROW+COL, data=a) # General Linear Model
> print(anova(model)) # Anova
Analysis of Variance Table

Response: YIELD
          Df Sum Sq Mean Sq F value    Pr(>F)
TRT        5 47.211  9.4421  7.5252 0.0004076 ***
ROW        5 34.442  6.8884  5.4900 0.0024352 **
COL        5 21.586  4.3171  3.4407 0.0209663 *
Residuals 20 25.095  1.2547
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> # Multiple Comparison Tests
> LSD <- LSD.test(model,"TRT",group=TRUE);LSD # Least Significant Difference
$statistics
   MSerror Df     Mean       CV  t.value      LSD
  1.254736 20 5.513889 20.31506 2.085963 1.349032
$parameters
        test p.ajusted name.t ntr alpha
```

```
  Fisher-LSD     none    TRT   6  0.05
$means
     YIELD      std r       se      LCL      UCL  Min Max    Q25   Q50    Q75
1 3.700000 1.3967820 6 0.4572993 2.746090 4.653910 1.75 5.0 2.7750 3.900 4.9125
2 4.733333 1.9130255 6 0.4572993 3.779424 5.687243 2.95 8.4 3.8125 4.225 4.7500
3 5.700000 2.4035391 6 0.4572993 4.746090 6.653910 3.10 9.3 3.6875 5.700 6.9625
4 5.266667 1.0971174 6 0.4572993 4.312757 6.220576 3.70 6.6 4.5125 5.550 5.9125
5 6.425000 0.5493178 6 0.4572993 5.471090 7.378910 5.40 7.0 6.4000 6.525 6.6875
6 7.258333 1.8252169 6 0.4572993 6.304424 8.212243 5.20 9.4 5.9500 6.850 8.9125
$comparison
NULL
$groups
     YIELD groups
6 7.258333      a
5 6.425000     ab
3 5.700000     bc
4 5.266667     bc
2 4.733333     cd
1 3.700000      d
attr(,"class")
[1] "group"

>
```

R Code for TWO FACTOR FACTORIAL ANALYSIS

```
d <- read.csv(file.choose(),header = T)
#d=read.table("clipboard",header=T)
attach(d)
str(d)
#Make as Factor
d$rep=as.factor(rep)# Make as Factor
d$FYM=as.factor(FYM)# Make as Factor
d$PSB=as.factor(PSB)# Make as Factor
model=aov(Yield~rep+FYM+PSB+FYM:PSB,data=d)
print(anova(model)) # Anova
library("agricolae")
LSD_FYM <- LSD.test(model,"FYM", group=TRUE);LSD_FYM
LSD_PSB <- LSD.test(model,"PSB", group=TRUE);LSD_PSB
```

OUTPUT:

```
> d <- read.csv(file.choose(),header = T)
> #d=read.table("clipboard",header=T)
> attach(d)
> str(d)
'data.frame':          36 obs. of  4 variables:
 $ FYM  : int  1 1 1 2 2 2 3 3 3 4 ...
 $ PSB  : int  1 2 3 1 2 3 1 2 3 1 ...
 $ rep  : int  1 1 1 1 1 1 1 1 1 1 ...
 $ Yield: num  6.83 15.59 12.85 20 15.61 ...
> #Make as Factor
```

```
> d$rep=as.factor(rep)# Make as Factor
> d$FYM=as.factor(FYM)# Make as Factor
> d$PSB=as.factor(PSB)# Make as Factor
> model=aov(Yield~rep+FYM+PSB+FYM:PSB,data=d)
> print(anova(model)) # Anova
Analysis of Variance Table
Response: Yield
          Df  Sum Sq Mean Sq F value   Pr(>F)
rep        2   0.065  0.0325  0.0084 0.991649
FYM        3  32.272 10.7572  2.7738 0.065469 .
PSB        2   6.957  3.4784  0.8969 0.422227
FYM:PSB    6 101.965 16.9941  4.3820 0.004657 **
Residuals 22  85.320  3.8782
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> library("agricolae")
> LSD_FYM <- LSD.test(model,"FYM", group=TRUE);LSD_FYM
$statistics
   MSerror Df     Mean       CV  t.value      LSD
  3.878179 22 14.89833 13.21832 2.073873 1.925262
$parameters
        test p.ajusted name.t ntr alpha
  Fisher-LSD      none    FYM   4  0.05
$means
     Yield      std r        se      LCL      UCL   Min   Max   Q25   Q50   Q75
1 13.35111 3.176131 9 0.6564364 11.98975 14.71248  6.83 17.10 12.85 14.54 15.16
2 15.69111 3.112649 9 0.6564364 14.32975 17.05248 10.29 20.00 14.15 15.61 17.17
3 15.64889 1.858268 9 0.6564364 14.28752 17.01025 12.05 18.29 15.36 15.47 16.72
4 14.90222 1.028941 9 0.6564364 13.54086 16.26359 12.93 16.11 14.21 15.21 15.69
$comparison
NULL
$groups
     Yield groups
2 15.69111      a
3 15.64889      a
4 14.90222     ab
1 13.35111      b
attr(,"class")
[1] "group"
> LSD_PSB <- LSD.test(model,"PSB", group=TRUE);LSD_PSB
$statistics
   MSerror Df     Mean       CV  t.value      LSD
  3.878179 22 14.89833 13.21832 2.073873 1.667326
$parameters
        test p.ajusted name.t ntr alpha
  Fisher-LSD      none    PSB   3  0.05
$means
     Yield      std  r        se      LCL      UCL   Min   Max     Q25    Q50     Q75
1 14.81333 3.657417 12 0.5684906 13.63436 15.99231  6.83 20.00 13.7800 14.970 17.2775
2 14.40750 1.601852 12 0.5684906 13.22852 15.58648 10.29 15.61 13.9200 15.230 15.4025
```

```
3 15.47417 2.005726 12 0.5684906 14.29519 16.65314 12.05 19.52 14.3025 15.795 16.3450
$comparison
NULL
$groups
    Yield groups
3 15.47417      a
1 14.81333      a
2 14.40750      a

attr(,"class")
[1] "group"
```

R CODE FOR SPLIT PLOT ANALYSIS

```
split <- read.csv(file.choose(),header = T)
#split=read.table("clipboard",header=T)
attach(split)
str(split)
library("agricolae")
#Make as Factor
split$rep=as.factor(rep)
split$mp=as.factor(mp)
split$sp=as.factor(sp)
model <- sp.plot(block = rep, pplot = mp, splot = sp, Y = YIELD)
LSD_MP <- LSD.test(y = YIELD, trt = mp,DFerror = model$gl.a, MSerror =
model$Ea,alpha = 0.05,  group = TRUE,console = TRUE)
LSD_SP <- LSD.test(y = YIELD, trt = sp,DFerror = model$gl.b, MSerror =
model$Eb,alpha = 0.05,
                group = TRUE,console = TRUE)
```

OUTPUT:

```
> split <- read.csv(file.choose(),header = T)
> #split=read.table("clipboard",header=T)
> attach(split)
> str(split)
'data.frame':        30 obs. of  4 variables:
 $ mp   : int  1 1 1 2 2 2 1 1 1 2 ...
 $ sp   : int  1 1 1 1 1 1 2 2 2 2 ...
 $ rep  : int  1 2 3 1 2 3 1 2 3 1 ...
 $ YIELD: num  73.6 71.8 78.6 74.5 70.8 73.8 66.2 72.5 69.3 66.2 ...
> library("agricolae")
> #Make as Factor
> split$rep=as.factor(rep)
> split$mp=as.factor(mp)
> split$sp=as.factor(sp)
> model <- sp.plot(block = rep,
+               pplot = mp,
+               splot = sp,
+               Y = YIELD)
```

```
ANALYSIS SPLIT PLOT:  YIELD
Class level information

mp        :  1 2
sp        :  1 2 3 4 5
rep       :  1 2 3

Number of observations:  30

Analysis of Variance Table

Response: YIELD
      Df Sum Sq Mean Sq F value    Pr(>F)
rep    2   1.18   0.588  0.0780    0.9253
mp     1   0.12   0.120  0.0198    0.9011
Ea     2  12.18   6.089
sp     4 399.88  99.969 13.2601 5.946e-05 ***
mp:sp  4  63.65  15.913  2.1107    0.1269
Eb    16 120.63   7.539
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

cv(a) = 3.7 %, cv(b) = 4.1 %, Mean = 67.01

> LSD_MP <- LSD.test(y = YIELD,
+                  trt = mp,
+                  DFerror = model$gl.a,
+                  MSerror = model$Ea,
+                  alpha = 0.05,
+                  group = TRUE,
+                  console = TRUE)

Study: YIELD ~ mp
LSD t Test for YIELD
Mean Square Error:  6.089333
mp,  means and individual ( 95 %) CI
     YIELD      std  r        se      LCL      UCL  Min  Max   Q25  Q50   Q75
1 66.94667 5.323381 15 0.6371464 64.20525 69.68809 59.8 78.6 63.05 65.6 70.55
2 67.07333 3.786907 15 0.6371464 64.33191 69.81475 60.9 74.5 64.65 66.2 68.70
Alpha: 0.05 ; DF Error: 2
Critical Value of t: 4.302653
least Significant Difference: 3.876953
Treatments with the same letter are not significantly different.
     YIELD groups
2 67.07333      a
1 66.94667      a
> LSD_SP <- LSD.test(y = YIELD,
+                  trt = sp,
+                  DFerror = model$gl.b,
+                  MSerror = model$Eb,
```

```
+               alpha = 0.05,
+               group = TRUE,
+               console = TRUE)

Study: YIELD ~ sp
LSD t Test for YIELD
Mean Square Error:  7.539083
sp,  means and individual ( 95 %) CI
     YIELD      std r       se      LCL      UCL  Min  Max    Q25   Q50    Q75
1 73.85000 2.703886 6 1.120943 71.47371 76.22629 70.8 78.6 72.250 73.70 74.325
2 67.66667 2.934394 6 1.120943 65.29037 70.04296 64.1 72.5 66.200 66.95 68.900
3 64.98333 1.747474 6 1.120943 62.60704 67.35963 63.0 67.7 63.625 65.10 65.675
4 64.70000 3.753931 6 1.120943 62.32371 67.07629 59.8 69.6 62.000 64.90 67.200
5 63.85000 2.546174 6 1.120943 61.47371 66.22629 60.9 66.6 61.550 64.25 65.900
Alpha: 0.05 ; DF Error: 16
Critical Value of t: 2.119905
least Significant Difference: 3.360587
Treatments with the same letter are not significantly different.

     YIELD groups
1 73.85000      a
2 67.66667      b
3 64.98333     bc
4 64.70000     bc
5 63.85000      c

>
```

POOLED RBD ANALYSIS

```
a <- read.csv(file.choose(),header = T)
#a=read.table("clipboard",h=T)
attach(a)
str(a)
# Make as Factor
a$TRT=as.factor(TRT)
a$Rep=as.factor(Rep)
a$Year=as.factor(Year)
# Packages-----
library("agricolae")
model=aov(PH~Year+Rep%in%Year+TRT+TRT:Year, data=a) # General Linear
Model
#model=aov(PH~Year+Rep:Year+TRT+TRT:Year, data=a)
print(anova(model)) # Anova
LSD <- LSD.test(model,"TRT",group=TRUE);LSD # Least Significant Difference
```

OUTPUT:

```
> a <- read.csv(file.choose(),header = T)
> #a=read.table("clipboard",h=T)
```

```
> attach(a)
> str(a)
'data.frame':	90 obs. of  4 variables:
 $ Year: int  1 1 1 1 1 1 1 1 1 1 ...
 $ TRT : int  1 2 3 4 5 6 7 8 9 10 ...
 $ Rep : int  1 1 1 1 1 1 1 1 1 1 ...
 $ PH  : num  110 118 120 121 111 ...
> # Make as Factor
> a$TRT=as.factor(TRT)
> a$Rep=as.factor(Rep)
> a$Year=as.factor(Year)
> # Packages-----
> library("agricolae")
> model=aov(PH~Year+Rep%in%Year+TRT+TRT:Year, data=a) # General Linear Model
> #model=aov(PH~Year+Rep:Year+TRT+TRT:Year, data=a)
> print(anova(model)) # Anova
Analysis of Variance Table
Response: PH
          Df Sum Sq Mean Sq F value    Pr(>F)
Year       2    9.9    4.97  0.6052    0.5496
TRT        9 3480.4  386.71 47.0625 < 2.2e-16 ***
Year:Rep   6   14.8    2.47  0.3004    0.9340
Year:TRT  18 1365.9   75.88  9.2351 8.973e-11 ***
Residuals 54  443.7    8.22
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> LSD <- LSD.test(model,"TRT",group=TRUE);LSD # Least Significant Difference
$statistics
   MSerror Df    Mean      CV  t.value      LSD
  8.216977 54 118.342 2.42224 2.004879 2.709181
$parameters
        test p.ajusted name.t ntr alpha
  Fisher-LSD      none    TRT  10  0.05
$means
         PH      std r       se      LCL      UCL    Min    Max    Q25    Q50    Q75
1  107.2589 4.916372 9 0.955509 105.3432 109.1746 100.25 113.10 102.75 109.25 111.08
10 115.3922 3.079597 9 0.955509 113.4765 117.3079 112.28 122.00 112.75 115.25 115.75
2  119.2200 2.692346 9 0.955509 117.3043 121.1357 116.00 123.10 117.20 118.20 122.00
3  117.9200 2.045049 9 0.955509 116.0043 119.8357 114.75 121.00 116.48 118.25 119.50
4  117.4589 4.136555 9 0.955509 115.5432 119.3746 110.10 121.25 116.08 119.75 120.75
5  110.0700 2.606070 9 0.955509 108.1543 111.9857 105.75 113.25 108.88 110.25 112.50
6  125.8689 5.445648 9 0.955509 123.9532 127.7846 116.50 133.83 123.20 123.80 129.63
7  128.6544 7.754823 9 0.955509 126.7388 130.5701 119.00 142.75 122.40 126.17 132.50
8  118.5467 7.763768 9 0.955509 116.6310 120.4623 109.40 128.50 113.72 116.25 128.25
9  123.0300 3.200309 9 0.955509 121.1143 124.9457 118.25 127.50 120.75 122.92 125.40
$comparison
```

Mushroom Farming – A Sustainable Agricultural Practice for Ensuring Food Security and Economic Resilience

Dr. Surajit Khalko
Associate Professor (Plant Pathology), Regional Research Station, Terai Zone,
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Global climate change, soil and water scarcity, soil degradation and increasing population are putting tremendous pressure on current agriculture and food production systems. These factors are threatening the Food and Nutritional security. Mismanagement of agro-industrial waste and rampant burning of crop residues has adverse impact. In order to maintain food and nutritional security, it is critical to improve waste management and recycling. Mushroom farming has the potential to alleviate poverty, hunger, malnutrition and also fulfil nutritional security as well as Ensure Economic Resilience

Mushrooms are highly nutritious food that are used all over the world as medicine, and dietary food. Mushrooms are grown on lignocellulose substrates such as crop residue, processed waste, saw dust wood chips etc. So, mushroom cultivation converts low–quality and low value waste materials to high–quality food. Mushroom farming has tremendous potential in ensuring Sustainability, Food security and Economic upliftment.

Mushroom Farming is Cultivation of edible fungi for food production which includes popular varieties like oyster, Paddy straw, Milky, Shiitake, and Button mushrooms. Mushroom farming is relevant in the context of impact of climate change, sustainability, food security and economic resilience. There is Growing global population demands sustainable food solutions and Mushroom farming has the potential to address food security and create economic opportunities. Mushrooms is a Nutrient-Rich Food Source containing high protein, vitamins, minerals, and antioxidants. It is having low in fat and calories, making them ideal for healthy diets. China leads in global mushroom production, followed by the USA and the Netherlands. Besides, Mushroom farming is growing in many developing countries including India

Nutritional value of Mushroom

Mushrooms are renowned as a valuable health food due to their impressive nutritional profile with low calories and rich in essential nutrients such as vegetable Proteins, Vitamins, Iron, Zinc, Fiber, Phosphorus and Potassium etc. As compared to cereals, mushrooms have relatively low calorie. The digestibility of mushroom protein from 71 to 90%, indicating that it can be efficiently utilized by the body. The protein in mushrooms consists of various amino acids, including all the essential amino acids required by adults. The carbohydrate content of mushroom is low (4-5% of fresh mushroom). Carbohydrate is present in the form of Chitin, Glycogen and Mannose, while starch is absent. So, it can be prescribed as excellent diet for diabetes patients. The fat content of mushroom is also very low (0.3%) in form of linoleic acid whereas, Cholesterol is absent. So, it is good food for heart patients. Mushrooms are rich in vitamins particularly riboflavin, nicotinic and folic acid. The presence of different minerals elements in mushroom increases the food value. Per 100 g fresh mushrooms contain 3-20 mg of Calcium,1-5 mg of Iron, 0.1- 1.2 mg of Copper, 0.1-0.5 mg Zinc, 18-70 mg of Phosphorus and 20-30 mg of Sulphur.

Medicinal Value of Mushroom:

Medicinal mushrooms are used as possible treatments for diseases. Research indicated that mushrooms have possible cardiovascular, anticancer, antiviral, antibacterial, antiparasitic, anti-inflammatory activities. Thus, many mushrooms have medicinal properties.

Sl No.	Name of medicinal Mushroom	Compound present	Medicinal Use
i.	*Ganoderma lucidum*	Ganoderic acid, Beta-glucan	Augments immune system, Liver protection, Antibiotic properties, Inhibits cholesterol synthesis
ii.	*Lentinula edodes*	Eritadenine and Lentinan	Lower down the cholesterol level, Anti-cancer agent
iii.	*Agaricus bisporus*	Lectins	Enhance insulin secretions
iv.	*Pleurotus sajor-caju*	Lovastatin	Lower the cholesterol level
v.	*Grifola frondosa*	Polysaccharide lectins	Increase insulin secretion, Decrease blood glucose
vi.	*Auricularia auricula*	Acidic polysaccharides	Decrease blood glucose
vii.	*Flammulina velutipes*	Ergothioneine Proflamin	Antioxidant, Anti-cancer activity
viii.	*Cordyceps sinensis (Caterpillar mushroom)-*	Polysaccharide components, Cordycepin	Increase the strength, Anti-aging properties, Anti-tumor effects, Anti-cancerous properties

Importance of Mushroom Farming considering the impact of Climate change on sustainability, food security and Economic resilience:

Food Security

Mushrooms are an excellent source of plant-based protein, vitamins (like D, B-complex), minerals (such as potassium, selenium, and iron), and antioxidants. Incorporating mushroom farming into local food systems - ensure a more stable food supply. Further, it can be grown in diverse conditions and urban spaces and even produced year-round, regardless of seasonal fluctuations or external climatic conditions. This consistent supply of food supports food security, even in challenging environment.

Economic Resilience

Mushroom farming provides an alternative income source for farmers which requires relatively low capital investment. It is a highly profitable venture for small-scale farmers and entrepreneurs. High-value crop with a relatively quick turnover time (harvest in 3–4 weeks). Furthermore, mushrooms having high market demand globally for both fresh and processed mushrooms.

Mushroom farming has the potential to generate employment. This is opportunity for farmers, harvesters, packers, and marketers of mushroom and it's processed products. Additionally, mushroom cultivation can create opportunities for women and youth. Thereby, facilitating employment in rural and underdeveloped areas.

Mushrooms can be cultivated using agricultural waste such as straw, sawdust etc which would otherwise go to waste. The spent mushroom substrate (the material left after harvesting) can be used as an excellent organic manure or animal feed, making the practice as part of a circular economy.

Beyond selling fresh mushrooms, there is potential for creating value-added products like dried mushrooms, mushroom powders, pickles and other processed foods. This increases the shelf life of the produce too. Mushroom processing or value addition opens new markets for mushroom farmers, enhancing income potential. On the other hand, diversification into medicinal mushroom products is also gaining popularity.

Environmental Sustainability of Mushroom Farming:

Mushroom farming is an efficient way to produce food with minimal land use and water consumption compared to traditional crops like grains or vegetables. Mushrooms can be cultivated on a small plot of land or in indoor environments, making them ideal for urban agriculture. It can be grown in small spaces, or unused agricultural land. The vertical farming potential makes mushrooms ideal for intensive farming systems.

Mushrooms contribute to climate resilience by improving soil health through the decomposition of organic waste. Furthermore, their cultivation emits fewer greenhouse gases compared to livestock farming or large-scale crop production.

Integration of mushroom farming with other agricultural practices, can enhance overall farm biodiversity and ecosystem health. Mushrooms require minimal chemicals, reducing the environmental impact of pesticides and fertilizers. Use of agricultural by-products (e.g., rice straw) for mushroom cultivation helps in recycling waste and mushroom farming does not deplete soil nutrients and can be grown without extensive land use.

Challenges in Mushroom Farming

i) Temperature and humidity control is essential for optimal growth, which may require specialized equipment
ii) Mushroom cultivation requires specific knowledge, such as composting techniques, spawn preparation, and pest management
iii) While demand for mushrooms is growing, farmers in remote areas may struggle with market access and distribution channel.

Overcoming Challenges of Mushroom Farming

i) Extension services and workshops can provide knowledge on best practices for mushroom cultivation
ii) Policies that promote small-scale farming and rural development can reduce entry barriers for new farmers
iii) Establishing co-operatives or local farmer networks to enhance market access and profitability
iv) Advancements in mushroom farming techniques, including automated systems and improved strains, can improve productivity.

The Future of Mushroom Farming:

Expanding Global Market: Rising awareness of the health benefits of mushrooms will continue to drive demand.

Integration with Modern Agriculture: Integration with circular economy practices by using agricultural waste as substrate for growing mushrooms

Technological Advances: Advances in controlled environment agriculture (CEA), such as hydroponic and aeroponic, mushroom farming, will further increase efficiency.

Mushroom farming offers an effective, low-impact solution for growing food in challenging environmental conditions. Mushroom is an affordable and Nutritious Food which can give Year-Round Production and having diverse Food Applications. Mushroom farming promotes entrepreneurship and provides new income streams for communities worldwide. It is having potential of job creation, income generation and opens new market by Value-Added products. With continued innovation and support, mushroom farming can play a pivotal role in global food systems and economic resilience. Hence, mushroom farming offers a promising solution for both food security and economic development. It supports sustainable practices and diversifies income sources for farmers, contributing to a more resilient and food-secure future. Governments, Organizations, Scientists and Farmers should support mushroom farming as a viable agricultural practice for a more resilient and food-secure future.

Techniques for detection of Plant viruses

Dr. Nandita Sahana,
Assistant professor, Department of Biochemistry
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Plant viruses are generally transmitted by insect vectors and cause considerable economic losses to crop plants. Plant viruses are a threat for sustainable agriculture because of the frequent emergence of new viral diseases. Mainly international trade, climate change, and the ability of viruses for rapid evolution attribute to the fast spread of plant viruses. Since there are no chemical control measures for viral diseases, the management strongly relies on a fast and accurate identification of the causal agent. The preliminary diagnosis is based on symptomology on the host plants. However, the specificity of diagnosis may be sacrificed if depended only on symptoms because several viruses may share similar characteristic symptoms. The molecular detection of plant viruses plays a crucial role because it provides accurate identification of the virus. Majorly DNA based and antibody-based detection systems are in use in plant virology.

1. **Immuno-based technique: Enzyme-linked immunosorbent assay (ELISA)**

A widely used conventional method for routine and large-scale testing of plant viruses. The protocol for enzyme-linked immunosorbent assay (ELISA) to detect plant viruses involves adding a trapping antibody, test antigen, and then an enzyme-conjugated antibody. The protocol also includes washing and developing the plates. There are different types of ELISA techniques that are commonly used for virus detection

- DAC-ELISA (Direct Antigen Coating Enzyme-Linked Immuno Sorbent Assay)
- DAS-ELISA (double antibody sandwich enzyme-linked immunosorbent assay)

A brief protocol for DAS ELISA is discussed below

The double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) is a plate-based technique for detecting plant viruses. The protocol for DAS-ELISA involves diluting antibodies, incubating, washing, and adding substrates.

Protocol

1. Dilute the antibody in coating buffer
2. Add the diluted antibody to each well of a microtiter plate
3. Incubate the plate at 37°C for 2–4 hours
4. Wash the plate with PBS-Tween
5. Extract the samples in extraction buffer
6. Add the extracted samples to duplicate wells
7. Incubate the plate overnight at 4°C
8. Wash the plate again
9. Add the enzyme conjugate to the plate
10. Incubate the plate at 37°C for 2–4 hours
11. Wash the plate again
12. Add the substrate to the plate
13. Incubate the plate at 37°C for 30–60 minutes

2. **Nucleic acid-based methods: PCR and RT-PCR**

Techniques such as polymerase chain reaction (PCR) and nucleic acid hybridization etc, are more sensitive and specific methods than serological methods for plant virus detection.

A overview of the protocol followed in PCR is given below

Principle:

Polymerase chain reaction (PCR) is technology molecular biology used to amplify a single copy or few copies of piece DNA exponentially in several magnitude, generating thousands to millions of copies of particular piece of DNA. PCR was discovered by Kary Mullis 1983 (received Nobel Prize Chemistry in 1993 for his work) and it has become now common and often indispensable technique used in molecular biology laboratory for variety of applications. These include molecular marker analysis, DNA cloning, sequencing, phylogenetic analyses, functional analyses of genes etc. the PCR technique is a useful means for detection of plant viruses from infected samples.

The technique relies on thermal cycling (cycles of repeated heating and cooling) of the reaction mixture for DNA melting and vitro enzymatic replication/amplification of the piece of DNA. A pair of primers (short oligonucleotides) having sequences complementary to the ends of the target DNA fragment and DNA polymerase (Taq polymerase) are necessary components to enable selective and repeated amplification. PCR applications employ heat-stable DNA polymerase, such as Taq polymerase (an enzyme originally isolated from the bacterium *Thermus aquaticus*). This DNA polymerase enzymatically assembles new DNA strand using the DNA building-blocks (dNTPs) based on the nucleotide sequence information present in the single stranded DNA as template. Primer is required for initiation of synthesis of new DNA strand.

The PCR technique uses thermal cycling, i.e., heating and cooling the PCR mix through a defined series of temperature steps. In the first step, two strands of the templet DNA double helix are physically separated by heating at high temperature (94°C), the step is called DNA melting. In the second step, the temperature is lowered down to allow primers to pair with their complementary sequences on the template strands. Selectivity of the PCR technique results from the use of primers that are complementary to the DNA fragment to be targeted for amplification. As PCR progresses, the DNA fragments generated serve as template for replication resulting into exponential amplification of the original DNA. PCR can be extensively modified to perform a wide array of applications in the basic, applied and genetic manipulation studies. PCR amplification is performed in thin wall tube. Components of the PCR mix in calculated amount (see Table) are pooled together and mixed well. Generally, master mix is prepared according to the number of reactions to be performed plus one extra reaction. Subsequently, desired volume (e.g. 20µl) of the master is dispensed into PCR tubes.

Solutions/reagents

Reaction-mix for PCR

S. No.	**PCR components**	**Stock conc.**	**Working conc.**	**Vol. of reagents**
1.	PCR Buffer (with 15mM MgCl2)	10x	1x	2 µl
2.	dNTPs	10mM	2mM	4 µl
3.	Forward primer (specific for the virus sequence)	10 µM	1 µM	2 µl
4.	Reverse primer (specific for the virus sequence)	10 µM	1 µM	2 µl
5.	Taq Polymerase	10U/ µl	1U	2 µl
6.	Mili Q H2o	-	-	6 µl
7.	Template DNA	25ng/ µl	50ng	2 µl
	TOTAL			20 µl

The PCR tubes containing the reaction mixture given a quick spin to collect the content in the bottom of the tubes. The PCR tubes are then placed in a thermal cycler (PCR machine) programmed according to the primers used the expected product size.

PCR program

S. NO.	Step	Temperature	Duration
1.	Denaturation	92-95°C	5 minutes
2.	Denaturation	94-95°C	1 minute
3.	Primer Annealing	45-65°C	1 minute
4.	Primer Extension	72°C	1 minute
5.	Final Extension	72°C	10 minutes
6.	Pause	4°C	∞ (infinity)

Protocol:

1. Add the reagents to an appropriately sized tube in the order provided in the table. (Select appropriate table for reaction setup: standard or readymix reagent.) For a large number of reactions, a mastermix without the template should be set up and aliquoted into reaction tubes. At the end, template should be added to appropriate tubes.
2. Mix gently by vortex to collect all components to the bottom of the tube.
3. The reactions are taken through series of 3 major cyclic reactions conducted in an automated, self-contained thermocycler machine. These three processes of the thermal cycling are repeated 20-40 times to produce lots of copies of the DNA sequence of interest.

- *Denaturation or stand separation* (92-95 °C): At this stage the reaction mix containing the template DNA and other ingredients is heated at 94-95 °C. during the process high temperature breaks the hydrogen bonds between the bases in two strands of template DNA and separates the two strands. This single strand act as template for the production of the new strands of DNA. It is important that the temperature is maintained at this stage for long enough to ensure that the DNA strands have separated completely. This step involves initial heating for 4-5 min and cyclic denaturation for 30s-1 min.
- *Annealing of primers* (45-65 °C): During this stage the reaction is cooled to 45-65 °C. This enables the primers to attach to a specific location on the single-stranded template DNA by way of hydrogen bonding (the exact temperature depends on the melting temperature of the primers you are using). Primers serve as the starting point for DNA synthesis. The polymerase enzyme can only add DNA bases to a double strand of DNA. Only once the primer has bound can the polymerase enzyme attach and start making the new complementary strand of DNA from the loose DNA bases. The two separated strands of DNA are complementary and run in opposite directions (from one end - the 5' end-to the other - the 3' end); as a result, there are two primers a forward primer and a reverse primer. This step usually takes about 45 seconds to 1 minute.
- *Extension/elongation stage* (72-80 °C): During this final step, the heat is increased to 72 °C to enable the new DNA to be made by Taq DNA polymerase enzyme which adds DNA bases. It attaches to the primer and then adds DNA bases to the single strand one-by-one in the 5' to 3' direction. The result is a brand-new strand of DNA and a double-stranded molecule of DNA.

4. The amplified DNA can be evaluated by agarose gel electrophoresis and subsequent ethidium bromide staining.

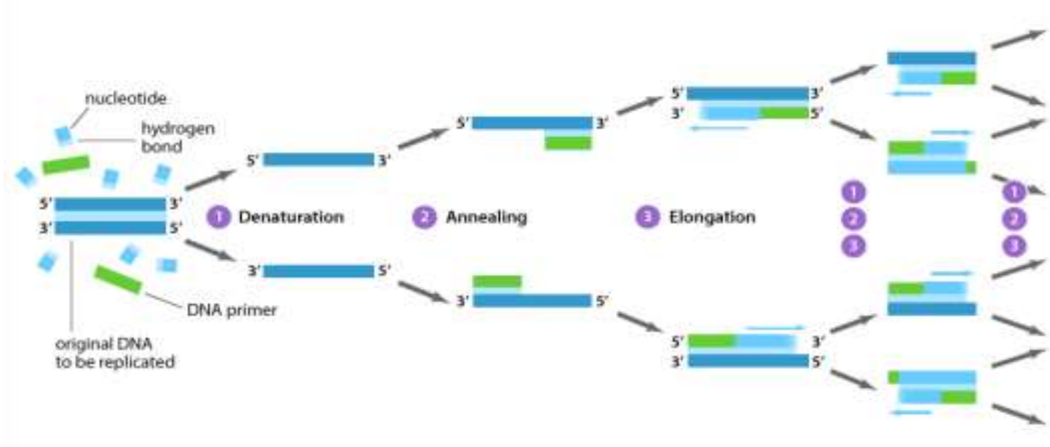


Figure: Schematic diagram of polymerase Chain Reaction

1 Denaturation at 92-96°C
2 Annealing at 55°C
3 Elongation at 72°C

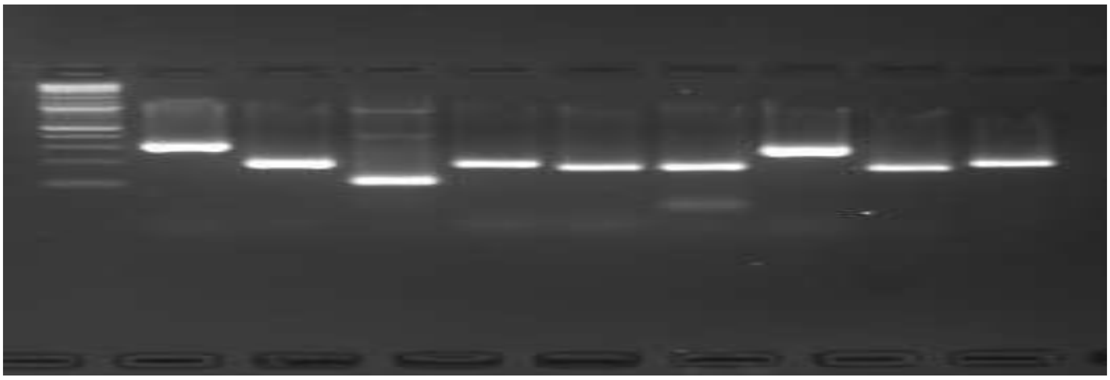


Figure: Agarose gel (3%) electrophoresis to visualize the amplification product.

M = DNA ladder; 1, 2, 3 = amplified product which depicts the desirable fragments of the viral DNA and ensure the presence of the virus in the given samples.

Plant tissue culture techniques for mass multiplication of quality planting material

Dr. Moumita Chakraborty
Asst. Professor, Dept. Of Genetics and Plant Breeding
Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Plant tissue culture is fundamentally the cultivation of plant organ, tissue or cell in test tubes on artificial media. This technique of plant cell & tissue culture is also called *in-vitro* technique to ensure the growth and development of explants. Micropropagation is the application of tissue culture technique to the propagation of plants starting with very small parts called explants. It is also necessary to provide suitable nutrient and proper atmospheric pressure for culturing. Mass multiplication of the crop can be achieved by the micropropagation of meristematic cell or organ culture in aseptic condition in the laboratory. For mass multiplication the following steps are necessary:
Proper identification of explant
Media Preparation
Inoculation and culture

Explant:

Explant is any excised tissue or plant parts such as leaf tissue, stem parts, cotyledon, hypocotyls, root parts, etc. The primary purpose of explant culturing is to induce callus cultures or to regenerate whole plantlets directly from it without the formation of callus. Different kinds of explants were used in micropropagation. For example, in case of orchids, shoot tip (*Anacamptis pyramidalis, Aranthera, Calanthe, Dendrobium),* axillary bud (*Aranda, Brassocattleya, Cattleya, Laelia)*, inflorescence segment (*Aranda, Ascofinetia, Neostylis, Vascostylis),* lateral bud (*Cattleya, Rhynocostylis gigantean),* leaf base (*Cattleya)*, leaf tip (*Cattleya, Epidendrum),* shoot tip (*Cymbidium, Dendrobium, Odontioda, Odontonia),* nodal segment (*Dendrobium),* flower stalk segment (*Dendrobium, Phalaenopsis)* and root tips (*Neottia, Vanilla)* are being used in micropropagation. In case of Banana sword sucker is used as explant.

Media Preparation:

The explants are cultured in the artificial condition. Therefore, nutrients are supplied artificially according to the medium formulated by several workers. The main objective of medium preparation is to culture the cell, tissue and organ in vitro. For different crops the requirement of nutrients are different. The concentration of different media also differs depending of explant. Universally most popular media is MS media.
The nutrient composition of MS media is as follows:

No	**Elements**	**Constituents**	**Milligram/liter**
1	Macronutrients	NH4NO3 KNO3 CaCl22H2O MgSO4 .7H2O KH2PO4	1650.50 1900.00 440.00 180.69 170.00
2	Micronutrients	MnSO4 4H2O ZnSO4 7H2O H3BO4 Nal Na2MoO4 .2H2O CaCl2.6H2O CuSO4.7H2O	16.19 8.60 6.20 0.83 0.25 0.025 0.025
3	Irons	FeSO47H2O Na2EDTA.2H2O	 37.30

4	Vitamins	Myoinositol Glycine Nicotinic Acid Pyridoxine HCL Thiamine HCL	100.00 2.00 0.50 0.50 2.00
5	Sugar (Energy source)	Sucrose	30000
6	Solidifying Agent	Agar	800

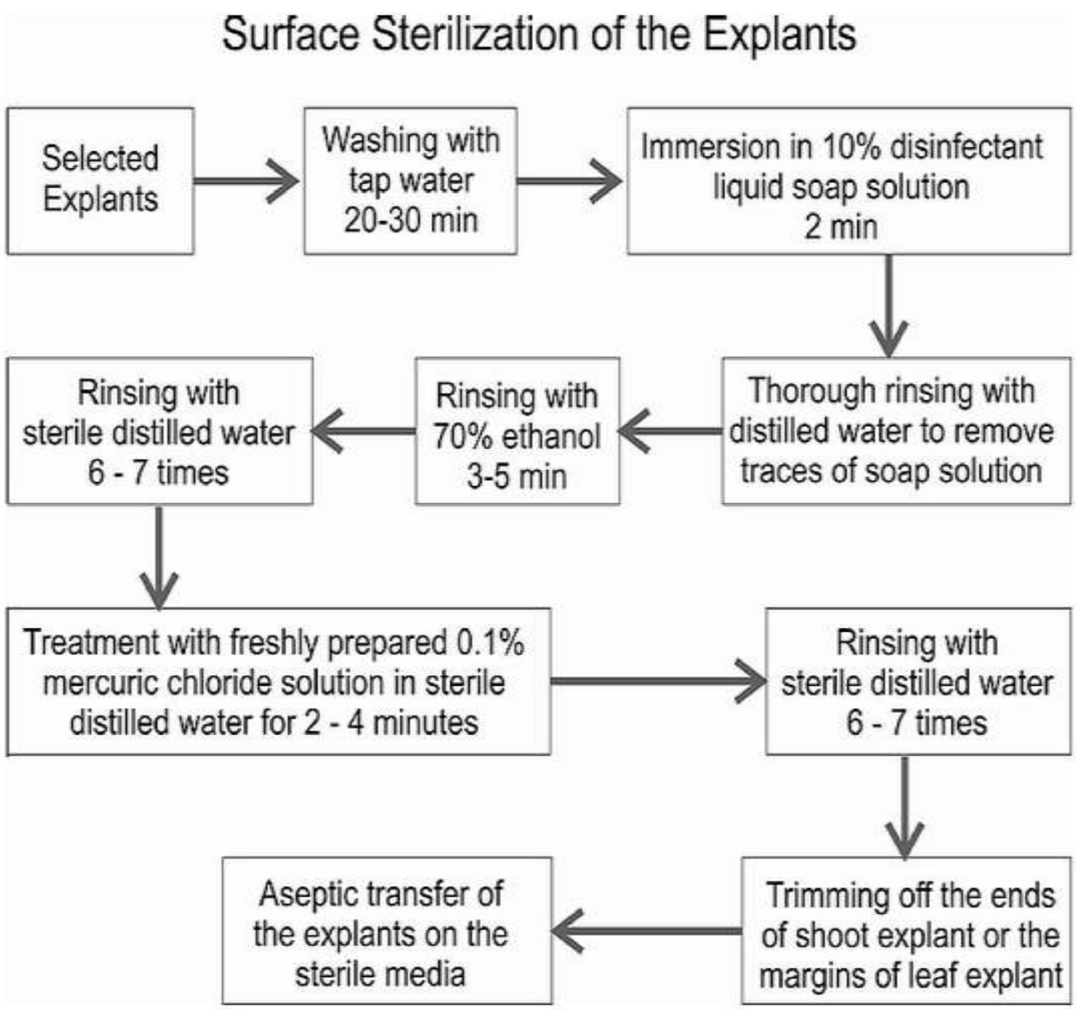
Along with these nutrient components the plant growth regulators or plant hormones are applied. The mostly used plant hormones are BAP, Kinetin, IAA, NAA, IBA, 2,4-D etc.

Mass Multiplication

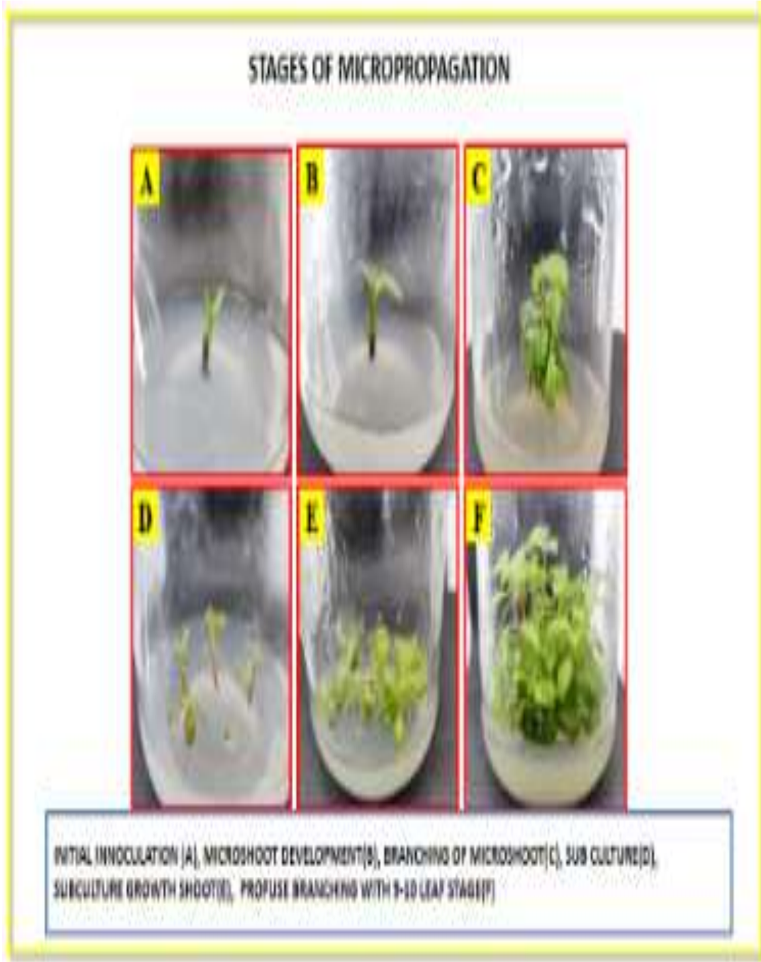
Plant production through organogenesis can be achieved by two modes: (i) Organogenesis through callus formation with de novo origin; and (ii) Emergence of adventitious organs directly from the explant. By varying the growth regulator levels, i.e. lowering the auxin and increasing the cytokinin concentration is traditionally performed to induce shoots from the explant. The next phase involves the induction of roots from the shoots developed. IAA or IBA auxins, either alone or in combination with a low concentration of cytokinin, are important in the induction of root primordia. Thus organ formation is determined by quantitative interaction, i.e. ratios rather than absolute concentrations of substances participating in growth and development. In this exercise, the procedure of organogenesis through both ways has been discussed.

List of materials required for mass multiplication (sterile items)

Instruments and glass goods	**Measurement**	**Use**
Culture tube	150× 25 mm	For keeping the initial culture
Jam bottle		For growing the culture
Glass Petri dish	90 mm	For explant sterilization under laminar airflow cabinet
Beaker	100 ml	For surface sterilization
Forceps	8”, 12”	For holding the explant For inoculation
Surgical scalpel	18cm	For dissection of the living material under laminar air flow cabinet
Arrow headed sharp needle		For dissecting out the unwanted materials
scissors	12 cm	For cutting root and shoot in aseptic condition


Surface Sterilization of the Explants
Selected Explants
Washing with tap water 20-30 min
Immersion in 10% disinfectant liquid soap solution 2 min
Thorough rinsing with distilled water to remove traces of soap solution
Rinsing with 70% ethanol 3-5 min
Rinsing with sterile distilled water 6 - 7 times
Treatment with freshly prepared 0.1% mercuric chloride solution in sterile distilled water for 2 - 4 minutes
Rinsing with sterile distilled water 6 - 7 times
Trimming off the ends of shoot explant or the margins of leaf explant
Aseptic transfer of the explants on the sterile media

Collection of explants (A), Cutting and Packing of sample in Ice box (B), Treatment of plant sample with fungicide, antibiotics etc. (C), Inoculations of sample with media & diff conc. of hormones (D), Proliferation of shoot tip in media (E), Growing of node and internodes in media (F).



Steps for micro-propagation through direct organogenesis

Explant

⬇

Surface sterilization

⬇

Inoculation

⬇

Swelling at the base of explant

⬇

Subculture

⬇

development of In-vitro plantlet and rooting

⬇

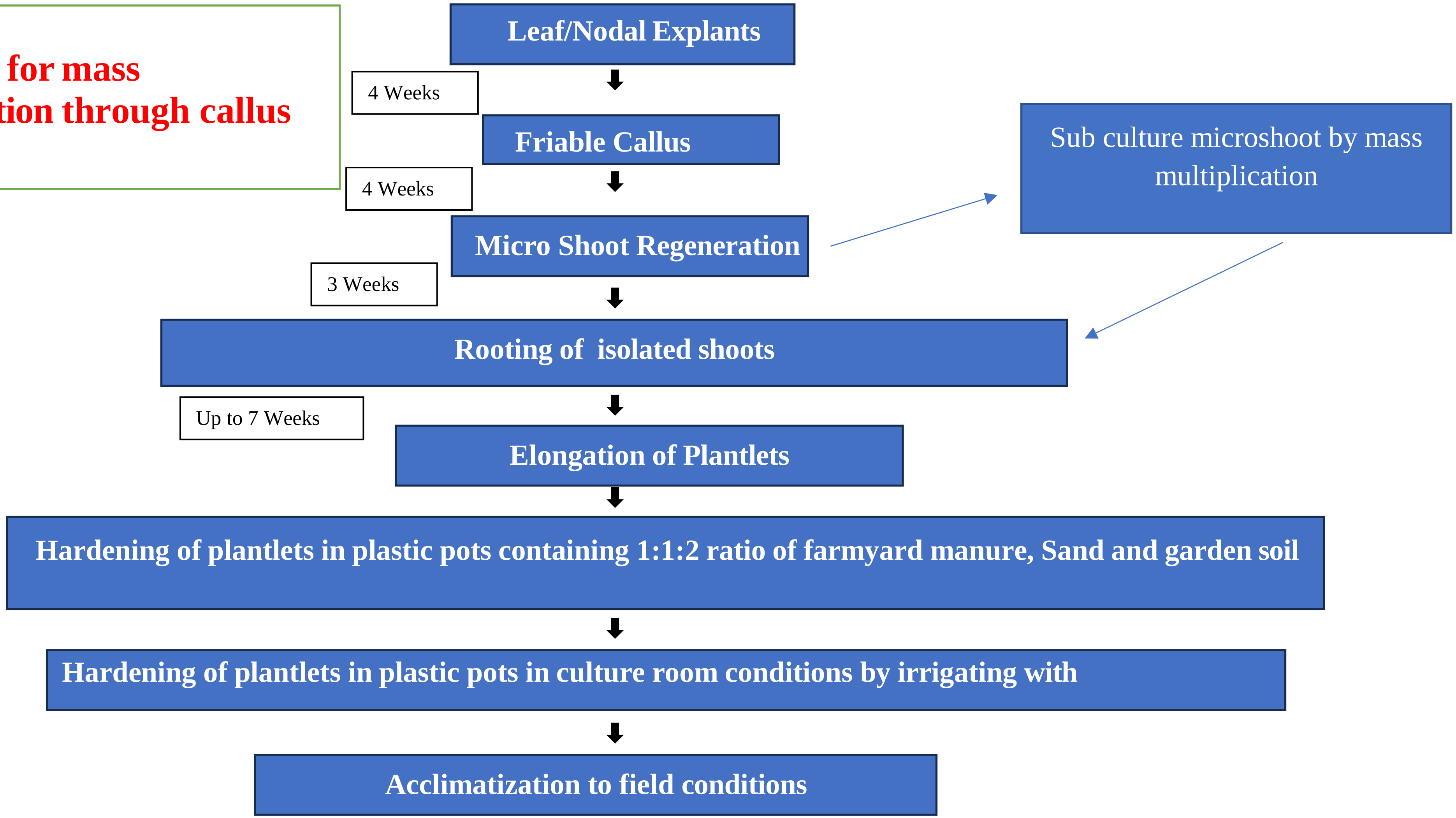
Hardening of plantlets in plastic pots containing 1:1:2 ratio of farmyard manure, Sand and garden soil

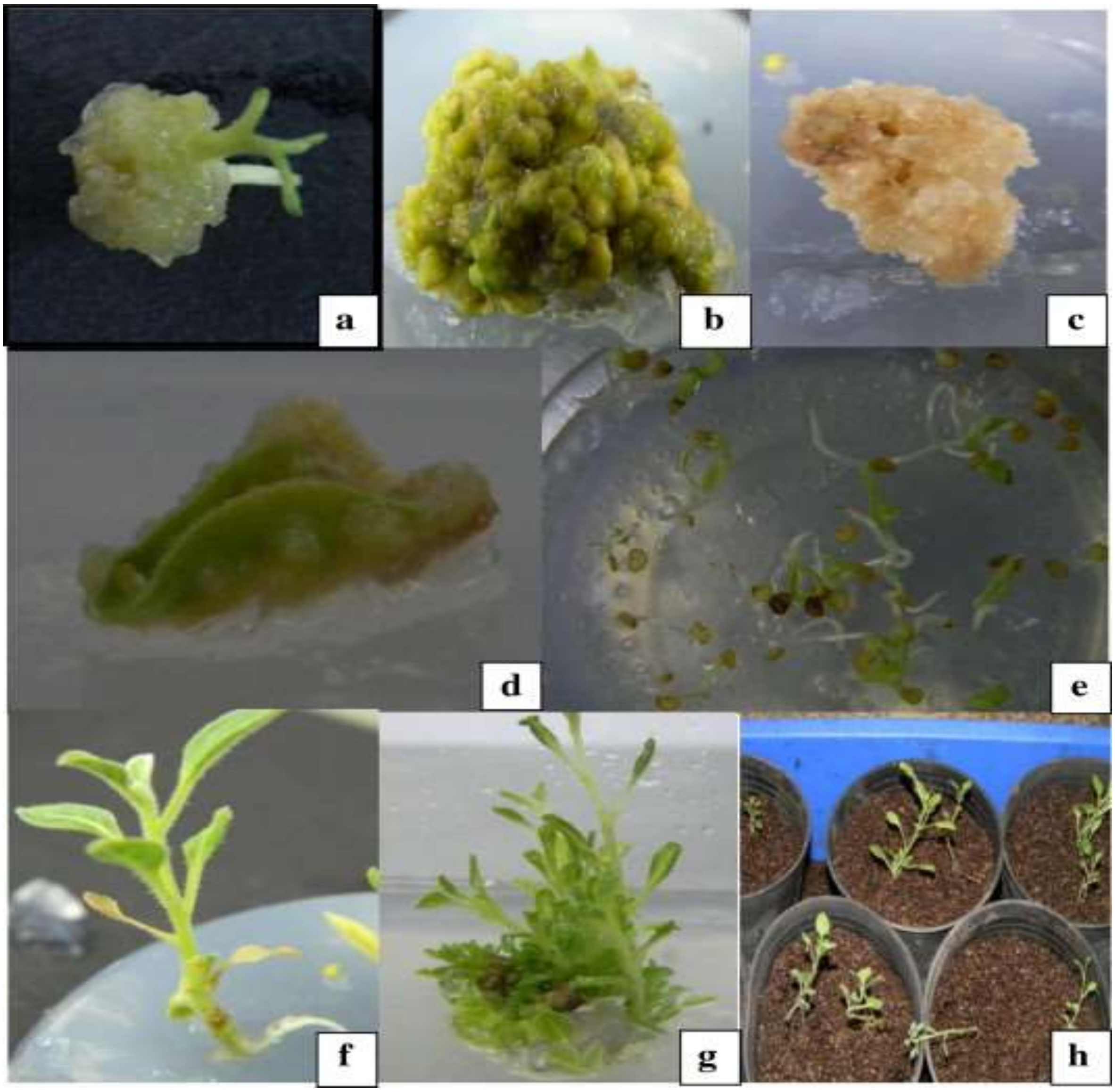
⬇

Fully hardened plant

⬇

Steps for mass multiplication through callus

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