

TRENDS IN AGRICULTURE AND TECHNOLOGY

Editors

**K. Vignesh
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Edited Book

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PREFACE

Agriculture has always been at the heart of human civilization, shaping societies, economies, and the environment. Over the centuries, this sector has transformed from subsistence farming to a technology-driven enterprise, addressing the challenges of feeding a growing global population while balancing the need for sustainability and environmental conservation.

This book, *Trends in Agriculture Technology*, explores the dynamic evolution of agricultural practices and innovations that are redefining how we cultivate, produce, and distribute food. From precision farming and artificial intelligence to biotechnology and renewable energy systems, the advancements in agricultural technology are not just tools—they are solutions to some of humanity's most pressing challenges.

The chapters of this book are designed to provide a comprehensive view of the latest trends, blending insights from cutting-edge research, case studies, and industry applications. We delve into areas such as digital agriculture, robotics, gene editing, climate-smart farming, and the growing role of data analytics. By doing so, we aim to showcase how these trends are creating smarter, more efficient, and resilient food systems.

This book is written for a broad audience, including agricultural professionals, policymakers, researchers, educators, and students. It seeks to inform and inspire readers about the transformative power of technology in agriculture and to spark new ideas and discussions about the future of this critical sector.

The journey of compiling this book has been one of learning and discovery. We are grateful to the researchers, innovators, and practitioners who have shared their knowledge and experiences to enrich this content. Their contributions highlight the collaborative nature of agricultural advancements and the importance of interdisciplinary approaches to tackling challenges in food security and sustainability.

We hope this book serves as a valuable resource and a source of inspiration for those invested in the future of agriculture. Let us move forward together in creating a world where technology empowers farmers, protects the environment, and ensures food security for generations to come.

- Editors

ABOUT THE BOOK

Trends in Agriculture Technology delves into the transformative role of technology in shaping the future of agriculture. With the global demand for food production increasing amidst challenges such as climate change, resource scarcity, and environmental sustainability, this book explores cutting-edge solutions that are driving agricultural innovation and reshaping farming practices worldwide.

The book is structured to provide readers with a holistic understanding of modern agricultural trends, covering a wide range of topics such as Precision Agriculture, Artificial Intelligence and Machine Learning, Biotechnology and Genetic Engineering, Climate-Smart Agriculture, Blockchain in Agriculture, Sustainable Practices and Regenerative Agriculture.

This book serves as an essential guide for agricultural professionals, researchers, students, policymakers, and anyone interested in the future of farming. Combining real-world examples, case studies, and expert insights, *Trends in Agriculture Technology* not only highlights current advancements but also envisions the potential of emerging technologies to address tomorrow's challenges.

By bridging the gap between traditional farming practices and cutting-edge innovations, this book inspires readers to think critically about the future of agriculture and the role technology will play in creating sustainable, efficient, and resilient food systems for the growing global population.

- *Editors*

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CHAPTER - 1

AGRI-CARBON MARKETS: BRIDGING AGRICULTURE AND CLIMATE SUSTAINABILITY THROUGH AN INNOVATION

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Introduction

Intervention of technologies with agriculture systems has revolutionizing the farm sector and agriculture landscape. Agri-carbon markets is one of such developments that has been gaining prominence in the recent years. Agri-carbon market innovation helps in hitting two birds with one stone, as it incentivizes sustainable farm practices besides it reduces carbon emissions released by industries. Agri-carbon markets sustain by selling and purchasing of carbon credits. Carbon credits is like earning credits by offsetting carbon from atmosphere back into the soil or into anything that acts like carbon sink. With the implementation of Agri-carbon markets, farmers and manufacturing companies gets the dual role of protecting climate along with initiating sustainable practices in farming which cuts off the usage of harmful chemicals and pesticides during cultivation. This in turn protect the soil health by maintaining quality carbon content along with balanced nutrients. If implemented properly, it paves way to realize India's journey of Net-zero carbon emissions by 2070. To realize the carbon market in practicality we need to understand how it works besides, government institutions and related departments should work on developing credible guidelines, rules and regulations to trade carbon credit. The challenges faced by stakeholders like small and medium farmers, and small enterprises find it difficult and expensive to trade in carbon credits as it needs training, capacity building, exclusion of small farm land, and for small enterprises it's not feasible as their GHG

emissions are far less when compared to big enterprises. If there are discrepancies in carbon trading it leads to unsustainable fluctuation of carbon prices. Thus, it is needed to focus research on developing regional and stakeholder-based models to trade in Agri-carbon credits.

GHG emissions around the world and India

According to Emissions Gap Report (2024), Global GHG emissions rose to a new high of 57 gigatons of CO₂ equivalent (CO₂e) in 2023 i.e., 1.3 per cent increase from 2022. India stands at third place in total GHG emissions with 4,140 MtCO₂e compared to China (1st) & US (2nd). India's GHG emissions levelled up by 6.1 per cent in 2023, contributing to 8 per cent of the global total although the country's historical contribution to global CO₂ emissions stands at only 3 per cent.

India's Fourth Biennial Update Report (BUR-4) stated that country's GHG emissions decreased by 7.93 per cent in 2020 when compared to 2019. Between 2005 and 2020, India's Emission Intensity of Gross Domestic Product (GDP) reduced by 36 per cent. It also reported that the agriculture sector contributed to 13.72 per cent of overall emissions, just after energy sector (75.66 per cent), while other sectors like Industrial Processes and Product Use (8.06 per cent), and Waste (2.56 per cent) contributes lowest.

Special report by Intergovernmental Panel on Climate Change (IPCC) stated that the world needs to cut its annual GHG emissions by at least 43 per cent from 2019 levels by 2030 to keep hopes alive of achieving the 1.5-degree goal, though the 1.5-degree mark has been started crossing since 2023. This shows the 1.5-degrees temperature goal set can be technically possible when government institutions and stakeholders like manufacturers and consumers take collaborative and calculated steps in climate conservation.

Current statistics related to India

Recent statistics reveals the diminishing soil arable qualities, where soil organic carbon has reduced from national average of 2.4 per cent in 1947 to merely 0.4 per cent today. Thanks to the continuous addition of chemical fertilizers for the past seven decades which led to the below threshold level of 1.5 per cent of soil carbon. This has indirectly affected nation's food security along with costing the huge loss of Rs 47.7 lakh crore over the last seven decades (\$564 billion), accounting to Rs 68,243 crore per annum (\$8.06 billion) in lost carbon value.

India's Forest and Tree Cover, along with other land use, sequestered approximately 522 MtCO_{2e} to reducing 22 per cent of the country's total CO_{2e} emissions in 2020. During 2005 to 2021, additional carbon sink of 2.29 billion tonnes of CO₂ created through forest and tree cover. As of October 2024, share of non-fossil sources in the installed Electricity Generation capacity was 46.52 per cent.

What are Carbon credits?

In a lay man term, Carbon credit is how much of the carbon has been stored back into the soil. Suppose if a farmer offset 1000 tons of atmospheric CO₂ into the sink (soil in this case), by practicing sustainable farming, then a company appreciates their good work of offsetting the emitted carbon back into the soil, by giving them carbon stars. The carbon stars basically are carbon credits. The company here is buying the carbon credits from the farmer by supporting them for the sustainable farm practices. This initiative supports sustainable agricultural practice along with indirect cause that reduces GHG emissions.

Indian scenario on Carbon trading

The Government of India launched the Carbon Credit Trading Scheme (CCTS) on June 28, 2023, under the Energy Conservation Act, 2001 (Amendment, 2022), with the aim of establishing India's carbon market (ICM). CCTS works on identifying the sectors to be included in the trading scheme, developing emission targets for the sectors to be included and ensuring the stability of the carbon price through mechanisms. National Steering Committee for Indian Carbon Market (NSC-ICM) has been formed under CCTS to supervise the Indian Carbon Market (ICM).

Mechanisms in carbon market:

Under compliance mechanism, a company based on its GHGs emissions needs to be mandatorily purchase carbon credits to comply with established emission caps under international and governmental agreement to combat climate crisis. Under this, NSC-ICM has finalized nine sectors under CCTS, which are Aluminium, Chlor Alkali, Cement, Fertiliser, Iron & Steel, Pulp & Paper, Petrochemicals, Petroleum refinery, and textile.

Under the offset mechanism, NSC-ICM has approved ten sectors, which include energy, industries, waste handling & disposal, agriculture, forestry, transport, construction, fugitive emissions, and solvent use. This mechanism is voluntarily based where NGOs and small industries can

participate voluntarily to offset the emissions and support the good cause as corporate social responsibility (CSR).

AGRI-CARBON MARKETS

In the agriculture sector, carbon credits can be purchased from projects or initiatives that implement sustainable practices to reduce GHG emissions or enhance carbon sequestration. Agri-carbon credits can be generated in various areas within agriculture sector are discussed below.

S. No.	Sustainable practices	Details
1.	No-till or reduced-till farming	As these practices reduce soil disturbance, helping the soil store more carbon, which offset carbon
2.	Cover cropping	Planting cover crops (like legumes or grasses) between main crops helps capture carbon and improve soil health
3.	Crop rotation	Rotating crops enhances soil carbon sequestration and reduces the need for synthetic fertilizers which helps in reducing emissions due to reduce in manufacture of chemical fertilizers
4.	Organic farming	Farm practices like using organic fertilizers (e.g., compost, manure) or biochar increases soil organic carbon levels
5.	Agroforestry	Integrating trees or shrubs into farmland captures carbon both in trees and soil
6.	Reforestation	Restoring degraded lands by planting vegetation generates carbon credits
7.	Manure management	Installing systems like biogas digesters to capture methane from manure generates carbon credits

8.	Feed additives	Using special feed additives can reduce methane emissions from livestock digestion (enteric fermentation)
9.	Alternate wetting and drying in rice cultivation	It reduces continuous flooding in rice paddies lowers methane emissions
10.	Efficient irrigation systems	Techniques like drip or sprinkler irrigation reduce water use and indirectly cut emissions
11.	Solar farming	Installing solar panels or wind turbines to power farms can generate carbon credits
12.	Biomass production plant	Using biomass energy (e.g., crop residues) instead of fossil fuels also qualifies for carbon credits
13.	Composting agricultural waste	Prevents methane emissions from organic waste which is suitable to offset for carbon credits
14.	Avoiding open burning of crop residues	Reduces direct GHG emissions and qualifies for carbon credits

Where can Carbon credits be purchased?

By investing in agriculture-based carbon credits, buyers not only offset emissions but also support sustainable farming, improved livelihoods for farmers, and healthier ecosystems. But real difficulty involves in how and where these can be purchased, this is discussed in the following sub-heading.

1. **Local carbon markets:** India is establishing its CCTS, which will eventually include agriculture-related credits. State-Level Initiatives, some states may promote agriculture-based carbon projects (e.g., agroforestry or water management).

2. **Voluntary carbon markets:** Gold Standard and Verified Carbon Standard (VCS) are the Internationally recognized certification bodies offer carbon credits from agriculture projects. Also, platforms like South Pole, Climate Impact Partners, or Terrapass facilitate purchases of credits from agricultural initiatives.
3. **Private project developers:** Companies like Grow Indigo, an Indian initiative, focuses on soil carbon sequestration projects with farmers often generates carbon credits for scale.
4. **Collaborative initiatives:** FAO's carbon program, supports sustainable agriculture projects globally. ICRAF (World Agroforestry Centre), runs agroforestry projects that generate carbon credits.

While calculation and measurement of carbon credits are standardized processes globally, including in India, to ensure credibility and consistency. These methods are based on quantifying greenhouse gas (GHG) reductions or carbon sequestration achieved by a project.

How carbon credits are measured?

The real question is how these can be measured. Consistent measurement can be the next challenge while implementing it but with appropriate quantification rules and guidelines internationally or nationally can improve the credibility of carbon credits.

One carbon credit represents 1 metric ton of CO₂ (or CO₂ equivalent gases) reduced, avoided, or removed from the atmosphere. The measurement process typically involves the following steps:

1. **Baseline Emissions:** The first step is by calculating the emissions that would have occurred without the project (the baseline). Example: How much CO₂ would a farm emit under conventional farming practices?
2. **Project Emissions:** Emissions are then calculated after implementing the project. Example: Reduced methane emissions after adopting alternate wetting and drying in rice cultivation.
3. **Net Reduction:** The difference between baseline emissions and project emissions is the net reduction, which determines the number of carbon credits generated. Formula: Net Reduction=Baseline Emissions–Project Emissions.

Standards and Protocols for Measurement

Globally, there are recognized protocols for calculating and verifying carbon credits like,

1. **International Standards:** Verified Carbon Standard (VCS) by Verra is common for forestry, agriculture, and renewable energy projects. Gold Standard focuses on high-impact projects like sustainable agriculture and renewable energy. Clean Development Mechanism (CDM) is followed under the Kyoto Protocol, used for projects in developing countries.
2. **National Standards in India:** Bureau of Energy Efficiency (BEE), oversees energy efficiency projects in India under schemes like PAT (Perform, Achieve, and Trade). CCTS framework under India's CCTS will develop guidelines and methodologies tailored to the Indian context, including agriculture.

Tools and Methodologies

Specified tools were developed globally like cool farm tool, COMET-Farm help and IPCC Guidelines provides detailed methodologies for calculating emissions and sequestration. Indian Network for Climate Change Assessment (INCCA) along with Soil health monitoring tools provides data and methodologies tailored to India's conditions.

Verification and certification

Before carbon credits can be sold, they must be verified and certified by third-party organizations to ensure they meet required standards. Verifiers inspect the project and verify emission reductions. Credits are then issued and registered on platforms like Verra or India's forthcoming CCTS registry.

Factors that affect calculation

Certain factors are listed which affects calculation and the care should be taken while measuring it. Those factors are type of activities like renewable energy, forestry, agriculture, or industrial efficiency have different methodologies; project scale like small projects (e.g., individual farmers) vs. large-scale projects (e.g., solar farms) get affected by quantification methodology; leakage of carbon credits, thus it is also significant to ensure the project doesn't shift emissions elsewhere (e.g., deforestation in one area leads to deforestation nearby).

Technological innovations enabling Agri-carbon markets

To carry out trading in Agri-carbon markets, there is need for various technological interventions at different phases some of which is discussed below.

1. **Precision agriculture:** Technologies like use of IoT, drones, and AI for efficient resource use and quantification of carbon sequestration in soils and crops.
2. **Soil carbon monitoring technologies:** Remote sensing and satellite-based carbon flux measurements along with ground-based sensors for checking soil organic carbon levels.
3. **Blockchain and digital platforms:** Use of transparent and traceable carbon trading systems. Example: Blockchain-based platforms for carbon credits.
4. **Data analytics and modelling:** Innovations like predictive models for estimating carbon offset potential and role of big data in monitoring and verification is significant in estimating carbon for carbon trading.

Challenges that follow during and after its implementation

Though there is uniqueness followed in this Agri-carbon market innovation, its not a cake walk to observe the positive impacts that is hindered by various barriers. The possible challenges that follow is discussed below.

Policy and regulatory challenges	
1. Lack of clear guidelines	Ambiguity in how emissions caps, baselines, and credit verification will be established can delay implementation
2. Coordination issues	Multiple agencies (like MoEFCC and MoP) involved might create overlaps or inefficiencies in decision-making
3. Legal enforcement	Ensuring compliance by large industries requires strong monitoring and penalties for non-compliance

Market functioning	
4. Price volatility	The price of carbon credits could fluctuate, making it difficult for industries to plan their investments or purchases
5. Credit oversupply	If too many credits are available, prices may drop, reducing incentives for emission reductions
6. Liquidity issues	Limited participants or trading volumes in the early stages could hinder the market's growth
Verification and credibility	
7. Monitoring emission reductions	To ensure that projects genuinely reduce emissions and are not "greenwashing" can be a challenge
8. Quality of credits	Standardizing the measurement, reporting, and verification (MRV) of carbon credits is essential to maintain trust
9. Double counting	Preventing the same credit from being sold or claimed multiple times requires robust tracking systems
Stakeholder participation	
10. Lack of awareness	Many industries and offset project developers might not fully understand the benefits or processes of participating in carbon markets
11. Inclusion of small industries	Small and medium enterprises/farms (SMEs) may face barriers due to limited technical or financial resources
12. Farmer and community involvement	Projects like forestry or agriculture require significant outreach and capacity-building among rural stakeholders
Technological and financial barriers	

13. High initial costs	Setting up offset projects (like renewable energy or carbon capture) can require substantial investment
14. Technology gaps	Limited access to advanced carbon reduction technologies could hinder progress in some sectors
15. Access to finance	Smaller entities might struggle to secure funding for emission-reducing initiatives
Global and competitive pressures	
16. International standards	India's market must align with global frameworks (like Article 6 of the Paris Agreement) to enable cross-border trade
17. Carbon border taxes	Countries like the EU are introducing carbon border adjustment mechanisms (CBAM), which could affect Indian exports if domestic carbon prices are too low
Social and environmental risks	
18. Equity concerns	If the market benefits only large industries, smaller stakeholders and rural communities may feel excluded
19. Impact on biodiversity	Overemphasis on carbon-sequestering projects (like monoculture plantations) could harm ecosystems
20. Conflict of interests	Balancing industrial growth with environmental goals requires careful planning to avoid resistance from industries

Strategies to overcome challenges

As the India's CCTS is being worked on these issues and expected to address it with region-specific methodologies and support mechanisms for small-scale projects. Indian institutions, departments and stakeholders of carbon markets thus needed to work in collaboration to focus on,

- Establishing clear and transparent policy frameworks.
- Investing into robust MRV systems and digital platforms to track credits.
- Creating awareness by the use of campaigns to educate stakeholders, including SMEs and rural communities.
- Ensuring equitable access to finance and technology for smaller players.
- Encouraging collaboration with global carbon markets for knowledge exchange and best practices.

With proactive measures, these challenges can be addressed, ensuring that the Agri-carbon market contributes effectively to India's climate goals.

Conclusion

This chapter explores the emerging concept of Agri-carbon markets as a transformative approach to integrating sustainability into agricultural practices. It highlights the role of technology, policy frameworks, and market incentives in creating a sustainable agricultural economy that contributes to carbon neutrality. Agri-carbon markets are in alignment with global sustainability goals (e.g., SDG 13: Climate Action). Leveraging Agri-carbon markets to achieve net-zero emissions targets by 2070 is promising platform for developing nations like India. Call for collaborative action to address challenges and scale opportunities should be thrust upon so that there would not be any potential hinderances while implementing it. This innovation helps in envisioning for a sustainable climate and carbon-neutral agricultural future.

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CHAPTER - 2

FROM CONCEPTS TO APPLICATIONS: THE FUNDAMENTALS OF MONITORING AND EVALUATION

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Abstract

The chapter discusses the critical role monitoring and evaluation play in sustainable agricultural development. M&E plays an important role in efforts toward increasing efficiency, accountability and impact assessment of projects. It therefore looks at foundational concepts such as measuring progress through indicators and assessing if objectives were achieved in a project. The other advanced frameworks discussed are the Kirkpatrick/Philip and Bennett Hierarchy models. Along with participatory approaches to promote inclusivity and systemic innovation, the chapter integrates theoretical principles with practical applications that provide valuable insights into designing and implementing effective M&E systems for sustainable agricultural initiatives.

Keywords: *monitoring, evaluation. Kirkpatrick, Bennet hierarchy*

Introduction

Agriculture has a crucial role to play in meeting the objectives of sustainable development goals. However, its development meets complex social, environmental, economic and international challenges. Sustainable agricultural development needs to be properly planned in research, policy, institutions and trade. Development planning refers to the process undertaken by governments and organizations to attain human welfare through strategic investments in projects-structured activities with objectives set in definite time frames. These projects result in short-term and long-term benefits, but the resources are limited, requiring optimal

allocation for maximal utility. Public investments generally involve economic, environmental and social impacts because human well-being depends on the environment's health. Resource use must be efficient because the resources are societal, or they come from society (Singh, 2022).

Monitoring, evaluation and impact assessment are important components of effective project management to ensure that a project progresses according to the plan and attains the desired impacts (Singh, 2022). In recent times, Monitoring and Evaluation, a new discipline, has gained significant attention from researchers and professionals as a branch of knowledge that has been practiced for a long time.

Globalization has increased its importance in the era of public administration as a result of the gradual evolution of civil society (Ojok, 2016). M & E has become a significant tool measure for delivering services. It provides services for inputs and also for the livelihood improvement of people (Sithomola and Auriacombe, 2019). Its importance has increased in recent times from organizations and other firms in the auditing sectors (Abrahams, 2015). It has been recently advocated by researchers that there is an increased need for the efficient monitoring and evaluation of programs, projects and policies (Kusek and Rist, 2004). Several studies necessitate the important role that monitoring and evaluation plays for project performance (Omar, 2022). Monitoring and evaluation has a crucial influence on the public sector through democratization for community participation, de-bureaucratization ensuring project accountability, organizational learning through transparency and better decision-making (Nelson, 2016).

Monitoring and evaluation are a continuing process to collect data regarding the results of efforts as compared with established goals and objectives; they involve tracking any other unexpected positive or negative consequences that may come out from project activities. It plays roles in a project cycle making it integral for effective management practice. It emphasizes the track of how things are proceeding and the performance to have a real insight at any point for decision-making of the project. On the other hand, evaluation is more holistic as it reviews experiences and analyses data to determine how successfully the objectives have been met.

Monitoring: According to the World Bank, it is a reporting function that is ongoing as it will provide management and other stakeholders with early

signs of progress toward achieving results. Monitoring collects information frequently to enable managers to make decisions in due time and as a basis for evaluation and learning. Inputs, work schedules, outputs and actions of the review are being aligned with the project plan.

This management function starts at a project's inception and continues from the time it is implemented until its completion. A plan must be operational for proper monitoring. Techniques include reporting review, assessing staff, collecting feedback from field visits, interviews, key informants and engaging the beneficiaries and the staff in participatory evaluations (Singh, 2022).

Evaluation: It aims at establishing whether the set objectives of a project have been achieved and to what extent. The project proposal should include expected impacts in terms of nature, scope and the target regions or groups. Ex ante evaluation and monitoring are useful inputs into the final evaluation.

Though evaluation and monitoring traditionally were viewed as two different approaches current views integrate monitoring and evaluation into one system aimed at improving the design and implementation of projects. The evaluation compares the costs of implementation against the costs and benefits attributable to the project. Identification of the costs of implementing a project is straightforward, but measurement of resulting benefits, particularly in environmental projects, can be difficult because many effects are indirect and long-term in nature (Singh, 2022).

Monitoring & Evaluation Framework

The M&E framework integrates the monitoring and evaluation timetable, data collection levels and components of the project hierarchy, project logical framework and results framework. As mentioned, a M&E system must use verifiable indicators to precisely mirror this sequence. To lessen the potential detrimental impact of external influences on local conditions the M&E system should also monitor rainfall, policies, other risks and hazards not only natural but man-made and market prices also. When describing findings, having information on these outside variables will also assist put the project in perspective

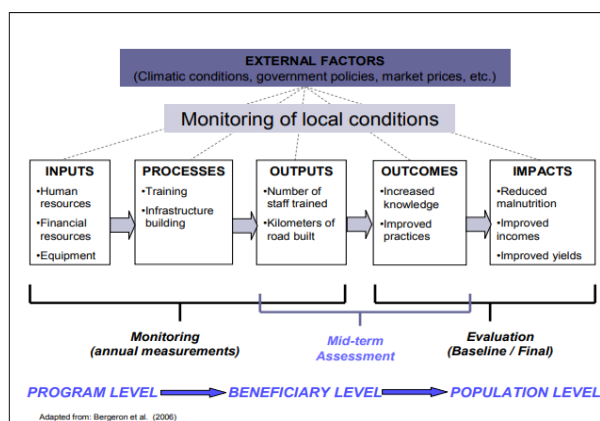


Figure 01: Monitoring and evaluation framework

Fundamental Reasons for Monitoring and Evaluation (M&E):

- a) **Accountability:** Clearly shows to stakeholders (donors, taxpayers, beneficiaries and partners) that actions, expenditures and results meet agreements or reasonable expectations.
- b) **Operational Management:** Provides critical information to coordinate human, financial and physical resources and improve performance.
- c) **Strategic Management:** Provides information to establish and change objectives and plans efficiently.
- d) **Capacity Building:** It increases the skills, self-reliance and confidence of the beneficiaries and implementers to successfully drive development initiatives.

Monitoring and evaluation (M&E) should be integrated both during a project's lifecycle and after its completion for valuable insights into both internal management and external accountability to stakeholders. It demonstrates results, impacts and trustworthiness, meeting the expectations of governments and organizations to provide evidence of success. There is growing emphasis on rigorous impact evaluations to empirically assess the effectiveness of development interventions.

Although such assessments are technically demanding and costly, they can help inform resource allocation and policy choices when applied to relevant projects. Indeed, designing M&E systems with such rigor from the outset is critical. In addition, M&E supports adaptive management by measuring performance, tracking progress, fostering learning, improving project design and building stakeholder partnerships.

Principles and approaches of monitoring:

To be effective, monitoring must have implications for decision-making. There must be a comparison or evaluation of progress against a baseline or standard value. If there is no baseline, it should be established using a pilot project. Monitoring methods differ depending on the intervention or project. Useful techniques to measure the progress of extension services include activity reporting, statistical analysis of administrative data and review of service records (Davis *et. al.*, 2021).

Monitoring progress requires the monitoring of different key performance indicators: input, effect, output and impact. These are all measurable markers of progress:

- ✓ Input measures resources, that is, 'how much' of staff time was spent on a project.
- ✓ Effect captures the outcome of the changes implemented.
- ✓ Output refers to deliverables that can be quantified, that is, training sessions held or advisory services rendered.
- ✓ Impact reflects long-term changes that resulted from the intervention.

Some field indicators that may be relevant in agricultural extension programs could include crop yields or livestock production, recorded and reported periodically. They can give insights into areas that require additional education or training for better efficiency. They could also show yield increases and conformity to performance targets. An indicator is good if it has validity, reliability, relevance, sensitivity, specificity, timeliness, and cost efficiency. Therefore, the quality of the indicators selected is critical to ensure accuracy and meaningful monitoring (Davis *et. al.*, 2021). He further suggested that linking monitoring to outcomes requires defining the expected objectives and results of a program before implementation. Without clear targets, progress cannot be effectively measured.

In agricultural extension, understanding market requirements like the certain yield from crops demanded in the market comes first. The monitoring of yields from individual farmers will surely give the service providers a realistic approach to meeting the target. Maintain respect for small-scale farmers within their limitations; contribute according to the land's capacity. From this calculation, you have a fair judgment of the participant's size and yield toward the target.

Approaches of monitoring

It has been studied in multiple literature related to monitoring that there are predominantly three approaches to monitoring. These approaches are:

Result-oriented approach:

This approach bases itself on outcomes, such as the degree to which the set objectives have been achieved. It relies on the assumptions of linearity and causality under which progress toward goal achievements can be measured. In this approach logistic charts are used as planning instruments and strategic planning complements this approach further. The major drawback of this approach is that it minimizes collective learning and a shared vision.

Constructive approach:

It emphasizes collective learning as a force for change and improvement that focuses on developing shared learning progression. Key issue analysis through individual storylines helps establish group reflection on insights that could be applied in future scenarios. The strength is built upon the sharing of experiences and the assimilation of diverse perspectives.

Reflexive approach:

This method combines result-oriented and constructive monitoring approaches. Grounded in a construction framework it also accords much importance to accomplishing concrete results. Above all, its systemic insight challenges prevailing practices for transformative purposes. It is very potent for projects aimed at building systemic innovation.

Major Models for Programme Evaluation

According to Deshler, (1997) program evaluation can follow several approaches, each with unique assumptions about data collection, analysis and success criteria. Selecting the appropriate method is essential for effective evaluation. These options provide flexibility to address diverse evaluation needs. Seven widely applicable models for extension evaluations are:

01.	Expert Model	05.	Goal-Free Model
02.	Attainment of Objectives Model	06.	Management Decision Model
03.	Naturalistic Model	07.	Experimental Model
04.	Participatory Evaluation Model		

1. Expert Model: This employs the opinion of experts who assess prepared documentation, conduct interviews and analyse the evidence against established standards or professional views. This model is widely used in international settings such as evaluations by FAO teams to identify the strengths and weaknesses in systems.

2. Goal-Free Model: It focuses on assessing outcomes without regard to specified goals or objectives. Evaluators attempt to examine facts regarding actual results, particularly concerning fulfilling the needs of farmers and determine deficiencies for enhancement. This approach employs open-ended interview methods and observations and foregrounds impacts created in practice rather than stated desires.

3. Attainment of Objectives Model: It compares the results of the program with stated goals to ascertain success. Has well-defined measurable goals; it assesses if they suit the needs of beneficiaries. The danger is that to ensure success, objectives might be very low and the processes that bring about outcomes can be ignored.

4. Management Decision Model: It gives actionable insights that inform decisions through the lifecycle of a program. Focuses on stakeholder participation and relevance to managerial needs. Challenges include marginalizing diverse farmer perspectives, like women in agriculture.

5. Naturalistic Model: It views programs as natural experiments, focusing on understanding their operation within real-world contexts. Involves multiple perspectives and fosters dialogue to address conflicts, refine policies and suggest improvements. Useful for diagnosing behaviours or systemic issues through stakeholder collaboration.

6. Experimental Model: This experimental model serves to establish whether learning achievements, a form of program outcomes, are a product of the program itself or independent factors and experiences. It consists of

at least two groups: the treatment group receiving the program intervention and the control group that does not receive any intervention. Although successful in establishing causality, it is hard to achieve in practice because of issues surrounding withholding treatment, being unable to control extraneous variables and high cost. This type of approach is best saved for situations where causal insights are critical, such as when evaluating pilot projects that are laden with significant stakes or potential outcomes.

7. Participatory Evaluation Model: This model engages educators and farmers in a process of critical reflection about activities undertaken to address persistent problems, such as the neglect of women in agriculture. Participants examine assumptions, behaviour and cause-effect relationships to determine where change is needed, implement new practices and assess outcomes.

It focuses on democratic participation and autonomy at the local level, which is also reflected in principles underlying action research from a participatory action point of view. This helps to empower participants and share responsibility in implementing the assessment and change of practices. Each model serves distinct purposes and is selected based on the program's goals, context and stakeholders involved. Some other important models of evaluations are as follows:

CIPP evaluation model of Stufflebeam

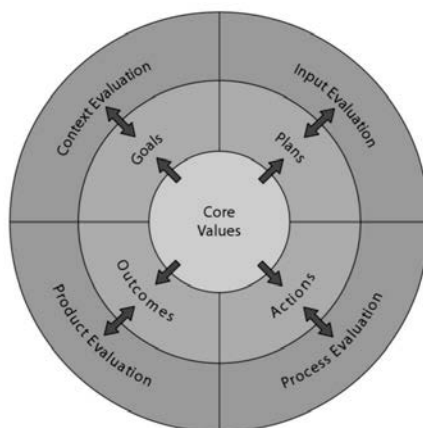


Figure 02: CIPP evaluation model

(Source: Stufflebeam, D. L., & Coryn, C. L. (2014). *Evaluation theory, models, and applications* (Vol. 50). John Wiley & Sons.)

The Context, Input, Process, and Product evaluation model helps in the comprehensive assessment of programs, projects, personnel, products, institutions and systems. It assesses needs, problems and opportunities within a given context. Input evaluation focuses on alternative strategies, work plans and budgets to identify whether the chosen implementation approaches are adequate. Process evaluation tracks, documents and assesses activities supporting efforts for improvement while at the same time maintaining records of accountability for action plan execution. Product evaluation measures short-term and long-term outcomes, including both the intended and unintended effects. Arrows between the type of evaluation and the evaluative focus denote a reciprocal relationship, thus the two are interdependent.

Kirkpatrick/Philip model of evaluation

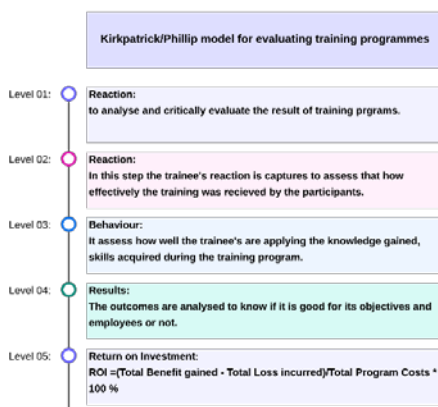


Figure 03: Kirkpatrick/Philip model of evaluation

The Kirkpatrick/Phillips Model of Evaluation assesses the effectiveness of training through four levels that Kirkpatrick proposed and an additional fifth level developed by Phillips. These include four levels *i.e.* Reaction: the measurement of participant satisfaction from training; Learning: the measure of knowledge or skill attained; Behaviour: assessment of the application of the acquired skills in the practical arena; Results: determining the effect of the training on the achievement of the organizational goals; and finally, Return on Investment (ROI) is a level added by Phillips which measures the monetary value achieved from the training versus the expenses incurred.

Phillip's ROI level adds a financial perspective, assessing the return on investment by comparing training costs to economic benefits such as increased productivity or cost savings. Together, these models provide a comprehensive framework for evaluating qualitative and quantitative outcomes, aiding informed decisions on training effectiveness and value.

Bennet's hierarchy model:

Bennett's Hierarchy Model, or the Targeting Outcomes of Programs (TOP) Model, is a structured framework for program evaluation, particularly in extension education and community development. It organizes outcomes into seven hierarchical levels, from simple to complex: Inputs (resources like staff, funds, and materials), Activities (actions such as training or workshops), Participation (audience involved), Reactions (immediate feedback and satisfaction), KASA (changes in knowledge, attitudes, skills, and aspirations), Practice Change (behavioural or practice modifications) and End Results (long-term impacts like economic benefits or sustainability).

The model links program efforts to outcomes, progressing from controllable elements to broader impacts. It aids in designing programs with clear objectives, measurable results and accountability. Commonly used in agricultural extension and community projects, the model ensures causal connections between activities and results, helping stakeholders understand and achieve program goals effectively.

Selecting Methods for Programme Evaluation: Choosing the Right Tools

The choice of evaluation methods should align with the evaluation's focus and the type of evidence needed to answer key questions. Below is an overview of commonly used data collection methods, highlighting their applications and benefits (Deshler, 1997):

1. Document Analysis: Analysing materials like meeting minutes, budgets, and reports provides insights into program inputs, participation levels, goals and challenges. While documents reveal operational difficulties, they often lack details on participant's motivations or experiences.

2. Observations: Observers, internal or external, track indicators like participation, leadership and conflict. Both qualitative and quantitative

data can be collected and visuals like videos or photos can communicate outcomes effectively. Observations can also prompt participant reflection and program improvements.

3. Interviews:

- a) **Key Informants and Oral Histories:** Explore issues in-depth with stakeholders and uncover unique perspectives.
- b) **Storytelling:** Captures evaluative judgments and experiences especially for illiterate participants.
- c) **Group Interviews/Focus Groups:** Encourage discussions based on shared geography or farm type uncovering unanticipated outcomes and insights.

4. Surveys: Standardized questionnaires gather data on practices, yields and technology preferences. Best suited for homogeneous populations, surveys may face limitations when applied to diverse groups.

5. Field Visits and Tours: Direct visits enhance understanding of program impacts. Mixed teams, including farmers and evaluators, observe, collect data and share findings. This holistic approach integrates technical, economic, and cultural insights.

6. Farmer Demonstration Documentation: Farmers conduct and document their field trials, fostering local pride and the adoption of effective technologies. Standardized methods for comparing practices help refine extension efforts.

7. Village Drama and Role Plays: Creative enactments reveal social dynamics, extension relevance and past challenges offering valuable feedback in an engaging format.

8. Maps: Maps illustrate extension resource access, sustainable practices and geographic impacts. Concept maps, collaboratively created, reveal assumptions and areas for improvement. Remote sensing and photographic comparisons track changes in environmental conditions like erosion or deforestation.

9. Case Studies: An in-depth exploration of specific farmer types or practices provides a nuanced understanding of motivations and barriers. Repeated interviews and additional data sources ensure comprehensive insights, with privacy safeguards for participants.

Evaluations can provide meaningful, actionable insights by selecting methods that align with the program's objectives and stakeholder needs.

Monitoring and evaluation: A comparison

Monitoring and Evaluation are not only the collection and analysis of information in tracking progress toward defined objectives but also to establish unintended positive or negative outcomes brought about by a project. As one of the most important management aspects, it fosters informed decision-making processes. Monitoring is the reporting of project progress and performance; evaluation takes a broader view that assesses the extent to which objectives have been achieved. Although different, monitoring and evaluation are closely related processes that together form an essential component of effective project management.

As monitoring conducts routine data collection and analysis to measure progress, detect trends and ensure activities align with targets and objectives, it yields time-variant and descriptive information that enables managers to track implementation, alter operations and justify budgetary needs. Monitoring pertains to projects, programs and policies. It provides ongoing input to stakeholders on successes and potential problems so that early action can correct problems and indicate future directions. A sound management information system facilitates monitoring through a dependable information flow that promotes valid decision-making and keeps projects on schedule.

Evaluation, in contrast, probes deeper into reasons why objectives are or are not achieved. It examines causality effectiveness; efficiency; sustainability; and the impact of interventions. Evaluations answer "why," "how," and accountability questions, using baseline studies as a point of reference. Conducted at intervals, some are formal (mid-term, terminal, ex-post), while others are informal, delivering ongoing, or process-focused evaluations to guide managers in modifying project design and implementation. Summative evaluations or impact assessments conducted at the close of a project examine both positive and adverse impacts, drawing lessons for the future. Organizational learning and accountability are promoted, thus strengthening internal reporting, auditing and planning, by both formal and informal evaluations.

A good M&E system feeds into broader public sector information systems, therefore allowing real-time decision-making and continuous

improvement. When integrated at all stages of a project's lifecycle, M&E promotes institutional memory, staff expertise and better planning and management practices.

Monitoring is checking on progress at intervals, usually related to the budget, resource usage and milestones of a project plan. It may also evaluate expected impacts that are observed as the project is implemented. In contrast, evaluation focuses on whether a project's objectives are realized, measuring the scale of impacts and comparing them against supposed outcomes.

Table 2: Key Features of Monitoring & Evaluation: A Comparison		
	Monitoring	Evaluation
0 1.	It is done to monitor actual progress, report decisions and corrective action, revise project plans and ensure accountability.	It is implemented to monitor and track performance, evaluate value and provide recommendations for long-term planning and organizational learning purposes while ensuring accountability.
0 2.	It is carried out during the project or program.	It is carried out periodically after the project.
0 3.	It is done by internal staff, who are involved in the program or project.	Evaluation can be carried out by internal or external agents.
<p><i>Source: Adopted from White, Graham, and Wiles, Peter. 2008. Monitoring Templates for Humanitarian Organizations. Commissioned by the European Commission Director-General for Humanitarian AID (DG ECHO); p. 40.</i></p>		

Participatory project monitoring and evaluation:

There has been an ever-growing recognition of the need to engage directly with stakeholders in development projects. Participatory approaches increasingly feature in appraisal, planning and managing infrastructure and natural resources. The process involves availing these

avenues of direct stakeholder participation in the monitoring and evaluation of project activities, outputs and outcomes.

Participatory monitoring and evaluation are a collaborative process among stakeholders to solve problems, generate knowledge and share knowledge with correct action taken through shared decision-making for inclusivity, enhanced accountability and better capture of diverse perspectives in documenting the progress and impact of the project.

Purpose and importance of conducting M&E

Monitoring and evaluation (M&E) contribute significantly toward holding the system accountable, enhancing performance and aligning outcomes with organizational objectives. Monitoring is done to provide regular updates on progression, address challenges, adjust operations and justify budgets. According to Singh (2022), the purposes of monitoring and evaluation can be summarised as follows:

- a) To achieve planned objectives or results.
- b) Strengthen the project management.
- c) Develop a common understanding of the project by its stakeholders.
- d) Build knowledge to inform improvements in the design and implementation of projects.
- e) Serve as an instrument of transparency and accountability.
- f) Seek public and political support.

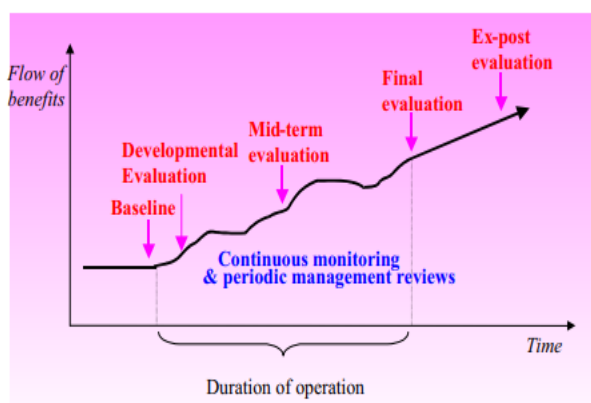


Figure04: Monitoring and Evaluation throughout the lifespan of any operation/project

Conclusion

M&E serves as indispensable tools for the achievement of sustainable agricultural development. M&E ensures that projects stay goal-oriented and resource-efficient by tracking progress, analyzing outcomes, and facilitating stakeholder collaboration. The chapter emphasizes integrating M&E throughout the project lifecycle, stressing the application of models such as Kirkpatrick/Philip and Bennett Hierarchy as a means of assessing both qualitative and quantitative impacts. The inclusion of participatory methods expands the process to engage multiple stakeholders and address systemic issues. Ultimately, adopting robust M&E practices builds organizational capacity, supports adaptive management and drives meaningful, long-term impacts in agricultural and developmental contexts.

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CHAPTER - 3

SUSTAINABLE NUTRIENT MANAGEMENT IN PIGEONPEA BASED INTERCROPPING SYSTEMS

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Pulses are the richest source of protein for the majority of the population of our country. Pulses are an important group of food crops that can play a vital role to address national food and nutritional security and also tackle environmental challenges. As a restorative crop of soil fertility, pulses have a unique position in cropping systems of wet land, dry land or rainfed agriculture. These are drought resistant and prevent soil erosion due to their deep root system and good coverage, because of these good characteristics pulses are called as “Marvel of Nature”. Pulses are equally important for maintaining soil health and sustainability of different cropping systems. India is the largest producer, consumer and importer of pulses in the world. Our country is predominantly vegetarian and pulses are the main source of quality protein and essential amino acids. The United Nations, declared 2016 as “International Year of Pulses” (IYP) to heighten public awareness of the nutritional benefits of pulses as part of sustainable food production aimed at food security and nutrition. Pigeonpea (*Cajanus cajan*) commonly known as redgram, arhar or tur is one of the most important pulse crops in India. Pigeonpea is excellent source of high quality protein and occupies an important place in vegetarian population. Globally, pigeonpea is grown in an area of 63.57 lakh hectares with a production of 54.75 lakh tonnes and productivity of 861.25 kg ha⁻¹ (FAOSTAT, 2021). In India, pigeonpea occupies 5.05 million hectares area with a production of 4.34 million tonnes and

productivity of 859 kg ha⁻¹ (DES, 2022). In Maharashtra area, production and productivity under pigeonpea is 11.95 lakh hectares, 9.71 lakh tonnes and 8.13 q ha⁻¹, respectively (DES, 2020). The productivity of pulses in our country including pigeonpea is not sufficient enough to meet the domestic demand of the population. Hence, there is need for enhancement of the productivity of pigeonpea by proper agronomic practices.

India has made spectacular breakthrough in production and consumption of fertilizers during last decades. Moreover, the continuous use of chemical fertilizers in intensive mono cropping system has led to reduction in the crop yields and resulted in imbalanced nutrients in soil which has adverse effect on soil physico-chemical properties.

The soil health and ecological hazards due to long term excessive use of chemical fertilizers also pose a serious problem. Hence, there is an urgent need to counterbalance these negative environmental impacts caused by chemical fertilizers. Organic inputs like crop residues, bulky and concentrated organic inputs, on farm cheap inputs, composts not only reduce the cost but help to build up soil humus and beneficial microbes, besides improving the soil physical properties. The scientific community all over the world is desperately looking for an 'economically viable, socially safe and environmentally sustainable' alternative to the agro-chemicals. Interest in food production without chemical fertilizer and pesticide practices is increasing. Such food is commonly referred as organic (Ramesh *et al.*, 2009). Farmyard manure is an effective and efficient source of nutrients to plants and soil microorganisms, additionally it improves physical, chemical and biological properties of the soil (Chahal *et al.*, 2020). Vermicompost has been recognized as an eco-friendly approach for converting organic wastes into high value organic manure rich in nitrates, available form of phosphorus, calcium, vitamins and natural plant growth regulators in balanced form which helps in restoration of natural fertility of soil (Ruan *et al.*, 2021). Neem cake applied as a soil amendment, it binds several macro and micro-nutrients, allowing their controlled release and limiting their loss by leaching (Jadon *et al.*, 2018) and added advantage by its insecticidal and nematicidal activity.

Intercropping has been recognized as beneficial cropping system compared to monocropping. Pigeonpea with its long duration and wide

row spacing forms an ideal intercrop with other crops *viz.*, soybean, foxtail millet and cotton. The space in between the rows is usually not utilized in the initial growth stages by pigeonpea, so it is remunerative to raise intercrops in between the pigeonpea rows, which will also suppress the growth of weeds and adds organic matter to the soil by leaf litters. Hence, integration of organic nutrient modules along with pigeonpea based intercropping system would surely influence agricultural sustainability by enhancing productivity along with maintaining dynamic soil nutrient status and safe environment. Based on the above points in view, the field experiment was taken up to evaluate sustainable nutrient management in pigeonpea based intercropping systems.

Methodology

The field experiment on sustainable nutrient management in pigeonpea based intercropping systems was conducted during *Kharif* season of 2019 at research farm of Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidhyapeeth, Akola, Maharashtra. The soil of experimental plot was clayey in texture and medium in organic carbon, low in available nitrogen, very low in available phosphorus and high in available potassium. The experiment was laid out in strip plot design (SrPD) with four main plot factors (intercropping system) and three sub plot factors (organic integrated nutrient management) and replicated thrice. The gross plot size is 9.0 x 10.0 m². The treatment consists of T₁ - sole pigeonpea, T₂ - pigeonpea + soybean (1:4), T₃ - pigeonpea + foxtail millet (1:4) and T₄ - pigeonpea + cotton (1:4) and three organic integrated nutrient management practices (OINM) *viz.*, N₁ - 100% FYM + vermicompost, N₂ - 75% FYM + vermicompost + 25% neem cake and N₃ - control (No manure). The spacing for pigeonpea, soybean, foxtail millet and cotton were 225 x 20 cm (paired row), 45 x 5 cm, 45 x 10 cm and 45 x 15 cm respectively.

The land was prepared by leveling as the plot was left fallow during past cropping years and one ploughing with iron plough followed by one harrowing was done and soil was brought into a fine tilth. Broad Bed Furrow (BBF) system which is known for efficient drainage during heavy rainy days; especially in the clayey textured soil, also to cater to soil moisture conservation in rainfed agriculture was adopted and the BBFs were prepared with combined tractor drawn broad bed furrow-seed drill along with sowing in a single operation. The seeds of pigeonpea and soybean were treated with *Rhizobium* and Phosphate Solubilizing Bacteria

(PSB), foxtail millet with PSB and *Azotobacter* and Cotton seed was delinted before it was treated with PSB and *Azotobacter*. Sowing was done immediately after receipt of sufficient rainfall in the last fortnight of June. Plant population was maintained with follow up operation by gap filling and thinning to obtain a proper plant stand. Pigeonpea (PKV-Tara), Soybean (AMT-1001) (Yellow gold), Foxtail millet (Co-1) and Cotton (AKA-7) were selected for the study as the varieties that are most recommended for the region and are highly suitable *Desi* varieties for organic agriculture. Seed rate were 12, 75, 3 and 12 kg ha⁻¹ of pigeonpea, soybean, foxtail millet and cotton respectively. Basal dose was applied with FYM and phospho compost according to the treatment requirements and top dressing was done with the application of vermicompost to meet the remaining nutrient requirement of the treatments. All mechanical and cultural practices of plant protection were adopted. Insect traps (pheromone trap, yellow sticky trap, light traps), bird distracters were installed in the field. Botanicals like dashparni, neem oil and bio-agents like *Verticillium lecanii* were sprayed against the sucking and cotton bollworms. One hoeing and three hand weeding by manual labour were carried out to maintain weed free condition and the biomass was mulched between the crop rows. Plants from net plot area of each crop were harvested separately according to their harvesting dates leaving border rows after collecting the five tagged observation plants. Pigeonpea, soybean and foxtail millet were harvested by manual labour by completely slashing the shoot while leaving the root biomass in the field. Cotton picking was carried out in three intervals by manual labours and seed cotton yield was weighed. The threshing of pigeonpea, soybean and foxtail millet was carried out manually by labour and the straw was spread over the field for in-situ decomposition. Cotton was slashed with tractor drawn slasher developed by Agricultural Engineering Department. The seeds of pigeonpea, soybean and foxtail millet were cleaned, dried and weighed.

Conclusion

Practicing the above methods of intercropping system, pigeonpea + soybean (1:4) intercropping system recorded the highest growth attributes *viz.*, plant height, number of leaves plant⁻¹, leaf area index, number of branches plant⁻¹, dry matter accumulation and yield attributes *viz.*, number of pods plant⁻¹, number of seeds pod⁻¹, yield (seed yield, stalk yield and biological yield), pigeonpea equivalent yield (PEY) and system productivity. Regarding organic integrated nutrient management practices

similar trend was recorded in application of 75% FYM + vermicompost + 25% neem cake. Therefore, this combination is recommended for sustaining the productivity with efficient utilization of organic nutrient sources in pigeonpea based intercropping systems.

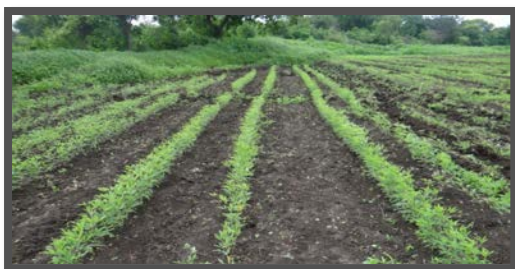
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Table 1. Seed yield (kg ha⁻¹), stalk yield (kg ha⁻¹), benefit cost ratio of pigeonpea, soybean, foxtail millet and cotton as influenced by intercropping systems and organic nutrient modules

Treatments	Seed yield (kg ha ⁻¹)				Stalk yield (kg ha ⁻¹)				Benefit cost ratio (BCR)
	Main crop	Intercrop			Main crop	Intercrop			
		PP	Soy	FM		Cot	PP	Soy	
T₁ – PP sole	721.8				2493.4				1.60
T₂ – PP + Soy	1043.6	1802.9			3241.7	2884.6			3.60
T₃ – PP + FM	609.2		774.7		1808.3		1317.1		2.00
T₄ – PP + Cot	618.6			625.0	1754.6			1750.1	2.30
SE(m)±	18.0				84.4				--
CD at 5%	62.1				291.9				--
B) Organic Integrated Nutrient Management (OINM)									
N₁ – 100% FYM + VC	825.2	2282.4	947.3	761.0	2425.1	3634.5	1590.2	2078.7	2.30
N₂ – 75% FYM + VC + 25% NC	922.2	2365.2	1083.9	864.6	2730.3	3766.9	1822.4	2368.7	2.90
N₃ – Control	497.5	761.0	292.8	249.4	1818.1	1252.3	538.6	802.8	1.90
SE(m)±	14.7				98.2				--
CD at 5%	57.6				385.5				--
C) Interaction (AXB)									
SE(m)±	24.8				192.6				--
CD at 5%	76.5				NS				--
GM	748.3	1802.9	774.7	625.0	2324.5	2284.6	1317.1	1750.1	--

Note: PP – Pigeonpea, Soy – Soybean, FM – Foxtail millet, Cot – Cotton, FYM – Farm Yard Manure, VC – Vermicompost, NC – Neem Cake.



T₁ - Sole pigeonpea

T₂ - Pigeonpea + soybean (1:4)



T₃ - Pigeonpea + foxtail millet (1:4)

T₄ - Pigeonpea + cotton (1:4)



Fig. 1. Pigeonpea based intercropping systems

CHAPTER - 4

SMART SEED COATINGS FOR ENHANCED GERMINATION, PROTECTION AND WEED MANAGEMENT

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Abstract

Smart seed coatings represent an innovative approach to enhancing agricultural productivity by integrating advanced materials and technologies into traditional seed treatment practices. These coatings, comprising hydrogels, nanomaterials, biopolymers and stimuli-responsive agents, provide targeted solutions to challenges such as inconsistent germination, abiotic and biotic stresses, and weed competition. By regulating moisture, delivering nutrients, and incorporating pest and weed suppression mechanisms, smart coatings enable precise and sustainable farming practices. This chapter explores the types, mechanisms, and applications of smart seed coatings, highlighting their potential to improve germination rates, enhance stress tolerance, and reduce environmental impact. Despite adoption and regulatory compliance challenges, these coatings hold immense promise for addressing global issues like food security and climate change. Continued research and innovation are essential to realize their transformative potential in modern agriculture.

Keywords: Enhanced Germination, Protection, Seed coatings and Weed Management.

Introduction

Seed coating involves the application of materials onto seeds to facilitate planting and improve seed quality by protecting them from biotic and abiotic stresses. While conventional coatings, often made from materials like clay, polymers, or fertilizers, have served this purpose for decades, their limitations have driven the evolution of smarter alternatives.

Smart seed coatings integrate advanced materials such as hydrogels, nanoparticles, and biopolymers that respond to environmental stimuli—such as moisture, temperature, light, or pathogens—to boost germination rates and provide adaptive protection. These coatings also incorporate weed management strategies, either by embedding herbicides or enhancing crop competitiveness through precise nutrient delivery. This chapter explores the types, mechanisms, applications, and challenges of smart seed coatings in modern agriculture.

Types of Smart Seed Coatings

1. Hydrogels

Hydrogels are water-absorbing materials that ensure consistent moisture supply for germination. By storing and gradually releasing water under low soil moisture conditions, hydrogels are particularly valuable in drought-prone areas. These coatings also support robust seedling growth by maintaining optimal hydration, enabling crops to outcompete weeds effectively.

2. Nanomaterial-Based Coatings

Nanotechnology enables the development of coatings that incorporate nanoparticles like silica, carbon nanotubes, or metal oxides. These materials enhance water retention, UV protection, and nutrient delivery. Nanoparticles also facilitate controlled release of herbicides, minimizing environmental impact and chemical runoff while targeting weeds precisely.

3. Biopolymer Coatings

Biodegradable biopolymers such as chitosan, alginate, and starch provide eco-friendly alternatives to conventional coatings. These materials can carry active ingredients like growth regulators, pesticides, or herbicides, releasing them in response to environmental triggers. Biopolymer coatings promote faster germination, protect seedlings from disease, and inhibit weed growth by creating localized zones of herbicidal activity.

4. Stimuli-Responsive Coatings

These coatings adapt to specific environmental factors such as moisture, temperature, pH, or light. For example, water-activated polymers form gel-like structures to retain moisture, while temperature-sensitive coatings release growth-promoting agents under optimal conditions. Some coatings also activate embedded herbicides in response to soil moisture or pH changes, ensuring selective weed suppression.

5. Pesticide, Fertilizer, and Herbicide-Loaded Coatings

Coatings embedded with pesticides, fertilizers, and herbicides use controlled release mechanisms to minimize waste and environmental impact. These coatings ensure that nutrients and protective agents are delivered directly to seeds, reducing the need for external applications and lowering production costs (Meena *et al.*, 2024).

Mechanisms of Action

1. Moisture Regulation

Hydrophilic materials such as hydrogels absorb and slowly release water, preventing desiccation and maintaining consistent moisture levels during germination. This steady hydration enables crops to establish quickly, reducing the window of opportunity for weeds to compete.

2. Nutrient Delivery and Controlled Release

Biodegradable polymers and nanomaterials allow for gradual nutrient release, ensuring sustained availability. By directing nutrients to the crop root zone, these coatings help seedlings outcompete weeds for essential resources like nitrogen and phosphorus.

3. Stimuli-Responsive Activation

Smart coatings respond to environmental cues, releasing growth-promoting agents under specific conditions such as moisture scarcity or optimal soil temperatures. Similarly, herbicides embedded in these coatings activate during critical weed growth stages, maximizing efficacy and minimizing crop damage.

4. Microbial Enhancement

Smart coatings can serve as carriers for beneficial microbes such as mycorrhizal fungi and rhizobacteria, which improve nutrient uptake and provide a protective barrier against pathogens. Certain microbial enhancements also produce allelopathic chemicals, naturally inhibiting weed germination and growth.

5. UV Protection

Coatings incorporating UV-blocking agents shield seeds from harmful radiation while maintaining moisture and breathability. This protection ensures healthy seedling growth, enabling crops to establish dominance over weeds.

6. Pest, Pathogen, and Weed Suppression

Incorporating pesticides, fungicides, and herbicides into coatings protects seeds from soil-borne pests and pathogens while directly suppressing weed growth around the seed zone. This targeted approach reduces reliance on post-emergence herbicide applications.

Rationale for Smart Seed Coatings

Seed coating practices date back to 1866, when wheat flour paste was used to coat cotton seeds. Over time, conventional coatings have faced challenges such as agrochemical overuse, pollution from non-biodegradable materials and excessive costs. Thick or hard coatings can hinder germination and reduce yields. Modern research addresses these issues by balancing high crop yields with minimal environmental impact. Advances in nanotechnology have introduced biologically active nanoparticles, offering dual benefits of pest protection and enhanced germination under stress conditions. By incorporating selective herbicides or enhancing crop competitiveness, smart coatings reduce reliance on repeated herbicide applications, aligning with sustainable agricultural practices (Saravanane *et al.*, 2023).

Applications in Agriculture

1. Improved Germination Rates

Smart coatings ensure seeds receive adequate moisture, nutrients, and protection, enhancing germination even in suboptimal conditions. Robust early growth helps crops establish dominance over competing weeds (Karthickraja *et al.*, 2024).

2. Drought and Stress Tolerance

Coatings that enhance water retention and release moisture gradually enable seeds to thrive in water-scarce regions. Stress-tolerant crops can outlast weeds during periods of low rainfall.

3. Precision Agriculture

Controlled release systems in coatings align with precision agriculture practices by delivering nutrients, pest control agents, and herbicides at the right time and in the right amounts. This reduces chemical usage and environmental impact while improving weed management (Bharathi *et al.*, 2024).

4. Sustainable Farming Practices

Eco-friendly, biodegradable coatings reduce reliance on chemical treatments, preserve soil health, and provide targeted pest and weed protection. By suppressing weeds at the germination stage, these coatings contribute to reduced herbicide dependence and better resource use efficiency.

5. Enhanced Weed Control

Smart coatings containing herbicides or allelopathic agents provide localized weed suppression, minimizing competition during critical growth stages. This integrated approach reduces the need for manual

weeding or excessive chemical inputs (Saravanane and Karthickraja, 2024).

Challenges

Adopting smart seed coatings faces several hurdles, including:

- **Farmer Education:** Many farmers, especially in developing regions, lack awareness of these technologies.
- **Distribution Complexities:** Ensuring coating integrity during storage and transport requires specialized packaging.
- **Environmental Variability:** Soil moisture, temperature and other factors influence coating effectiveness, necessitating further research to ensure consistent performance under diverse conditions.
- **Regulatory Compliance:** Coatings with herbicidal properties must adhere to stringent safety and environmental regulations.

Conclusion

Smart seed coatings represent a transformative advancement in agricultural technology, offering targeted protection, improved germination, controlled nutrient release, and effective weed management. By integrating weed suppression mechanisms, these coatings enhance their value in modern agriculture while addressing global challenges like food security and climate change. However, further research is needed to explore their long-term effects, scalability, and regulatory implications. With continued innovation, smart seed coatings have the potential to revolutionize sustainable farming practices worldwide.

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CHAPTER - 5

PARTICIPATORY EXTENSION RESEARCH AND APPROACHES

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Introduction

Participatory Extension Research and Approaches

Agricultural extension is a crucial component of the agricultural sector, especially in developing countries involving the transfer of knowledge and information from researchers to farmers to improve agricultural productivity, efficiency, and profitability. However, the traditional extension approaches, which are mostly top-down and expert-driven approach, have been criticized for not effectively addressing the needs and challenges faced by farmers. Finding an answer to these issues, participatory extension research and approach (PERA) has emerged as a promising alternative that emphasizes the active participation of farmers in the extension process (Sethi and Sharma, 2022). Participatory research (PR) encompasses research designs, methods, and frameworks that use systematic inquiry in direct collaboration with those affected by an issue being studied for purpose of action or change. Participatory research engages those who are not necessarily trained in research but belong to or represent interests of people who are focus of research. Researchers utilizing a participatory research and approach often choose research methods and tools that can be conducted in a participatory, democratic

manner that values genuine and meaningful participation in research process. Participatory Extension Approach (PEA) has emerged as a promising approach to agricultural extension that prioritizes the active participation and empowerment of farmers in the development process. The historical evolution of PEA shows how it has emerged as an alternative to traditional top-down extension approaches. PEA emphasizes the use of participatory tools and techniques such as Participatory Rural Appraisal (PRA), Farmer Field Schools (FFS) and Participatory Technology Development (PTD) to enable farmers to participate actively in the extension process with encompassing the key principles of community participation, relevance, and sustainability. Improved farmer knowledge, skills, and practices, as well as improved social capital and rural livelihoods are the crucial benefits of PEA. At the same time challenges, including resistance to change, limited resources, power dynamics, lack of institutional support, and inadequate monitoring and evaluation hinders the implementation of PEA. However, with effective communication, capacity building, and enabling policy environments, PEA has the potential to promote sustainable agriculture and rural development. It is a bottom-up and participatory approach that recognizes farmers as experts in their own contexts and promotes the co-creation of knowledge and solutions through collaboration between farmers and extension agents and grounded in the principles of participation, empowerment, and ownership.

Importance of Participatory Research

1. Participatory research brings out views of local people: reality, challenges, and understanding of problems and solutions.
2. Participatory research can therefore produce surprising insights for policy, and may challenge assumptions on which policy frameworks are based.
3. Participatory research may also reveal why certain development interventions intended to help poor are not actually used by local people.
4. Participatory research is humanistic approach to enhanced through involvement of everyone in solving social problems.

Methods of Participatory Research

A research method is typically thought of as a means of data collection or data generation.

1. **Surveys:** Informal participatory survey methods can be used for gathering of data at different phases of programme implementation, and for analysis of SPFS-related issues by the farming communities themselves. The main

principles of informal data-gathering include multidisciplinary team work, triangulation and flexibility.

2. **Action Research:** Participatory Action Research is a qualitative research methodology that involves researchers and participants collaborating to understand social issues and take actions to bring about social change. It is an umbrella term for all research approaches that engage stakeholders in each step of the research process.
3. **Community Based Participatory Research:** A cutting-edge paradigm for research, community-based participatory research (CBPR) integrates knowledge and action to enhance community health and lessen health inequities. and involves co-creating the research agenda and priorities and promotes mutual understanding across partners. CBPR integrates the cultural and social dynamics that are crucial to successful research and program implementation.
4. **Focus Group:** A gathering of eight or more persons, generally six or ten, to investigate and talk about a new product or other issue. The group discusses the subject at hand and exchanges ideas, knowledge, and feedback. Individuals are free to persuade other participants of their ideas and to freely exchange thoughts.
5. **Participatory Evaluation:** In a participatory evaluation, the role of the evaluator is to facilitate discussions rather than to achieve an external 'objective' assessment. It is more likely that several different viewpoints will be included in any findings as opposed to an overall consensus.
6. **Cooperative Inquiry:** Working with others who share your interests and concerns can help you better understand the world around you, make sense of your life, come up with fresh perspectives, learn how to make changes you may want to make, and figure out how to do things more effectively. This process is known as cooperative inquiry.
7. **Participation Action research:** Engaging in Participatory Action Insiders and outsiders collaborate to determine what needs to be investigated, design the study (including what will be measured and how), and gather the required data in a continuous cycle of research. After that, this data is applied practically or used to spark original research ideas.

Participatory Research Techniques and Tools

Participatory research Techniques (PRT) encompasses research designs, methods and frameworks that use systematic inquiry in direct collaboration with those affected by an issue being studied for the purpose of action or change. Participatory research engages community stakeholders in the research process, from problem identification and developing the research question, to dissemination of results. There is increasing recognition in the field of health research that community-engaged methods can be used throughout the research process.

1. **Direct Observation:** Direct observation is the collection of information using your senses. By observing, you can document activities, behavior, and physical aspects of a situation without having to depend on peoples' willingness or ability to respond accurately to questions.
2. **Participatory Mapping and Modelling:** Many PMs involve local people analyzing their situation using pictures, diagrams and symbols rather than just words. Mapping and modelling are common tools and take many forms including social, resource, mobility, environmental and vulnerability maps.
3. **Transect Walks and Guided Field Walks:** Transect walks are a participatory exercise, where members of the community, planners and other municipality representatives walk through different areas of the neighborhood, interviewing passers-by and drawing a map with observations of characteristics, risks and existing solutions after the walk.
4. **Seasonal Calendars:** The distribution of seasonally fluctuating phenomena (such as economic activity, production activities, issues like debt, illness or disease, migration, and natural events/phenomena, etc.) over time can be visually represented using a seasonal calendar.
5. **Daily-Activity Profiles:** It is temporal analysis on a daily basis. It also helps in comparing the daily schedule of different individuals or groups. The daily schedule is also known as daily activity schedule, daily activity profile, daily routine and 24-hour clock chart.
6. **Semi Structured Interviewing:** Semi-structured interviews are a blend of structured and unstructured types of interviews. Unlike in an unstructured interview, the interviewer has an idea of what questions they will ask.

Unlike in a structured interview, the phrasing and order of the questions is not set.

7. **Time Lines:** A timeline is a visual representation of a chronological sequence of events along a drawn line that helps a viewer understand time relationships. The term can be used to refer to things in the past or future, or that are purely conceptual. Increasingly, timelines combine text and graphic as infographics.
8. **Venn Diagrams:** A Venn diagram uses overlapping circles or other shapes to illustrate the logical relationships between two or more sets of items. Often, they serve to graphically organize things, highlighting how the items are similar and different.
9. **Wealth and Well-Being Rankings:** Wellbeing ranking is based on local people's perception of wealth, ranking, and wellbeing with regard to income and assets and their views on socio- economic disparities between households (HH).
10. **Case Studies and Stories:** They describe any reporting of actual events as story, but I believe that is not necessarily the case. So, this is my stab at a differentiating way of defining what makes a story: A case study is a factual representation of what happened along with some analysis that provides insights and learning for the future.

Some other different Participatory Research Techniques (PRT) enlist below

Permanent-Group Interviews; Local Histories; Matrices; Traditional Management Systems and Local-Resource Collections; Profiles; Folklore; Songs; Poetry and Dance; Shared Presentations and Analysis; Night Halts

Participatory Research Applications

- ❖ Helps in choosing research methods and tools that values genuine and meaningful participation in the research process.
- ❖ Collaboration with stakeholders, community, constituents and end-users in the research process.
- ❖ Research participants increases their knowledge and ideas as well as valid analysis of social reality, thus, more relevant solutions are achieved.

- ❖ Both researchers and subjects of the study gain more from the research process when the researchers attain greater sensitivity and self-awareness of the problems.
- ❖ Helps in developing good relationship among the research team, research participants, and people in the community.

What is Participatory Extension Approach?

Through the village organization committees, all village members participate in the identification, prioritization and analysis of problems, the creation of action plans to solve the problems, and the implementation and monitoring of the activities. This participatory learning process is known as the Participatory Extension Approach. PEA offers a process for enabling rural residents to participate in the implementation of action plans that tackle pressing issues that the communities have determined to be important. The goal of this community-based extension programme is to promote ongoing collaborative learning between locals and professionals. PEA encompasses all aspects of rural and agricultural development. Residents in the community may be able to access services from other rural service providers and development organizations in the area through PEA.

Objectives of Participatory Extension Approach (PEA)

The overall objectives of the PEA process are:

- ❖ To empower and mobilize the rural populace by incorporating them in all stages of the development and execution of initiatives
- ❖ To reinforce the ongoing process of decentralization
- ❖ To improve the organization, coordination, and provision of rural services
- ❖ To improve the way social and rural development are managed

The specific objectives include

- ❖ To assist the community in recognizing and prioritizing its issues, opportunities and potentials
- ❖ to provide community members with the tools to assess issues, identify causes and suggest solutions
- ❖ Including locals in the creation of plans of action to address their issues
- ❖ To give the community's problems legitimacy. Given that the plans are the result of their labour, the citizens acknowledge and control them.
- ❖ To facilitate the mobilization of resources from both inside and outside the community to carry out the action plan and to exert pressure on various partners (government agencies, non-governmental organizations and other active institutions in the rural region) to provide timely, high-quality services.

- ❖ To motivate the inhabitants to keep an eye on and assess how their action plans are being carried out. NB: The aforementioned precise goals illustrate the procedure that the PEA has in mind.

Key features of Participatory Extension Approach (PEA)

The key features of PEA are:

1. Everybody living in the community participates
2. Residents of the community determine their priorities, make their own choices and create their own schedule.
3. A more thorough and organized method of planning
4. Plans are wide-ranging and cover every aspect of rural development.

General Principles of Participatory Extension Approach (PEA)

A. Group Learning Process / Community Mobilization

- ❖ The impoverisher's power stems from their sheer quantity, but if they lack organisation, that quantity means nothing.
- ❖ It is only via collective examination and engagement that the world's complexity will become apparent.
- ❖ People must be enlisted to participate in equal partnerships, plan and act, share knowledge and skills and learn from one another.

B. Building Community Capacity

- ❖ To recognize issues, organize and oversee measures to address them.
- ❖ To engage in technological development by combining external and indigenous concepts.
- ❖ To be more precise, appropriate interventions, compromise and negotiation are necessary to achieve sustainable growth.
- ❖ Everyone is unique and significant, and while opinions differ, everyone is taken into consideration when pursuing diversity.

Tools and Techniques used in Participatory Extension Approach

Participation Extension Approach is to alter public perceptions of the environment and encourage the adoption of policies that support rural and agricultural development. Many advancements have been made in the application of participatory techniques. While some of these are more concerned with supporting farmer-led research and extension, others are more focused on community empowerment. Still others are more concerned with issue diagnosis. In every instance, experts in the sector are involved in the design process to listen to and learn from farmers.

A number of tools and technology has been evolved and evaluated for proper implementation of participatory approaches which are summarized Below:

1. Rapid Rural Appraisal
2. Participatory Rural Appraisal
3. Participatory Needs Assessment
4. Participatory Learning and Action
5. Participatory Monitoring and Evaluation (PME)

1. Rapid Rural Appraisal (RRA)

A device for gathering data and information from rural residents and communities for use by outside parties. involves semi-structured interviews, walks, observations, written data, and information, if accessible. lacks accuracy and its value is mostly determined by the opinion of an outsider, either person or group. helpful for familiarization and maybe for confirming or ground-testing more in-depth analysis. has the benefit of being quite rapid.

2. Participatory Rural Appraisal (PRA)

The RRA, but with the community taking part in the process of obtaining and interpreting information and being the main recipient of it—an insider orientation as opposed to an outsider one as in RRA. Individuals and/or the community actively engaged in information sharing, problem identification and analysis, priority setting, solution development, implementation, and impact assessment. helps communities to determine the competencies required to manage their own development initiatives.

3. Participatory Needs Assessment (PNA)

The community informs and actively participates in determining needs and limitations. By involving all interest groups and formal and informal organizations in the process, priorities are defined and fundamental data is obtained from which community action plans may be created.

4. Participatory Learning and Action

Through the participatory development method known as "participatory learning and action," rural communities are engaged by facilitators, change agents, and extension professionals. Beginning with the gathering, sharing, and analysis of local data, this process progresses

through a rigorous, long-distance learning phase before a proactive community member acts to advance their own development.

5. Participatory Monitoring and Evaluation (PME)

The method by which the neighborhood keeps track of how well the action plan is being implemented. incorporates the community in a recurring participatory assessment process to ascertain the results of the actions carried out. Communities establish performance metrics to assess the action's total impact, lessons learnt and success or failure.

Other Kinds of Tools and Techniques used in Participatory Extension Approach

- A. Farmer Field Schools(FFS)
- B. Participatory Technology Development (PTD)
- C. Community-based organizations (CBOs)
- D. Communication and information sharing

A. Farmer Field Schools(FFS)

A group-based learning process that uses participatory methods to build farmers' knowledge and skills in specific areas of agriculture. FFS involves regular group meetings, hands-on learning, and experimentation to promote the adoption of improved practices and technologies

B. Participatory Technology Development (PTD)

A process that involves farmers and extension agents working together to co-create and test new agricultural technologies and practices. PTD emphasizes the active participation and ownership of farmers in the development process.

C. Community-based organizations (CBOs)

Local organizations formed by farmers to collectively address common challenges and interests. CBOs can be used as a platform for promoting the active participation and ownership of farmers in the extension process.

D. Communication and information sharing

PEA emphasizes the importance of two-way communication and information sharing between farmers and extension agents. This can involve the use of various communication channels, such as mobile phones, radio, and other digital technologies, to promote effective and timely sharing of information and knowledge.

Participatory Extension Approach (PEA) Cycle and the Key Stages
The steps in the participative process follow a sensible order

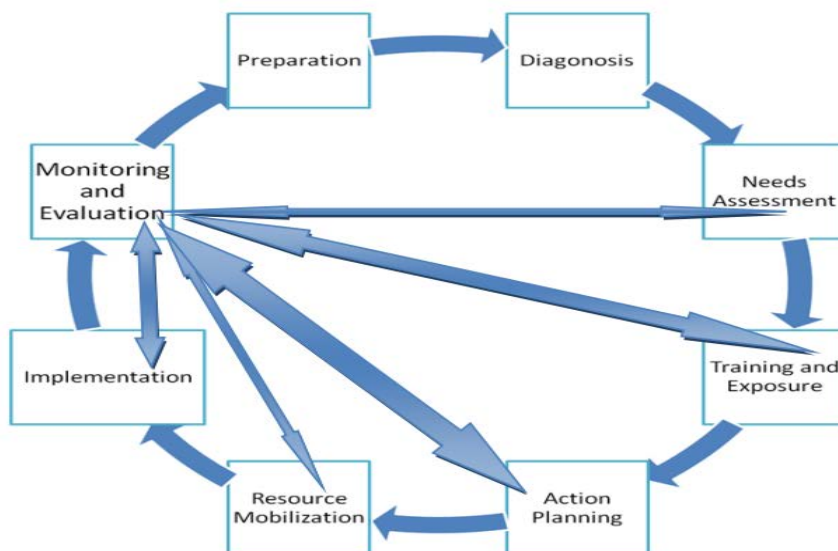


Figure 1: Participatory Extension Approach (PEA) Facilitation Cycle

Benefits of Participatory Extension Approach

PEA has gained increasing attention in recent years as an alternative to traditional top-down extension approaches that did not fully address the needs and challenges faced by farmers. Below are some of the key benefits of PEA.

1. Improved relevance and effectiveness:

PEA enable extension agents to gain a better understanding of the local needs and challenges faced by farmers, leading to the development of context-specific and relevant solutions that are more effective in addressing the challenges faced by farmers.

2. Increased adoption and sustainability of agricultural practices:

PEA fosters a sense of ownership and empowerment among farmers, leading to increased adoption and sustained use of agricultural practices and technologies. This helps to promote long-term sustainability and impact.

3. Enhanced knowledge sharing and learning:

PEA creates opportunities for farmers and extension agents to exchange knowledge and experiences, leading to mutual learning and increased capacity building among both groups. This promotes innovation and the development of more effective and context-specific solutions.

4. Increased social capital:

PEA promotes the development of relationships between farmers and extension agents based on trust, collaboration, and mutual learning. This leads to the development of social capital, which can support the continued co-creation and adaptation of agricultural technologies and practices.

5. Improved livelihoods:

PEA contributes to improved livelihoods of farmers through increased productivity, profitability, and resilience. By promoting the adoption of appropriate and effective agricultural practices and technologies, PEA can contribute to increased food security and improved livelihoods.

Challenges in Implementing Participatory Extension Approach

However, implementing PEA is not without its challenges. Below are some of the key challenges that need to be addressed to ensure a successful implementation of the PEA.

A. Resistance to change:

Farmers and extension agents may be resistant to change and may be hesitant to adopt new and unfamiliar approaches. It is important to recognize and address this resistance through effective communication and engagement strategies.

B. Limited resources:

Implementing PEA requires significant time, resources, and capacity building, which may be limited in some contexts. This can pose a challenge to the widespread adoption and implementation of PEA.

C. Power dynamics:

PEA involves the active participation and empowerment of farmers, which can challenge traditional power dynamics and hierarchies. This can lead to resistance and pushback from those who feel threatened by these changes.

D. Lack of institutional support:

The success of PEA depends on institutional support and enabling policy environments that promote the adoption of participatory

approaches. However, such support may be limited in some contexts, leading to challenges in implementing PEA.

E. Inadequate monitoring and evaluation:

Effective monitoring and evaluation are critical to the success of PEA, but they are often overlooked or inadequately addressed. This can make it difficult to assess the impact of PEA and to identify areas for improvement.

Conclusion

Participatory Extension Research and Approach (PERA) is a participatory and farmer-oriented approach that aims to promote sustainable agricultural development by engaging farmers as active participants in the extension process representing a significant departure from traditional top-down extension approaches to promote sustainable agriculture and rural development. It emphasizes the active participation and empowerment of farmers in the development process and prioritizes the co-creation and adoption of context-specific and relevant agricultural practices and technologies that meet the needs and challenges of local farmers. This approach has the potential to address the limitations of traditional extension approaches and contribute to the development of context-specific and effective agricultural technologies and practices. Addressing the challenges in implementing PEA requires effective communication, capacity building, and enabling policy environments to support the successful implementation of participatory approaches.

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CHAPTER - 6

ADVANCES IN DIAGNOSTIC TOOLS FOR PLANT PATHOLOGY

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INTRODUCTION

Plant diseases continue to pose a significant threat to global agricultural productivity, affecting food security and the livelihoods of millions. Accurate and timely diagnosis of plant diseases is critical to developing effective management strategies. Over the years, the field of plant pathology has seen remarkable progress in the development of diagnostic tools, ranging from traditional methods to cutting-edge technologies. This chapter explores the latest advancements in diagnostic techniques for plant diseases, focusing on innovations that enhance speed, accuracy, and accessibility.

From molecular diagnostics, including PCR-based assays and next-generation sequencing, to advanced imaging techniques like hyper spectral and thermal imaging, these tools are revolutionizing how we detect and monitor plant pathogens. We will also examine the role of bioinformatics and artificial intelligence in interpreting diagnostic data and providing actionable insights for disease management. The integration of these

technologies promises to not only improve disease surveillance but also offer solutions for early detection, precise identification, and more sustainable agricultural practices.

This chapter aims to provide a comprehensive overview of the state-of-the-art diagnostic tools, discussing their principles, applications, and the challenges that remain in the quest for better disease management solutions. By highlighting these advancements, we aim to inspire further innovation and collaboration in the field of plant pathology, ensuring healthier crops and more resilient agricultural systems for the future.

EMERGING DIAGNOSTIC TOOLS IN PLANT PATHOLOGY

1. Molecular Diagnostics

a. Polymerase Chain Reaction (PCR) and its Variants

Polymerase chain reaction (PCR) has become the cornerstone of molecular diagnostics in plant pathology. PCR amplifies specific DNA sequences, enabling the detection of pathogens even when they are present in low concentrations.

- **Traditional PCR:** The use of conventional PCR for detecting plant pathogens such as fungi, bacteria, viruses, and nematodes is widespread. PCR is particularly effective in detecting pathogens in asymptomatic plants, making it ideal for early disease management.
- **Quantitative PCR (qPCR):** This variation of PCR allows for the quantification of pathogen DNA, providing insights into pathogen load in plants. qPCR is particularly useful in understanding disease progression and determining the effectiveness of treatments.
- **Multiplex PCR:** This technology enables the simultaneous detection of multiple pathogens in a single sample, reducing time and resource consumption. It is invaluable in detecting polyphagous pathogens or those causing similar symptoms.

b. Loop-Mediated Isothermal Amplification (LAMP)

LAMP is a nucleic acid amplification technique that does not require complex thermal cycling equipment, making it a portable and cost-

effective diagnostic tool. LAMP is ideal for field-based diagnostics, where rapid and on-site pathogen detection is crucial.

- **Advantages:** LAMP is known for its speed, simplicity, and high sensitivity, making it an attractive alternative to PCR in many settings, especially in resource-limited environments.
- **Applications:** LAMP has been successfully applied to the detection of viruses, fungi, and bacteria in various crops, including rice, tomato, and citrus.

c. Next-Generation Sequencing (NGS)

Next-generation sequencing (NGS) technologies have revolutionized plant pathology by enabling high-throughput and comprehensive analysis of plant-associated microorganisms. Unlike traditional PCR, NGS can detect a wide array of pathogens in a single test, even those that have not yet been characterized.

- **Metagenomics:** NGS-based metagenomics allows for the identification of unknown or emerging pathogens by sequencing all DNA present in a sample. This is particularly important in the context of diseases with undefined etiologies or when dealing with new and evolving pathogens.
- **Amplicon Sequencing:** By targeting specific genetic markers, amplicon sequencing offers a more focused approach to pathogen identification and diversity analysis, providing valuable data on microbial communities and their interactions with plants.

d. CRISPR-based Diagnostics

The CRISPR-Cas system, originally used for genome editing, has shown great potential in diagnostic applications. CRISPR-based diagnostics are highly specific and can detect nucleic acids from pathogens with unmatched sensitivity and speed.

- **CRISPR-Cas12/Cas13:** These systems can be engineered to recognize specific DNA or RNA sequences, and upon detection, they trigger a signal that can be read using simple instruments such as lateral flow devices. This has led to the development of

CRISPR-based point-of-care tests, offering rapid and accurate pathogen detection in the field.

e. Microarray-based Technologies

Microarrays are another powerful tool in plant pathology, allowing for the simultaneous detection of multiple pathogens through hybridization to probes arrayed on a chip.

- **Gene Expression Profiling:** Microarrays can also be used to monitor plant responses to pathogen infections by analyzing gene expression. This is valuable for understanding plant-pathogen interactions and identifying disease resistance genes.
- **Pathogen Detection:** Plant pathogen-specific microarrays have been developed for the detection of a wide range of viruses, bacteria, and fungi, providing a comprehensive diagnostic tool.

2. Biosensors

- **Electrochemical Biosensors:**

Electrochemical biosensors are a popular diagnostic tool due to their simplicity, sensitivity, and rapid response time. They operate by detecting changes in the electrical properties (such as current, voltage, or impedance) when a pathogen-specific biomolecule interacts with the sensor's surface.

Working Principle: Electrochemical biosensors typically consist of a biological recognition element (like antibodies, nucleic acids, or enzymes) immobilized on an electrode. When a target pathogen is present, the biological element binds to it, causing a measurable change in the electrical signal. This signal can be correlated with the presence and concentration of the pathogen.

Applications in Plant Pathology:

- **Pathogen Detection:** These biosensors can detect specific pathogens, such as fungi, bacteria, and viruses, with high specificity and sensitivity.
- **On-Site Diagnostics:** Electrochemical sensors can be used for rapid on-field testing, allowing farmers and researchers

to monitor plant health without needing complex laboratory equipment.

- **Real-Time Monitoring:** Continuous monitoring is possible, enabling early detection of infections before they spread.

Advantages:

- **High Sensitivity:** Capable of detecting low concentrations of pathogens.
- **Portability:** Devices are small and portable, allowing for easy deployment in the field.
- **Cost-Effectiveness:** Compared to traditional methods, electrochemical biosensors are relatively inexpensive.

- **Optical Biosensors:**

Optical biosensors use light to detect biological interactions. They measure changes in light properties, such as absorbance, fluorescence, or refractive index, when a pathogen interacts with the sensor's surface.

Working Principle: Optical biosensors rely on the binding of a target pathogen to a biological element on the sensor surface. This binding causes a change in light transmission, reflection, or fluorescence, which is detected and analyzed.

Applications in Plant Pathology:

- **Fluorescence-Based Detection:** Certain plant pathogens, like bacteria and viruses, can be detected using fluorescence-based optical biosensors. The fluorescence signal is enhanced upon pathogen binding, providing a clear indication of infection.
- **Surface Plasmon Resonance (SPR):** This technique measures changes in the refractive index at the sensor surface when pathogens bind to the recognition element. SPR sensors are particularly useful for detecting fungal pathogens.

- **Immunosensing:** Immunosensors that utilize antibodies or antigens can detect specific plant diseases by recognizing the pathogen's unique molecular signatures.

Advantages:

- **Label-Free Detection:** Optical biosensors can often detect pathogens without the need for complex labeling techniques.
- **Real-Time Analysis:** These sensors can provide real-time detection of infections, offering quick insights into plant health.
- **Multiplexing Capabilities:** Some optical biosensors can detect multiple pathogens simultaneously, enabling broader disease screening.

3. Imaging Technologies

a a. Hyperspectral and Multispectral Imaging

Hyperspectral and multispectral imaging have emerged as cutting-edge diagnostic tools in plant pathology, enabling non-invasive, precise detection of plant diseases and pests. These technologies rely on capturing images across multiple wavelengths of light, from visible to infrared, which provide valuable insights into the plant's health status.

- **Hyperspectral Imaging:** This technology captures hundreds of spectral bands, offering a detailed analysis of the plant's biochemical and structural properties. By analyzing the reflected light across different wavelengths, hyperspectral imaging can detect subtle changes in the plant's physiology, often before symptoms are visible to the human eye. This allows for early detection of diseases, such as fungal infections, bacterial blights, and viral diseases, which often alter the chemical composition of the plant. It can also be used for monitoring environmental stresses like drought and nutrient deficiencies.
- **Multispectral Imaging:** Unlike hyperspectral imaging, multispectral imaging captures light in fewer spectral bands, typically ranging from 3 to 10 bands. Despite having fewer data points, multispectral imaging is more cost-effective and can still

provide crucial diagnostic information. This technique is widely used in agriculture for detecting disease symptoms, leaf chlorophyll content, and plant stress. It can be applied in both field and controlled environment conditions, offering a valuable tool for remote sensing and precision agriculture.

Both techniques offer non-destructive, high-throughput methods for monitoring crop health, enabling rapid and accurate disease detection, and facilitating early interventions. These imaging technologies are integral to precision agriculture, where timely diagnosis can lead to more targeted and effective management strategies, minimizing the use of chemicals and reducing crop loss.

b. Thermal Imaging

Thermal imaging technology captures the heat emitted by objects, allowing for the visualization of temperature variations on plant surfaces. In plant pathology, this technique is used to detect changes in plant temperature that may indicate disease presence or stress.

- **Temperature Variations:** Infected plants often exhibit altered temperature profiles due to changes in their physiological processes. For example, fungal or bacterial infections can lead to localized changes in leaf transpiration, causing thermal anomalies. By using infrared thermography, plant pathologists can identify these temperature differences, which may signal the onset of diseases such as powdery mildew, root rot, or vascular wilt diseases.
- **Water Stress Detection:** Thermal imaging can also be used to monitor plant water status. During drought conditions or water stress induced by disease, plants may lose their ability to regulate temperature through transpiration, which can be detected as temperature variations across plant tissues. This helps in early diagnosis of water-related stresses, even before visible symptoms like wilting or discoloration appear.
- **Precision in Disease Management:** Thermal imaging is particularly beneficial in large-scale agricultural operations where traditional diagnostic methods may be time-consuming and labor-intensive. It allows for the rapid identification of affected areas, guiding targeted treatment interventions, and reducing the spread

of disease. Additionally, it can be used in conjunction with other diagnostic technologies like multispectral or hyperspectral imaging for a comprehensive understanding of plant health.

4. Nanotechnology-Based Diagnostics

Nanoparticle-Based Assays

Nanoparticle-based assays harness the unique properties of nanoparticles to detect plant pathogens at very low concentrations. These assays often use gold nanoparticles, silver nanoparticles, or carbon-based nanoparticles, which interact with specific biomolecules produced by pathogens. The key features of nanoparticle-based assays include:

- **Enhanced Sensitivity:** Nanoparticles increase the surface area for pathogen interaction, improving detection sensitivity.
- **Colorimetric Detection:** Many nanoparticle assays change color upon binding with pathogen-specific antigens, making detection visible without complex instrumentation.
- **Multiplexing Capabilities:** Nanoparticles can be engineered to detect multiple pathogens simultaneously, increasing the efficiency of diagnostics.

2. Quantum Dots

Quantum dots (QDs) are semiconductor nanoparticles that exhibit unique optical properties, such as fluorescence, which can be tailored for specific applications in plant pathogen diagnostics. Quantum dots are used in various diagnostic methods such as:

- **Fluorescence Imaging:** QDs can be conjugated to antibodies or nucleic acids that bind to pathogen-specific targets. Their intense and stable fluorescence makes them ideal for high-sensitivity imaging and detection.
- **Biomarker Detection:** QDs can be designed to bind to specific biomarkers expressed by pathogens, allowing for precise detection in plant tissues.
- **Rapid and Accurate Detection:** The high quantum yield of QDs enables rapid detection even at low pathogen concentrations.

3. Digital Platforms and Artificial Intelligence

Nanotechnology-based diagnostic tools are increasingly integrated with digital platforms and artificial intelligence (AI) to improve diagnostic accuracy and decision-making. AI algorithms process complex data from diagnostic tests, enabling faster, more accurate results. Some applications include:

- **AI-Driven Image Analysis:** Using AI, images generated from nanoparticle assays or QD-based fluorescence can be analyzed in real-time to detect subtle changes in plant health, which could indicate the presence of pathogens.
- **Predictive Analytics:** AI models can predict the likelihood of plant disease outbreaks by analyzing environmental data, pathogen detection results, and historical trends.
- **Automated Systems:** AI-enabled automated diagnostic systems can perform high-throughput testing, processing large amounts of data quickly, which is especially useful for large-scale farming operations and research settings.

INTEGRATION INTO PRECISION AGRICULTURE

In the realm of precision agriculture, the integration of advanced diagnostic tools for plant pathology has revolutionized how crop health is monitored and managed. Precision agriculture relies heavily on the use of cutting-edge technologies such as remote sensing, drone imagery, sensors, and machine learning algorithms to monitor the condition of plants in real time. These tools enable the detection of early signs of plant diseases with high accuracy, which is crucial for timely intervention. In plant pathology, the use of molecular diagnostic techniques, such as PCR (Polymerase Chain Reaction) and metagenomics sequencing, has enhanced the ability to identify pathogens at a genetic level, even before symptoms appear on plants. Furthermore, the integration of soil health monitoring and climate data allows for a more holistic understanding of the environmental factors that contribute to disease outbreaks. The use of decision support systems (DSS), which combine diagnostic data with predictive modeling, enables farmers to implement targeted, site-specific management practices. This minimizes the use of chemical inputs and reduces the environmental footprint while optimizing crop health and yield. By leveraging these advancements, precision agriculture is transforming plant pathology into a

proactive, data-driven discipline that supports sustainable agricultural practices.

CHALLENGES AND FUTURE DIRECTIONS

The challenges in plant pathology diagnostic tools include the need for high sensitivity, rapid detection, and cost-effectiveness, especially in resource-limited areas. Current methods often struggle with complexity, accuracy, and scalability. Future directions should focus on developing portable, user-friendly technologies that can integrate molecular techniques, such as CRISPR-based assays and next-generation sequencing, for real-time field diagnostics. Moreover, enhancing artificial intelligence and machine learning models for data interpretation could significantly improve diagnostics. Collaborative efforts between researchers, industry, and policymakers will be crucial in overcoming these challenges, ensuring early disease detection and effective management strategies for sustainable agriculture.

CONCLUSION

In conclusion, the advancements in diagnostic tools for plant pathology have significantly enhanced early detection, accurate identification, and efficient management of plant diseases. These innovations, including molecular techniques, imaging systems, and bioinformatics, are crucial for improving crop health, ensuring food security, and supporting sustainable agricultural practices.

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CHAPTER - 7

GENDER ANALYSIS FRAMEWORKS AND TOOLS FOR WOMEN'S EMPOWERMENT

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Abstract

Frameworks for gender analysis are crucial for comprehending and resolving gender inequalities in a variety of domains, such as education, agriculture, and health. By analysing the roles, responsibilities, and resource access of men and women, these frameworks such as the Gender Analysis Matrix (GAM) and Moser's Triple Roles Framework offer formal methods for evaluating and addressing gender inequality. The triple responsibilities of women such as productive, reproductive, and community-based are highlighted in Moser's paradigm, underscoring their concurrent contributions to the welfare of the home and society. In order to address cultural and socioeconomic variables that affect gender roles, GAM places a strong emphasis on community participation. The frameworks pinpoint both strategic needs such as strengthening decision-making authority and removing structural obstacles and practical needs, including everyday basics. They encourage communities to assess and question established conventions that impede equity and support participatory planning. These strategies are utilized in agriculture to ensure inclusion and less hardship for women by coordinating extension activities with gender roles. By addressing gendered vulnerabilities in health, they enhance everyone's access to treatments and results. By promoting

cooperation and inclusivity, these frameworks guarantee the sustainability of interventions in addition to promoting equity and empowerment. They are crucial for making significant strides toward gender equality in a variety of cultural and socioeconomic contexts because of their adaptability and transformative methodology.

Introduction

Women plays a significant and majority of the roles in the agricultural and allied sectors such as weeding, sowing, animal feeding, poultry rearing etc., and they also considered to play different roles in the society and household including mother, wife and animal caretaker too (Balgah. *et.al.*, 2019). In this regards they have ability and endurance to play triple roles so called in gender context such as productive role, reproductive role and community role (Moser, 1989). Analysing the differences between men and women would help us to better understand their roles, responsibilities, and power relations (EIGE, 2024). Therefore, it could lead to special focus on the women's empowerment in the spheres of social, economic, political, health, psychological, legal and spiritual (Longwe, 2002). For women's empowerment, we need to focus gender mainstreaming the different programmes, projects, polices that should be identifiable through the help of different frameworks, tools given by various authors worldwide. Particularly to focus vulnerabilities and capacities, there was a framework developed to find out strengths, weaknesses and how to overcome weaknesses (Anderson and Woodrow, 2019).

Gender Analysis

A mainstreaming method begins with gender analysis, which is an investigation of the roles and interactions that exist between men and women. Gender analysis finds, examines, and guides measures to rectify disparities that result from the disparities in power between men and women, or the distinct roles that each plays, and the effects that these disparities have on their lives, health, and general well-being.

Frameworks and tools

A collection of principles, concepts, or a structure for measuring something or anything that is applied harmoniously. In our context which is related to measurement of gender analysis.

Familiar frameworks and their authors

S. No	Frameworks/Tools	Authors/Institutions
1.	Harvard Gender Analysis Framework	Harvard Institute for Int. Dev., USA
2.	Gender equality and empowerment	Sarah Longwe
3.	People oriented planning	UNHCR
4.	Gender Analysis Matrix (GAM)	Rani Parker
5.	ABC Analysis of Gender	Wanjiku Mukabi Kabira and Masheti Masinjila
6.	Gender planning in third world countries	Caroline Mosher
7.	Social relations Framework	Naila Kabeer
8.	Socio-economic and Gender Analysis (SEAGA)	FAO, Rome, Italy
9.	Guidelines for the Analysis of Gender and Health	Liverpool School of Tropical Medicine, England
10.	Triple roles Framework	Caroline Mosher
11.	Capacities and Vulnerabilities Analysis (CVA)	Anderson and Woodrow

1. Gender Analysis Framework of Harvard Institute

It has known as **gender roles framework**. It was one of the pioneer frameworks developed in USA. This grid/matrix maps the labour of men and women in a community and highlights significant distinctions in order to assist planners in designing projects that are more effective and enhancing overall productivity. There are four primary parts to it.

1. An "**activity profile**" asks who does what, by age, time, and workplace, and lists all pertinent productive and reproductive tasks.
2. An "**access and control profile**" enumerates the tools utilized to execute the labour and the rewards received from it, as well as who controls and has access to those rewards

3. An "**Influencing factors**" and "trends" graphic shows the elements that have an impact on the gender differentiation of resources or activities this aids in locating opportunities and limitations from outside sources.

4. Project identification, design, execution, and assessment are the fourth stages of the project cycle. A "**Project Cycle Analysis**" examines project concepts or areas of intervention considering social change and gender-disaggregated data.

The planner will be guided by a series of questions at each step. They consider, among other things, the needs of women, their access to or control over resources and benefits, the project staff's awareness of those needs, and the participation of women in implementation and assessment. Personnel, organizational structures, operations and logistics, budgets, and flexibility are examined in the questions being implemented.

2. Women's Empowerment Framework (Sara Hlupekile Longwe)

Sara had developed a framework for analysing gender issues in order to find out the root causes of gender gaps or discrimination then developed the five levels of empowerment framework to effectively deals with the women's level of empowerment.

Condensed synopsis of identified gender concerns

Gender Gap: A quantifiable difference between men and women in areas such as access to resources, education, or property ownership. These disparities are unfair and demonstrate the existence of gender-related problems.

Gender Discrimination: Inequitable treatment that leads to gender disparities, frequently aimed at girls and women. It results from governmental policies that restrict equal opportunities, legal frameworks, or social norms.

Patriarchal Control: A structure in which men predominate in positions of decision-making, hence sustaining gender inequity and male privilege.

Patriarchal Belief: Concepts that present inequality as normal or unalterable and use biological explanations, religious interpretations, or cultural norms to support male supremacy.

Coercion: When patriarchal views questioned, violence, such as institutional or domestic abuse, used to impose male control or subjugation.

Women's Empowerment Process

Patriarchal systems entrench gender issues; bottom-up strategies should replace top-down approaches. Empowering women enabling them to take greater control over public decision-making is essential to dismantling discriminatory practices and achieving equitable resource distribution and gender roles. Empowered women actively reform policies and systems that perpetuate inequality. Male-dominated administrative structures maintain male privilege, assigning women the majority of responsibilities while allowing men to disproportionately reap societal benefits. Historical evidence reveals that male leaders rarely advance gender equality voluntarily. In gender, politics, as in all power dynamics, authority must be claimed, not passively awaited. (Sara, 2002).

The Women's Empowerment Framework: The Five Levels of Access to

1. Welfare
2. Access
3. Conscientisation
4. Mobilisation
5. Control

1. Welfare

The lowest level at which a development intervention may aim to close a gender gap is referred to as welfare. Here, "welfare" refers to a change in socioeconomic standing, such as better income, housing, or nutritional status. However, if an intervention is limited to this welfare level, we are discussing the provision of these benefits to women rather than their creation or acquisition. Women are thus the passive recipients of advantages that are "given" from above at this level of empowerment, which is zero.

2. Access

Since women raise their own status in comparison to men by their own efforts and organization because of having greater access to resources, access is here, described as the first degree of empowerment. For instance, female farmers can enhance their overall well-being and productivity by raising access to knowledge, land, water, markets, and skill development. However, were they "given" information deemed suitable by "higher authorities"? Alternatively, did they expand

access for themselves? If the latter, it indicates the start of a conscientisation process, in which they identify, evaluate, and act to address their own issues.

3. Conscientisation

The process by which women come to understand that structural discrimination, not personal shortcomings, is the cause of their inferior status known as conscientisation, and it inspires group action to remove obstacles to resource access. In order for women to recognize the underlying reasons of inequality and plan for change, improved information and communication are essential. Progressive women's leadership is essential to up ending long-standing patriarchal conventions and advancing the cause of equity.

4. Mobilization

Mobilization is the next action of conscientisation, which turns awareness into action. It entails women banding together to discuss issues, come up with solutions, and act as a group to end discriminatory practices. By connecting local groups with the global women's movement to exchange triumphs and join the larger fight for equal rights, effective communication broadens this effort. By organizing, modifying already-existing women's organizations, and establishing connections with the international sisterhood to fortify the struggle for gender equality, leadership plays a critical role in promoting mobilization.

5. Control

When women get direct access to resources and equal decision-making authority, they can acquire control and stop depending on patriarchal structures to provide them what is properly theirs. This phase symbolizes the result of empowerment and group effort. In order to share effective tactics that may be modified for use in different countries, like those created in Zambia to assist widows in maintaining their property rights, information and communication are essential. Reducing poverty and marginalization among women in Southern and Eastern Africa requires addressing behaviour's like property grabbing.

Conscientisation, mobilization, access, participation, and control are the five stages that make up a circular process rather than a strictly sequential one. Gaining more control makes it easier to obtain resources, which raises women's socioeconomic standing and strengthens their capacity to effect more change.

Three levels of participation issues in project design

1. **Negative shade** – **Never** talking about women issues openly into the project, makes it 100 percent left out situations.
2. **Neutral shade** – **Identified** women issues but not concerning about them and deliberately not including them in a project.
3. **Positive shade** – **Identified** issues and having more concern about them to take actions in the project. Respecting and honouring them equal to men

Women's empowerment is essential to rural development because it encourages their involvement and mobilization, which naturally develops leadership to confront and eradicate gender discrimination. Since empowerment is the foundation for meaningful participation in rural development programs, it is imperative to prioritize it to address the oppression and marginalization of women in many Third World nations.

3. People Oriented planning (UNHCR)

This framework familiarly known as POP and is actually a sequel of the Harvard analytical framework by refining its lacunas and adapted for the refugees situations. **Canadian International Development Agency. (CIDA)** funded for this development. Mary Anderson and Howarth modified it for the **United Nations High Commission on Refugees.**

Aim: It must promote the equitable sharing of sponsor's resources to all with specific targeting and decreasing the differences between the sexes while allocating resources

Components of the framework

1. The determinants Analysis (Refugee population profile)
2. The activities analysis
3. The use and control of resources analysis

Key factors to consider in the framework

Change: After any disasters or wars, the people position changes rapidly and largely. In that, time men and women should stay strong and support

each other for changing their positions like before they lived. Strong mentality, values and perception are formed to recover from those hard situations is very important.

Participation: Participant readiness and willingness is very crucial for the success of any development interventions.

Importance of analysis: Major emphasis on progressing their socioeconomic and demographic conditions

4. Gender Analysis Matrix

Rani Parker created the Gender Analysis Matrix (GAM) in 1993 to address the need for a framework suitable for grassroots efforts. GAM is explained by Parker (1993) utilizing the questions What, Why, Who, When, and How. A participative instrument assesses the impact of agricultural production, processing, and marketing practices on men.

Women treated differently in the community. The community-focused approach encourages participants to examine cultural disparities between men and women and challenge gender stereotypes. A community can evaluate men and women's labour habits to determine their impact on wellbeing, time utilization, and earning potential. If a discriminatory activity against women were identified, the community can take action to promote equality.

Fundamentals of GAM summarized into three points

1. Community Knowledge: Both men and women in the community possess all relevant information about themselves and their community.

2. Facilitator's Gender Awareness: While community people do not require gender understanding, extension agents who facilitate GAM must comprehend gender analysis.

3. Transformative Impact: GAM promotes transformative change by allowing the community to identify problems and validate solutions collectively.

Best Practices using GAM

- Discuss each problem area with all levels of the community, including women's groups, men's groups, households, and the larger community.
- Ensure that mixed groups have an equal representation of men and women.
- Use a trusted third party (e.g., an extension agent) to encourage

discussions, broker solutions, and resolve issues.
 - Determine how each problem affects community members based on gender roles, tasks, opportunities, and goals.
 - Follow-ups must be conducted to assess progress, adapt interventions, track changes, and identify unexpected results.

GAM Matrix: An Overview

GAM Matrix

Intervention	Labor	Time	Resources	Culture
Men				
Women				
Household				
Community				

(Source: FAO)

The Gender Analysis Matrix (GAM) is a tool for analysing interventions based on their effects across four dimensions: **labour**, **time**, **resources**, and **culture**, with categories for men, women, households, and communities.

Coding System:

Symbol Plus (+) indicates the outcome is consistent with community aims or cultural traditions.

Symbol Minus (-) indicates the outcome contradicts community goals or cultural traditions.

Question Mark (?): Uncertainty regarding congruence with community goals or procedures.

Flexible Categories

Additional categories (e.g., for specific groups like girls) can be created as needed.

Time Commitment

The process usually takes 2-3 hours to complete.

Outcome

A finished, coded matrix demonstrates how proposed treatments affect various groups and dimensions.

GAM Tool 1: Levels of Analysis

Men: This category includes males of all ages from the target demographic or community.

Women: Refers to women of all ages in the target group or community.

Household: All individuals living under the same roof. Define "household" according to cultural context (for example, extended family in some culture)

Community: This term refers to the entire community. Define "community" clearly, as it can refer to a variety of groups with different interests.

Key Variables: Refine the matrix by taking into account age, class, ethnicity, caste, and other social aspects.

GAM Tool 2: Impact Analysis

Labour: Examines how tasks have changed, what skills needed, how many people are involved, and whether more labour needed.

Time: Monitors variations for time required to finish tasks.

Resources: Analyses shifts in who has access to and authority over resources like as money, land, and knowledge.

Socio-Cultural Factors: Assesses how the intervention has affected gender roles, social standing, and cultural barriers.

5. ABC of Gender Analysis (Wanjiku Mukabi Kabira and Masheti Masinjila)

This analytical technique developed by the Forum of African Women Educationalists (FAWE) in order to identify and remove the various obstacles that are present in the risk of developing a gender-neutral curriculum. Thus, the awareness and information generated among the various participants in this process, including curriculum creators,

illustrators, artists, publishers, writers, tutors, and designers. It provides the credible and realistic gender screening for review of textbooks, materials and resources so it could empower the boys, men, girls and women specifically in different context.

It is mainly focusing on the finding of disparities and discrimination and leading to visionary thinking such as what is discrimination? Why these we need? What will done?

A. Components of the framework

The framework divided into two interconnected sections: Part I covers presentation, framework usage, analysis, and tactics. While the first concerns the text's composition, the second focuses on identifying gender disparities using both qualitative and quantitative data, which leads to the development of suitable solutions for closing the gaps.

B. Use of the framework

It is main thing to understanding the gender responsiveness of textbooks and other educational materials and what might be changed to fulfil the interests and distinct characteristics of the men, women as well boys and girls. It is quite favourable in various circumstances where fairness and equality of access to knowledge ensured. The framework also suggests eradicating the negative points against gender. Lastly this framework can be applied to different disciplines may be some exception also there, but it is very dynamic tool to change accordance with different subjects.

C. Analysis and Strategies

Data collected from the above sections could lead to the analysis part and asking our self-questions include

- What gender gaps exist?
- How we can fulfil these gaps?
- What are the different strategies to solve?
- How we can execute these strategies to solve and resolve the gaps?

This part aids in determining the fundamental causes of the circumstance that the analysis depicts. Among the contributing factors may be

- Socialization.
- Customs and conventions
- Cultural expectations.
- The instructors' backgrounds.
- The sex of the editors, writers, illustrators, or instructors.
- Publishers' attitude.

Addressing gender gaps in education through awareness, analysis, and action is the focus of the **ABC of Gender Analysis**. Educating and training educators, publishers, and legislators on the importance of including gender responsiveness into texts, instruction, and assessments is one of the main tactics. For effective implementation, policies must include mechanisms for building capacity and require gender-responsive materials. Closing gaps requires gender analysis of textbooks and classroom materials, which makes this framework an essential resource for curriculum authors, publishers, and educators.

6. Gender planning framework (Caroline Mosher)

This framework tends to introduce the triple roles of women and its implications for the different development process. Moser developed it in the 1980s at University of London, UK. It follows the approach called gender and development and more concentrating on the gender strategic needs and relations. It focuses on the role identity, needs assessment, decision makers within family, disaggregating control of resources, keeping a balanced responsibility in the triple roles, ultimately it discovers the gender inequalities to solve and resolve it properly at policy, project or programme level.

Moser proposed the division of (women's) labour into three groups: childcare and household-related reproduction; production (agricultural labour or other commercial endeavours); and sociocultural (community-based) roles. In contrast to men, who tend to be more involved in production and community-oriented activities and less involved in family chores, the majority of women in developing nations frequently take on numerous tasks at once.

Heart of the Mosher's Framework

1. Women's Triple Role
2. Practical and Strategic gender needs

3. WID/GAD Approaches

Components of Framework

Component 1: Gender triple roles identification: as it mentioned above different sub roles under three main roles including productive, reproductive and community roles.

Component 2: Gender needs assessment: Practical needs and Strategic needs, this framework mainly concentrating on the strategic needs because the women do not easily achieve it, as they are subordinate to men in social status. Rights such as decision-making power, legal, equal remuneration, control on their own body, sex, removing domestic, workplace violence, and sexual harassment.

Practical needs are day-to-day necessary requirements or immediate things required to run the life, it is quite achievable everywhere around the world, and those considered as basic amenities. Such as food, water, shelter, cloths etc.

Component 3: Decision making and disaggregation within household

The components deals with what are the resources available and how the allocations happens within the household and by whom? In addition, who is the superior decision maker and problem solver?

Component 4: Balancing the triple role

Planned programme, project or policy should created in such a way that must not narrow down too much responsibilities in one main role like too much focus into community role while leaving rest of roles or too much focus into productive role while not caring other main roles such as reproductive and community role. Therefore, it must maintain the balance in roles and responsibilities of all main roles so called “triple role”.

Component 5: Differentiating between distinguished aims in interventions

This tool mainly used for the evaluation of the development interventions and what kind of frameworks can used in the future works. Moser framework appreciate to find out transformation or change of

subordinate positions of women through policies, projects, programmes and what extent they able to meet out practical and strategic gender needs. To support the above statements she has given five policy approaches namely welfare, equity, anti-poverty, efficiency and empowerment.

Component 6: Encouraging participation of women, gender based institutions in planning interventions

Premier gender institutions, gender analyst, feminist, social workers should become the part of the planning, designing, implementation and execution of the development programmes to identify and eradicate the discriminative activities or bias towards the women in the society.

Example: Central Institute of Women in Agriculture (CIWA), Bhubaneswar

7. Social Relations Framework by Naila Kabeer

In partnership with academics, activists, and policymakers, Naila Kabeer of Sussex University's Institute of Development Studies in the United Kingdom established the Social Relations framework for gender study.

This framework built on several key theoretical concepts

1. **Development:** Viewed as the process of enhancing human well-being.
2. **Social Relations:** According to Kabeer, these structural relationships generate systemic disparities in how different groups can be positioned.
3. **Institutional Analysis:** Gender inequality is not only a micro-level issue (e.g., within households) but is perpetuated across various institutional levels (macro, meso, and micro). Institutions, defined as frameworks of rules that guide social or economic objectives, reinforce and reproduce social inequalities. Kabeer analyses the assumption of ideological neutrality and independence of institutions, noting that changes at one institutional level can affect others.
4. **Institutional Characteristics:** Kabeer identifies five common aspects of institutions which are rules, resources, people, activities, and power for understanding social and gender inequality.

Examining these dimensions, helps analyse who benefits and who loses in the gender hierarchy.

5. **Gender Policies:** These can be categorized as:
 - **Gender-blind:** Ignore gender differences, reinforcing inequalities.
 - **Gender-neutral:** Operate within existing gender roles without challenging them.
 - **Gender-sensitive:** Recognize gender inequalities and aim to address them through policy.
 - **Gender-positive:** Actively address gender inequalities by changing norms and structures.
 - **Gender-transformative:** Focus on reshaping gender relations to empower women and promote shared control over resources.
6. **Causes of Gender Inequality:** The analysis of immediate, underlying, and structural causes of gender disparities involves understanding factors and their impacts on different groups.

Steps for Applying the Framework:

1. Analyse development in terms of human well-being.
2. Investigate the role of social relations in creating systemic disparities.
3. Assess institutional structures and their role in perpetuating inequalities.
4. Identify and analyse institutional characteristics (rules, resources, power, etc.).
5. Categorize gender policies to evaluate their impact on inequality.
6. Examine the causes of gender inequality at different levels (immediate, underlying, and structural).

8. SEAGA Framework

The **Socio-Economic and Gender Analysis (SEAGA)** framework, developed by the **Food and Agriculture Organization (FAO)**, is a development approach that combines socio-economic and gender analysis to ensure that development efforts meet the real needs of people. SEAGA's goal is to align development outcomes with the needs of individuals, particularly in terms of gender and socio-economic status.

Key components of the SEAGA framework include:

1. **Socio-Economic and Gender Analysis:** It integrates socio-economic analysis with gender analysis to understand the linkages among social, economic, and environmental patterns within communities. This helps in clarifying the division of labour (especially by gender) and identifying resource use and control patterns. It also aids in understanding community participation and institutional roles.
2. **Levels of Analysis:**
 - **Field Level:** Focuses on individuals, especially men and women, households, and communities. It examines socio-economic differences within these groups.
 - **Intermediate Level:** Involves institutions and services that connect the field and macro levels, such as markets, credit systems, communication, transportation, and services like health and education.
 - **Macro Level:** Focuses on national and international policies, economic and social plans, including trade, finance, and national development agendas.
3. **Guiding Principles:**
 - **Gender roles are key:** Understanding how gender affects roles and responsibilities within the community.
 - **Disadvantaged people are priority:** Ensuring that those who are most marginalized are a focus of the analysis.
 - **Participation is essential:** Engaging local communities, particularly women and men, in identifying priorities and solutions.

The FAO provides practical tools for field workers, development planners, and policymakers to implement SEAGA in their work, ensuring that gender and socio-economic factors are central to development planning.

9. Gender Analysis Framework for Health

The Gender Analysis Framework for health is a systematic approach developed by the Gender and Health Group at the Liverpool School of Tropical Medicine. This framework addresses the role of gender

in health disparities and seeks to integrate gender considerations into health policies, research, and services. Its foundation lies in recognizing that gender influences vulnerability to illness, access to healthcare, and overall health outcomes.

Components of the Framework

The framework consists of three core components:

1. Patterns of Ill-Health

Identifies who suffers from various illnesses, focusing on differences across gender, age, socio-economic class, and ethnicity.

2. Factors Affecting Ill-Health

Explores the reasons why certain groups are more susceptible to specific health issues, considering social, economic, and cultural dynamics.

3. Responses to Ill-Health

"Gender roles and norms influence how men and women respond to illness, including their access to and use of healthcare services."

Each component involves the use of matrices to analyse factors such as environment, activities, bargaining positions, access to resources, and societal gender norms.

How It Works: The framework applied in a stepwise manner

1. **Data Collection:** Gather quantitative and qualitative data on morbidity and mortality, disaggregated by sex, age, and other social factors.
2. **Analysis:** Use the matrices to identify disparities and uncover root causes, focusing on how social and economic contexts intersect with gender roles.
3. **Strategy Development:** Formulate actionable plans to address gender inequities in health through policy design, resource allocation, and service delivery improvements.

Application in the Field of Health

- Highlight gender-specific health vulnerabilities, such as women has increased exposure to diseases due to caregiving roles or men's occupational health risks.
- Design gender-sensitive interventions that address barriers like socio-cultural norms restricting women's access to healthcare or men's reluctance to seek care for stigmatized conditions.
- Enhance equity by tailoring health services to meet the unique needs of different gender groups, improving both effectiveness and inclusivity.

For example, it is helpful in reproductive health to ensure that maternal healthcare services address not only biological needs but also social determinants like resource allocation and decision-making power within households. Similarly, in infectious disease management, the framework identifies how gendered activities, like water collection or farming, affect exposure risks and healthcare-seeking behaviours.

10. Moser's Triple roles framework

It is a powerful tool for understanding the division of labour and addressing gender-specific needs within households and communities. Developed by Caroline Moser, this framework introduces the concept of women's "**triple roles**": productive, reproductive, and community roles. It emphasizes how women often juggle multiple responsibilities simultaneously, while men typically engage more in productive and community-managing roles.

Components of the Framework

1. **Reproductive Roles:** Tasks related to childbearing, caregiving, and household maintenance, such as cooking, cleaning, and fetching water. These activities are largely unpaid and often undervalued.
2. **Productive Roles:** Economic activities like farming, trading, or producing goods for sale or consumption. While both men and women participate, women's contributions frequently overlooked due to their dual burden of productive and reproductive roles.

3. **Community Roles:** Involvement in social and community work, ranging from organizing events to managing community resources. Men often take on political roles, while women tend to volunteer for social improvements.

How It Works

The Moser framework operates through several key steps

1. **Activity Mapping:** Involving men, women, and children in identifying their daily tasks using the triple roles framework.
2. **Needs Assessment:** Differentiating between practical gender needs (immediate, tangible resources like food or water) and strategic gender needs (structural changes like improved decision-making power or education).
3. **Analysis and Discussion:** Using the mapped activities and identified needs to analyse gender disparities and discuss strategies to address them.
4. **Intervention Design:** Tailoring programs to meet the identified needs while minimizing additional burdens, particularly on women.

Application in Agricultural Extension

1. **Map Household Activities:** To get a complete picture of each person's responsibilities, have men, women, boys, and girls identify everyday tasks using the triple roles framework.
2. **Determine Needs:** Separate strategic needs like decision-making authority or time autonomy from practical needs like daily resource requirements.
3. **Examine and Make a Plan:** Talk about the results with participants to make sure treatments lessen their workload and to match extension program times with women's availability.
4. **Customize Interventions Collaboratively:** Include men and women in the creation of gender-sensitive extension initiatives that successfully meet their unique needs and roles.

11. Capacities and Vulnerabilities Analysis (CVA)

The foundation of the CVA is the idea that a person's current strengths (or capabilities) and shortcomings (or vulnerabilities) dictate how a crisis affects them and how they react to it.

(March. *et.al.*, 1999)

The term "capabilities" describes the inherent advantages that people and social organizations possess. They have to do with people's beliefs and attitudes, as well as their material and physical resources and social resources. People's capacities, which are developed over time, dictate their capacity to handle and bounce back from crises.

Vulnerabilities are long-term conditions that make it harder for people to deal with long-term catastrophes or the abrupt onset of disasters. They also increase a person's vulnerability to calamities. Vulnerabilities predate disasters, increase their intensity, complicate effective disaster response, and persist after a disaster.

Main Components of the CVA Framework (March. *et. al.*, 1999)

1. Physical or Material Capacities and Vulnerabilities

This dimension assesses tangible resources, such as agricultural tools, land, water access, and infrastructure. It examines how these resources, or their lack, impact a community's ability to respond to crises. In agricultural extension, understanding material vulnerabilities like water scarcity or soil degradation enables targeted interventions that address specific needs.

2. Social or Organizational Capacities and Vulnerabilities

This category explores the social fabric, including governance structures, family roles, and community networks. It recognizes that societal norms and hierarchies can either strengthen or hinder community resilience. For example, agricultural cooperatives or women's networks can be pivotal in knowledge dissemination and resource-sharing, but social exclusion can exacerbate vulnerabilities.

3. Motivational and Attitudinal Capacities and Vulnerabilities

This dimension focuses on psychological and cultural factors, such as confidence, belief systems, and expectations. In agriculture, motivational aspects influence how farmers perceive new technologies or their ability to adapt to environmental changes. Addressing these factors is crucial for fostering a sense of agency and encouraging the adoption of innovative practices.

Application of CVA in Agricultural Extension

The CVA framework is invaluable in agricultural extension as it provides a structured approach to designing effective interventions. By

identifying material vulnerabilities like inadequate irrigation systems, extension programs can offer technical solutions tailored to local conditions. Social capacities such as established community networks can be leveraged to ensure widespread adoption of new techniques. Additionally, addressing motivational vulnerabilities, such as resistance to change due to past failures, can foster a proactive attitude toward agricultural innovation.

CVA Matrix Example for Agricultural Extension

Category	Vulnerabilities	Capacities
Physical/Material	Limited access to water, tools, and agricultural technology.	Knowledge of traditional farming methods; locally available resources.
Social/Organizational	Exclusion of women in decision-making; weak cooperative structures.	Strong informal networks; presence of community leaders for mobilization.
Motivational/Attitudinal	Fatalism due to repeated crop failures; low trust in extension programs.	Resilience built from past crises; willingness to experiment with solutions.

Conclusion

Frameworks for gender analysis are crucial for locating and resolving inequalities across a range of industries. In order to balance women's triple roles in production, reproduction, and community management, they assist in mapping roles, identifying needs, and designing inclusive solutions. Through meeting strategic and practical demands, these tools empower women, advance equity, and foster collaborative decision-making. Evolution of these frameworks according to the current situations may help to do comprehensive analysis, which are crucial for promoting inclusive and sustainable development because of their participatory approach.

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CHAPTER - 8

EVOLUTION OF MANAGEMENT THEORIES ON HUMAN RESOURCE MANAGEMENT

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Abstract

The area of management has changed the most, and the most recent management theories stem from classical and neoclassical principles. The classical theory laid the foundation of management science, focusing on, among other things, the efficiency of the organization and the hierarchy of the organization. The human element was introduced by the neoclassical concepts of social dynamics, employee welfare, and motivating people in organizations. These theories of management have all influenced modern procedures that aim to create a balance between the human-centred approach of leadership and the structural discipline of the organization. The modern management theories like systems theory, team-building techniques, and contingency theory have their foundation on the principles and include teamwork, flexibility, and substances such as quantitative analysis. Because organizations are seen as active, open systems that interact with their environment, then creative and adaptive management approaches become necessary. The pillars of planning, organizing, leading, and controlling are still critical for the attainment of effectiveness and efficiency. Managers can create a solid framework for decision-making and problem-solving by integrating the methodologies of various management schools. This evolution indicates that management is both a

science and an art, which in turn assists organizations in surmounting various challenges. Finally, neoclassical and classical philosophies are still part of modern management, fostering a balance between human influences on and goals of the organization.

Introduction

The word “management” is derived from a French language term called “menage,” which means housekeeping. It is generally saying a special group of people who are active in achieving special goals for themselves and general goals for others. According to Mary Parker Follet, “It is an art of getting things done through other people.” Managers usually manage the other people to do the work rather than working by themselves. Leadership forms an essential part in the proper and effective resource management. The styles are many. The evolution of the philosophies of management takes us from the pre-industrial revolution to the time of the two World Wars and then to the 1960s and 1980s, where significant economic growth took place. Over the last few decades, the management theories have evolved and become more complex as there has been a shift from behavioural sciences to quality control and then organisational structures. In its most basic form, human resource management (HRM) is the idea of organising a group of people towards predetermined objectives, and it has been around since the first humans settled on Earth. In the early 19th century, management theories got started to upgrade and elevate themselves and eventually led to the origin of classical organisational theory in the early 20th century (e.g., Fayol's administration and Weber's bureaucracy) (Chandan, 2002). In 1927, neoclassical theories gained momentum, such as behavioural school theory (e.g., Mayo's work), but they were well recognised in the mid-20th century (Dale., 1965). Modern management science schools, recent developments (e.g., systems approach, contingency theory, chaos theory, and team building) are gaining more scope and are adaptive in nature. According to the current environment we are living in, these originated in the 1950s and are still running in the different organizations. (Miftari, 2024)

Rationale behind understanding theories

All organisations exist with different objectives and goals, but it is not a wonder that resources were underutilized. Lack of effective management by upper management. There are no universal laws or regulations to run the organisations with management, and there is a lack of technical skills, training undergone, coordination, and cooperation in the

organisations, as well as an absence of systematic and cohesive performance from personnel. So, there is a need to comprehensively understand different theories focused on different outcomes or problems to apply in your own situation and working organisations.

However, there is a great deal of misunderstanding about what management is, what management theory and science are, and how to apply them because of the diversity of methods to management analysis, the tangle of research, and the quantity of opposing viewpoints. Analysis of managerial events is necessary. Some academics have referred to this situation as "the management theory jungle" for this reason (Koontz 1961). Although the jungle's flora has altered slightly since then, new methods have emerged, and more traditional methods have acquired new terminology and meanings; management science and theory advancements nevertheless retain the traits of a jungle.

Familiar Definitions

1. Management is the process of designing and maintaining an environment in which people work together in groups, efficiently, to accomplish objectives or goals (Koontz & Weinrich 1990, p. 4).
2. Management is an organ; organs can be described and defined only through their functions. (Peter F. Drucker)
3. "Management is the function of executive leadership anywhere." – (Ralph C. Davis)
4. To manage is to forecast and plan, to organise, to control, and to direct and coordinate resources effectively. This involves not only setting goals and objectives but also ensuring that all team members are aligned and motivated to achieve them. (Henry Fayol)

Natural characteristics of management

I. Management as science

It deals with people in a more scientific manner for their selection, work style, processing of tasks, creating outcomes, etc.

Ex. Scientific management theory of Fredrick W. Taylor, who is known as the father of scientific management

II. Management as an art

The creative, intuitive, and individual components of management are highlighted by the concept of management as an art. Like how an artist crafts a masterpiece, it entails applying experience, judgement, and talent to accomplish desired results. To inspire others, resolve issues, and reach choices, managers need to be creative, have good people skills, and be able to adjust to different circumstances.

III. Management as a profession

A profession is often governed by a code of ethics and standards of practice and is dedicated to serving the public or advancing a specific field. Examples include medicine, law, engineering, and teaching.

IV. Management as a group activity

It is usually several people working together with coordination and cooperation to achieve the common goals and objectives and separately focusing their individual goals as well.

Three levels of management

I. Top level

Which is considered an administrative point that includes critical thinking, planning, rules, regulations, decision-making, allocation of resources, and setting different goals and aims in the organization. Overall direction, exercising powers on employees, grievance addressal, etc., are the main roles of the top-level management. Conceptual and designing skills are utmost necessary at this level.

II. Middle level

Which is known as executory functions. It links the top and bottom levels of management as a bridge between them. Mainly concentrated on the execution of fixed policies, frameworks, goals, and objectives by the top level. Building cooperation and motivation from the bottom level to the top level. All three skills are required in this level, such as technical skills and humanistic skills, but conceptual skills are gaining importance.

III. Lower level

is ground-level or field-level management. They get commands and instructions from the middle-level management and transfer the ground-

level staff for actual operations to be done. Divide the big plans into relatively small and short plans for easy completion. This level consists of foremen, supervisors, and sales officers. Technical skills are absolutely required, followed by humanistic skills.

Peculiar difference between administration and management

According to Chester Banard, there is difference in terms of terms of their application, but meanings are mostly same in his book called functions of the executive. Administration is operational in both top and middle level only as they exercising powers, policies, plans down to the lowest level but management occurs at all levels of organization. Management is answerable to the administrative but not vice versa, with some exceptions.

Theories of management

I. Classical theories

1. Administrative theory (Henry Fayol)

No matter what type of organization we are working on, but we must employ the administration things from the top to bottom level of the organization for effective decision making, policy regulations and supervision. That's why it got the name of "Universality", and we can find the principles of administrative theory on modern management theories too. He is widely regarded as founding father of modern management theory. According to him, planning, organising, co-ordinating, commanding and controlling are the functions of management. (Dale., 1965).

Fourteen principles of administration

1. Principle of authority and responsibility

Authority (Power) and responsibility (Duties) should be equally balanced like a "weight balances". Socially and legally determined rights to exercise power and decision-making is known as authority and obligation on the part of employees to stick on the tasks, decisions and duties of order is known as responsibility.

2. Unity of command

Only one boss must derive orders to the respective personnel for ensuring that clear line of command and avoiding role ambiguity.

3. Unity of direction

All activities in specific objective should be handled by one manager with same rules and regulations.

E.g. All the production activities in the company handled by one manager himself such as raw materials selection, procurement, preparation, preproduction, production etc.,

4. Scalar Principle / line of command

Line of authority from top level to bottom level in an organisation is known as scalar chain principle, which is complimentary to the unity of command. More the clearer of scalar chain principle, more the effectiveness in decision-making and greater would be the efficiency

5. Division of work

According to specialization of work labours could be departmentalized for improving efficiency in achieving the goals and objectives of the organisation.

6. Discipline

It is necessary to the organisation (“**sine qua non**”- **Latin expression**). Employees should obey to the rules, regulations, norms or standards of the administration which maybe self-discipline or enforced discipline.

7. Subordination of individual interest to general interest

The individual interest should not surpass the general interest, and it is inclusive within the general interest of the organization. General interest given more importance than the individual interest.

8. Remuneration

Equal pay for the work done by the employees of the organisation for both men and women. Systematic and controlled reward to pay the good performance.

9. Centralisation / Decentralisation

It also could be balanced one with proper decision-making powers vested in superiors while maintaining the certain level of subordination in decision making to reduce burden on top level superiors.

10. Order

A place for everything and everything in its right place. Right person on the right job at a right time is essential to good and timely performance of all elements in the organization.

11. Equity

It is a sense of maintaining fairness and kindness to all the employees irrespective of their age, sex, birthplace, language etc., to maintain friendly environment.

12. Stability of staff

It implies the job security to the personnels who are competent, punctual, disciplined and talent enough to strive long enough in the positions.

13. Initiative

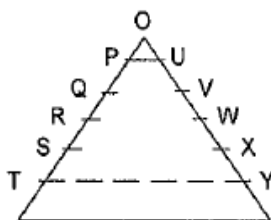
Without any restrictions from authority, all levels of management can create their own plans, strategies and execute them in a volunteer manner. All kinds of organizations should offer this freedom for creativity and smooth flow of work environment.

14. Esprit de corps (French word: Unity, Mutual loyalty)

Working with team spirit, cooperation among employees for creating synergically efficient organizations

Gangplank by Henry Fayol (Emergency bridge)

It is the process of accelerating the communication while decreasing the restriction. To actively make a conversation with same level hierarchy personnels known as cross sectional or **lateral communication**. It violates the principle of **scalar chain**.



Example: If T want to speak with someone in this figure. Typically, a message will travel from T to O via S, R, Q, and P, and from O it will descend to Y via U, V, W, and X. However, without undermining the chain of command, a Gangplank (dotted line) could be established between T and Y if communication must happen right away. So, it is also called as **short-circuit communication**.

Fayol divided the administrative activities into six groups (Chandan, 2002)

1. Technical, 2. Commercial, 3. Financial, 4. Security, 5. Accounting and 6. Managerial.

In these six groups, managerial was prime concern and it was exclusively covered by those above mentioned five functions of management.

2. Bureaucratic theory

Complete formal system of management to improve the effectiveness and efficiency of the organization. As the name suggests, bureaucratic administration is centred on a strict framework with a defined hierarchy, a distinct division of labour, and comprehensive policies and procedures. It offers a guide for the most effective way for an organisation to function.

According to Max Weber (1864–1920), it has seven traits

(i) Regulations (official directives for workers' conduct while they are on the job)

(ii) Impersonality (every worker is assessed in accordance with regulations and information)

(iii) Division of labour, which is the division of labour into more specialised, simpler tasks

(iv) Authority structure (identifies who has the authority to make decisions of varying importance at different levels within the organisation)

(v) Hierarchical structure (helps control the behaviour of employees by making clear to everyone where he or she stands in relation to everyone else in the organisation)

(vi) Lifetime career dedication, wherein job stability is ensured provided the worker is technically competent and performs well

(vii) Rationality (managers use scientific and logical reasoning)

The bureaucratic method works well when an organisation must manage a lot of standard data, when client needs are predetermined and unlikely to change, and when technology is regular and consistent, and the company must manage the work of multiple staff members to provide the client with a standardised service or product. A tribal chief's authority would be one example. The second type of power is charismatic, when the leader's authority stems from personal traits. Because followers believe in magical abilities, they bow to such authority. disclosures, or the leader's bravery (Weber, 1947).

Drawbacks

- i. Organization as a giant machine with human as active robots
- ii. Mainly emphasising on the incentives only
- iii. Ignorance of social, physical and psychological needs of human
- iv. Over rules and regulations that are rigid and static in nature
- v. Very formalised patterns and no call for changes over a period

3. Scientific Management theory

It is well accepted and acknowledged that among all traditional theories and it is based on below four assumptions. (Chandan, 2002)

1. To replace the outdated rule-of-thumb approaches, a science for every aspect of a man's work must be developed.
2. Workers must be selected, trained, and developed scientifically rather than being left to select their own duties and train themselves as best they can.
3. The creation of a culture of enthusiastic collaboration between management and employees to guarantee that tasks could be completed in line with scientifically developed protocols
4. The nearly equal distribution of work between management and employees, with each group taking on the tasks for which it is most qualified, as opposed to the previous scenario in which workers bore much of the responsibility (Accel Team (2004), Motivation in the workplace – theory and practice).

One of the most significant figures in terms of his influence on management service practice and management philosophy to this day is Frederick Winslow Taylor (1856–1915). Taylor led the charge in publishing "Principles of Scientific Management" in 1909. Who is known as father of scientific management because of his significant contributions.

The scientific management movement, a management philosophy that placed a strong emphasis on enhancing work practices by study and observation. Additionally, he popularised the use of financial incentives, which are sums of money given to employees whose output above a set threshold. All components of his framework for a successful company.

- (i) Clearly defining authority.
- (ii) responsibility
- (iii) separating planning from operations
- (iv) employee incentive programs
- (v) management by exception
- (vi) task specialisation

Functional foremanship concept

Taylor placed a strong emphasis on specialisation and conducted in-depth research on the interactions between individual workers and machines in production facilities. He was able to determine and quantify a worker's bodily movements while carrying out a task by using a time-and-motion study, whereby enabled him to examine the effects of these movements on an employee's output. Additionally, Taylor promoted the division of labour through functional foremanship, in which each work area is allocated a specific number of foremen, each of whom oversees the employees in their area of speciality.

Other pioneers in the scientific management field theories

Charles Bedaux (1887–1944), Henry Gantt (1861–1919), and Frank and Lillian Gilbreths (1868–1924) were some prominent names in the field of scientific management theorists. The laws of human motion were created by the Gilbreths through their many studies. The concepts of the economy of motion were the source of this success. For their area of study, they created the term “motion study” to distinguish it from those

who were involved in “time study.” They believed that method study should be twinned with this technique. They argued that employees should also have regular breaks, such as lunch or time for refreshments. The laws on child labour and the regulations that are established for employee protection from the life-threatening settings were all forged because of their efforts.

Neo-classical theories

The theories which built upon the principles of traditional theories with added components such as human behaviour, reactions, responses, interrelationships and relationships within the organization. Under the neoclassical approach, two significant groups including the behavioural school and the human relations school, emerged in the 1920s and 1930s. Elton Mayo and his associates conducted the Hawthorne studies in the late 1920s and early 1930s, which led to the behavioural viewpoint. It brought concerning a Human Relations Movement that incorporated the Theory X and Theory Y approaches of Douglas McGregor.

I. Behavioural theories

It deals with the study on how the managers must act and react with employees and how employees react and responds to the organizational rules, regulations, goals and objectives. Behavioural theories that emphasise the significance of group dynamics, complicated human motives, and the manager's leadership style came into being during the dramatic social and cultural transformations that took place in the 1920s and 1930s. Along with focussing on two competencies which are communication and teamwork. it also highlights the social and economic demands of employees and how the social environment of the company affects the amount and calibre of work performed. The term "human relations school of management" refers to this growing emphasis on human issues. Among the more well-known thinkers in this area were Frederick Herzberg (1923–2000), Abraham Maslow (1908–1970), Douglas McGregor (1906–1964), Rensis Likert (1903–1981), Elton Mayo (1880–1949), Mary Parker Follett (1868–1933), Chester Barnard (1886–1961), and David McClelland (1917 – 1998) and Chris Argyris (1923 – 2013).

1. Human relations theory (Elton Mayo)

Elton Mayo is a well-known behavioural theorist who, between 1924 and 1933, collaborated with Fritz Rothlisberger and William Dickson

to perform a groundbreaking study of the Western Electric Company's Hawthorne Plant in Chicago. Throughout his research, Mayo was able to shift the emphasis from physical and individual factors to the value of groups in the workplace, which calls for sociological and psychological analysis. Individual, workgroups and participative management are three important elements of it.

Important Aspects of the Hawthorne Experiments

1. **The illumination experiment** is about testing the relationship between productivity and lighting. There is no clear link in the outcomes indicating that other factors may have an impact on the production process.

2. **The Relay Assembly Test Room Experiment** was about the social and physical aspects like informal supervision, work hours, and periods of rest. It was concluded that the sociological/psychological variables including the cohesiveness of a group, being acknowledged, along with an environment that prompted participation were factors that affected productivity.

3. **Mass Interview Program:** A tool that utilized interviews became an insightful method for getting information on the perceptions of employees. The emphasis of the program was thus placed on the human and social factors.

4. A deep analysis of group dynamics and informal norms was made during the **Bank Wiring Test Room Experiment**. The experiment showed that groups often create their criteria for performance that hinder them from producing better results.

The Hawthorne Studies' Contributions

1. Organizations are social systems, not just technical-economic entities.
2. Psychological and social needs drive employee behaviour alongside economic incentives.
3. Cooperative attitudes and participative management are vital for success.
4. Two-way communication strengthens human relations.
5. Employee satisfaction directly impacts productivity.
6. Informal groups play a crucial role in organizational dynamics.

7. Employee morale is key to higher output, emphasizing the importance of the human element in management.

8. Money is not always a motivator for employees

2. Hierarchy needs theory of management

It is way related to job satisfaction and building their career based on fulfilling the basic needs of human to think over the top needs which are self-esteem and self-actualisation. It was developed by Abhram Maslow. It is quite applicable in the context of workplace motivation, education, counselling. etc., This theory also known as human motivation theory.



Fig.1. Illustration of basic needs to top level needs in five needs theory of Maslow

3. Three needs theory by Clayton

By classifying Maslow's hierarchy of needs into the ERG theory (Existence, Relatedness, and Growth), Clayton Alderfer expanded on it (ERG means Existence, Relatedness and Growth needs, Human Needs in the Organisational Setting Free Press, New York, 1972). To complement the ERG theory, Alderfer has put up a regression theory. According to his theory, people will put twice as much effort into a lower category if requirements in a higher category are not satisfied. The "push" idea, which holds that an individual

is driven or motivated by an internal condition, urge, or need, can be applied to both Maslow's and Alderfer's theories.

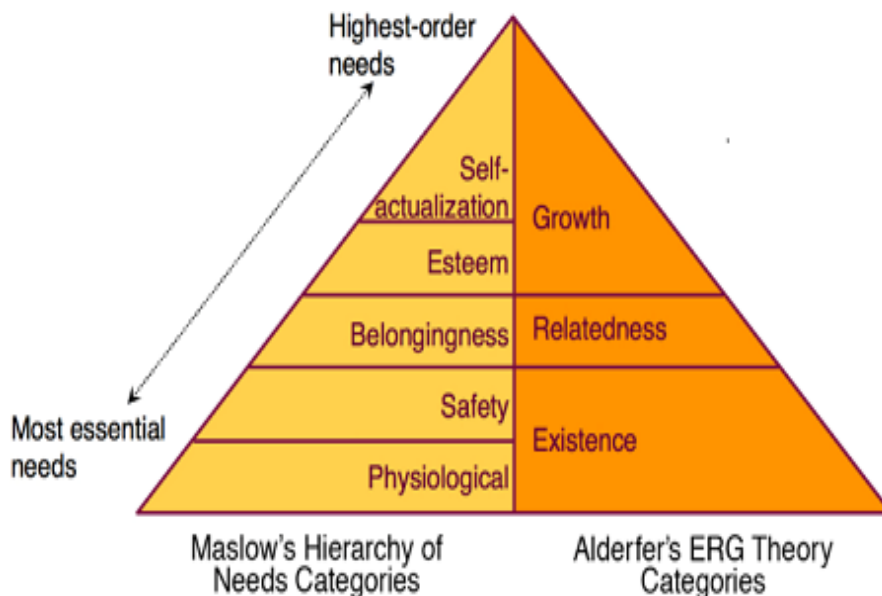


Fig. 2. Illustration of relationships between Maslow's needs and Clayton needs theory

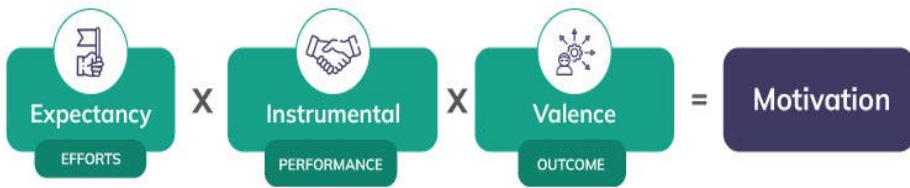
3. Expectancy Theory

The "Expectancy Theory," on the other hand, was put forth by Victor Vroom in 1964 and discusses the steps a person takes to make decisions. According to expectation theory, workers at a company will become more motivated if they think that

- (i) Getting better job performance will result from more effort
- (ii) Improved job performance will result in organisational rewards, like a pay rise or other benefits
- (iii) The employees in issue value these organisational rewards.

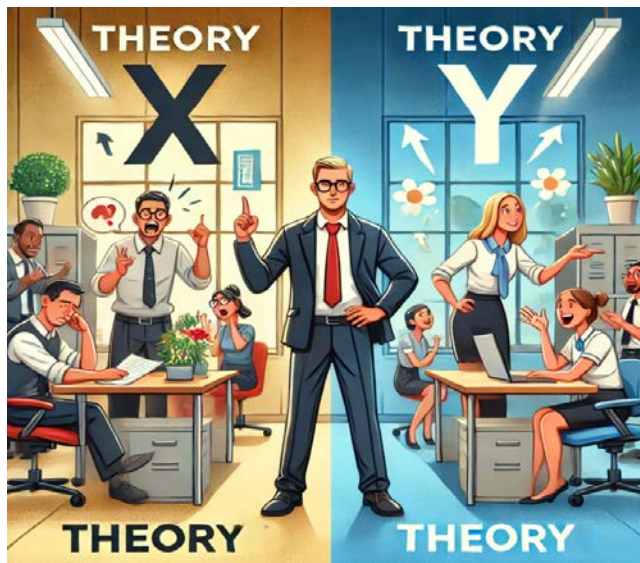
According to Vroom's view, actions lead to deliberate decisions among options with the goal of maximising pleasure and minimising pain. In his theory, he included three characteristics that are crucial in determining which element to choose: valence (V), expectancy (E), and instrumentality (I). It is widely known as "Pull theory".

Vroom's Expectancy Theory



4. Theory X and Y

It was developed by Douglas McGregor and published in his book called “The Human Side of Enterprise” in 1960. The assumptions concerning two different types of workers in this theory will be explained by author. Type 1 workers are known as inherent disliking to work, work environment, organizational climate. This is the so-called "stick and carrot" management philosophy. They should be ordered every time and continuous monitoring needed for those kinds of people in the organization.



(Source: LinkedIn)

Fig. 3. Depicting the workplace and nature of behaviour of employees and managers

Type 2 workers are enthusiastic in nature towards doing challenging tasks in the workplace, sticking to the norms of the organization, regular and punctual in times, not motivated by the money but the responsibilities.

This is so called 'stick and carrot' philosophy of the management.

X type people are more static, rigid and lethargic in nature whereas Y type people are more flexible, dynamic and faster in nature.

5. Hygiene and Motivation Theory

It was developed by Frederick Herzberg, known as two factor theory, that deals with two main components and their sub elements in it. This theory derived based on the research study conducted with 200 respondents comprised of accountants and engineers. The results revealed by the study was two main component which leads to motivation and satisfaction in the workplace. Those are known as hygiene or extrinsic factors and motivators or intrinsic factors.



Fig. 4. Showing the different factors in Motivation and Hygiene components

Intrinsic factors

They are also known as motivators or satisfiers; presence of this sub-elements leads the employees to get motivated for doing and surviving in their job role, but absence of these factors doesn't lead to dissatisfaction.

Extrinsic factors

They are called as hygiene factors or dissatisfiers; presence of these may not motivate the employees but absence of these factors leads to dissatisfaction to the employees.

6. McClelland Needs Theory

He is a Harvard psychologist, analysed different people and their work settings to arrive to this theory that people are work actively to accomplish their goals which leads to effective organisational management. That assumptions are based on three motives for three different needs in the workplace.

- 1. Needs for achievement:** to success in the workplace, personal goals, capable of many things
- 2. Needs for affiliation:** to maintain better human relationships such as interpersonal relationships, intraorganizational relationships, societal relationships
- 3. Needs for power:** to exercise control over others to get things done, decision makers, authorities vested in individuals.

Modern Management theories

Traditional and neoclassical theories made the basement to this kind of modern theories to suit the current generation organizations and focussed more on the dynamic and flexible characteristics rather than sticking to the rules, regulations or old concepts. Under the modern theories there are some to mention such as Systems approach, Contingency theory, Team building theory, Mathematics theory and Chaos theory. These theories started to revolutionize the management in the period of early 1950s.

Points of Distinction	Classical Approach	Neo-Classical Approach
Organizational Focus	Functions and economic demand of workers	Emotion and human qualities of workers
Structure of organization	Impersonal and mechanistic	Social system
Application	Autocratic management and strict rules	Democratic process
Emphasis	Discipline and rationality	Personal security and social demand
Work goal of worker	Maximum remuneration and reward	Attainment of organisational goal
Concept about workers	Economic being	Social being
Content	Scientific management, administration and bureaucratic management.	Hawthorne experiment, human relations movement and organisational
Relations in organization	Formal	Informal
Nature of organization	Mechanistic	Organistic

Source: Sarker, Rafiul and Khan , 2013

Fig. 5. Distinctive features between Classical and Neo-classical approach-based theories

1. Systems approach theory

In this organization is considered as system and organic in nature, it consists of different sub elements that are interrelated and interconnected to function effectively together to accomplish goals and objectives. It is dynamic in nature to respond to the environment and has its own boundaries to function.

Five main components in the systems theory

One way to think of a system is as having **inputs** (like raw materials, cash, technology, and people), **processes** (like organising, planning, inspiring, and managing), and **outputs** (like goods or services) and **results** (such as improved client or customer productivity or quality of

life). Each of these four system components provides **feedback** to the others.

2. Contingency theory

It is also called as Situational theory. According to the situational or contingency theory, managers must consider every facet of the current circumstance while making decisions and act on the elements that are most important to the circumstance. In essence, it is the method that "it depends." For instance, an autocratic approach is most likely the most effective when commanding troops in Iraq. A more facilitative and participatory leadership style is most likely ideal while running a hospital or university.

3. Chaos theory

Tom Peters (1942) promotes the Chaos hypothesis. Global events today appear to be as unpredictable and chaotic, and organisations are no exception. However, managers have operated for many years on the belief that organisational events can always be managed. As a result, a novel theory that acknowledges that events are rarely under control is known as "chaos theory".

According to chaos theory, systems inevitably become more complex, which makes them more volatile and necessitates greater energy expenditure to maintain. They look for greater structure to keep things stable when their energy expenditure increases. This pattern persists until the system breaks up, merges with another intricate system, or disintegrates completely. For the latter, an efficient manager will be required.

4. Team building theory

The philosophy or method of team building. This philosophy places a strong emphasis on continuous development, best practices, and quality circles. It is a theory that primarily depends on teamwork. Additionally, it highlights lowering the levels of hierarchy and flattening the management pyramid. Ultimately, it comes down to managing consensus, which means include more individuals at all levels in the decision-making process.

5. Mathematical theory

It was rooted from the decisional approach theory and gained momentum in this modern world using statistical models and processes for the management of organization. It is also known as Quantitative approach to management because it gives the different quantitative data for better decision making and management of resources within the organisation. Critical Path Method and Program Evaluation and Review Techniques are the most widely used practices in this kind of management.

Conclusion

Modern management ideas have been deeply influenced by classical and neoclassical. Classical management presents businesses as organised entities that are controlled by managers. Neoclassical emphasizes the welfare of employees and human connections. Combining both approaches creates balanced management. Modern concepts view organizations as open systems that interact with environment and increase efficiency. Every theory offers its perspective enabling managers judgmental powers. They are therefore able to solve organizational problems and increase productivity by linking theory with practice. Management involves planning organizing leading and controlling to achieve objectives effectively and efficiently. This is as both classical thought which established management as and an organized field and neoclassical approach which emphasized employee welfare would have it.

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CHAPTER - 9

IMPACT OF SALT STRESS ON MORPHOLOGY AND PHYSIOLOGY OF *Solanum virginianum* L.

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Abstract

Salinity stress refers to unfavorable results of excessive salt primarily sodium chloride, (NaCl₂) in soil or water influencing plant growth and development. It is a major environmental stress that affects agricultural productivity, especially in arid and semi-arid regions. Salinity stress significantly impacts the morphological traits of plants, including those in the *Solanum* genus, while specific studies on *Solanum virginianum* L. (yellow-fruit nightshade) are limited, insights from related species suggest that it may experience comparable morphological changes under saline conditions. Therefore, this study focused on understanding the salinity stress response of the medicinal plant *Solanum virginianum* L. by evaluating various morphological-physiological parameters. *Solanum virginianum* L. (also known as *Solanum xanthocarpum*) is a highly valued medicinal plant belonging to the family Solanaceae. It is widely recognized for its significant therapeutic properties and is used in natural medicine systems like Ayurveda and Siddha for centuries. The plant is rich in alkaloids, steroids, flavonoids, saponins, and glycosides. Solasodine, solamargine, and solanine are some of the key bioactive compounds contributing to its medicinal effects. The experiments followed CRBD with five replicates. Various concentrations of NaCl₂ (25 – 100 mM) were applied to the plants, while untreated plants were maintained as control. During the initial seven weeks, plants were irrigated with normal water to ensure healthy establishment and baseline growth. After seven weeks,

plants were subjected to salinity stress by irrigating them twice a week with solutions containing various concentrations of NaCl₂. The morphological and physiological growth parameters were observed and recorded until 16 weeks. Morpho-physiological traits development decreased significantly when salt concentrations increased.

Keywords: Salinity Stress, *Solanum virginianum*, NaCl₂, solamargine, fresh, RWC.

Introduction

Salinity is a key environmental stress that significantly dwindles crop productivity. Most of the crop plants are highly sensitive to elevated salt levels in the soil, which disrupt water uptake, nutrient balance, and cellular processes. As the global region of salinized land continues to grow, addressing this challenge becomes increasingly critical for renewable agriculture and food safety. Salinity considerably affect nearly all phases of plant development including: sprouting, vegetative and reproductive development. It is calculated that that nearly half of cultivable land might be vanished in mid-21st era due to soil salinity and improper agricultural practices and climatic factors (Islam et al., 2019). It is estimated that approximately 1.2 billion hectares of terrain globally are influenced by varying levels of saltiness. In India alone, around 6.73 million hectares of earth are wedged by saltiness and related issues (Singh, 2017). Soil salinity poses a significant challenge for agriculture, particularly in irrigated areas, that suppresses plant growth because high levels of sodium and chlorine ions lead to ionic imbalance, osmotic stress, nutrient imbalances and oxidative stress, negatively affecting plant morphology, biomass production, and biochemical profiles (Paul, 2012). To manage salt stress, plants employ several adaptive mechanisms, such as sequestering Na⁺ ions into vacuoles through osmotic adjustment (Rahneshan et al., 2018). Salt stress exerts significant effects on medicinal plants, often altering their physiology, metabolism, and secondary metabolite production, while excessive salinity can inhibit growth and reduce biomass, it can also enhance the synthesis of specific bioactive secondary metabolites, which may be critical for both the plant's adaptation and their pharmacological significance. Since ancient time therapeutic plants are amongst the most vital crops, though the results of saltiness on conventional crops was considerably studied, there is constrained information regarding its impact on medicinal plants (Aghaei and Komatsu, 2013). *Solanum virginianum* L. is an annual herbaceous plant commonly known as (yellow berried

nightshade) called in Tamil as Kantankathiri, belonging to the family Solanaceae. *Solanum* is regarded as the chief and most complex genus within the Solanaceae family (Edmonds and Chweya, 1997). Species of *Solanum* exhibit significant variation in phenotypic traits, including plant habit, leaf size, and shape. There are other synonyms of *Solanum virginianum* L. which are, *Solanum xanthocarpum* Schrad. and H. Wendal. and *Solanum surattense* Burm. The plant is indigenous to several countries, in India it is recorded in tropical and subtropical regions and it is widely used by the tribal and local peoples (Salunkhe et al., 2022). Herbal medicines hold a notable role in primary healthcare, particularly in developing countries (Smith et al., 1994). It has been reported that various parts of *S. virginianum* holds a wide range of phytochemicals such as solanosine, coumarins, solanosidine, solanocarpine, solamorgine, solanocarpidine, esculentin, aesculin, caffeic acid, stigmaterol, carpesterol, daucosterol, campesterol, lupeol and diosgenin (Tekuri et al., 2019). Plant roots, play pivotal role in traditional Ayurvedic medicine, particularly in the formulation of Dashmularishta, an herbal tonic. It is commonly used to support the health and well-being of lactating mothers. This plant is highly medicinal and its various parts are used for cough, asthma, fever, chest pain, heart disease, indigestion, sore throat, rheumatism, gonorrhoea, colic, constipation, arthritis, and toothache (Rita et al., 2011; Rane et al., 2014). This study was aimed to understand the response of *Solanum virginianum* L. subjected to salt stress by evaluating its morphological and physiological characteristics.

Materials and Methods

Seed Germination

Solanum virginianum L. seeds were procured from MG Naturals certified seed company, Tamil Nadu. The seeds were surface disinfected with ethanol (70%, 5 min) trailed by rinsing with sterile distilled water for 3 min to remove any traces of alcohol. Thereafter, seeds were allowed to germinate in the soil using earthen pots (20 cm height and 30cm breadth). Distilled water (control) or varying concentrations of NaCl₂ were added and the pots were maintained until germination. The Experiments were conducted in the PG and Research Department of Botany laboratory, TPGASC (A) Trichy. After the germination period the whole plant of *Solanum virginianum* L. was collected and authenticated by Centre for Molecular Systematics and Rapinat Herbarium in St. Joseph's College (Autonomous), Tiruchirappalli. The herbarium Voucher specimen no. I.M.004 was kept in the Department of Botany, TPGASC for future reference.

Experimental design

The experiments were conducted in earthen pots and each pot was filled with sand, red soil and farmyard manure in ratio of 1:2:1. The seeds were sown in earthen pots which was holed at the bottom to avoid water logging. The experiments were arranged in a Completely Randomized Block Design (CRBD) with five replicates. The experiment contains four treatments and one control with each having five replicates. During initial stages of plant growth, irrigation was carried out every two days with 500 ml distilled water for establishing plant roots. Thereafter the plants were treated twice a week with varying concentrations of NaCl₂ (25mM, 50mM, 75mM, and 100 mM) and untreated plants were kept as control (0mM). All the pots were irrigated with equal amount of water. Thereafter control treatment without the addition of salt was maintained throughout the experiment for comparison and analysis. After the growth of the plants, results were recorded up to 16 weeks and finally subjected to statistical analysis.

Seed germination percentage

Seed germination was studied expending the following formula (Kumar et al., 2011).

$$Gp = \text{Sum of sprouted seedlings} / \text{Total amount of seeds planted} \times 100$$

Morphological parameters

The morphological features were measured at every week and the following observations were evaluated in control and treated plants: height of the individual plants (measured using a glass scale and thread) from earth level to top of the main shoot expressed in cms, number of branches and leaves, number of leaves fallen, number of roots, leaf length (cms), leaf area (cms), branch length (cms), root length (cms), shoot diameter (mm), and root diameter (mm).

Physiological parameters

Fresh weight and dry weight

After 16 weeks of salt treatment, the fresh (FW) and dry weight (DW) of plant samples were determined. The plants were carefully uprooted, washed under running tap water, blotted dry, and weighed. After the plants were completely freed of moisture, they were air-dried for few days to determine their dry weight which was measured using an analytical scale, with a precision of 0.0001 g (Atom A107 electronic balance).

Relative Water Content (RWC %)

RWC was calculated by determining the FW, TW and DW of plant samples (Kapoor and Pande, 2015). After fresh weight was evaluated, leaves were placed in water for 3 hours to turn it turgid and the weight was

measured. Further the leaves were oven-dried to evaluate their parched mass. The following formula was used to assess RWC of plant samples,

$$\text{RWC} = (\text{FW}-\text{DW}) / (\text{TW}-\text{DW}) \times 100$$

Statistical analysis

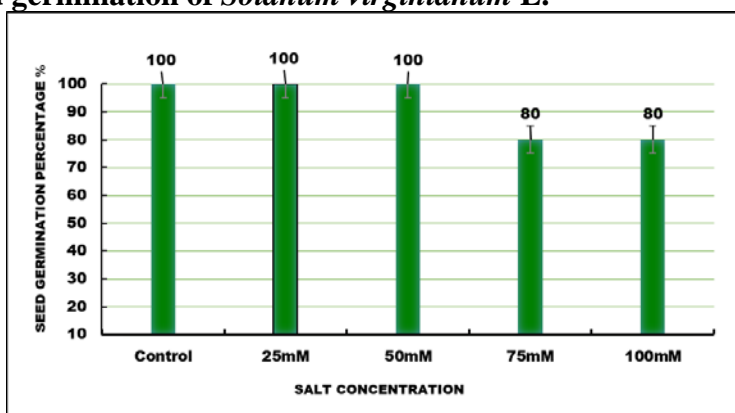
Five plants were used for each NaCl₂ treatment (25, 50, 75,100 mM), in addition to a control. About five earthen pots were used for each treatment, and all experiments were repeated five times. Observations were recorded weekly, and the data for each recorded parameter were subjected to ANOVA. The ANOVA was conducted to detect substantial variations amid treatment means, which were equaled to DMRT at 5% level of consequence (Gomez and Gomez, 1976).

Results and Discussion

Seed germination percentage

The germination rate of *S. virginianum* seeds were assessed after 14 days of planting in different concentration of NaCl₂ (25, 50, 75, 100 mM). The results showed that germination percentage significantly reduced as NaCl₂ concentration increased. 100% germination was achieved until 50 mM NaCl₂. However, plants treated with 75 mM and 100 mM showed only 80% seed germination compared to the control (Fig. 1). Previous study reported that germination percentages of *S. nigrum* and *S. lycopersicum* significantly reduced as NaCl₂ content increased (Khateeb et al., 2019).

Figure 1. Effect of different concentrations of sodium chloride (NaCl₂) on seed germination of *Solanum virginianum* L.



Salinity was reported to adversely affect plant growth and development, hindering seed germination, seedling growth (Kumar and

Srivastava, 2018). Similarly, when seventeen mungbean varieties were subjected to salinity stress, seed germination declined indicating that increasing salinity adversely affected seed germination (Mankar et al., 2021). Salinity reduces the soil's osmotic potential relative to the internal osmotic potential of the seed, thus inhibiting water absorption during seed imbibition (Munns, 2002; Atta et al., 2023). The rate of seed germination was reduced, and the germination period was also delayed. Furthermore, embryo viability can be negatively affected by salinity even after germination because of excessive deposit of sodium and chloride ions (El Sabagh et al., 2021).

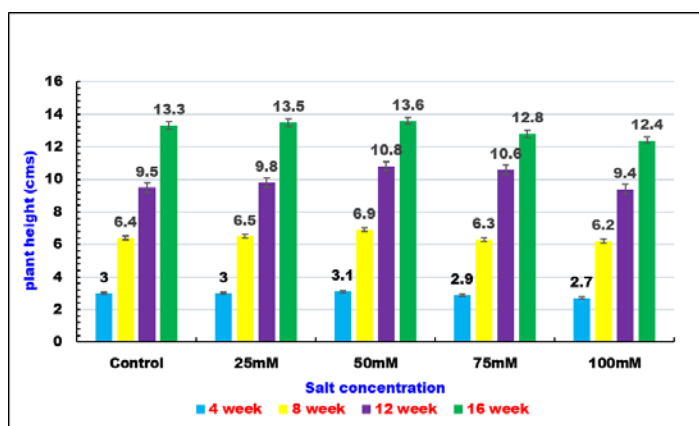
Morphological parameters

Plant height

Compared to the control, maximum plant height (13.6 cms) was observed at 50 mM NaCl₂ beyond which growth gradually decreased (Fig. 2). An earlier study reported that under 400 mmol/L NaCl₂ conditions, the plant height of *P. talassica* × *P. euphratica* gradually declined (Liu et al., 2022). Similarly, increasing salt concentration reduced plant height of *Oenanthe javanica* (Kumar et al., 2021).

Another study reported that *Chrysanthemum* plant height was decreased with increasing salt concentration (Lee and Iersel, 2008). Height of *Ulmus pumila* decreased with increasing salt concentrations (Feng et al., 2014). The plant height was reduced by high levels of salinity due to diverse factors, including water stress, specific ion toxicity, ion imbalance, and induced nutritional deficiencies.

Figure 2. Effect of different concentrations of NaCl₂ on plant height (cms) of *Solanum virginianum* L.



Number of leaves, leaf length, and leaf area

The maximum number of leaves (15), leaf length (8.8 cms), and leaf area (10.3 cms) were achieved at 50 mM NaCl₂, beyond which they gradually decreased (Figs. 3, 4 and 5). Increasing NaCl₂ concentrations declined various growth indices such as leaf length, width, area, and number (Liu et al., 2022). Similarly, the *S. lycopersicum* and *S. nigrum* plant leaf number was declined as NaCl₂ concentration increased (Khateeb et al., 2019).

Studies have reported that salinity stress pointedly affected the number of leaves and leaf area of *A. paniculata* (Kumar and Srivastava, 2018). Similarly, the leaf count of three varieties of *Pisum sativum* plants gradually decreased as salinity concentration increased (Ishrat et al., 2022). Similarly, *Chrysanthemum* leaf area decreased with increasing salt concentration of NaCl₂ (Lee and Iersel, 2008). Salinity reduces the size of individual leaves and the overall leaf area of plants. Plant growth and leaf area expansion of crops such as beans, cotton and tomatoes were significantly hindered by salt stress (Lee and Iersel, 2008).

Figure 3. Effect of different concentrations of NaCl₂ on number of leaves in *Solanum virginianum* L.

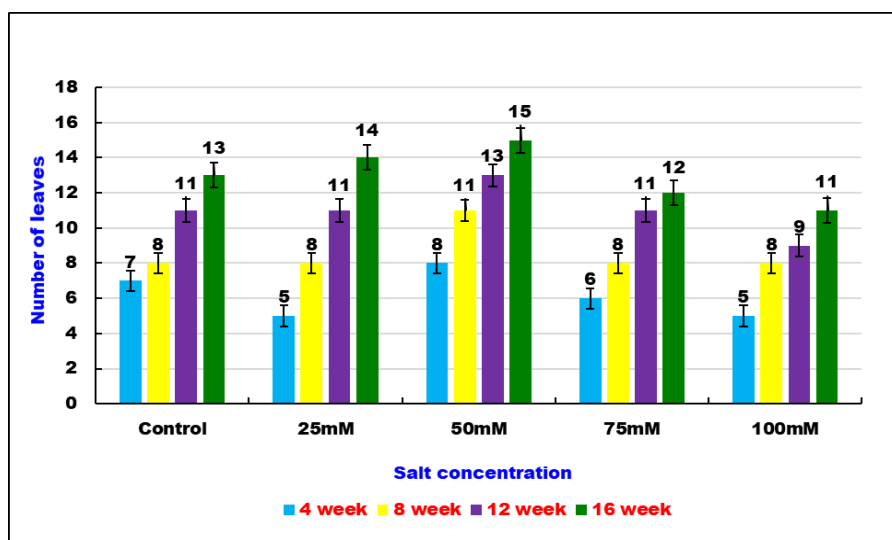


Figure 4. Effect of different concentrations of NaCl₂ on leaf length (cms) of *Solanum virginianum* L.

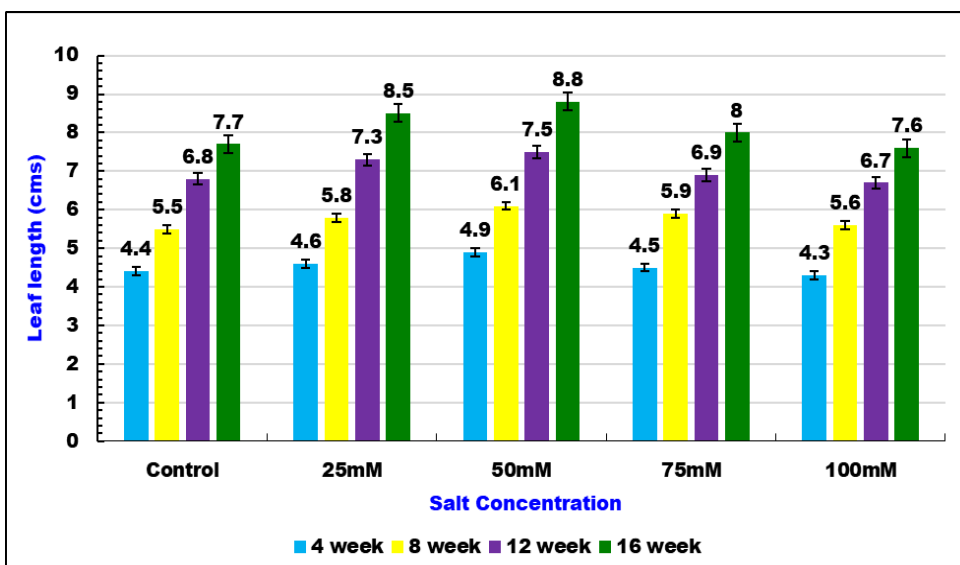
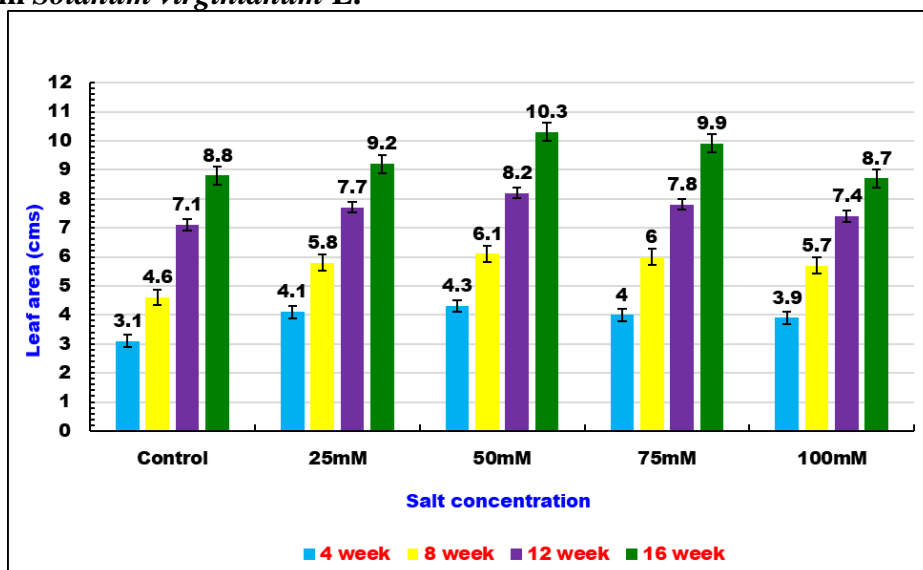


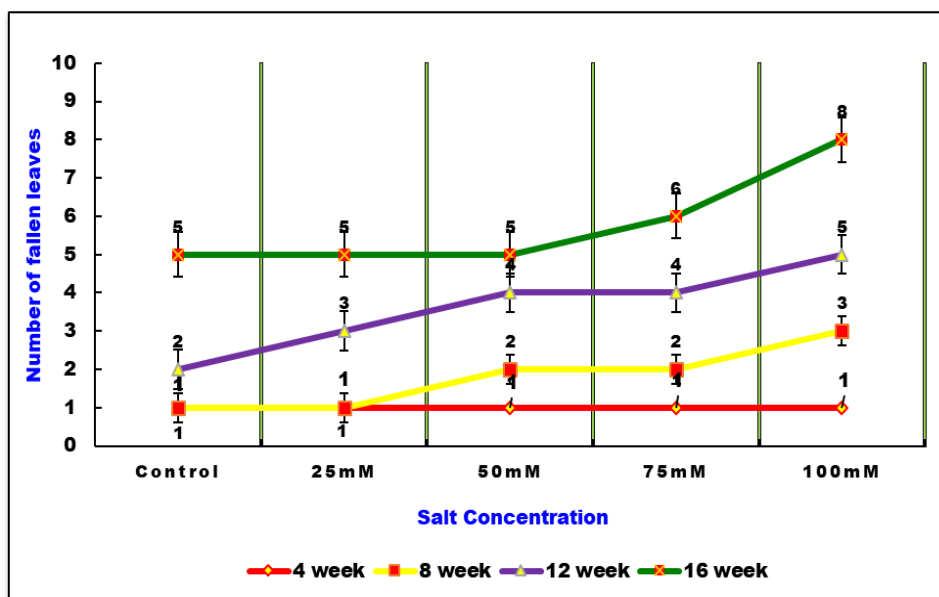
Figure 5. Effect of different concentrations of NaCl₂ on leaf area (cms) in *Solanum virginianum* L.



Number of fallen leaves

The present study revealed that an increase in salt concentration led to an increase in the number of leaves withered. Maximum leaf fall was observed at 100 mM salinity (Fig. 6). Generally, leaf fall occurs as the plant leaves mature and die. Based on our results, this may be due to a high accumulation of sodium in the soil.

Figure 6. Effect of different concentrations of NaCl₂ on number of fallen leaves in *Solanum virginianum* L.



Number of branches and branch length

In this study, compared to the control the maximum branches (14) and branch length (6 cms) were achieved in 50mM NaCl₂ salinity beyond this concentration it gradually decreased (Figs. 7 and 8). Previous study reported NaCl₂ stress significantly inhibited the number of branches of *Ulmus pumila* seedlings, with increasing concentration (Feng et al., 2014). Earlier it was reported that number of branches were gradually decreased with increasing salt concentration (Muhammad and Hussain, 2010). Previous research indicates that increased NaCl₂ concentration significantly decreased the number of branches in cultivars of *Oenanthe javanica* (Kumar et al., 2021).

Figure 7. Effect of different concentrations of NaCl₂ on number of branches in *Solanum virginianum* L.

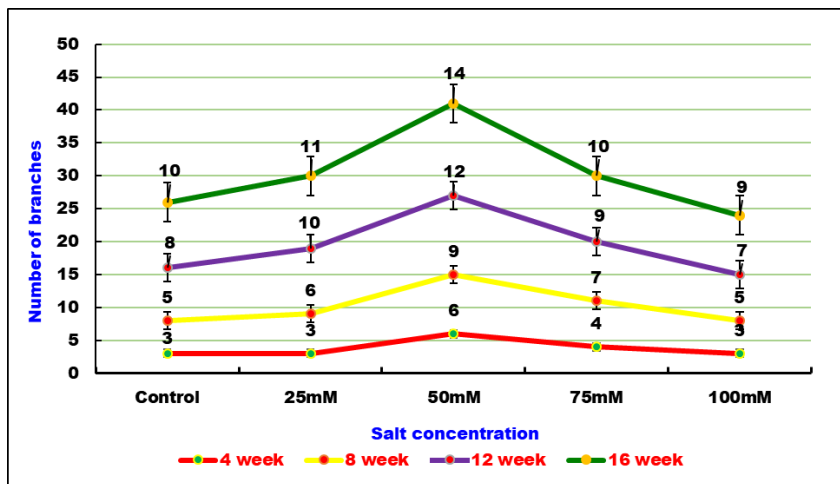
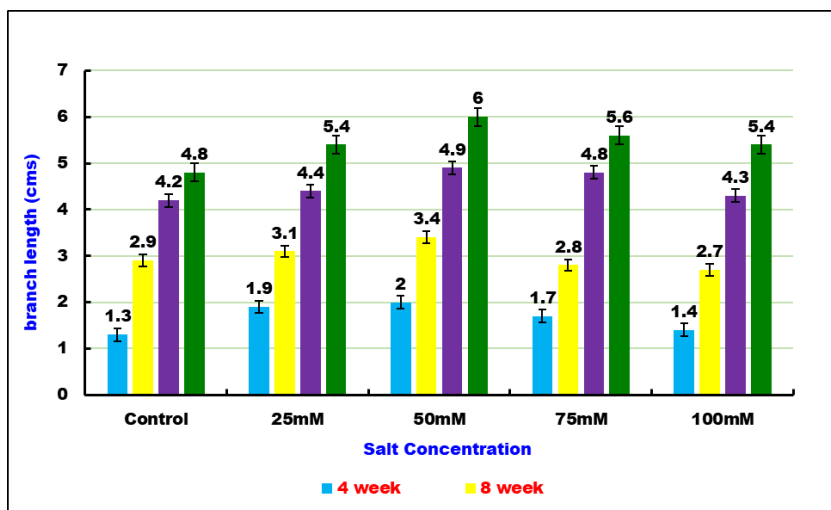


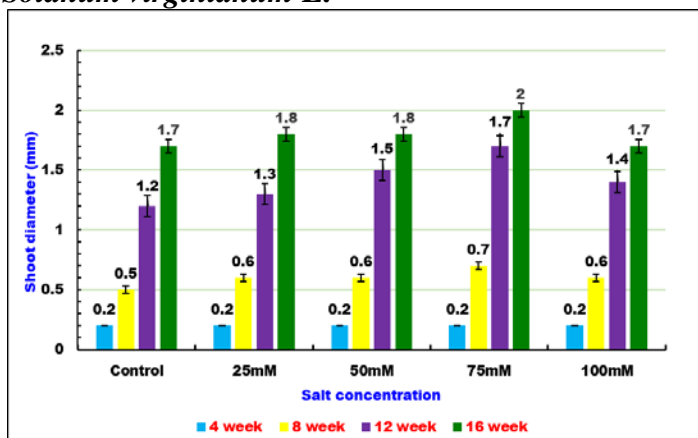
Figure 8. Effect of different concentrations of NaCl₂ on branch length of *Solanum virginianum* L.



Shoot diameter

Research disclosed that compared to control, shoot diameter gradually increased to (2 mm) at 75 mM NaCl₂, but decreased at 100 mM salinity (Fig. 9). Similar results were reported in *S. nigrum* and *S. lycopersicum* (Khateeb et al., 2019).

Figure 9. Effect of different concentrations of NaCl₂ on shoot diameter (mm) of *Solanum virginianum* L.



Number of roots, root length and root diameter

The maximum number of roots (22), root length (20.8 cms), and root diameter (1.6 mm) were observed at 75mM salinity compared to the control (Figs. 10, 11 and 12). A previous study reported that number of roots and root length of *S. nigrum* and *S. lycopersicum* were disturbed by increasing NaCl₂ concentration (Khateeb et al., 2019). Similar results reported that root length in barley genotypes significantly decreased as salt concentration increased (Sadiq et al., 2024).

Figure 10. Effect of different concentrations of NaCl₂ on number of roots in *Solanum virginianum* L.

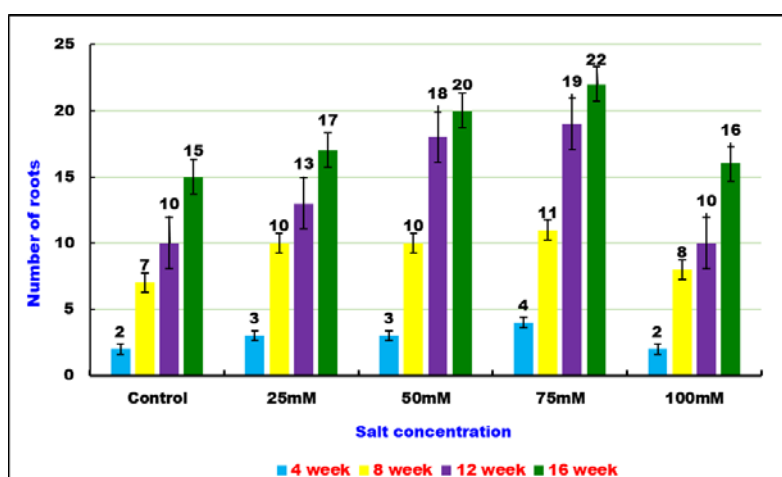


Figure 11. Effect of different concentrations of NaCl₂ on root length (cms) of *Solanum virginianum* L.

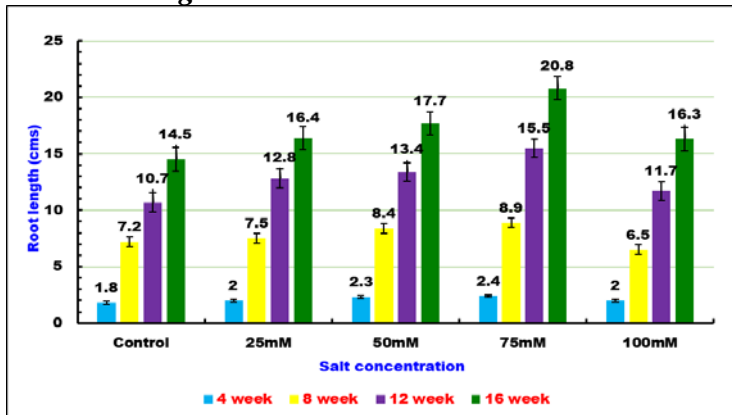
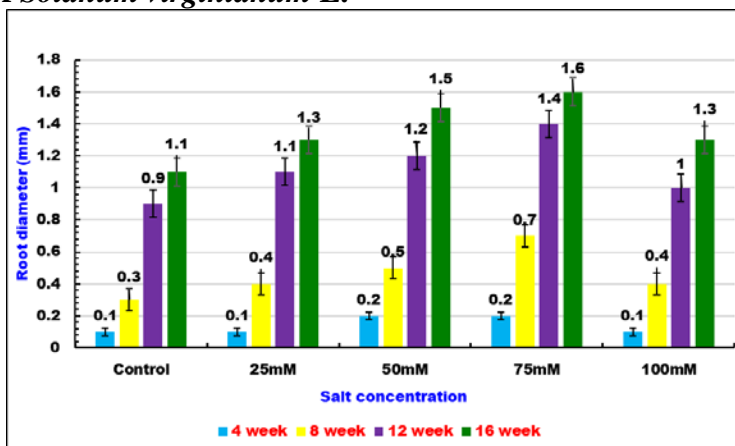


Figure 12. Effect of different concentrations of NaCl₂ on root diameter (mm) of *Solanum virginianum* L.



Fresh and Dry weight

FW and DW of the plant were steadily reduced as NaCl concentration increased. Maximum fresh and (13.0 gms) dry weights (9.7 gms) were observed at 25mM NaCl₂ beyond which it reduced (Table 1). Before researches have also reported that when the NaCl₂ concentration increased fresh and dry weight significantly declined in *Oenanthe javanica* (Kumar et al., 2021) and tomato plants (Romero-Aranda et al., 2001; Lee and Iersel, 2008). Similar results were also stated in *Salvia miltiorrhiza* (Gengmao et al., 2014). Salinity reduced fresh and dry weight in barley genotypes (Sadiq et al., 2024). An earlier study reported that as salt concentration increased, the overall fresh and dry weight of *Sesuvium portulacastrum* gradually decreased (Wang et al., 2023).

Table 1. Effect of different concentrations of NaCl₂ on fresh and dry weight (gm) of *Solanum virginianum* L.

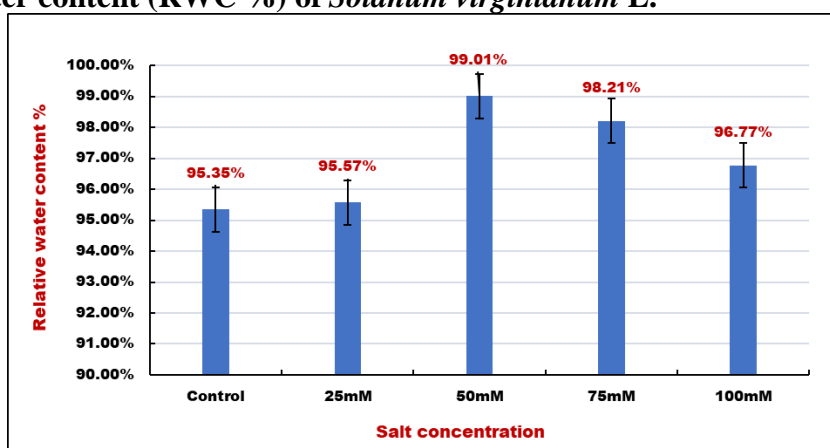
Salt Concentration NaCl ₂ (mM)	Plant parts	Fresh weight (gms)	Dry weight (gms)
		Mean ± SE	Mean ± SE
Control	Leaf	2.3±0.152	1.7±0.057
	Shoot	2.8±0.033	2.6±0.066
	Root	0.6±0.057	0.4±0.033
	Whole plants	5.7±0.120	4.8±0.033
25mM	Leaf	5.7±0.088	3.9±0.057
	Shoot	5.8±0.066	4.5±0.066
	Root	1.5±0.033	1.3±0.033
	Whole plants	13±0.133	9.7±0.033
50mM	Leaf	4.2±0.120	3.5±0.057
	Shoot	4.5±0.033	3.8±0.057
	Root	1.2±0.057	0.6±0.057
	Whole plants	9.9±0.145	7.9±0.057
75mM	Leaf	3.7±0.057	3.0±0.088
	Shoot	3.8±0.066	3.3±0.057
	Root	1.4±0.033	1.1±0.066
	Whole plants	8.9±0.057	7.5±0.173
100mM	Leaf	2.6±0.057	2.3±0.057
	Shoot	2.4±0.088	1.9±0.057
	Root	0.4±0.033	0.2±0.033
	Whole plants	5.4±0.133	4.5±0.088

Relative Water Content

After NaCl₂ treatment the RWC of the leaves of *Solanum virginianum* L. was determined, as NaCl₂ concentration increased RWC %

was gradually decreased. Compared with control the maximum RWC (99.00%) was observed in 50mM salinity (Fig. 13). Analogous results have been reported in cultivars of *Oenanthe javanica* (Kumar et al., 2021). The RWC of *Populus talassica* × *Populus euphratica* was found decreased at increasing salt concentration (Liu et al., 2022). Identical results were obtained in leaves of *Sesuvium portulacastrum* (Wang et al., 2023). These results agreed with our results. The diminished water accessibility beneath stress circumstances or the inability of root systems to compensate for water loss through transpiration greatly reduced the Relative Water Content (RWC).

Figure 13. Effect of different concentrations of NaCl₂ on Relative water content (RWC %) of *Solanum virginianum* L.



Conclusion

Plant development and yield are greatly lessened through salt stress, exceptionally in dry and semi-dry areas where soil saltiness is prevalent. Salt stress leads to ionic imbalance and osmotic stress, which severely impact plant morphology, reduce biomass, and disrupt key biochemical processes, ultimately causing significant plant damage. This stress affects various physiological aspects such as water uptake, nutrient absorption, and cellular homeostasis, leading to reduced growth, yield, and overall plant health. Our experimental results clearly proved that excessive accumulation of NaCl₂ in soil inhibited morphological and physiological growth parameters of *Solanum virginianum* L. Understanding how plants respond to salinity at functional, biochemical, and molecular levels enables researchers to develop salt-tolerant crops by identifying key genes and paths associated with salt tolerance. Improving crop yield under salinity stress is vital for nurturing growing global population, particularly in localities with salty soils.

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CHAPTER - 10

ETHNOBOTANICAL INVESTIGATION OF ALRAYAN HILLS FOR THE MANAGEMENT OF GYNECOLOGICAL PROBLEMS

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Abstract

An ethnobotanical survey was carried in Kalrayan hills to document medicinal herbs that can be used to treat gynecological disorders. About 26 plant species belonging to 21 families were recorded. Traditional healers used different components of plants, such as leaves (42%), roots (23%), seeds (15%), stems (8%), fruits (8%) and whole plants (4%) in medicine preparations. According to the study, the documented plants contain bioactive compounds that can help cure gynecological issues and leaves are the predominant plant part used in medicine preparations. The survey underscores the significance of indigenous knowledge in managing gynecological health and the importance of sustainable harvesting methods to preserve these natural resources. Conservation measures are crucial in guaranteeing the survival of these therapeutic plants in light of the rising stress on forest ecosystems. The findings support further research to examine the pharmaceutical potential of these plants in treating gynecological disorders and offers useful knowledge about traditional healing methods.

Keywords: Ethnobotanical survey, gynecological disorders, PCOS, cancer, medicine.

Introduction

Among the mega diversity countries in the world, India is home to more than 45,000 plant species. The country's main areas with a high biodiversity are the Eastern and Western Ghats and the Northeastern hills. India's 426 biomes, 25 biotic provinces, 10 vegetation zones, and 16 agro-

climatic zones all showcase its unmatched diversity. Of the country's extensive plant life, between 15,000 and 20,000 species have substantial therapeutic significance. But only 7000 to 7500 of these species are used therapeutically by traditional tribes (Natarajan et al., 2012). Medicinal plants have always been an essential component of human civilization, providing a multitude of resources in addition to food and shelter. The potential of plants as a natural remedy is among their most amazing features. People have used plants' therapeutic qualities to treat illnesses and advance general well-being throughout history. Herbal medicine is the technique of treating a variety of illnesses with plant-based procedures; it is a tradition that is ingrained in the traditions and customs of communities all over the world (Kropi et al., 2024).

Wild medicinal plants have been a vital component of traditional treatment systems, and indigenous societies have developed a variety of application techniques to make use of these natural resources. Around the world, farming populations have resorted to using wild plants as food and medicine over time. There are also plants used in traditional medicine to treat illnesses, but they are also an important source of sustenance for rural and underprivileged communities. Because it provides crucial insights into possible new sources for herbal medications, research on indigenous peoples' ethnomedicinal use of plants is becoming more and more essential (Khadim et al., 2024). Approximately 80% of people worldwide receive their primary medical treatment from traditional herbal medicine, and many contemporary pharmaceutical medications that cure a variety of illnesses are based on plant-based medicines (Clement et al., 2015). Almost 95% of medicines in India are plant-based concoctions from traditional systems including Siddha, Ayurveda, Unani, and homeopathy. These systems' primary source material is plants that have been gathered from the wild (Balamurugan et al., 2018). Women around the world have long utilized herbal medicine, and its significance in both curing ailments and preserving general health is increasing. There are still many health problems that women face today that traditional medicine finds challenging to treat. Herbal medicines continue to be an essential complement or alternative for women's health and well-being in some areas where access to contemporary healthcare options is restricted or non-existent (Jiao et al., 2022). Therapeutic plants are still a major source of healthcare in rural regions and are essential for women's reproductive health. Traditional treatments are frequently used to treat gynecological problems, which are among the most significant reproductive health conditions. Gynecology deals with a variety of women's health issues,

such as morning sickness, leucorrhea, irregular menstruation, menopausal symptoms, abortion, anti-fertility medications, and difficulties during childbirth. Traditional medicine continues to be the primary source of treatment in isolated areas with limited access to contemporary medical facilities and strong cultural beliefs in the efficacy of folk medicine. In indigenous societies, it enriches daily life and attends women's health concerns (Niyaz et al., 2023). Through the introduction of numerous life-saving treatments, the Indian medical system has significantly improved healthcare around the world since ancient times.

The development of remedial medications in India has been significantly influenced by the indigenous knowledge of Indian tribes. These tribes have developed a variety of medicinal formulations to treat different menstruation diseases or disorders. This research was intended to conduct an ethnic survey of medicinal plants extant in Kalrayan hills that possessed therapeutic capabilities against gynecological issues.

Methodology

Study area

The Kalrayan Hills are a well-known hill range in Tamil Nadu, which is situated in southern India's Eastern Ghats. They create a natural barrier between the Palar River basin to the north and the Kaveri River basin to the south, along with the Pachaimalai, Javadi, and Shevaroy Hills. The 1,095-square-kilometer hills, which stretch northeast from Salem District and span other districts in Tamil Nadu, reach heights of 2,000 to 3,000 feet. In Tamil Nadu, the districts of Salem and Villupuram are naturally separated by the Kalrayan Hills. Salem is roughly 70 kilometers from the hills, and Kallakurichi, the closest city, is roughly 56 kilometers away. The Chinna (Little) Kalrayans in the north and the Periya (Big) Kalrayans in the south make up the two halves of the range. The Periya Kalrayans rise higher, averaging 4,000 feet, than the Chinna Kalrayans, which average 2,700 feet. The soil in the Kalrayan Hills is rich in plant life and the surface is comparatively smooth. Deciduous woods predominate over elevations over 800 meters, while scrub vegetation flourishes up to 400 meters. Growing on the remote plateaus of the highlands are sholas, a special kind of high-altitude stunted evergreen forest. The Megam falls, Periyar falls, and Gomukhi dam are among the foothills' attractions. On a hot summer day, the cool, flower-scented water at these locations is very soothing. The Kalrayan hills are known for its tranquil ambiance, mild climate, and lovely botanical garden. Only a few isolated tribal communities are dispersed throughout the hill range, which is largely uncharted and unspoiled (Kallakurichi District info, 2025).

Field visits, interviews and data collection

Five field surveys were conducted to document the use of medicinal herbs in the investigation area between July and October 2024. Semi-structured interviews were conducted amongst the residents in the area to gather information pertaining to plants. Male and female respondents as well as traditional healers were among the informants. The ethnobotanical survey recorded the plant collections in the research area, including their binomial names, vernacular names, habits, parts used, and therapeutic properties. Traditional healers' utilization of local herbal medicines in treating gynec issues was the main focus of this investigation.

The inhabitants possessed extensive familiarity of therapeutic plants located in their surroundings. The abundance of expertise of medicinal plants amid the hill tribals is based on hundred years of trust and explanation. To record plant details along with the ethnomedicinal knowledge provided by traditional healers, a field data sheet was meticulously prepared. For each collected ethnomedicinal plant, information was recorded on the name of the informant, age, date of interview, vernacular name of plant, the plant portion expended for healing, process of preparation, other plants or agents used as constituents, methods of administration, etc. (Ginko et al., 2023). The details were collected in their native language (Tamil) and finally the entire data were deciphered into English.

Plant collection and Preservation

In both flowering and fruiting conditions, samples of plants were collected. In the instance of no flowering and fruiting conditions, with the aid of local healers and well-informed people, the plant twig with small leaves were collected to establish the precise identity of plants and also to find information about their environment for suitable identification. For the scientific classification and preparation of herbariums, medicinal plant samples were collected. For every herbarium sheet and field notebook, essential information such as specimen number, scientific name, location, and distinguishing characteristics were diligently recorded. Further photographs of medicinal plants were taken and recorded information for each plant.

Benchmark techniques were adopted for plant material processing, drying, stacking, plant specimen preparation and storage (Jain, 1964). Voucher samples were prepared and classified in triplicates of medicinal plants. The plants, along with their precise nomenclature, were systematically arranged in alphabetical order based on their family name, vernacular name, and ethnomedicinal uses. Flora of Presidency of Madras

(Gamble, 1935) and Tamil Nadu Carnatic's Flora (Matthew, 1983) were followed to identify and nomenclature the plants listed. APG III (The Angiosperm Phylogeny Group, 2009) was preceded by the International Plant Names Index (IPNI) to classify the species. At the PG and Research Department of Botany Herbarium, TPGASC, Tiruchirappalli, all preserved specimens were deposited and maintained.

Results and Discussion

Ethnomedicinal diversity

The data gathered during an extensive survey in the Kalrayan Hills is the basis for the findings and discussion in this study. The details include each voucher specimen's botanical name, popular name, ecological distribution throughout the province, sections of the plant being used, and therapeutic indications (Table 1). Local specialists with knowledge of therapeutic herbs were interviewed and direct field surveys were used to collect the dataset. According to the survey, 26 ethnomedicinal plants used for treating gynecological issues belonging to 21 families were ascertained (Fig. 1). Several research from the southern states of India have also reported the dominance of families such as the Euphorbiaceae, Mimosaceae, Lamiaceae, Combretaceae, and Malvaceae (Simbo, 2010; Ahmad et al., 2014).

Plant habits

The majority of the therapeutic plants were herbs (54%), followed by shrubs (16%) trees and climbers (15% each) (Fig. 2). Herbaceous plants present in abundance make them the most frequently used for medicine preparation among the traditional healers (Sivasankari et al., 2014). This trend is in line with the results of earlier ethnomedicinal research carried out in other parts of India (Ayyanar and Ignacimuthu, 2011). The reason for the greatest reliance on herbaceous medicinal plants is their increased accessibility, as many of them are obtained from the wild. Nonetheless, the harvesting of wild plant species puts a great deal of strain on forest resources. Therefore, in order to guarantee the sustainable use of these resources, conservation measures must be implemented (Ralte and Singh 2024; Thakur et al., 2024).

Table 1. Medicinal plants used in the treatment of gynecological problems

Voucher No.	Binomial Name	Vernacular Name	Family	Habit	Parts Used	Medicinal Uses
KH01	<i>Abutilon indicum</i> (L.) Sweet	Country Mallow Thuththi	Malvaceae	Shrub	Root	Amenorrhea, PCOS
KH02	<i>Acacia farnesiana</i> (L.) Willd.	Huisache Kasthurivel	Mimosaceae	Shrub	Seed	Leucorrhoea
KH03	<i>Aristolochia indica</i> L.	Indian Birthwort Eeswaramuli	Aristolochiaceae	Climber	Root	Menstrual disorders
KH04	<i>Asparagus racemosus</i> Willd.	Buttermilk root Ammalkodi	Asparagaceae	Climber	Root	Ovulation
KH05	<i>Boerhavia diffusa</i> L.	Red Spiderling Mookarattai	Nyctaginaceae	Herb	Whole Plant	Leucorrhoea
KH06	<i>Cardiospermum halicacabum</i> L.	Soapberry Mudakkatthaan	Sapindaceae	Climber	Leaf	Amenorrhea
KH07	<i>Catharanthus roseus</i> (L.) G. Don	Madagascar Periwinkle Nithyakalyani	Apocynaceae	Herb	Leaf	Menorrhagia
KH08	<i>Cissus quadrangularis</i> L.	Veldt grape Pirandai	Vitaceae	Shrub	Stem	Irregular menstruation
KH09	<i>Cleome viscosa</i> L.	Asian Spider flower Naaivaelai	Capparaceae	Herb	Leaf	Menstrual disorders
KH10	<i>Clitoria ternatea</i> L.	Blue Pea Sangupushpam	Fabaceae	Herb	Root	Leucorrhoea
KH11	<i>Cucurbita maxima</i> L.	Buttercup squash Parangi	Cucurbitaceae	Climber	Seed	Overactive bladder

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KH12	<i>Euphorbia heterophylla</i> L.	Milkweed Paal perukki	Euphorbiaceae	Herb	Leaf	Lactation
KH13	<i>Euphorbia hirta</i> L.	Hairy spurge Amman pacharisi	Euphorbiaceae	Herb	Leaf	Lactation
KH14	<i>Feronia elephantum</i> Correa	Wood Apple Vilaa	Rutaceae	Tree	Fruit	Menorrhagia
KH15	<i>Glinus lotoides</i> L.	Lotus sweet juice Siru seruppadai	Molluginaceae	Herb	Root	Gonorrhea
KH16	<i>Lippia nodiflora</i> (L.) Michx.	Frog fruit Poduthalai	Verbenaceae	Shrub	Leaf	Gonorrhea
KH17	<i>Mimosa pudica</i> L.	Touch-me-not plant Thottal sinungi	Mimosaceae	Herb	Leaf	Vaginitis
KH18	<i>Ocimum basilicum</i> L.	Basil Thiruneetru pachilai	Lamiaceae	Herb	Leaf	Gonorrhea
KH19	<i>Ocimum canum</i> Sims.	Hoary basil Naathulasi	Lamiaceae	Herb	Leaf	Gonorrhea
KH20	<i>Odina wodifer</i> Roxb.	Indian Ash Tree Odhiyam	Anacardiaceae	Tree	Leaf	Menstrual disorders
KH21	<i>Pedaliium murex</i> L.	Large Caltrops Perunerunchil	Pedaliaceae	Herb	Seed	Amenorrhoea, Dysmenorrhoea
KH22	<i>Physalis minima</i> L.	Bladder Cherry Sodakku thakkali	Solanaceae	Herb	Leaf	Urinary disorders
KH23	<i>Sida acuta</i> Burm. F.	Mallow Arivaalmanaipo ondu	Malvaceae	Herb	Root	Leucorrhoea

KH24	<i>Terminalia arjuna</i> (Roxb.) Wight. & Arn	Arjun tree Marutham	Combretaceae	Tree	Stem	Menorrhagia
KH25	<i>Terminalia chebula</i> Retz.	Chebulic Myrobalan Kadukkai	Combretaceae	Tree	Fruit	PCOS
KH26	<i>Tribulus terrestris</i> L.	Puncture vine Nerunchil	Zygophyllaceae	Herb	Seed	PCOS

Fig. 1. Number of plants belonging to each family

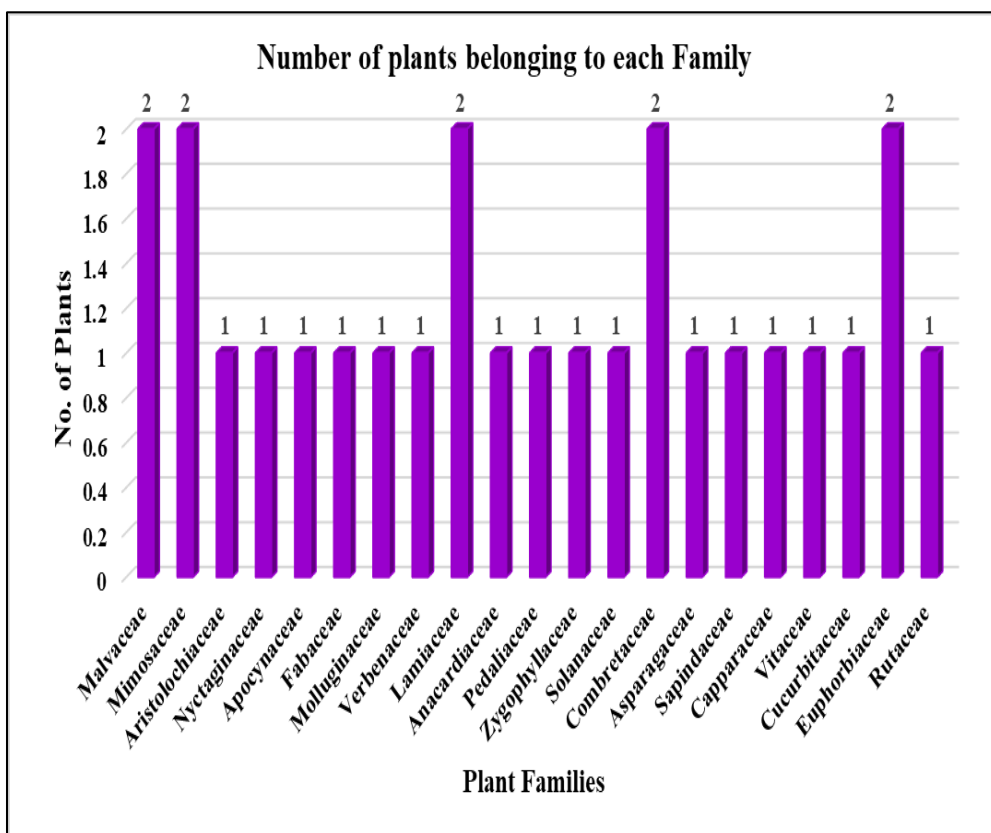
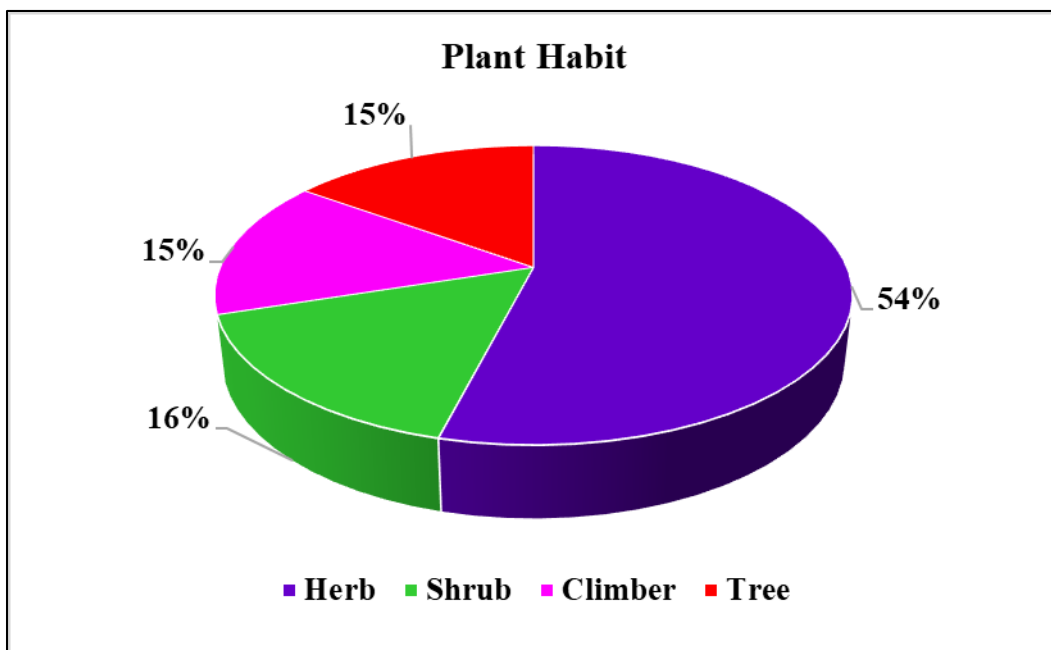


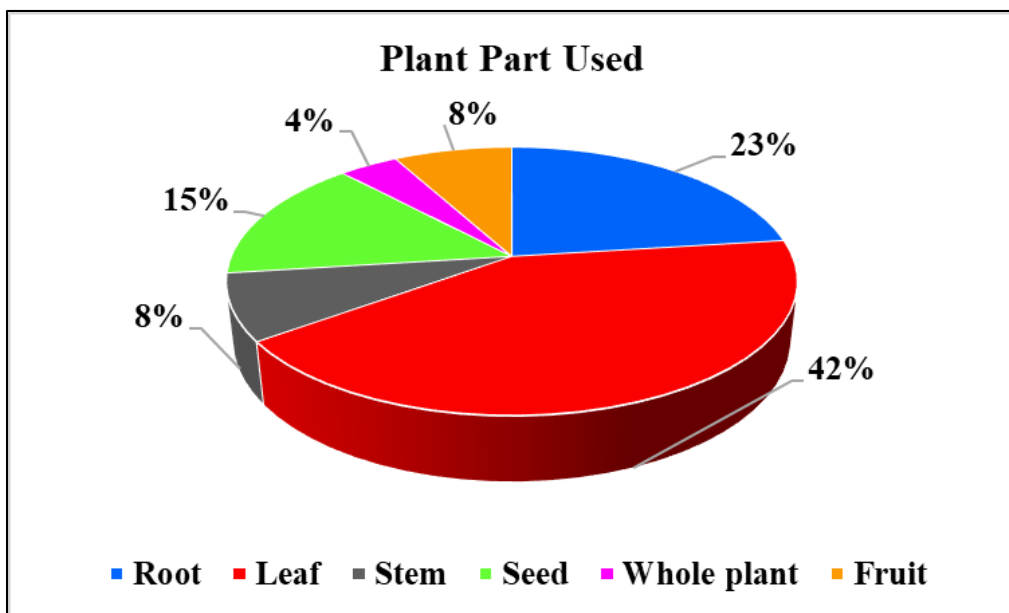
Fig. 2. Habits of Plants surveyed



Parts used, mode of preparation, and administration

Several diseases in the Kalrayan Hills are treated with the 26 plants included in this study. Research into growth habits of medicinal plants in Pachamalai showed that indigenous people used leaves, roots, stems, barks, shoots, latex, flowers, fruits, seeds, oil and whole plants to prepare medicines. The most often used plant parts were leaves (42%), roots (23%), seeds (15%), stems and fruits (8% each) and complete plants (4%) (Fig. 3). Many traditional cultures in India use leaves to make herbal medications (Polat and Satil, 2012; Sivasankari et al., 2014; Rajalakshmi et al., 2019). One of the main reason's leaves are used so widely is that they are easier to gather than fruits, flowers, or subterranean portions. Leaves have a lot of active regions where different secondary metabolites are produced. Since leaves can be easily obtained from plants than other parts of plants such as fruits, flowers, roots, etc. they were more frequently used in herbal medicine (Giday et al., 2009). The advantage of collecting a high number of leaves is that the harm to the plant community's habitats is less as compared to utilizing roots and barks (Boadu and Asae, 2017).

Fig. 3. Plant parts used in medicine preparation



Conclusion

The Kalrayan hills ethnobotanical survey demonstrates the important role that native plants play in treating menstruation problems, a prevalent health issue among the local population. According to the study, traditional healers use a wide variety of 26 plant species from 21 families to treat gynecological issues, especially those associated with menstruation. The most often used plant parts were leaves, which were chosen because they were readily available and contained bioactive substances. Other plant parts that were used included roots, seeds, stems, and fruits. This survey emphasizes the necessity for sustainable harvesting methods and the significance of local knowledge in maintaining the therapeutic potential of plants. Since a large number of these plants are wild, conservation measures must be taken immediately to guarantee that these priceless medicinal plants will be accessible to future generations. The results of this study not only help to document the Kalrayan Hills' traditional healing methods, but they also serve as a foundation for future research into the possible pharmacological qualities of these plants in the treatment of feminine disorders. For better health management of women, future studies should concentrate on confirming the medicinal effectiveness of these plants, guaranteeing their long-term usage, and fusing traditional knowledge with contemporary healthcare systems.

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CHAPTER - 11

BIO-PROSPECTING OF SEAWEED FOR SUSTAINABLE AVIATION FUEL

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ABSTRACT

The current fossil fuel reserves are not sufficient to meet the increasing demand for global energy consumption and very soon will become exhausted. The recent advancements in biofuel production from food crops have raised ethical concerns due to the food-versus-fuel debate, as using crops like soybean, palm, canola, and rapeseed (first-generation biofuels) for energy leads to rising global food prices and a reduction in land available for food production, ultimately contributing to food scarcity, especially in developing countries like India. In this context, lignocellulosic residues, which are non-edible second-generation biofuel feedstocks, have been suggested as a promising alternative. Marine algae, particularly stand out as one of the most efficient non-edible feedstocks for biofuel production compared to terrestrial crops. The increased CO₂ emission into the atmosphere has triggered the need to look for alternative, renewable and sustainable energy sources. Seaweeds are marine macroalgae, which can be grown in shallow saltwater regions. They absorb CO₂ from the atmosphere while performing photosynthesis. The existence of components such as carbohydrates and lipids, and the deficiency of lignin which reduce the production of biofuel cost, create macroalgae an enviable feedstock for various biofuels' generation. Seaweed, particularly through processes like hydrothermal liquefaction (HTL) can be converted into biofuels like Synthetic paraffinic kerosene which is a type of bio jet fuel suitable for aviation. The blending of algal biofuels with conventional jet fuels is certified under ASTM (American Society for Testing and Materials) standards, making it suitable for commercial aviation. This blending reduces the aviation industry's carbon footprint by 82% while

ensuring combustion efficiency and compatibility with standard Jet A1 formulations, promoting a more sustainable future for aviation.

Keywords: Biofuel, seaweed, aviation biofuel, and carbon footprint.

Introduction

The transportation sector's liquid fuel consumption, accounting for 30% of global energy consumption, is projected to increase by 80% between 2006 and 2030, posing a global energy crisis due to the exhaustion of fossil fuel reserves in less than 30 years. The increasing atmospheric CO₂ concentration necessitates the introduction of alternative clean energy feedstocks. Sustainable and renewable energy is seen as a strategic option to improve energy self-sufficiency, security, CO₂ emissions reduction, and economic stability.

Seaweed

Seaweeds are multicellular, macroscopic, eukaryotic, and autotrophic organisms.

They are classified into three groups based on thallus color:

- Chlorophyta (green algae) – *Ulva*, *Caulerpa* and *Cladophora*.
- Rhodophyta (red algae) - *Gracilaria*, *Gelidiella* and *Kappaphycus*.
- Ochrophyta—Phaeophyceae (brown algae) - *Sargassum*, *Turbinaria*, *Laminaria*, *Ascophyllum nodosum*.

Seaweeds are mainly found in coastal ocean areas. Seaweeds are valuable for producing a wide range of products and energy. They are used in human and plant health, cosmetics, agriculture, food and construction (Zhao *et al.*, 2022).

General morphology of seaweed

The thallus acts as a large leaf-like structure of the organism. In case of strong water current, more resistant blades can be formed as morphological modification. The floats, also called air bladders or vesicles, are normally oval which provides buoyancy to the algae to float on the water surface. The stipe provides flexibility to the algae. The holdfast ensures the firm attachment of the algae to the substratum/rock.

Nutrient content in seaweed in aspects of biofuel production

Carbohydrates are crucial as they can be converted to bioethanol and biomethane. Green, brown, and red seaweeds generally contain 52-57% carbohydrates, making them efficient substrates for ethanol production (Offei *et al.*, 2018). Protein content in seaweed ranges around

10-20%, though it varies by species. High protein levels can be beneficial for co-products in a biorefinery setup, where proteins may serve as by-products while the carbohydrates are utilized for fuel. While seaweed is generally low in lipids (around 1-5% of dry weight), certain species like *Spatoglossum macrodontum* contain lipid levels above 10%, with a high proportion of fatty acids suitable for biodiesel production. The ash content, primarily minerals, can vary significantly by species and harvesting season, often comprising around 20-30% of dry weight. High ash levels can be challenging for certain biofuel processes due to mineral build-up. Unique to seaweed are polysaccharides like alginate, fucoidan, and laminarin, especially in brown seaweeds. These polysaccharides support bioethanol production through fermentation and can be converted into other bio-based chemicals.

Cultivation practices of seaweeds

Fragmented seaweed pieces are used as seed material for cultivation. The material should be healthy, brittle, and shiny with young branches. Ideal sites for seaweed farming are sheltered bays, lagoons and coral reefs with stable ground and a moderate water turnover. Optimal water quality parameters for seaweed growth include salinity of 25 ppt, pH of 8.2-8.7, temperature of 25-30 °C and water current of 30-60 cm.

Farming Methods

Single Rope Floating Raft (SRFR)

Seaweed fragments are hung on cultivation ropes attached to a floating rope system. The rope is held afloat with floats and anchored with stakes.

Tube Net Method

Seaweed is cultivated in net tubes attached to bamboo rafts. The tubes are kept buoyant with floating materials.

Monoline Method

Seaweed seedlings are planted on ropes attached to bamboo poles, forming a grid-like structure. Seaweed can be harvested by hand or using a scissor knife after 45-63 days of cultivation. The harvested seaweed is washed to remove debris. Drying can be done in the sun for 2-3 days, resulting in a moisture content of 35-39%.

Integrated Multi-Trophic Aquaculture (IMTA)

Integrating seaweeds into aquaculture systems, such as shrimp or fishponds, can be highly effective. The seaweed utilizes excess nutrients released from the system, improving water quality and enhancing the overall productivity.

Aviation Bio-fuel

An aviation biofuel (also known as bio-aviation fuel (BAF) or bio-jet fuel) is a biofuel used to power aircraft. It is a sustainable aviation fuel (SAF). Biofuels are biomass-derived fuels from plants, animals, or waste; depending on which type of biomass is used, they could lower CO₂ emissions by 20–88% compared to conventional jet fuel. Sustainable biofuels are an alternative to conventional fuels.

First-generation biofuels are typically derived from edible feedstocks like vegetable oils and corn sugar. While some first-generation biofuels may not be harmful to the environment, governments have been de-incentivizing them in favor of second-generation biofuels or advanced biofuels. Second-generation biofuels are derived from non-edible, non-food feedstocks such as aquatic biomass, woody biomass, agricultural and forest residues, and municipal solid waste. These fuels have a lower impact on food supply and land-use change. Algae biofuel is sometimes considered a third-generation biofuel due to its potential for high yields and minimal land use requirements. The potential of seaweed as a biofuel source for aviation fuels is gaining traction due to its high productivity and minimal resource requirements. Seaweed, particularly through process like hydrothermal liquefaction (HTL) can be converted into biofuels suitable for aviation.

Biofuel Production process

- Transesterification - Bio-diesel
- Pyrolysis - Bio-oil, Bio char, Biogas
- Gasification - bio jet fuel
- Anaerobic Digestion - biogas
- Fermentation - Bioethanol
- Direct Combustion - Co₂, energy

Pyrolysis

This is the thermal decomposition of algal biomass in the absence of oxygen, is used for the production of liquid fuel (bio-oil), solid fuel (biochar) and gaseous fuel products. Conventional Pyrolysis is conducted at medium temperatures over a long duration. Used as fuel and fertilizer,

helps reduce atmospheric CO₂, and improves soil water retention and nutrient efficiency. Fast Pyrolysis Can be used directly as fuel, a petroleum replacement, or a source of valuable chemicals. The process is efficient for algae biomass due to the absence of phenolic compounds. Flash Pyrolysis is conducted at very high temperatures for an extremely short duration. Suitable for further refining into various energy and chemical products.

Hydrothermal Liquefaction (HTL)

HTL is a promising method for converting algal biomass, including seaweed, into bio-crude oil, which can be further refined into aviation kerosene. The process operates under high temperature and pressure, producing a nutrient-rich aqueous phase and solid char alongside bio-crude oil. Challenges include the high nitrogen content in the bio-crude, necessitating catalytic upgrading to meet aviation fuel standards (Kulikova *et al.*, 2024).

Hydro processing

HEFA (Hydro processed Ester and Fatty Acids) process converts algae oil into synthetic paraffinic kerosene (SPK), a type of bio-jet fuel. It involves removing impurities and oxygen molecules from the oil using hydrogen treatment (Gutiérrez-Antonio *et al.*, 2014).

Gasification

This initial step converts the renewable biomass (such as wood chips, agricultural residues, or municipal solid waste) into a gas mixture primarily composed of carbon monoxide (CO) and hydrogen (H₂). The biomass is heated without oxygen, breaking it down into gas. Fischer-Tropsch Process converts the synthesis gas (CO and H₂) from gasification into a mixture of hydrocarbons. The synthesis gas is passed over a catalyst under specific conditions, producing a range of hydrocarbons, including waxes, paraffins, and olefins. Hydrotreating removes impurities and upgrades the hydrocarbon mixture from the Fischer-Tropsch process. The hydrocarbon mixture is treated with hydrogen gas in the presence of a catalyst to remove sulfur, nitrogen, and oxygen compounds, resulting in a cleaner product. Hydrocracking/Isomerizing breaks down the long-chain hydrocarbons into shorter, more desirable molecules suitable for biofuels. The hydrotreated mixture is further processed using hydrogen gas and a catalyst to break down long-chain hydrocarbons into shorter chains and to isomerize them (rearrange their molecular structure) to improve fuel

properties. Fractionation is the final step that separates the resulting mixture into different fractions based on their boiling points. The mixture is heated in a fractionation column, and the different fractions are collected at various levels. The final products obtained are bio-jet fuel, renewable diesel, naphtha, methane, and hydrogen.

Transesterification

Biodiesel production from algae involves the chemical conversion of algal biomass through transesterification. This process involves the reaction of triglyceride (lipid) with alcohol in the presence of a suitable catalyst such as acidic, alkaline, or enzyme-based to produce fatty acid methyl esters (FAME) with glycerol. The process reduces the high viscosity of algal oils, making them suitable for blending with petroleum diesel for use in diesel engines without modifications.

Comparison of algal aviation biofuels with fossil fuels

Algal biofuels have a calorific value around 29-40 MJ/kg, depending on the extraction and refinement methods used. For instance, biodiesel derived from algal oil through transesterification has a calorific value of approximately 40 MJ/kg, similar to conventional diesel fuel (Fulke *et al.*, 2010), (Vijayaraghavan & Hemanathan, 2009). Aviation kerosene, such as Jet-A1, has a calorific value typically around 42.8 MJ/kg, slightly higher than most algal biofuels (Yang *et al.*, 2016). However, algal biofuels meet ASTM D7566 standards for drop-in fuels when properly refined.

Studies indicate that algal biodiesel achieves similar or slightly higher brake thermal efficiency (BTE) compared to conventional diesel. For example, algal biodiesel blends showed thermal efficiency improvements of about 7.2% with the use of additives such as diethyl ether (Joshi & Thipse, 2019). In another study, algal biodiesel demonstrated comparable BTE to diesel, attributed to the fuel's oxygen content, which improves combustion (Ratomski *et al.*, 2023). Petroleum diesel typically has a slightly higher energy density, leading to marginally better performance in standard engines.

Blends of algal biofuels (e.g., 20% algal biodiesel with 80% diesel) have been found to optimize thermal efficiency while reducing emissions, achieving efficiencies close to neat diesel (Sharmila *et al.*, 2015). Using some of these fuels directly in commercial engines can cause issues like engine fouling, incomplete combustion, low fuel atomization, and contamination of lubrication oil.

Algal biodiesel production emits 55,400 g CO₂ equivalent per million BTU, compared to 101,000 g CO₂ equivalent for low-sulfur petroleum diesel, achieving approximately a 45% reduction in emissions. A detailed lifecycle analysis showed algal biodiesel avoids about 75 g CO₂ equivalent emissions per MJ of energy compared to petroleum diesel, demonstrating significant GHG benefits (Batan *et al.*, 2010). Algal biofuels are considered closer to carbon neutrality because the CO₂ absorbed during algae growth offsets emissions during fuel combustion (Sander & Murthy, 2010).

Advantages of seaweed as biofuel

Seaweed cultivation has a low environmental impact and can be done in areas unsuitable for agriculture. Seaweed absorbs carbon dioxide during photosynthesis, making it a carbon-neutral fuel source. Seaweed grows rapidly, offering a high yield of biomass. Seaweed-based biofuels can significantly reduce greenhouse gas emissions by up to 82% compared to fossil fuels. Seaweeds contain significant amounts of carbohydrates, primarily in the form of sugars like glucose, galactose, and mannitol. This makes them highly suitable for fermentation processes aimed at producing bioethanol and biobutanol. Unlike terrestrial biomass, seaweed has a low lignin content, which simplifies the conversion process as lignin typically complicates fermentation in wood-based biofuels. Seaweed cultivation does not require arable land or freshwater, making it a sustainable alternative to land-based crops used for biofuels.

Challenges and Considerations

Scaling up seaweed cultivation and processing to meet large-scale fuel demands requires significant investment and technological advancements. The economic feasibility of seaweed-based biofuel production depends on factors like seaweed cultivation costs, processing costs, and fuel prices. While seaweed cultivation is generally considered sustainable, it is essential to assess potential impacts on marine ecosystems and biodiversity.

Conclusion

Seaweed is the best alternative fuel to conventional fossil fuel in all sectors. The aviation sector alone contributes 2% of global CO₂ emissions. To reduce the GHG emission, we focus on seaweed which helps in reducing the carbon footprint by nearly 80%.

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CHAPTER - 12

SMART IRRIGATION SYSTEMS AND IOT FOR EFFICIENT WATER MANAGEMENT

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Abstract

Integrating Internet of Things (IoT) in irrigation systems revolutionizes water management, enabling precise and efficient use of resources. Smart irrigation systems leverage real-time data from sensors to monitor soil moisture, temperature, humidity, and weather conditions, optimizing irrigation and nutrient delivery. This innovative approach reduces water wastage, lowers operational costs, and enhances crop yields while being customizable for different crops and soil types. Incorporating advanced technologies like GSM-GPRS modems, cloud computing, and wireless communication standards, these systems provide farmers with real-time monitoring and control. Additionally, IoT-based solutions address global water scarcity through conservation techniques such as rainwater harvesting and reverse osmosis. Despite challenges in adoption, the future holds immense potential for integrating AI, machine learning, and wireless sensor networks to enhance efficiency further. This chapter explores the benefits, technologies, and prospects of IoT-based smart irrigation systems in promoting sustainable agricultural practices.

Keywords: Internet of Things (IoT), Smart irrigation, Precision agriculture and Water management.

Introduction

The IoT-based smart irrigation system revolutionizes water management in agriculture by providing precise irrigation tailored to the crop type, growth stage, and environmental conditions. This innovative approach leverages sensors, historical data, and satellite imagery to

optimize irrigation practices. The system integrates a network of soil moisture, temperature, and humidity sensors, along with weather condition monitors. These sensors transmit data to a central control unit equipped with algorithms that determine the optimal irrigation schedule and volume. This energy-efficient and cost-effective system significantly reduces water wastage, enhances crop yields and minimizes operational costs (Karthickraja and Saravanane, 2024). Its customizable design allows adaptation to specific crops and soil types. Additionally, farmers benefit from real-time monitoring through GSM-GPRS modules, which provide sensor readings and insights via platforms like ThingSpeak. Such advancements mark a paradigm shift toward sustainable, data-driven agricultural practices.

Smart Irrigation Technologies

Technologies such as the Internet of Things (IoT), sensors, and smartphone tools empower farmers with real-time data to optimize irrigation. IoT extends internet connectivity to devices, enabling seamless communication and user-friendly interfaces for system management. Automation driven by IoT enhances productivity by optimizing resources, including water, fertilizers, and seeds.

The key components included are:

- **Sensors:** Critical for monitoring soil temperature, moisture, and weather conditions, helping conserve resources and mitigate environmental impacts.
- **IoT Systems:** Facilitate real-time data collection and communication between devices, ensuring informed decision-making and precise resource application.

By adopting smart irrigation systems, farmers achieve higher yields with reduced input costs and environmental impact (Karthickraja *et al.*, 2022).

Water Management

Water management is a critical aspect of agriculture, especially in the face of global water scarcity. Effective management involves maintaining optimal soil moisture levels to ensure precise water application. This reduces costs, conserves resources, and enhances crop productivity while addressing environmental challenges.

Key water management strategies include:

1. **Measure/Metre/Manage:** Monitoring and managing water usage effectively.

2. **Smart Landscaping and Irrigation:** Employing efficient designs and technologies to reduce waste.
3. **Rainwater Harvesting:** Capturing and utilizing rainwater for irrigation.
4. **Reservoir Construction:** Creating storage solutions for consistent water supply.
5. **Reverse Osmosis Control:** Ensuring high water quality for irrigation.

These methods, when implemented effectively, ensure sustainable resource use and improved agricultural outcomes.

Proposed System

The proposed IoT-based smart irrigation system combines hardware and software components to optimize water management.

A. Hardware Components

1. **Moisture Sensing Section:** Two YL-69 soil moisture sensors equipped with LM393 comparator modules measure soil moisture under varying conditions. These sensors utilize electrical resistance to determine moisture levels and provide accurate readings through digital and analog outputs.
2. **Control Section:** Sensor data is transmitted to an Arduino board featuring an ATMEGA328P microcontroller. This board controls motor operations for sprinklers and communicates with a GSM-GPRS SIM900A modem, enabling IoT functionalities such as real-time data transmission and system monitoring.

B. Software Components

The system features a PHP-designed webpage hosted online with a database for storing and analysing sensor readings. Real-time data updates and analytics are displayed through platforms like ‘ThingSpeak’, allowing farmers to monitor and adjust irrigation schedules remotely.

Communication Technologies

Effective communication is essential for IoT-enabled irrigation systems. Technologies can be categorized based on their data transmission capabilities:

1. **Short-Range, Low-Power Devices:** Ideal for transmitting small data packets efficiently.
2. **Long-Range, High-Power Devices:** Suitable for transmitting large data volumes over extended distances.

Common communication standards include:

- **Wi-Fi:** Affordable and widely available but limited in range.
- **GSM:** Reliable for long-range communication through mobile networks.
- **LoRa:** Long-range, low-power technology ideal for remote agricultural areas.
- **MQTT:** Lightweight protocol for low-power consumption, less common in irrigation but efficient in niche applications.

Cloud Technologies

Cloud computing plays a pivotal role in IoT-based irrigation systems by facilitating large-scale data storage and analysis. Sensor data is processed and stored in the cloud, enabling users to access real-time information remotely (Saravanane *et al.*, 2024). Cloud platforms, both free and paid, support data analysis and research, enhancing decision-making and operational efficiency. Middleware further improves system connectivity by streamlining communication between applications, ensuring seamless performance and scalability. By integrating cloud technology, agricultural systems minimize risks and optimize resource use.

Benefits of IoT Systems in Irrigation

- **Reduced Water Consumption:** Efficient systems minimize wastage by ensuring precise irrigation.
- **Enhanced Cost Efficiency:** Automation reduces labour and operational costs.
- **Improved Performance:** Real-time data enables informed decision-making.
- **Lower Energy Use:** Advanced technologies optimize energy consumption.
- **Reduced Crop Wastage:** Healthier crops result from consistent and precise irrigation.

Advantages of Smart Irrigation

- **Water Conservation:** Efficient systems ensure minimal water use.
- **Consistent Watering:** Automated schedules maintain uniform irrigation.
- **Resource Efficiency:** Optimized resource use reduces environmental impact.
- **Cost Savings:** Lower operational costs benefit farmers.

- **Increased Crop Yields:** Healthier crops and improved productivity.

Additionally, smart systems detect and repair leaks promptly, monitor water quality to prevent pollution and improve public health standards (Karthickraja *et al.*, 2024).

Disadvantages of Traditional Irrigation Methods

- **Uneven Water Distribution:** Leads to inconsistent crop growth.
- **Waterlogging:** Common on uneven land, causing inefficiency.
- **Labor-Intensive:** High manual effort reduces overall productivity.

Future Aspects

IoT-based smart irrigation systems hold significant potential for future developments:

1. **Integration with IoT Systems:** Combining irrigation systems with weather stations, crop monitoring devices, and precision farming tools.
2. **AI and Machine Learning:** Employing advanced algorithms for predictive and adaptive irrigation control.
3. **Wireless Sensor Networks:** Reducing wiring complexity while enhancing field coverage and scalability.

These advancements promise increased efficiency, sustainability and profitability in agriculture (Saravanane *et al.*, 2023).

Conclusion

The IoT-based smart irrigation system offers a transformative approach to addressing inefficiencies in traditional irrigation methods. By leveraging sensors, microcontrollers, and cloud technologies, it ensures optimal water usage, supports sustainable farming practices, and enhances resource management. Real-time monitoring enables informed decision-making, resulting in healthier crops and improved productivity. As agriculture adapts to modern challenges, these systems provide a pathway to efficient, sustainable, and technologically advanced practices.

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CHAPTER - 13

ARTIFICIAL INTELLIGENCE IN BIOTECHNOLOGY

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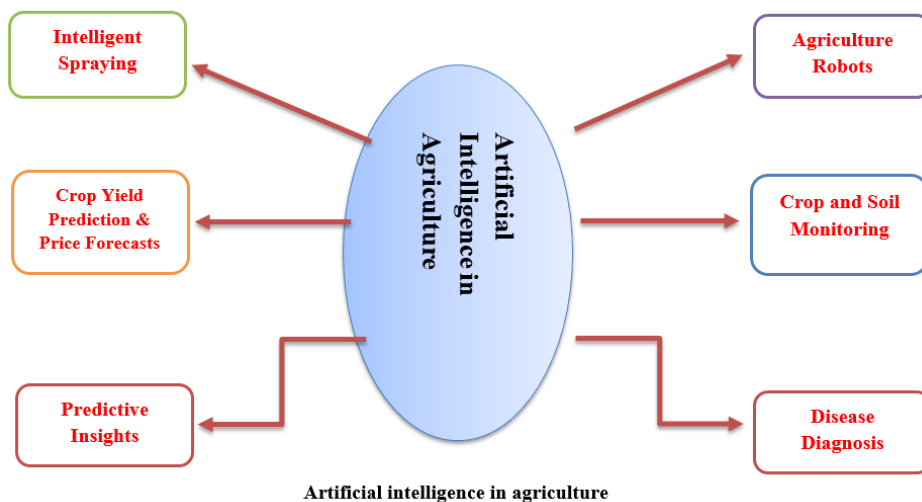
Introduction

The goal of computer science's artificial intelligence (AI) field is to build machines with intellect comparable to that of humans. This refers to creating algorithms and models that imitate human intelligence so that computers can process difficult tasks, learn from data, and adapt to new environments (Abonamah, Tariq, & Shilbayeh, 2021). The AI field of natural language processing (NLP) is becoming more and more important. Voice assistants, chatbots, and machine translation applications profit from this technological advancement since it makes it possible for machines to comprehend, interpret, and generate human language. The development of Natural Language Processing (NLP) has significantly increased the effectiveness of information transmission between humans and machines (Kuddus, 2022). Another significant use of computers is computer vision, or their capacity to interpret and analyse visual data from the outside environment. This technique has applications across a wide range of sectors, including autonomous vehicles and medical imaging. AI-based diagnostic tools can analyse medical images with extreme precision, assisting medical professionals in identifying anomalies and diseases.

Artificial Intelligence in Agricultural Biotechnology

Agricultural biotechnology, Medical biotechnology, Animal biotechnology, Industrial biotechnology and Bioinformatics are some of the subcategories of biotechnology. Let's examine how these biotechnological fields are impacted by artificial intelligence.

Biotechnology companies are currently using AI/ML solutions to create autonomous robots that can perform crucial agricultural chores, like harvesting crops far more quickly than people. Drone data processing and analysis are accomplished through the use of computer vision and deep learning techniques. This facilitates crop and soil health monitoring. ML algorithms are useful for monitoring and forecasting a range of environmental changes, such as weather variations that affect crop productivity. The field of smart agriculture is likewise being significantly impacted by digital transformation. There are a plethora of discrete, frequently incompatible solutions in agricultural digital ecosystems.



Molecular breeding is the process of using technologies from molecular biology, namely the genetic modification of DNA, to enhance the characteristics of plants or animals. Molecular marker assisted or genomic selection, as well as genetic engineering or gene manipulation, are some of the tools. The technology of plant tissue culture is helpful for commercial plant multiplication.

AI in Medical biotechnology

Medical biotechnology produces medications and antibiotics from live cells to enhance human health. Genetically engineered cells and DNA research are also included in order to boost the creation of significant and advantageous features. Drug discovery makes extensive use of machine learning and artificial intelligence. Based on established target structures, mechanical learning aids in the identification of small compounds with potential therapeutic advantages. Because machine learning uses actual results to improve diagnostic tests that is, the more diagnostic tests that are conducted, the more accurate the results that can be obtained it is commonly employed in diagnostic testing. AI also contributes to a reduction in radiation treatment planning time, which improves patient care and saves time. The development of EHRs with evidence-based medicine and clinical decision-making programmes is another area where Artificial Intelligence and Mechanical Education have shown promise. Apart from the aforementioned uses, this technology finds extensive use in the fields of genetic engineering, imaging, personal medicine, pharmaceutical administration, etc.

Artificial Intelligence in Industrial Biotechnology

The goal of industrial biotechnology is to replace biopolymers, which are now used in a variety of applications including novel chemicals, fibres, automotive components, fuel, and manufacturing processes. To enable efficient manufacturing and higher-quality products, the Internet of Things (IoT), machine learning, and intelligent practice analyse machines, forecast endpoints, fix equipment, etc. The necessary molecular design is necessary for artificial intelligence and computer-assisted designs. Robots and machine learning are used to test the success of achieving the target molecule and to magnify species.

Artificial Intelligence in Animal Biotechnology

The branch creates genes or mutations in animals using cellular biological procedures to increase the animals' sustainability for use in industry, medicine, or agriculture.

One field where artificial intelligence and machine learning models are useful is animal breeding. Breeding animals with highly desirable qualities on their own so that their progeny can also have those traits is a relatively common procedure known as selective breeding. When genetic

features are chosen and bred into animals, this process is applied at the cellular level. Large genomic data sets and a wide range of genomic sequences are interpreted using machine learning.

1. Encouraging Innovations: From Research to Industry:

Over the last ten years, there has been a need for expedited innovation in the areas of pharmaceutical manufacture and preparation, industrial chemicals, food-grade chemicals, and alternative biochemistry-related staples. AI in biotech is essential for fostering innovation not just in labs but also all the way through a drug's or compound's lifespan (all the way to the point where it's put on the market). AI-based tools and applications helped the target market and made it easier to build molecular structures. Machine learning is a branch of artificial intelligence that eliminates the need for manual experimentation in science labs by assisting with complex permutations and mixes of different compounds to choose the right combination.

Artificial Intelligence (AI) is being used in biotechnology to produce advancements that will make it easier to perform prophetic analysis, which predicts market demand for specific drugs or chemicals. By using cloud computing, AI in biotech may help manage the efficient delivery of the essential supplies required by the industry.

2. Open-Source AI Frameworks: Accelerated Data Processing:

Scientists from all around the world are observing AI programmes that will handle the laborious data analysis and upkeep of nature information. Activities such as protein compositions, chemical research, cistron writing, and other critical information processing are routinely examined to provide more accurate and timely results. AI programmes for ASCII text files, such as water.ai and CRISPR libraries, are playing a significant role in this regard by freeing up research laboratory staff from tedious duties like data entry and analysis. With the use of AI in biotechnology, attention providers and scientists will be able to spend more of their efforts on innovation-driven procedures by doing away with manual functions.

3. Expanding the Agricultural Biotechnology Boundaries: Improving Both Quality and Quantity:

When it comes to genetically engineering plants to produce more and better crops, biotechnology is crucial. Artificial intelligence (AI)-based techniques are becoming indispensable to the current genetic

modification process in order to evaluate crop possibilities, identify and contrast features, and predict a reasonable yield. In addition to these instruments, the agricultural biotechnology industry uses robotics, an Associate in Nursing branch of computing, for packing, harvesting, and other necessary operations. AI in biotech also assists in identifying trends in the impending fabric movement by integrating weather forecasts, field characteristics, and the availability of pesticides, fertilizers, and seeds.

4. Shortening the Timeline for the Discovery of New Medications and Vaccines

Newer diseases spread quickly across continents in today's globalized environment. In order to contain such diseases, the biotechnology industry is thus in a race against time to produce novel medications and vaccines. The fields of computer science and machine learning play a critical role in accelerating the process of identifying the right compounds, assisting with their synthesis in laboratories, conducting efficacious knowledge analysis, and supplying the market. Currently, operations that may take five to ten years have been reduced to two or three years because to the use of computer science in biotechnology.

5. Encouraging Global Communication: Disseminating Biotechnology Advancements across the Globe

AI systems are clever because they give scientists all across the world access to current information on novel medications and other technological advancements. Numerous machine learning techniques enable scientists to gather information, comprehend the patterns of a specific sickness in a far-off place, and utilise that information to build analytical models for their surroundings. Since AI was first used in biotech, the accuracy of scientific models has increased several times over. These are the primary strategies, although artificial intelligence (AI) and associated technologies are also significantly changing the biotechnology sector. Artificial intelligence will be used in biotechnology in the future to benefit humanity by making significant strides in the biological sciences and technology.

IV. Conclusion:

Artificial Intelligence (AI) is a very broad term that is used today generally and practically for everything where any Digital Information Processing System processes any data. Digitization and digital transformation are thus central to the beginning of any application of AI. Whether we like it or not, artificial intelligence (AI) will undoubtedly play

a bigger role in the future. Future goals include open science, open data, and fair AI systems that benefit all living things on Earth.

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CHAPTER - 14

INTEGRATED FARMING SYSTEM (IFS)

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Introduction

Integrated farming system is a sustainable agricultural system that integrates livestock, crop production, poultry, fish, and non-agricultural components such as agroforestry, horticulture, and beekeeping, in a single farming system. It is based on the concept that 'there is no waste' and 'waste is only a misplaced resource' which means waste from one component becomes an input for another part of the system. IFS approach is considered to be the most powerful tool for enhancing profitability of farming systems especially for small and marginal farmers to make them bountiful.

In the 1950s and 1960s, many developing countries were facing food shortages due to low agricultural productivity and a lack of resources to invest in modern agricultural technologies. To address these challenges, agricultural researchers and policymakers began to promote integrated farming systems as a way to increase productivity while reducing costs.

In the 1970s and 1980s, the concept of IFS gained more recognition and was adopted by several countries as a national policy. India implemented an Integrated Farming System Research project in the 1970s, which aimed to develop sustainable farming systems for small-scale farmers. Other countries such as China, Thailand, and Indonesia also adopted IFS as a national policy.

Today, integrated farming systems are becoming increasingly popular among farmers around the world, particularly small-scale farmers who are looking for sustainable ways to increase their productivity and

income. IFS are seen as a way to achieve sustainable agricultural practices that balance environmental, economic, and social goals.

Aim and Objectives of IFS

The main objective of an integrated farming system is to promote sustainable agriculture and rural development by utilizing resources efficiently, promoting biodiversity, and reducing negative environmental impacts.

1. Soil Conservation:

IFS involve the use of different cropping systems, such as intercropping and crop rotation, which help to maintain soil fertility and prevent soil erosion.

2. Biodiversity conservation:

IFS involve the integration of different components, such as trees, crops, and animals, which helps to promote biodiversity on farms. This helps to conserve wildlife habitats and prevent the loss of biodiversity.

3. Environmental sustainability:

IFS aim to promote sustainable agricultural practices that balance environmental, economic, and social goals. This involves reducing the use of chemical fertilizers and pesticides, conserving water resources, and reducing greenhouse gas emissions.

4. Food security:

Increase food production and reduce food insecurity by promoting sustainable agricultural practices that increase productivity and reduce the risk of crop failure.

5. Empowerment of small-scale farmers:

IFS are particularly relevant to small-scale farmers who may have limited resources and may face challenges in adopting modern agricultural technologies. IFS can help to empower small-scale farmers by providing them with sustainable farming practices that improve their productivity, income, and overall well-being.

Characteristics

An integrated farming system (IFS) is a sustainable agricultural production system that involves the integration of different agricultural and non-agricultural components. The characteristics of an IFS are as follows:

1. Integration:

IFS emphasizes the integration of different farming components, such as crops, livestock, and trees, into a single system to optimize the use of resources and reduce waste.

2. Diversification:

IFS seeks to promote diversity by growing a variety of crops, raising different types of livestock, and incorporating other components such as fish ponds and beekeeping into the farming system.

3. Resource conservation:

IFS promotes the conservation of natural resources, such as soil, water, and biodiversity, through practices such as crop rotations, intercropping, agroforestry, and the use of organic and natural fertilizers.

4. Efficiency:

IFS seek to optimize resource use and minimize waste by using integrated pest management (IPM), efficient water management, and other sustainable practices.

5. Livelihood improvement:

IFS aims to improve the livelihoods of farmers by increasing productivity, diversifying income streams, and improving food security and nutrition.

6. Sustainability:

IFS seeks to create a more sustainable farming system that can adapt to changing environmental and economic conditions, while also contributing to climate change mitigation and biodiversity conservation

7. Farm management:

IFS requires proper farm management practices such as proper planning, monitoring and evaluation, record keeping and decision-making for effective utilization of resources.

8. Social benefits:

IFS can help to improve the livelihoods of rural communities by providing them with sustainable farming practices that improve their productivity, income, and overall well-being.

9. Adaptability:

IFS can be adapted to different agro-climatic zones, production systems, and cultural practices. It can be customized according to the specific needs and conditions of farmers.

Components of Integrated Farming System

1. Piggery
2. Poultry
3. Duckery
4. Fishery
5. Plantation crops
6. Apiary
7. Mushroom Cultivation
8. Vermicomposting
9. Fruit cultivation

Integrated Farming System Models

There is no one specific model. IFS models vary depending on resource Availability, Farm's physical location, Access to markets, water availability, and agro-climatic conditions. Each farm plans according to its available resources, scope, and needs.

Model 1:

Horticulture + Piggery + Fisheries + Plantation Crops

- Pig dung acts as excellent pond fertilizer and some fishes feeds directly on the pig excreta.
- Pond water is used for cleaning pigsties and bathing the pigs
- Plantation trees as shade for the fishery pond or planted as fodder production between orchard trees to prevent soil erosion

Model 2:

Horticulture + Duckery + Fishery + Plantation crops + Vermicomposting + Apiary

- Vermicomposting can be used either for commercial or manure for crop.
- Ducks excreta for pond fertilizer while they get their feeds requirements from aquatic weeds etc.
- Apiary: Honey production and for pollination.
- Duck houses are constructed on pond dikes. Hence no additional land is required.

Model 3:

Agriculture + Horticulture + Poultry + Fishery Fruits crop + Vegetables and Spices Crop + Field crops + Plantation Crops Fishery + Vermicompost unit + Piggery.

Model 4:

Agriculture + Horticulture + Poultry + Fishery + Azolla + Mushroom.

- Mushroom cultivation: Straw residues for manuring, composting, mushrooms.
- Poultry: Egg/ meat, Manure, feeds for pig, income.
- Azolla: Bio-fertilizer, balanced feed for all cattle's, natural fertilizer for rice.

IFS models for India's Agro-ecological cell

AEC is a specific point with a unique combination of land, soil and climatic characteristics. IFS models for different zones in India. The All India Coordinated Research Project (AICRP-ICAR) on the IFS network has established various science-based IFS models across 15 agro-climatic regions covering 23 states and 2 UTs.

1. Cold desert zones: Pastures with forestry, sheep, goats, rabbits and limited crops like millets, wheat, barley, vegetables, and fodders.

2. Arid and desert zones: Animal husbandry with camels, sheep, and goats with pearl millet, wheat, pulses, oilseeds, and fodders.

3. Western and Central Himalayas zones: Horticultural crops with agricultural crops like maize, wheat, rice, pulses, and fodders on terraces, pastures with forestry, poultry, sheep, goats, rabbits and Himalayas native animal yak.

4. Eastern Himalayas:

- ✓ Horticultural crops with agricultural crops like maize, wheat, rice, pulses and pasture on terraces, pastures with forestry, sheep, goats, rabbits, yak, and cold-water fisheries (Altitudes more than 2,000 meters above mean sea level).
- ✓ Maize, rice, French bean, rice bean, pigs, poultry, fishery, and Cole crops like cabbage. (more than 1,000 meters above mean sea level).
- ✓ Rice, pulses, dairy, fish culture, and vegetables. (Lower than 1,000 meters mean sea level).

5. North Indian Plains: Fertile and Productive region. Crop such as rice, maize, wheat, mustard, pulses, and along with dairy.

6. Central highlands: Crops such as millets, pulses, and cotton along with dairy cattle, sheep, goat, and poultry.

7. Western Ghats: Mountain range in Kerala. Crop such as Plantation crops, rice and pulses and livestock components including cattle, sheep and goats.

8. Delta and coastal plains: low lying and flat land that is adjacent to the sea coast. Rice and pulse crops along with fish and poultry.

Conclusion:

Integrated Farming System is a promising approach for enhancing productivity and profitability of farming systems especially for small and marginal farmers through recycling the farm by-products and efficient utilization of available resources. Further, it achieves sustainable agricultural practices that balance environmental, economic, and social goals. It generates employment opportunities to the farming communities and provides a better economic returns and nutritional security.

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CHAPTER - 15

ADOPTION LEVEL OF SUGARCANE CULTIVATION PRACTICES BY THE MARGINAL FARMERS IN CUDDALORE DISTRICT

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Abstract

. The adoption of technology is a complex patterns of mental and physical activities. Several personal, psychological, economic and social factors largely determine the extent and nature of adoption and also continuance of the technology. So for this inefficiency, lack of proper and timely training for extension personnel was also attributed as one of the foremost reasons. The study was carried out in six villages from six blocks of Cuddalore District. A total number of ten sugarcane technologies with technological units were elected for the study. The eighty respondents were selected from six villages using proportionate random sampling method. Data collection was done through a well constructed and pre-tested interview schedule. The collected data were tabulated and analyzed by using appropriate statistical tests. As the extent of adoption was also found to be low among marginal farmers, low cost or no cost technologies maybe developed and recommended to them. It is also suggested that the knowledge on yield contributing factors in sugarcane must be imparted.

Key Words: Marginal farmers, Sugarcane technologies

INTRODUCTION

India, by contributing 20.4 per cent production ranks second among sugarcane growing countries of the world for both area and production of sugarcane . In this country, sugarcane is an important cash crop in the agriculture sector, which shares 7 per cent of the value of agricultural output and occupies only 2.5 per cent of the country's gross cropped area. India , resource poor type of agriculture is being practiced in majority of cases. About 43.00 per cent of the total sugarcane area is covered by marginal and small farmers in the country. The resource poor marginal and

small farmers function differently than the resource rich big sugarcane cultivators. The determinants of the appropriateness of a technology for marginal farmers are complex than the simple yield maximization per unit land a common target for most of the agricultural researchers.

The practices which is heavily dependent on purchased inputs and sensitive to environmental variations will not be sustainable on small farms. Therefore, there exists a wide technology gap. It is because the conditions existing at the research stations and on marginal and small farms have considerable difference. The adoption of technology is a complex patterns of mental and physical activities. Several personal, psychological, economic and social factors largely determine the extent and nature of adoption and also continuance of the technology. So for this inefficiency, lack of proper and timely training for extension personnel was also attributed as one of the foremost reasons.

The study was conducted in six villages from six blocks of Cuddalore District. A total number of ten sugarcane practices with technological units were selected for the study. The eighty sugarcane growers were selected from six villages using proportionate random sampling method. Data collection was done through a well constructed and pre-tested interview schedule. The collected data were tabulated and analyzed by using appropriate statistical tools.

Measurement of Adoption

The proportions of actual/recommended practices for each of the technological units of particular sugarcane technology were calculated and multiplied by the corresponding weight ages to get the Adoption Index of that technological unit.

Then these adoption indices of technological units were summed up for a particular sugarcane technology and divided by the total number of technological units for which the values were added. This was multiplied by the corresponding weights of that sugarcane technology to get Adoption Indices of the sugarcane technologies. Such adoption indices of all the sugarcane technologies were added together and then divided by the total number of sugarcane technologies to obtain the adoption index of sugarcane cultivation.

Adoption of sugarcane cultivation practices by marginal farmers

Sl. No.	Recommended cultivations practices	Marginal farmers	
		Number	Per cent
1	Sett selection	80	100.00
2	Sett treatment	5	6.25
3	Planting	80	100.00
4	Herbicide application	13	16.25
5	Bio-fertilizer application	6	7.50
6	Phosphatic fertilizer application	53	66.25
7	Nitrogenous fertilizer application	59	73.75
8	Potash fertilizer application	72	90.00
9	Control of early shoot borer	57	71.25
10	Use of bio-control agent	-	-

* Multiple response

1. SETT SELECTION

Sett selection was observed as the major practice prevalent in the entire study area. All the respondents (100.00 per cent) adopted the recommended practice of selection of setts in the sample. As all the farmers had realized the need for selection of diseases free setts and practical this for a longer time, this become a routine practice

2. SETT TREATMENT

Only 6.25 per cent of marginal farmers have done sett treatment . Lack of visible impact of fungicide treatment might be the possible reason for poor adoption.

3. PLANTING

Planting was observed as the major practice prevalent in the entire study area. All the respondents (100.00 percent) adopted the recommended method of planting in the total sample irrespective of the categories. All the cultivators were aware of recommended method of planting.

4. NERBICIDE APPLICATION

The herbicide Atrazine is recommended for the sugarcane crop. Only 16.25 per cent of marginal farmers had adopted the practice. High cost of herbicide and inadequate knowledge regarding the herbicide were the reasons expressed by sugarcane cultivators for their non- adoption.

5. BIO-FERTILIZER APPLICATION

Only 7.50 per cent of the farmers adopted the bio-fertilizer application. Inadequate knowledge about bio-fertilizer and lack of visible impact might be the reason for non-adoption.

6. PHOSPHATIC FERTILIZER APPLICATION

Use of recommended split of phosphatic fertilizer was adopted by marginal farmers is 66.25 per cent. This might be due to the fact that the sugar factory supplied the fertilizer in time, which in turn might have necessitated the farmers to apply the fertilizer.

7. NITROGENOUS FERTILIZER APPLICATION

Of the total respondents, most (73.75 per cent) of the respondents had applied the recommended dose of nitrogenous fertilizer in appropriate time. and most of the farmers expressed that they could see the vigorous and sturdy growth of the crop immediately after the application of nitrogenous fertilizers. This might be the reason for the higher level of adoption of nitrogenous fertilizer application.

8. POTASH FERTILIZER APPLICATION

Use of recommended dose of potash was adopted by almost all the respondents (95.41 per cent) adopted. Most of the farmers expressed that they could get yield if they apply potash fertilizer. It might be the reason for the higher level of adoption of potash application.

9. CONTROL OF EARLY SHOOT BORER

Early shoot borer was the most common pest in the study area. The control measures were adopted by most of the respondents (71.25 per cent) in total sample of the marginal farmers. Almost all the farmers have been practicing this for a long time and hence it become a routine practice.

10. USE OF BIO-CONTROL AGENT

None of the farmers had adopted the bio-control agent practice in marginal farmers category. Inadequate knowledge and non-availability of egg cards might be attributed as the reasons for non-adoption.

CONCLUSION

. The adoption of technology is a complex patterns of mental and physical activities. Several personal, psychological, economic and social factors largely determine the extent and nature of adoption and also continuance of the technology. So for this inefficiency, lack of proper and timely training for extension personnel was also attributed as one of the foremost reasons. As the extent of adoption was also found to be low among marginal farmers, low cost or no cost technologies maybe developed and recommended to them. It is also suggested that the knowledge on yield contributing factors in sugarcane must be imparted.

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CHAPTER - 16

BIOSENSORS IN PLANT DISEASE MANAGEMENT

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Introduction

Phyto-pathogens are one of the causes for decrease agricultural productivity. This is due to emerging of various plant diseases. Early detection of phyto-pathogens plays a crucial role in plant health monitoring. It allows managing disease infections in glass house as well as in the field and in addition preventing introduction of new plant diseases. Recently, biosensors have emerged and widely used as diagnostic tools in clinical, environmental and food analysis.

Biosensors

A biosensor is an analytical device containing an immobilized biological material like enzyme, antibody, nucleic acid, hormone, organelle or whole cell which can specifically interact with an analyte and produce physical, chemical or electrical signals that can be measured. An analyte is a compound (e.g. pesticide) whose concentration has to be measured. Biosensors basically involve the quantitative analysis of various substances by converting their biological actions into measurable signals.

History of biosensors

Leland C. Clark, who invented the first enzyme electrode in 1962, laid a start for biosensor technology. In the 1980s, the application of

biosensor technology to agriculture began, particularly for detecting plant diseases caused by bacteria, fungi, and viruses.

S. M. A. F. K. Al-Mamary and R. J. Cook explored biosensor applications for detecting plant pathogens in the environment. S. H. Lee and D. M. G. P. Chillemi are two notable researchers who contributed to the development of early immunosensors and DNA hybridization techniques for detecting plant pathogens.

Basic principles of Biosensors

Biosensors are analytical devices used to detect biological or chemical reactions through a biological component that produces a measurable signal. These devices combine a biological element (such as enzymes, antibodies, or microorganisms) with a transducer to convert the biological interaction into a quantifiable signal (such as electrical, optical, or thermal).

1. Biorecognition Element

It is responsible for detecting the target molecule or analyte like enzyme, nucleic acids etc.

2. Transducer

It converts the biological recognition event into a measurable signal. The transducer typically converts the biochemical interaction (e.g., binding of an antibody to an antigen) into a signal that can be quantified.

3. Signal Processing

The signal generated by the transducer must be amplified, filtered, and processed to obtain accurate and meaningful data. The processed signal is then displayed or recorded, often on a digital screen.

4. Detection and Output

The output is the final measurement of the analyte, which is usually displayed on a screen or recorded in a data format.

5. Specificity and Sensitivity

Specificity is an ability of the biosensor to detect only the target analyte and no other substances. Sensitivity is a biosensor's ability to detect low concentrations of the target analyte.

Types of Biosensors Used in Plant Pathology

1. Immunosensors

These sensors use antibodies or antigens to specifically bind with a target pathogen or toxin, triggering a measurable signal. Detection of plant viruses (e.g., *Tobacco mosaic virus*), bacteria (e.g., *Xanthomonas* species), and fungal pathogens (e.g., *Fusarium* species).

2. Nucleic Acid Biosensors

They detect specific sequences of DNA or RNA associated with pathogens, using methods such as PCR (Polymerase Chain Reaction), LAMP (Loop-Mediated Isothermal Amplification), or hybridization techniques. Detection of plant pathogens, particularly viruses and fungi, by identifying pathogen-specific genes or genomic regions.

3. Enzymatic Biosensors

These use enzymes that interact with substrates specific to the target pathogen or its metabolic products, producing a measurable signal (often an electrochemical one). Detection of metabolites produced by plant pathogens (e.g., mycotoxins, phenolic compounds).

4. Optical Biosensors

These sensors rely on the optical properties of materials that change when exposed to specific biological interactions, such as fluorescence, color change, or surface plasmon resonance (SPR). Detection of plant viruses, fungi, or bacteria through changes in optical properties when a pathogen interacts with a sensor surface.

5. Electrochemical Biosensors

These sensors detect changes in current, voltage, or impedance as a result of biological reactions between the sensor surface and target pathogen. Detection of bacterial infections (e.g., *Pseudomonas* species) and fungal infections.

Uses of Biosensors in plant disease management

1. Early Detection of Plant Diseases

Biosensors are capable of providing rapid and sensitive detection of plant pathogens at the molecular level, which helps in providing better strategies for disease management. (Kumar *et al.* 2019). It detect plant pathogen or disease before symptom appears. Enzyme-linked immunosorbent assays (ELISA) biosensors are commonly used to detect plant viruses.

2. Monitoring of Environmental Conditions Favorable to Pathogens

Environmental monitoring using biosensors aids in preventing plant diseases by identifying risk factors related to the growth conditions of pathogens (Hernández *et al.* 2020). It can monitor environmental factors like temperature, humidity etc., which act as a predictive models for disease outburst. Sensor network used to predict development of fungal diseases.

3. Detection of Pathogen-Specific Molecules

Molecular biosensors offer highly specific pathogen detection based on the unique genetic makeup of the pathogen. (Patel *et al.* 2017). DNA biosensors can detect specific genetic sequences associated with *Phytophthora infestans*. These biosensors detect specific molecules like proteins, DNA or toxin that are released by pathogens.

4. Pathogen Resistance Monitoring

Microbial biosensors can be employed to detect resistant strains of plant pathogens, helping in the development of new resistant plant varieties. Monitoring pathogen resistance - fungicide-resistant plant pathogens. (Santos *et al.* 2019)

5. Precision Agriculture

Biosensors in precision agriculture for reducing chemical inputs and enhancing sustainability in plant disease management (Yang *et al.* 2018). Nanobiosensors can be used for localized detection of pathogens in the soil or plant tissues.

Biosensors used for specific plant diseases

1. Electrochemical biosensor

This electrochemical sensor utilizes antibodies to specifically capture *Xanthomonas campestris* bacteria from plant samples. Once captured, the sensor detects changes in impedance or voltage, which can be correlated with the bacterial concentration, providing a quick and reliable detection method for bacterial wilt (Williams *et al.* 2020).

2. Optical biosensor (Surface Plasmon Resonance)

This biosensor uses Surface Plasmon Resonance (SPR) to detect the pathogen. A specific antibody against *Phytophthora infestans* is immobilized on a sensor surface, and when the pathogen is present, it binds to the antibody, resulting in a measurable change in refractive index (Lee *et al.* 2019).

3. DNA-based biosensor (Polymerase Chain Reaction with electrochemical detection)

A DNA probe is designed to specifically bind to sequences unique to *Fusarium oxysporum*. The sensor then amplifies the target DNA using PCR and detects the presence of the pathogen by measuring the change in electrical properties after the hybridization of the target DNA with the probe. (Liu *et al.* 2021).

4. Colorimetric biosensor

A colorimetric sensor uses enzyme-labeled antibodies or peptides to bind to the *Ralstonia solanacearum* bacteria. The binding leads to a color change in the presence of the bacteria, which can be easily observed visually (Zhang *et al.* 2022).

5. Nanoparticle-based biosensor

This sensor uses gold nanoparticles functionalized with antibodies or RNA probes specific to the TMV virus. Upon interaction with the virus, the nanoparticles aggregate, leading to a change in optical properties, which can be detected using UV-Vis spectroscopy (Wang *et al.* 2020).

Conclusion

Early detection of emerging plant diseases plays an important role in plant disease management and also could reduce the damage caused by plant diseases. Meanwhile, biosensors for plant disease detection are at lab level, it is expected to be portable devices in the future for an efficient diagnostic. Biosensing approaches are being suitable for fast, sensitive testing of small number of samples and for ensuring the quality of disease-free plant materials. These biosensors provide the capability to detect plant diseases efficiently and in real time, leading to better disease management practices and minimizing the environmental impact of chemical treatments.

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CHAPTER - 17

INTRODUCTION TO PLANT QUARANTINE

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The term 'Quarantine' means simply forty i.e., 40 days period. This was more commonly referred to the period of detention for ships arriving from countries subject to epidemic diseases such as the Bubonic plague, cholera and yellow fever. The crew and the passengers used to be compelled to remain isolated on board for sufficient period to permit the diseases to develop and be detected. The purpose of the health authorities was to establish adequate detention period. Later on, the term 'Quarantine' came to be only used for the detention and the practices connected with it. The term got associated from the human disease field to the animal disease field and later on adopted to cover protective methods for the exclusion of pests and diseases of agricultural and horticultural crops.

Plant quarantine laws were first enacted in **France** (1660), followed by Denmark (1903) and USA (1912). These rules were aimed at the rapid destruction or eradication of barberry bush which is an alternate host of *Puccinia graminis tritici*. In India, plant quarantine rules and regulations were issued under **Destructive Insects and Pests Act (DIPA)** in 1914. In India, 16 plant quarantine stations are in operation by the "Directorate of plant protection and quarantine" under the ministry of food and agriculture, government of India.

Destructive Insects and Pests Act (DIPA) 1914

- Power of Central Government to regulate or prohibit the import of articles likely to infect
- Power of Central Government to make rules
- Power of State Government to make rules

Importance

The entry of a single exotic insect or disease and its establishment in the new environment continues to cause great, national loss till such time it is brought under effective control. In certain cases a country has to spend a few million rupees before success in controlling the introduced insect pest or disease is achieved.

International plant protection convention the first effort towards international agreement on Plant Protection was made in 1914 under the auspices of the International Institute of Agriculture in Rome. This was followed by an International Convention of Plant Protection by over 50 member countries of the Institute in 1919 and certain Agreements regarding the issue and acceptance of phytosanitary certificates were finalized. The project received a set back due to Second World War and was later on revived by the FAO. In post-war period International action in Plant Protection and particularly in plant quarantine was encouraged by FAO with the establishment in 1951 of the International Plant Protection Convention. This agreement was constituted with the purpose of securing common and effective action to prevent the introduction and spread of pests and diseases of plants and plant products as to encourage Governments to take all steps necessary to implement its prevention

Under article 3 of that International Plant Protection Convention, the Plant Protection Agreement for South East Asia and Pacific Region was sponsored by F.A.O in 1956, and India became in party to this Agreement in the same year the along with Australia, Sri Lanka, the U.K., Laos, Netherlands, Indonesia, Portugal and Vietnam. Our Government agreed to adopt legislative measures specified in the Convention for the purpose of securing common and effective action to prevent the introduction and spread of pests and diseases of plants and plant products and to promote measures for their control and also agreed to assume all responsibilities for the fulfillment within its territories of

all requirements under the Convention. It was agreed that the Government shall make provision for an official plant protection organization,

The legislative measures against crop pests and diseases were initiated under the DIP Act of 1914 which was passed by the then Governor General of India in Council on 3 February 1914. Prior to the establishment of the Directorate of Plant Protection, Quarantine and Storage in 1946, under the Ministry of Food and Agriculture, the various rules and regulations of the DIP Act were enforced by the customs department. The quarantine regulations are operative through The Destructive Insects and Pests Act, 1914 (which has been revised 8 times from 1930 to 1956 and amended in 1967 and 1992. The provisions of the DIP Act are

The plant quarantine service is centrally organized and administered through the **Directorate of Plant Protection, Quarantine and Storage established under the Ministry of Agriculture (Department of Agriculture and Co-operation)** which is headed by the **Plant Protection Adviser** to the Government of India and having its headquarters at N.H. IV, Faridabad, Haryana State. Import regulations.

The major activities of PLANT QUARANTINE:

- **Inspection of imported agricultural commodities** for preventing the introduction of exotic pests and diseases inimical to Indian Fauna and Flora
- **Inspection of agricultural commodities meant for export** as per the requirements of importing countries under International Plant Protection Convention (IPPC)
- **Detection of exotic pests and diseases already introduced** for containing/controlling them by adopting domestic quarantine regulations.
- Undertaking **Post Entry Quarantine Inspection** in respect of identified planting materials.
- Conducting the **Pest Risk Analysis (PRA)** to finalise phytosanitary requirements for import of plant/plant material.

Plant quarantine measures are of 3 types.

1. *Domestic quarantine*
2. *Foreign quarantine*
3. *Total embargoes*

Domestic Quarantine

Under the DIP Act, the Directorate of Plant Protection, Quarantine and storage has the responsibility to take the necessary steps and regulate the inter-state movement of plants and plant material in order to prevent the further spread of destructive insects and diseases that have already entered the country. The sole object of enforcing domestic quarantine is to prevent the spread of these diseases from infected to non-infected areas. Currently, domestic plant quarantine exists in four diseases, wart (*Synchytrium endobioticum*) of potato from 1959, bunchy top (virus) of banana from 1959, mosaic (virus) of banana from 1961 and apple scab (*Venturia inaequalis*) from 1979. Most of the states in India have plant quarantine laws to avoid entry of plant pests and diseases

- a. **Bunchy top of banana:** The export and the transport from the States of Assam, Kerala, Orissa, West Bengal, Tamil Nadu to any other State of Banana plant or any other plant of the genus *Musa*, including sucker, stem, leaf, flower, and any other part thereof which may be used for propagation, or the materials of banana plant or any other plant of the genus *Musa*, which are used for packing and wrapping, excluding the banana fruit is prohibited.
- b. **Banana mosaic :** The export and transport from the States of Maharashtra and Gujarat of any plant of Banana or any other plant of genus *Musa* including the sucker, stem, flower and any other part thereof, but excluding leaf and fruit thereof is prohibited
- c. **Potato wart:** The export to potato tubers from the State of West Bengal to any other State or territory of India is prohibited.
- d. **Apple scab:** The Directorate of Horticulture, Himachal Pradesh worked out a detailed scheme for the eradication of scab, and also issued a notification in 1978, prohibiting the export of planting material of apple outside the State.

In Tamil Nadu as per Madras pests and Diseases Act of 1919, quarantine regulations are periodically enforced. e.g., cardamom mosaic prevalent in Anamalai area of Coimbatore District and is free from Nelliampatti area. Hence the movement of diseased plant material from Anamalai to Nelliampatti area is prevented.

Limitations

There are many limitations to implementing domestic plant quarantine in India due to the vastness of the country and the unrestricted movement of plant material from one state to another. As a result the diseases like bunchy top and mosaic of banana have spread to several other states. However, the wart disease, golden nematode of potato, and scab of apple are restricted in the states where they were initially noticed.

Rules and regulations issued prohibiting the movement of insects and diseases and their hosts from one state to another state in India is called domestic quarantine.

2. Foreign quarantine:

Rules and regulations issued prohibiting the import of plants, plant materials, insects and fungi into India from foreign countries by air, sea and land. Foreign quarantine rules may be general or specific. General rules aim at prevention of introduction of pests and diseases into a country, where as the specific rules aim at specific diseases and insect pests. The plant materials are to be imported only through the prescribed ports of entry.

Agencies involved in plant quarantine

The authority to implement the quarantine rules and regulations framed under DIP Act rests basically with the **Directorate of plant Protection, Quarantine & Storage (DPPQ&S)**, Faridabad, Haryana. under the Ministry of Agriculture & Farmers welfare. This organization handles bulk import and export of seed and planting material for commercial purpose. Under this organization 46 seaports, 24 airports and 24 land frontiers are functioning. These are the recognized ports (Totally 73) for entries for import of plant and plant material. The names and places of the ports and stations are as follows.

The Government of India has also approved **three other national institutions** to act as official quarantine agencies, especially for research material.

1. National Bureau of Plant Genetic Resources (NBPGR)

The NBPGR in New Delhi and its regional station at Hyderabad in the agency involved in processing of germplasm, seed, plant material of agricultural, horticultural, and silvicultural crops of all the institutions

of Indian Council of Agricultural Research (ICAR) functioning in the country.

2. Forest Research Institute (FRI), Dehra Dun, for forestry plants and

3. Botanical Survey of India (BSI) for other plants.

3. Total embargoes:

Total restriction on import and export of agricultural commodities. It is an official ban on trade or other commercial activity with a particular country applied when **pest risk is very high.**

LIST OF PLANT QUARANTINE STATIONS IN INDIA

Presently, there are **73 Plant quarantine Stations** at different International Airports, Seaports and Land Frontiers implementing the Plant Quarantine Stations regulations with its Headquarters at Faridabad.

RPQS,

- 1. Mumbai**
- 2. Kandla**
- 3. Chennai**
- 4. Bengaluru**
- 5. Kolkata**
- 6. New Delhi**
- 7. Amritsar**

Plant Quarantine Stations under RPQS, Chennai

1. RPQS, Chennai
2. PQS, Coimbatore
3. PQS, Tuticorin
4. PQS, Tiruchirapalli
5. PQS, Madurai
6. PQS, Cuddalore*
7. PQS, Kakinada
8. PQS, Vishakapatnam
9. PQS, Krishnapatnam
10. PQS, Guntur
11. PQS, Machilipatnam*
12. PQS, Pondicherry*

Activate
Go to Settings

Phytosanitary certificate: It is an official certificate from the country of origin, which should accompany the consignment without which the material may be refused from entry.

These are documents issued by an official of an exporting country, or country of re-export, attesting to the freedom from pests and admissibility into the destination country for specific plants or plant

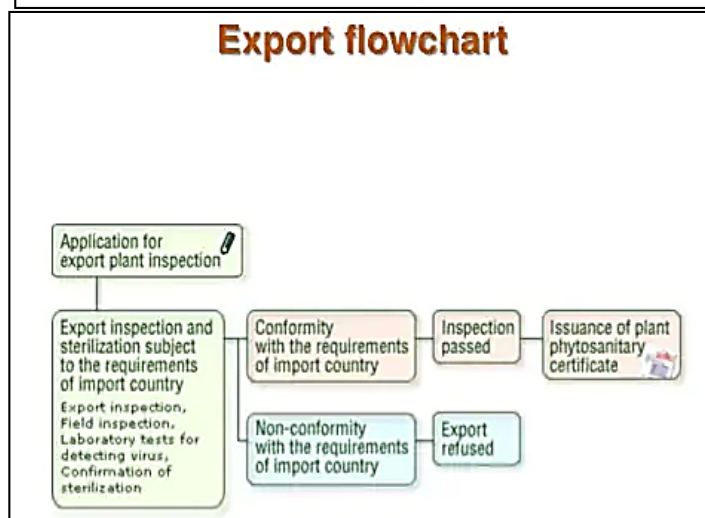
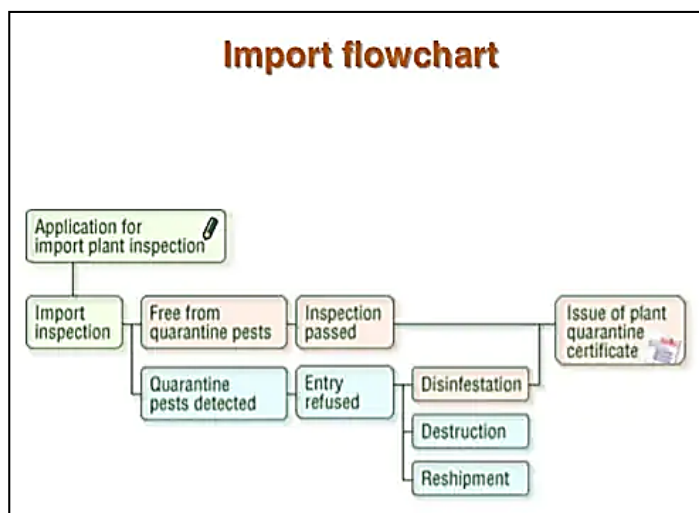
products Phytosanitary certificate performs the following tasks at the port of entry.

SCHEDULE-IV
[See clause 3 (2), 10(2) and 11(1)]
List of plants/planting materials and countries from where import is prohibited along with justifications

S. No.	Plant species/variety	Categories of plant material	Prohibited from the countries	Justification for Prohibition
1.	Banana, Plantain and Abaca (<i>Musa spp.</i>)	Rhizomes/Suckers	Central & South America, Hawaii, Philippines and Cameroon	Due to incidence of destructive pests such as Moko wilt (<i>Burkholderia solanacearum</i>) race 2 and Cameroon marbling (phytoplasmas)
2.	Cassava or tapioca (<i>Manihot esculenta</i>)	Seed/Stem cuttings	Africa & South America	Due to incidence of destructive pests such as: Super elongation (<i>Sphaceloma manihoticola</i>), Cassava bacterial blight (<i>Xanthomonas campestris</i> pv. <i>manihotis</i>) - American strains, Cassava witches "broom" (<i>phytoplasma</i>) and several cassava viruses.
3.	Cocoa (<i>Theobroma cacao</i>) and plants species belong to Sterculiaceae, Bombacaceae and Tiliaceae.	Freshbeans/Pods/Bud wood/Grafts Rootstock/ Saplings	West Africa, Tropical America and Sri Lanka.	Due to incidence of destructive pests such as: Swollen shoot virus and related virus strains of cocoa, Witches broom (<i>Crinipellis (Marasmius) perniciosa</i> Watery pod rot (<i>Monilia (Moniliophthora) roleri</i>), Mealy pod (<i>Trachysphaera fructigena</i>), Mirids (<i>Sahlbergia singularis</i> & <i>Distantiella theobroma</i>), Cocoa moth (<i>Acorocercops cramerella</i>), Cocoa capsid (<i>Sahlbergiella theobroma</i>), Cocoa beetle (<i>Steirastoma brevis</i>), Seedling damping-off (<i>Phytophthora cactorum</i>), Chestnut downy mildew (<i>Phytophthora katsurayae</i>) and Blackpod of cocoa (<i>Phytophthora megakarya</i>).

Coconut (<i>Cocos nucifera</i>) and related species of Cocoideae	Seed nuts/ Seedlings/ Pollen/Tissue cultures etc.	Africa (Cameroon, Ghana, Nigeria, Togo and Tanzania), North America (Florida in USA, Mexico); Central America and Caribbean (Cayman Islands, Bahamas, Cuba, Dominican Republic, Haiti, Jamaica) Philippines and Gaum Brazil (Atlantic Coast), Trinidad, Tobago, Grenada, St. Vincent, Barbados, Belize, Honduras, Costa Rica, El Salvador, Panama, Columbia, Venezuela and Ecuador, Surinam (Dutch Guyana), Sri Lanka.	Due to incidence of destructive pests such as: Palm lethal yellowing (phytoplasma) and related strains, Cadang cadang & Tinangaja (viroid), Lethal boll rot (<i>Marasmiellus cocophilus</i>), Red ring (<i>Rhadinaphelenchus cocophilus (palmarum)</i>), South American Palm weevil (<i>Rhyncophorus palmarum</i>), Leaf minor (<i>Promecotheca cumingi</i>) and Palm kernel borer (<i>Pachymerus spp.</i>)
Coffee (<i>Coffea spp.</i>) and related species of Rubiaceae	Beans (seeds) /Berries (freshly harvested)/ Grafts/ Budwood/ Seedlings/ Rooted cuttings etc.	Africa and South America	Due to incidence of destructive pests such as American leaf spot (<i>Mycena citricolor</i> , syn. <i>Omphalia flavida</i>), Coffee berry disease (<i>Colletotrichum coffeanum</i> var. <i>virulens</i>), Tracheomyces (<i>Gibberella xylariodes</i> , syn <i>Fusarium xylarioids</i>), Powdery rust (<i>Hemeleia coffeicola</i>), Phloem necrosis (<i>Phytomonas leptovisorum</i>) and Coffee viruses (coffee ringspot, leaf rugosity, leaf curl, leaf crinkle and mosaic viruses), Coffee berry borer (<i>Hypothenemus hampei</i> , <i>Sophronica ventralis</i>) and Coffee thrips (<i>Diarthothrips coffeae</i>).

- Identify type of plants or plant products
- Identify area where plants or plant products were grown
- Determine if the plants or plant products were treated in country of origin and if so, identify the treatment
- Determine if quarantine requirements are met
- Confirm that plant products meet specific certification requirements



PQ Form 21		
PHYTOSANITARY CERTIFICATE (To be typed or printed in block letters)		
No. _____		
From Plant Protection Organisation of _____	To: Plant Protection Organisation(s) of _____	
Description of Consignment		
Name and address of exporter		
Declared name and address of consignee		
Number and description of packages		
Distinguishing marks		
Place of Origin		
Declared means of conveyance		
Declared point of entry		
Name of produce and quantity declared		
Botanical name of plants		
This is to certify that the plants or plant products described above have been inspected according to appropriate procedures and are considered to be free from quarantine pests and practically free from the injurious pests and that they are considered to conform to the current phytosanitary regulations at the importing country		
Desinfestation and/ or Disinfection Treatment		
Date _____	Temperature: _____	
Duration: _____	Chemical (active ingredient) _____	
Treatment _____	Concentration _____	
Additional information: _____		
Additional declarations:		
Place of issue:	Stamp of Organization	Name &
Date of issue		Signature of authorized officer
No financial liability with respect to this certificate shall attach to..... (Name of Plant Protection Organisation) or to any of its officers or representatives*.*Optional clause		

Post Entry quarantine (PEQ): Despite every precaution of inspection, certification and treatment, it is not always possible to guarantee that a consignment is completely free from pathogens. In doubtful cases it is advisable to subject plants to a period of growth in isolation under strict supervision in the importing country (post-entry quarantine).

During post-entry quarantine plants must be kept under close supervision, so that any pest or disease which appears may be immediately detected and grown under optimum conditions, so that symptoms are not marked by physiological disturbances

"post-entry quarantine" means growing of imported plants in confinement for a specified period of time in an isolated condition either in glass house, poly house or isolated field or any other facility for disease development and symptom expression under close supervision so that infected lot is detected and measures are taken to contain its spread.

- Plants are given sufficient time to grow and express symptoms of any pest if they have been infected before import
- Thereby we can identify and detect the infected plants in the imported lot and destroy it before spread

Post Entry Quarantine in India. -

(1) Plants and seeds, which require post-entry quarantine as laid down in **Schedule V** and **VI** of this Order,

2. Plants/seeds which require **post entry quarantine**: Cocoa, citrus, coconut, groundnut, potato, sugarcane, sunflower, tobacco and wheat.

These plants should be grown in **Post-Entry Quarantine (PEQ)** facilities (established by **importer** at his cost) Approved and certified by the **Inspection Authority (IA)** as per the guidelines prescribed by the **Plant Protection Adviser**.

- for **certification of PEQ facilities** established by importer application should be submitted to the Inspection Authority with DPPQ&S
- **On arrival of the consignment**, the importer shall produce this certificate before the Officer-in- Charge of the Plant Quarantine (PQ) to get provisional clearance under PEQ
- Importer should **intimate the Inspection Authority** in advance about the date of planting
- **permit the Inspection Authority** complete access to the PEQ facility at all times
- Importer should extend necessary **facilities to the Inspection Authority (IA)** during his visit
- **Inspection of the consignment** in PEQ facility shall be carried out at frequent interval by **Inspection Authority** jointly with the nominated Officers of DPPQS.

- **frequency of the inspections** shall be decided considering the growing period of the consignment subject to a **minimum of two** inspections
- Where the plants in the PEQ are **found to be affected by pests and diseases** during the specified period the inspection authority shall either: -
 - **Order the destruction** (if the pest or disease is exotic) or order for taking **Curative measures** (if the pest or disease is not exotic) and permit the release only after curative measures have been observed to be successful.
 - If materials to be Destroyed it should be done as directed by the IA and **under his supervision**
 - At the end of final inspection, the Inspection Authority shall **forward a copy of the report** of PEQ inspection duly signed by him **to the Plant Protection Adviser** under intimation to officer-in-charge of concerned PQ station.
 - **Final decision** regarding release of the consignments shall be granted only by **Plant Protection Adviser** by taking into consideration of inspection report.

Pest Risk Analysis (PRA):

- The process of evaluating biological or other scientific and economic evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it
- Pest risk analysis is set of activities, in which the probability and the severity of impact of a particular pest is assessed the means of reducing these are evaluated, and the results of this review are shared with those involved
- It helps to ensure that decisions on the control of imports and exports are based on sound science, are related to the risks involved and have minimal impact on trade.

Why is PRA done?

- To protect the country's agriculture from damages that can be caused by harmful (quarantine) pests which can be brought in along with imported commodities;
- To evaluate and manage risk from specific pests and internationally traded commodities

- Identify and assess risks to agricultural and horticultural crops forestry and the environment from plant pests
- To create lists of regulated pests
- To produce lists of prohibited plants and plant products
- To assist in identifying appropriate management options

Plant diseases introduced into India before/after enforcement of plant quarantine laws:

S.No.	Pests	Native Place	Year of introduction
1	Coffee rust (<i>Hemileia vastatrix</i>)	Srilanka	1879
2	Late blight of potato (<i>Phytophthora infestans</i>)	England	1883
3	Rust of chrysanthemum(<i>Puccinia carthami</i>)	Japan/Europe	1904
4	Flag smut of wheat (<i>Urocystis tritici</i>)	Australia	1906
5	Downy mildew of grape (<i>Plasmopara viticola</i>)	Europe	1910
6	Downy mildew of maize (<i>Sclerophthora</i>	Java	1912
7	Downy mildew of cucurbits (<i>P. cubensis</i>)	Srilanka	1918
8	Black rot of crucifers (<i>Xanthomonas campestris</i>)	Java	1929
9	Foot rot of Rice (<i>Fusarium moniliforme</i>)	South East Asia	1930
10	Leaf spot of sorghum	South Africa	1934
11	Powdery mildew of rubber (<i>Oidium heveae</i>)	Malaya	1938
12	Blank Shank of Tobacco	Holland	1938
13	Fire blight of pear	England	1940
14	Crown gall of Apple/pear (<i>A. tumefaciens</i>)	England	1940
15	Bunchy top virus	Srilanka	1940
16	Canker of apple (<i>Sphaeropsis</i> spp.)	Australia	1943
17	Wart of potato (<i>Synchytrium endobioticum</i>)	Netherlands	1953
18	Bacterial blight of paddy (<i>X. oryzae</i>)	Philippine	1959
19	Golden Nematode of potato	Europe	1961
20	San Jose scale of apple	Italy	1900
21	Wooly aphid of apple	Australia	1928
22	Sunflower downy mildew (<i>Plasmopara halstedii</i>)	Australia	1985

Diseases not yet entered into India: Swollen shoot of cocoa, leaf blight of rubber and many viral diseases.

CONCLUSION:

Quarantine is an important protocol for international food trading.

- To prevent dumping of low quality goods in the country
- Increasing competence of the manufacturers to compete in the international market
- Protecting the nation from introduction & spread of exotic pests and diseases
- Overall safety and welfare of nation's economy and mankind
- If Quarantine regulations were made mandatory in past, today India would have been free from important diseases like leaf rust of coffee(Srilanka), late blight of potato (UK), Bunchy top of banana(Srilanka), onion smut of onion(Europe) etc

CHAPTER - 18

AIR MASSES, ITS CLASSIFICATION AND ITS CHARACTERISTICS

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INTRODUCTION

- Air masses are largely responsible for bringing about changes in the day-to-day weather
- Therefore, air masses also play a dominant role in producing different types of climate
- Cyclones and anticyclones characterize the weather of temperate region. these cyclones are associated with the motion of air masses
- If the air mass is lying on the land surface for a longer period, then it will become warm or cold depending upon the temperature of the underlying surface
- Air mass lying on the ocean absorbs moisture and transports this moisture to the land surface
- During World War I by Norwegian meteorologists, Wilhelm B Jerkens and Jacob B Jerkens . this concept is now known as air mass analysis
- In the next decades the air mass analysis proved of immense help in short-range forecasting covering a period of 24 to 36 hours
- Air mass analysis technique enabled meteorologists to understand various weather phenomena more clearly

DEFINITION:

- Air mass can be defined as a large air volume with uniform temperature and moisture.
- These masses can stretch thousands of miles horizontally over the earth's surface, and vertically from ground level to the stratosphere (10 miles) into the atmosphere.
- When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area. The homogenous regions can be the vast ocean surface or vast plains and plateaus.
- The air with distinctive characteristics in terms of temperature and humidity is called an Air mass. It is a large body of air having little horizontal variation in temperature and moisture.
- Air masses form an integral part of the global planetary wind system. Therefore, they are associated with one or other wind belt.
- They extend from the surface to lower stratosphere and are across thousands of kilometres.

AIR MASSES FORMS

- Air masses form over source regions, giving them uniform temperature and humidity.
- Moreover, low wind speeds prevent these large volumes from moving. So, while they stay stationary over a region, they acquire the conditions of that region, either temperature or humidity.
- Then as wind speeds increase, they move to other areas, still keeping their source region's states.
- They can also clash with different air masses in other regions and cause a storm

CHARACTERISTICS OF AIR MASSES

- It has nearly uniform conditions of temperature and humidity at any given level of altitude.
- It extends thousands of kilometers across the surface of the earth and can reach from ground level to the stratosphere.
- When winds move air masses, they carry their weather conditions from the source region to a new region.
- Maritime air masses form over the water and are humid. Continental air masses form over land and are dry.
- It must be large. A typical air mass is more than 1600 kilometres across and several kilometres deep.
- At any given altitude in the air mass, its physical characteristics primarily temperature, humidity, and stability are relatively homogeneous.
- It must be distinct from the surrounding air, and when it moves, it must retain its original characteristics and not be torn apart by differences in airflow.

SOURCE REGIONS:

- Area where air masses form are known as source regions
- Conditions which produce air masses are well developed over the tropical seas and hot deserts during much of the year and over the arctic region , particularly in winter –primary source regions air masses
- If the air that passes over such a region can be transformed rapidly , it may acquire unique characteristics such regions are referred to as secondary source regions
- Primary source regions may be either warm or cool because the air may be stagnant for longer periods
- The secondary source regions should either be relatively warmer than the overlying air

- The main source regions are the high-pressure belts in the sub-tropics (giving rise to tropical air masses) and around the poles (the source for polar air masses).
- Source Region establishes heat and moisture equilibrium with the overlying air mass.
- When an air mass moves away from a source region, the upper level maintains the physical characteristics for a longer period. This is possible because air masses are stable with stagnant air which does not facilitate convection. Conduction and radiation in such stagnant air are not effective.

Meteorologists classify air masses based on where they are formed

There are 4 types of air masses on based latitude

Arctic: These air masses form in the arctic region and are very cold.

Tropical: These air masses form in low lying latitudes and are warm up to a moderate level.

Polar: These air masses form in the high-latitude region and are cold.

Equatorial: They start forming over the equator and are warm.

Meteorologists classify them based on the surface.

These distinctions are

- *Maritime:* maritime one's form over the water bodies and are filled with moisture.
- *Continental:* whereas, the continental one's form over the land and are arid.

Air Mass Categorization of the USA

Continental polar

- This type of air mass forms over large land masses like northern Canada. Mostly stable, these are free of condensation forms as they form over the land.
- When these air masses get heated or moistened from the ground, they are capable of producing snow or rain.

Maritime polar

- They form over large water bodies and pick up considerable moisture. They move towards the land in middle and high latitudes.
- They are responsible for producing heavy rain when forced up mountain slopes or can be caught up in cyclonic activity.

Continental tropical

- This type of air mass emerges in the lower latitudes over deserts or interiors of land masses. They usually develop in summer.
- It is subject to great heat, and due to the lack of moisture on the ground, they are typically arid

Maritime tropical

- They form over the vast tropical oceans and contain much moisture. They are responsible for producing rain.
- In case it moves poleward, it is cooled by the ground surface and produces fog. Over the continental areas, they are strongly heated and responsible for convectional rain or thunderstorms

Air mass	symbol	Source region	Temperature (° c)	Specific humidity (gm/kg)
Maritime equatorial	<u>mE</u>	Warm ocean between 15°N-15°S	27°	19
Maritime tropical	<u>mT</u>	Warm ocean between 15°N or S	24°	17
Continental tropical	<u>cT</u>	Subtropical deserts 15°N or S	24°	11
Maritime polar	<u>mP</u>	Midlatitude oceans 40°-60°N or S	4°	4.4
Continental polar	<u>cP</u>	Northern continental interior 40°-60°N or S	-11°	1.4
Continental Arctic and Antarctic	<u>cAA</u>	North and south poles 60°-90°N or S		

Influence of air masses on world weather

- The properties of an air mass which influence the accompanying weather are vertical distribution temperature (indicating its stability and coldness or warmness) and the moisture content.
- The air masses carry atmospheric moisture from oceans to continents and cause precipitation over landmasses.
- They transport latent heat, thus removing the latitudinal heat balance.
- Most of the migratory atmospheric disturbances such as cyclones and storms originate at the contact zone between different air masses and the weather associated with these disturbances is determined by characteristics of the air masses involved.

CHAPTER - 19

EFFECT OF TEXTILE DYEING EFFLUENT ON SEED GERMINATION AND SEEDLING GROWTH IN *Vigna radiata* (L.) R. WILCZEK VARIETIES CO-6 AND CO-GG-902

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ABSTRACT

Green gram (*Vigna radiata* (L.) R. Wilczek) is one of the most important pulse crops, grown in almost all parts of India. Increased agricultural practices need more water and scarcity of water increases the demand too. The application of waste water for irrigation purpose has been suggested as one of the methods of disposal as well as meeting the water demands. Hence, the present study was undertaken with the objective to analyze the effect of textile dyeing effluent on seed germination and seedling growth of green gram. Two varieties of green gram viz., Co-6 and Co-GG-902 were tested with various dilutions of textile dyeing effluent such as 25%, 50%, 75% and 100% (raw effluent) using distilled water as diluting agent as well as the control. In control and in 25% effluent treatment, there was 100% seed germination observed in both the varieties. At higher concentrations of the effluent, seed germination was inhibited, the inhibition rate increased with increase in effluent concentration. At 100% effluent treatment, no seed germination was observed in Co-6 variety and 10% seed germination was observed in Co-GG-902 variety. Seedling growth was also inhibited at higher concentrations of the effluent, the rate of inhibition was higher in Co-6 variety than Co-GG-902. There was no significant difference between the seedling growth in control and 25% effluent treatment in both the varieties.

Keywords: Textile dyeing effluent, seed germination, shoot length, root length, green gram.

Introduction

Green gram (*Vigna radiata* (L.) R. Wilczek) also referred as mung bean is an important pulse crop, cultivated throughout India. It is the third important pulse cultivated in India and contains 20% to 25% protein (Anita et al., 2017). It is largely used to make dal from the whole, split or dehusked seeds. It originated in India and one of the most priced pulses of this country. Variety of phytochemicals such as polyphenols and polypeptides were reported from this plant, which are antioxidant in nature, moreover, green gram and its extract is reported to possess various activities such as hypolipidemic, hypotensive, anticancer and hepatoprotective (Hou et al., 2019). It is primarily a crop of rainy season, however, with early maturing varieties, it has proved to be an ideal crop for spring and summer seasons. Proteins of green gram are easily digestible and it fortifies the dietary protein needs of humans. As it does not contain flatulence effect of other pulses, it is suggested for all aged people starting from infants to old aged people. Increase of human population increased industrialization and it ends with huge disposal of waste water. On the other hand, agricultural practices need more water for irrigation. Recycling and reuse of wastewater in agriculture is not only helpful for conserving the plant nutrients and water for irrigation but also offers a low-cost technology for the disposal of wastewater from the view point of environmental pollution abatement (Parameswari and Udayasooriyan, 2013). Hence, the present study was conducted with the objective of using textile dyeing effluent (a common industry waste water of Salem district) for seed germination and seedling growth in green gram.

Materials and methods

Seeds of commonly used green gram varieties (Co-GG-902 and Co-6) in Salem locality were collected from Assistant Agricultural Directory Office, Seelanaikkanpatty bypass, Salem-636201. Effluent was collected from common sewer near dyeing industry at Salem. The present study was carried out in the Department of Botany, Government Arts College, Salem-7. Textile dyeing effluent at different concentrations (25%, 50% and 75%, using distilled water as diluting agent), raw effluent (100% effluent) and distilled water (control) were used in this study. Ten healthy, uniform sized seeds were selected for each treatment and were pretreated with effluent (above mentioned concentrations) and distilled

water for 24 hours prior to sowing them on wet cotton bed in petri plates. The seeds were sown on wet cotton bed and kept under dark for 2 days, later transferred to normal room conditions. Triplicates were maintained for each treatment to avoid experimental errors. Seed germination was recorded after 2nd day and 5th day of seed sowing and percentage was calculated. Seedling growth (length of shoot and root) was observed on 7th day after seed sowing and mean value was calculated.

Results and Discussion

Seed germination was recorded after 2nd day and 5th day of seed sowing in both varieties. On the 2nd day, the emergence of radicle was considered as germination and on the 5th day, both radicle and plumule emergences were considered as germination. In both the varieties, on 2nd day, 100% germination was observed in all tested concentrations. But, on 5th day, there was a difference observed in germination percentage.

In control and in 25% effluent treatment, 100% germination was observed but in higher concentrations, germination percentage was reduced in both the varieties. In raw effluent treatment (100%), no seed was germinated in Co-6 variety, whereas, in Co-GG-902 variety, 10% germination was observed (Figure 1). Consistent with present research, Parameswari (2014) reported that lower dilution of effluent did not have adverse effect on growth and vigour index of green gram Co-6 variety. Above 25% dilution, effluent inhibited germination and growth of paddy (Parameswari and Udayasooriyan, 2013), this report also supports the present observation. Similarly, high concentration of textile dyeing effluent inhibited seed germination in okra (Sadek et al., 2016).

Seedling growth was observed on 7th day of seed sowing. Seedlings of control and 25% effluent treatment had similar growth pattern in terms of shoot and root growth. Increase in the effluent concentration drastically reduced the growth of seedlings, higher the effluent concentration, inhibition was more. As stated earlier, at 100% effluent treatment, no seed germination was observed in Co-6 variety. In Co-GG-902 variety, germination was initiated in 10% seeds, but further growth of the seedlings was not observed (Figure 2 and 3).

Figure 1. Effect of Textile dyeing effluent on seed germination in green gram (*Vigna radiata* (L.) R. Wilczek) varieties Co-GG-902 and Co-6 after seven days of seed sowing

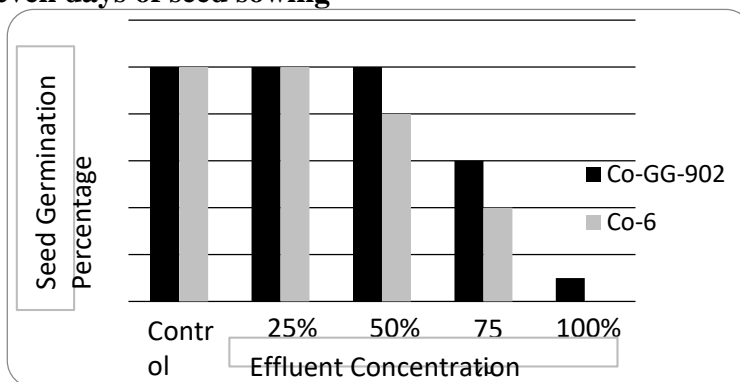
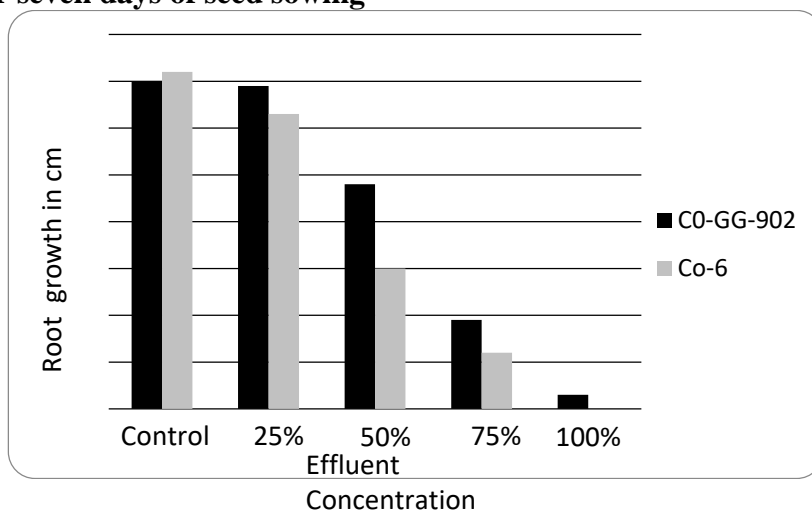
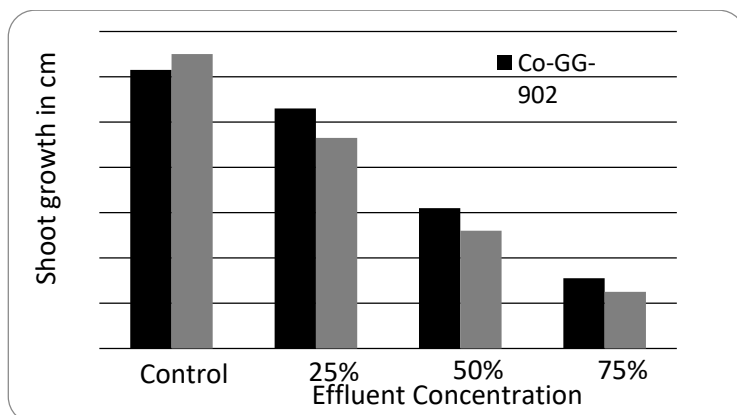


Figure 2. Effect of Textile dyeing effluent on root growth in green gram (*Vigna radiata* (L.) R. Wilczek) varieties Co-GG-902 and Co-6 after seven days of seed sowing



Similar to the present investigation, seedling growth was reduced with the textile effluent treatment in chickpea (Mayuri et al., 2015). Similarly, effluent at high concentrations reduced the growth in Pea, lentil and gram (Gufran Khan et al., 2011) and in wheat and mustard (Kurmi et al., 2023). In agreement with the present investigation, textile dyeing effluent reduced the growth in okra (Sadek et al., 2016) and in country beans (Hassan et al., 2013).

Figure 3. Effect of Textile dyeing effluent on shoot growth in green gram (*Vigna radiata* (L.) R. Wilczek) varieties Co-GG-902 and Co-6 after seven days of seed sowing

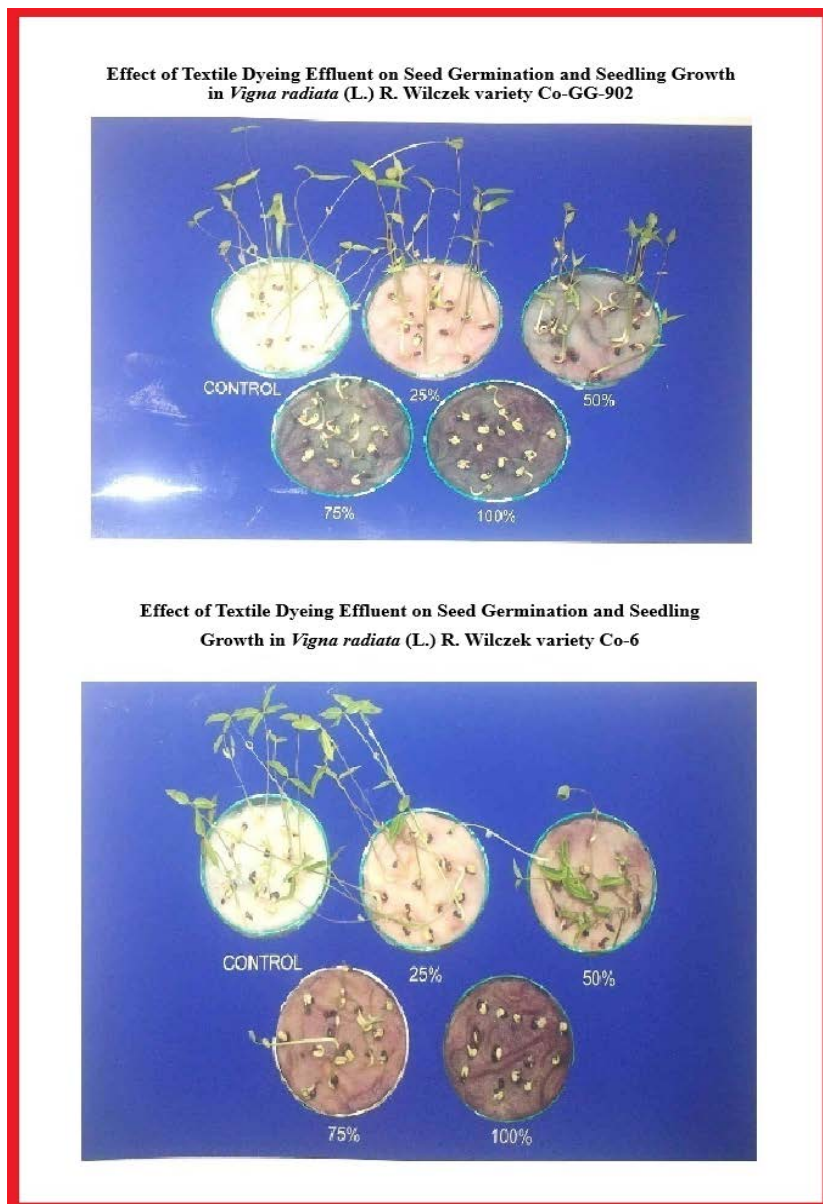


In the present investigation, the effect of textile dyeing effluent on seed germination and growth of green gram seedlings was tested using different dilutions of the effluent. At lower concentration, seedling growth was similar with the control, but higher concentrations of the effluent severely inhibited the growth in both tested varieties such as Co-6 and Co-GG-902. This preliminary observation supports the use of diluted effluent (up to 25%) for the irrigation purpose in green gram field. Further research may be conducted to confirm the present investigation in terms of yield performance both at qualitative and quantitative traits.

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Plate 1. Effect of textile dyeing effluent on seedling growth in green gram (*Vigna radiata* (L.) R. Wilczek) varieties Co-GG-902 and Co-6 after 10 days of seed sowing



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CHAPTER – 20

CLIMATE CHANGE AND IMPACTS: AN EMPHASIS LESSONS FOR SUSTAINABLE AGRICULTURE

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Abstract

Climate change poses a significant threat to global agricultural systems, impacting food security, livelihoods, and ecosystem stability. As the agriculture sector is both a contributor to and a victim of climate change, there is an urgent need to align farming practices with sustainable development goals to ensure resilience and adaptability. This chapter explores the multifaceted impacts of climate change on agriculture, including declining crop yields, soil degradation, water scarcity, and increased vulnerability to pests and diseases. It emphasizes the need for climate-resilient strategies such as agroecology, conservation agriculture, and the adoption of climate-smart technologies. Furthermore, it discusses the role of innovative technologies, policy frameworks, and stakeholder collaborations in fostering sustainable agricultural practices. By synthesizing key lessons and best practices, this chapter provides actionable insights and a strategic roadmap for transitioning to sustainable agriculture in the face of a changing climate. It concludes by stressing the importance of integrating science, policy, and grassroots action to build resilient agricultural systems that can sustain food production while mitigating the adverse effects of climate change.

Key words: Climate change, Agriculture, Food security, Adaptability

Introduction

Climate change has emerged as one of the most pressing challenges of the 21st century, with profound implications for global ecosystems, economies, and societies. Among the sectors most vulnerable to climate variability and extremes is agriculture, which forms the backbone of food security and rural livelihoods worldwide. Agriculture is not only a victim of climate change but also a significant contributor to it, accounting for a substantial share of greenhouse gas emissions through activities like deforestation, livestock rearing, and the use of synthetic fertilizers. The intricate relationship between climate change and agriculture is both complex and dynamic. Rising temperatures, shifting precipitation patterns, and the increasing frequency of extreme weather events such as droughts, floods, and cyclones threaten to disrupt agricultural productivity and stability. These impacts are further exacerbated in developing countries, where agriculture often relies heavily on natural resources and traditional farming systems. In this context, the concept of sustainable agriculture has gained prominence as a pathway to address the dual challenge of ensuring food security while minimizing environmental degradation. Sustainable agriculture emphasizes practices that enhance resource-use efficiency, maintain ecological balance, and build resilience to climatic shocks. However, achieving this requires a paradigm shift in how agriculture is managed, involving innovative technologies, robust policies, and active stakeholder engagement. This chapter delves into the critical impacts of climate change on agriculture and explores lessons learned from adaptive strategies and sustainable practices. It highlights the role of climate-smart agriculture, agroecological approaches, and technological innovations in mitigating adverse effects and fostering resilience. By drawing insights from case studies and global best practices, this chapter seeks to provide a comprehensive understanding of how agriculture can adapt to and thrive in a changing climate, ensuring food security and sustainable livelihoods for future generations.

Climate Change and Sustainable Agriculture

Climate change is a global challenge with profound consequences for agriculture, the cornerstone of food security and rural livelihoods. Rising temperatures, unpredictable rainfall patterns, and the increasing frequency of extreme weather events such as droughts, floods, and storms pose significant threats to agricultural productivity. These impacts are particularly severe for smallholder farmers in developing regions, where

traditional farming systems depend heavily on natural resources and climate stability. Furthermore, agriculture itself is a contributor to climate change, accounting for a considerable share of global greenhouse gas emissions through practices such as deforestation, methane emissions from livestock, and the excessive use of chemical inputs. This interdependence underscores the urgent need to align agricultural practices with sustainability goals to build resilience and mitigate climate impacts.

Sustainable agriculture emerges as a vital solution to address these challenges, aiming to balance productivity, environmental health, and social equity. By promoting practices such as conservation agriculture, agroforestry, efficient water management, and the use of climate-resilient crop varieties, sustainable agriculture reduces the ecological footprint of farming while enhancing its capacity to withstand climatic shocks. Technological innovations, including precision farming, digital advisory systems, and renewable energy integration, play a crucial role in enabling this transition. Additionally, policy support, capacity building, and the integration of traditional knowledge are critical to fostering climate-resilient agricultural systems. Together, these approaches pave the way for a sustainable future where agriculture not only adapts to climate change but also contributes to its mitigation, ensuring food security and livelihoods for generations to come.

Climate Change Drivers and Patterns

Climate change is driven primarily by the accumulation of greenhouse gases (GHGs) in the atmosphere, resulting from human activities such as the burning of fossil fuels, deforestation, industrial processes, and agricultural practices. Carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) are the major contributors, with agriculture playing a significant role through livestock emissions, rice paddies, and fertilizer use. These gases trap heat in the Earth's atmosphere, leading to global warming and disrupting the planet's natural climate systems. Urbanization, land-use changes, and unsustainable consumption patterns further exacerbate the problem, pushing natural systems beyond their capacity to adapt.

The effects of these drivers are manifest in shifting climate patterns, including rising global temperatures, altered precipitation regimes, and an increased frequency and intensity of extreme weather events such as droughts, floods, and heatwaves. Seasonal changes, such as delayed monsoons or shortened growing seasons, are already being observed in

many parts of the world. Polar ice caps and glaciers are melting at unprecedented rates, leading to rising sea levels and changes in oceanic currents. Regional variations in climate impacts are significant, with tropical and subtropical regions, often home to vulnerable communities, experiencing the most severe consequences. These patterns underscore the urgent need for collective action to mitigate emissions and adapt to a rapidly changing climate.

Impacts of Climate Change on Agriculture

Climate change significantly disrupts agricultural systems by altering the environmental conditions necessary for crop and livestock production. Rising temperatures affect crop growth cycles, leading to reduced yields in heat-sensitive crops such as wheat, rice, and maize. Prolonged droughts and erratic rainfall patterns strain water resources, making irrigation challenging and jeopardizing rainfed farming, particularly in arid and semi-arid regions. Increased frequency of extreme weather events, such as floods and cyclones, damages crop, destroys infrastructure, and erodes soil fertility, further intensifying food insecurity. Additionally, shifting climate zones force farmers to adapt to unfamiliar growing conditions or abandon traditional crops, often at a high economic cost.

Livestock and fisheries are equally vulnerable, with heat stress reducing livestock productivity and altering aquatic ecosystems critical for fish populations. Climate change also exacerbates the prevalence of pests, diseases, and invasive species, compounding challenges for farmers. The impacts are particularly severe for smallholder and subsistence farmers, who have limited access to resources and technology for adaptation. These disruptions not only threaten food production but also have cascading effects on rural livelihoods and global food systems, highlighting the urgent need for climate-resilient agricultural practices and policies to mitigate and adapt to these challenges.

Lessons from Climate-Resilient Agricultural Practices

Climate-resilient agricultural practices offer vital lessons in adapting to the challenges posed by climate change while ensuring long-term sustainability. Conservation agriculture, which emphasizes minimal soil disturbance, crop rotation, and permanent soil cover, has demonstrated its ability to improve soil health, enhance water retention, and reduce greenhouse gas emissions. Agroforestry systems, combining trees with

crops or livestock, offer multiple benefits, including carbon sequestration, biodiversity enhancement, and protection against extreme weather events. Integrated farming systems, which optimize the use of resources through diversification of crops, livestock, and fisheries, provide both economic stability and environmental resilience. These practices showcase the importance of harnessing ecological processes to build farming systems that are more robust to climatic shocks.

Technological innovations also play a pivotal role in advancing climate-resilient agriculture. The adoption of climate-smart technologies such as drought-tolerant crop varieties, precision irrigation, and weather-based advisory services has enabled farmers to optimize resource use and mitigate risks. Community-based approaches, such as participatory breeding and knowledge-sharing networks, highlight the value of integrating traditional wisdom with modern science. Additionally, the success of these practices often hinges on supportive policies, access to financial incentives, and capacity-building programs. Together, these lessons underscore the need for a holistic approach that integrates technology, policy, and local knowledge to foster agricultural systems that are adaptive, sustainable, and capable of thriving under changing climatic conditions.

Role of Technology and Innovation

Technology and innovation are central to building climate-resilient agricultural systems that can adapt to the challenges posed by climate change. Advanced technologies like precision farming, remote sensing, and Geographic Information Systems (GIS) enable farmers to monitor and manage their resources more efficiently. For instance, precision irrigation techniques such as drip and sprinkler systems help conserve water and optimize crop yields, even under water-scarce conditions. Climate-resilient crop varieties developed through genetic engineering and conventional breeding offer solutions to withstand drought, heat, salinity, and pest infestations. Weather forecasting and agro-advisory services, powered by big data and artificial intelligence, allow farmers to make timely decisions and mitigate risks associated with unpredictable weather patterns.

Digital technologies are transforming agricultural value chains by enhancing connectivity and access to information. Mobile apps and online platforms facilitate real-time communication between farmers, extension services, and markets, promoting knowledge sharing and informed

decision-making. Renewable energy solutions, such as solar-powered irrigation systems and cold storage, reduce dependence on fossil fuels while increasing energy efficiency. Innovative business models, including public-private partnerships and climate-smart financing, further drive the adoption of these technologies at scale. Together, these advancements demonstrate the transformative potential of technology and innovation in fostering sustainable and resilient agricultural systems, ensuring food security, and mitigating the impacts of climate change.

Interlinkages Between Climate Change and Agriculture

The relationship between climate change and agriculture is both complex and bidirectional. On one hand, agriculture is a significant driver of climate change, with practices such as deforestation, intensive livestock farming, and the use of chemical fertilizers contributing to greenhouse gas emissions, particularly methane and nitrous oxide. On the other hand, agriculture is highly vulnerable to the effects of climate change, with rising temperatures, shifting precipitation patterns, and the increasing frequency of extreme weather events directly impacting crop yields, livestock productivity, and soil health. This interconnection creates a feedback loop where climate change exacerbates the challenges facing agriculture, while agricultural practices further contribute to the intensification of climate change.

As agriculture both influences and is influenced by climate change, it is essential to adopt climate-smart agricultural practices that reduce emissions while enhancing resilience. Strategies such as agroecology, sustainable land management, and the use of climate-resilient crop varieties can mitigate the negative impacts of climate change on food production while simultaneously reducing the agricultural sector's carbon footprint. Additionally, integrating biodiversity conservation into farming systems helps maintain ecosystem services like pollination and pest control, which are vital for agricultural productivity. By recognizing and addressing these interlinkages, it is possible to foster agricultural systems that are not only more sustainable but also more adaptive to the changing climate, ensuring food security for future generations.

Climate-Smart Agriculture: Integrating Mitigation and Adaptation

Climate-Smart Agriculture (CSA) is a holistic approach that seeks to integrate both mitigation and adaptation strategies to address the challenges posed by climate change while ensuring food security and

sustainable agricultural development. Mitigation in CSA focuses on reducing the greenhouse gas emissions associated with agricultural practices, such as through the adoption of low-carbon technologies, improved livestock management, and soil carbon sequestration techniques like agroforestry and cover cropping. On the adaptation side, CSA emphasizes enhancing the resilience of agricultural systems to climate impacts, such as droughts, floods, and pests, by promoting climate-resilient crop varieties, water-efficient irrigation systems, and integrated pest management. This dual approach ensures that agriculture contributes to climate change solutions while safeguarding the productivity and livelihoods of farmers in a changing climate.

The integration of mitigation and adaptation in CSA is essential for creating sustainable agricultural systems that can withstand the increasing unpredictability of climate patterns. Successful implementation of CSA involves the adoption of context-specific practices that consider local climatic conditions, socioeconomic factors, and available resources. It also requires strong policy support, including incentives for climate-smart practices, capacity-building for farmers, and investment in climate-resilient infrastructure. CSA not only contributes to lowering emissions but also helps farmers manage risks and optimize production in the face of environmental challenges, providing a pathway for agriculture to become a central player in global climate solutions.

Socioeconomic Implications and Policy Responses

The socioeconomic implications of climate change on agriculture are profound, disproportionately affecting smallholder farmers, rural communities, and marginalized groups. Reduced agricultural productivity due to erratic weather patterns, pests, and diseases exacerbates poverty and food insecurity, particularly in developing countries where farming is a primary livelihood source. Climate-induced migration is becoming more prevalent, as resource scarcity and land degradation force rural populations to seek opportunities in urban areas. Gender disparities are also amplified, as women, who play a critical role in agriculture, often face limited access to resources, technology, and decision-making processes necessary for climate adaptation. These challenges highlight the urgent need for inclusive approaches that address equity and livelihood security in the face of climate change.

Policy responses play a crucial role in mitigating these impacts and fostering resilience. Governments and international organizations must

prioritize investments in climate-smart infrastructure, such as water storage systems and resilient supply chains, to reduce vulnerabilities. Subsidies and incentives for adopting sustainable agricultural practices can encourage farmers to transition to low-carbon and resource-efficient systems. Policies that integrate climate risk insurance, access to credit, and social safety nets help buffer the financial risks associated with climate shocks. Moreover, fostering multi-stakeholder collaborations and participatory decision-making ensures that policies are locally relevant and inclusive. Together, these responses create a framework for addressing the socioeconomic challenges of climate change while promoting sustainable agricultural development.

Future Directions for Climate-Agriculture Linkages

As climate change continues to evolve, it is crucial to scale up climate-smart agricultural practices that combine mitigation and adaptation strategies, such as agroecology, precision farming, and agroforestry. Advancements in technology, including digital tools for monitoring, precision irrigation, and climate-resilient crop varieties, will play a pivotal role in optimizing resource use and reducing environmental impacts. Additionally, policies that promote collaboration between governments, research institutions, and farmers, while ensuring access to financial resources and climate risk insurance, will be key in supporting transitions to more sustainable agricultural systems. Strengthening the capacity of farmers, particularly smallholders, through education, training, and extension services will ensure that climate-resilient practices are widely adopted. Ultimately, achieving long-term food security in the face of climate change requires a holistic approach that integrates agricultural, environmental, and social dimensions, empowering communities to adapt and thrive in a changing climate.

Conclusion

The impacts of climate change on agriculture are profound and multifaceted, affecting food security, rural livelihoods, and environmental sustainability. As agricultural systems face increasing stress from rising temperatures, erratic rainfall, extreme weather events, and shifting pest dynamics, it is imperative to adopt sustainable practices that can both mitigate these challenges and enhance resilience. Lessons from climate-resilient agricultural practices, such as agroecology, precision farming, and the integration of climate-smart technologies, demonstrate the potential for agriculture to thrive despite changing conditions. However, these efforts

require comprehensive policy support, increased access to innovative solutions, and the empowerment of farmers, especially smallholders, to build adaptive capacity. As we move forward, the interlinkages between climate change and agriculture will continue to evolve, demanding collaborative efforts across sectors, countries, and communities. By embracing a holistic approach that integrates scientific advancements, traditional knowledge, and climate-conscious policies, we can pave the way for a more sustainable and resilient agricultural future. The lessons learned today will guide the global agricultural community in ensuring that food production remains robust, equitable, and environmentally sound in the face of an uncertain climate future.

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CHAPTER - 21

SMART IRRIGATION PRACTICES: OPTIMIZING WATER USE EFFICIENCY

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Abstract

Smart irrigation practices focus on enhancing water use efficiency (WUE) through advanced technologies and optimized irrigation systems. Surface irrigation, drip irrigation, and sprinkler irrigation are key techniques. Drip irrigation delivers water directly to the plant roots, reducing evaporation and wastage, while sprinkler systems distribute water uniformly across larger areas. Precision irrigation is central to smart irrigation, utilizing real-time data to optimize water application. Soil moisture-based irrigation relies on sensors to monitor soil water levels, ensuring irrigation is timed efficiently. Evapotranspiration (ET) controllers adjust water supply based on local weather conditions, matching water delivery with plant needs to maximize WUE. Remote sensing (RS)-based irrigation uses satellite or drone imagery to assess crop health and water stress, aiding large-scale irrigation decisions. Optical sensors, for plant-based irrigation, detect water stress by analyzing light reflectance from plants, helping farmers identify when crops require water. Smart irrigation monitoring systems incorporate cloud-connected controllers that track soil moisture and environmental factors, automating irrigation and enabling precise adjustments. These systems reduce water waste, improve crop yields, and promote sustainable water management, making them essential tools for modern agriculture.

Introduction

Water is predominantly used in the agricultural sector, with around 70% of global water withdrawals being used for irrigation (Simionesei *et al.*, 2020). This percentage is projected to further increase due to population growth and higher food demand. Effective irrigation systems and water management policies have the potential to maintain farm productivity in the presence of limited and expensive water resources. A precision or smart irrigation system is a sustainable water saving method for maximizing crop yield and reducing the undesirable environmental impacts from irrigation (Mason *et al.*, 2019). Smart water management is crucial for precision irrigation to increase crop yields, cut costs, and support environmental sustainability. Precision irrigation involves a strategy that takes into account the spatial and temporal variations of water stress. This approach is improved by utilizing data-enabled technologies to implement smart irrigation systems. Several irrigation scheduling techniques have been developed and tested on a large scale by various researchers, including soil moisture sensor (SMS) controllers, evapotranspiration (ET) controllers, and rain sensors (RS). The continuous evolution of sensors, driven by technological advancements, has made them increasingly intelligent, compact, and integrated. This progress is largely due to the widespread adoption of IoT technology in agriculture. The growth of digital technologies and the development of embedded sensors have further contributed to this advancement. Agricultural sensors, which are used for monitoring soil, weather, water, and crops, offer diverse functionalities and play a crucial role in collecting valuable data on agricultural production. These sensors provide critical insights that aid farmers in making informed decisions. Numerous studies have explored the application of smart technologies in agriculture, including the use of IoT, Wireless Sensor Networks (WSNs), and advanced smart sensors to enhance precision farming practices. The management of irrigation and the improvement of crop water productivity using conventional deficit irrigation (DI) techniques have received increasing research attention in recent decades (Rathore *et al.*, 2021). The principal idea behind this approach is to apply less water than the plant actually needs (Kovalenko *et al.*, 2021). This leads to an increase in water use efficiency, while still maintaining crop yield above acceptable levels (Razzaghi *et al.*, 2020). In this chapter, we delved into various smart strategies for precision

irrigation, focusing on how innovative technologies and data-driven approaches are transforming water management in agriculture.

Irrigation System Techniques

There are various irrigation methods available, but the primary objective remains to distribute water evenly across the entire field, ensuring that each plant receives an adequate supply. Modern irrigation systems are designed to deliver water directly to the crops or root zone, significantly improving efficiency. These advanced methods minimize water waste, ensure uniform distribution of water, conserve energy, and effectively manage irrigation practices (FAO. 2020). Modern irrigation systems are engineered to deliver water directly to the crops or root zone, maximizing efficiency. These innovative methods significantly minimize water waste, ensure even distribution, conserve energy, and streamline the overall irrigation process for improved management.

Surface Irrigation System

Surface irrigation systems are designed to uniformly and efficiently supply water to the root zone reservoir, minimizing plant stress while conserving vital resources such as water, nutrients, energy, and labor. These systems also serve additional purposes, such as cooling the surrounding environment for temperature-sensitive fruits and vegetables or warming the climate to protect plants from frost in colder regions. Moreover, irrigation systems are used to leach salts from the root zone, soften soil for improved cultivation, and distribute fertilizers and insecticides across the field (FAO., 2020). Due to its simplicity and low energy requirements, surface irrigation is one of the most widely used irrigation methods. However, issues such as deep percolation and uneven water distribution often result in poor irrigation efficiency. To address these challenges, various studies have been conducted to improve the efficiency of surface irrigation (Muluneh *et al.*, 2022, Worqlul *et al.*, 2019, Akalu *et al.*, 2022, Pramanik *et al.*, 2022, Shi *et al.*, 2022).

Drip Irrigation

Drip irrigation, also known as trickle irrigation, is a vital method for addressing global water scarcity. This technique delivers water directly to the root zone of plants, drop by drop, making it one of the most water-efficient irrigation methods due to reduced evaporation and runoff. In

modern agriculture, drip irrigation is often paired with organic or inorganic (plastic) mulches, offering additional benefits like reduced evaporation, increased soil warmth, and weed control. However, a major challenge with drip irrigation is emitter blockage, which significantly affects irrigation uniformity and efficiency, potentially disabling the system and reducing crop productivity (Shi *et al.*, 2022).

Barkunan *et al.* (2019) introduces an automated drip irrigation system, which was tested on a paddy field over a three-month period. The results demonstrated significant water savings, with the system conserving approximately 41.5% more water compared to conventional flood irrigation and 13% more than traditional drip irrigation under the experimental conditions.

Wang *et al.* (2022) explores the effects of surface drip irrigation (DI), subsurface drip irrigation (SDI), and alternating drip irrigation (ADI) on tomato yield and root-soil microbial interactions. The uniformity of moisture distribution in the root zone (0–60 cm depth) decreased in the order of SDI > DI > ADI. The SDI method resulted in tomato root lengths that were 4.83 and 3.94 times larger than those in the ADI and DI methods, respectively. Root length in the ADI treatment was 1.23 times longer than in the DI treatment, leading to varied root-soil microbial interactions. The SDI treatment showed the most positive root-soil-microbe interactions, followed by ADI and DI. These interactions influenced tomato yield, with the SDI method improving yield by 9.77% and 7.77% compared to DI and ADI, respectively. Additionally, tomato yields in the ADI method were 24.09% higher than in the DI method. The study concludes that different drip irrigation systems can regulate tomato productivity by affecting root-soil-microbe interactions, and the findings can be used to optimize drip irrigation to enhance these interactions and improve crop yield. Furthermore, modern drip irrigation systems significantly conserve water, particularly for crops like paddy, which require varying amounts of water as they grow.

Çetin *et al.* (2019) aims to evaluate production efficiency (WP), economic water productivity (EWP), and land productivity (LEP) levels in cotton cultivation using different irrigation water amounts and drip systems, including surface drip irrigation (SDI) and subsurface drip irrigation (SSDI). The study analyzed data from a two-year experiment conducted during the 2016 and 2017 cotton growing seasons. Results

showed that SSDI reduced water usage and increased water productivity by applying irrigation based on plant water requirements, making it more suitable for modern farming practices. The study concludes that improving water productivity and achieving significant water savings for farmers requires consideration of WPing, EWP, WP, and LEP in irrigation techniques.

Sprinkler Irrigation

Sprinkler irrigation operates by spraying water into the air, allowing it to fall like rainfall over the field. The amount of water sprayed is regulated by water pressure, which flows through a network of pipes and exits through small nozzles. The size of the nozzles must be carefully chosen based on the sprinkler system design and operating pressure. This method allows water to be applied uniformly at a controlled rate, ensuring that the necessary amount for crop irrigation and replenishing the root zone is delivered efficiently, while minimizing soil leakage (Goap *et al.*, 2018). A wide variety of crops can be grown using the sprinkler irrigation method, including vegetables such as onions, potatoes, carrots, garlic, and lettuce; spices like cardamom and pepper; flowers such as jasmine and carnations; oilseeds like sunflower, groundnut, and safflower; and fibers like cotton and sisal (Bortolini *et al.*, 2019). Sprinkler irrigation is suitable for various soil types, with the exception of heavy clay (FAO,2020). It offers system mobility and water conservation, making it ideal for irrigating crops with high plant density, particularly oilseeds and vegetables (FAO,2020). There are several types of sprinkler irrigation systems classified by portability, including fully portable, semi-portable, semi-permanent, and fully permanent systems.

Reducing the working pressure of sprinkler systems can significantly decrease the energy consumption associated with sprinkler irrigation. However, this reduction in pressure inevitably alters the hydraulic performance of the sprinkler and affects the nozzle shape. To investigate these changes, experiments were conducted to evaluate the effects of operating pressures, injector shape, and injector diameter on various factors, including flow rate, throw radius, irrigation water rate, droplet size, droplet velocity of the rotating sprinkler, and the kinetic energy of water droplets impacting the surface soil. These experiments aimed to assess the spray characteristics of different non-circular sprinklers. The study calculated watering similarity coefficients for

circular and non-circular injectors by varying the spacing and operating pressures of rectangular sprinklers. Results indicated that under the same operating pressure and nozzle size, the flow rates from both circular and non-circular injectors were equivalent; however, the throw radius of the circular nozzle was larger than that of the non-circular nozzle. Additionally, the circular nozzle produced larger droplets compared to its non-circular counterpart (Chen *et al.*, 2021). Conversely, sprinkler heads are categorized into three types based on their water distribution methods and the volume of water they deliver across the land.

Table 1. provides a concise comparison of various irrigation methods based on several key parameters that influence the selection of an appropriate irrigation technique. These parameters include soil type, suitable slopes, compatible crops, appropriate irrigation water, and the layout requirements of each system.

Smart Strategies for Precision Irrigation

Four primary smart irrigation techniques remote sensing, SMS alerts, evapotranspiration-based controllers, and optical sensors are available to reduce water wastage in agricultural irrigation.

Irrigation management based on soil moisture

Soil moisture content (SMC) measurements can help estimate both soil water balance and the required irrigation for crops (Qin *et al.*, 2021). Dukes (2005) noted that irrigation scheduling often uses sensor data to monitor timed events. When SMC surpasses a configurable threshold, irrigation is omitted. Combining soil sensor data and weather information led to a substantial improvement in weekly citrus tree irrigation estimation, as reported by Navarro-Hellín *et al.* (2016). In this section, different smart irrigation systems used as SMS are reviewed.

A wireless RFID system was used to connect soil temperature and moisture sensors, allowing for real-time monitoring and irrigation scheduling of cotton crops. While the system effectively tracked soil water tension, the irrigation system was unable to respond promptly to the plants' immediate water needs. Vellidis *et al.* (2008) proposed using a smart sensor array in conjunction with a variable rate irrigation system to address these shortcomings.

A hygrometer, coupled with an Arduino Uno and a temperature sensor, was used to monitor soil moisture and regulate water supply. The Arduino would activate the water supply whenever soil moisture dropped below a predetermined threshold. Farmers could access this information on their smartphones via a cloud server (Kothawade *et al.*, 2016). IoT-based systems, often incorporating humidity sensors or remote sensing (RS), have been used for smart irrigation of various crops, including wheat and beans. Regression algorithms have been employed to estimate the required water quantity for subsequent irrigation (Jha *et al.*, 2017) and (Kumar *et al.*, 2017).

A wireless robot equipped with a Raspberry Pi 2 Model B was used to perform various tasks, including pesticide spraying, moisture sensing, and controlling electric motors. A camera connected to the Raspberry Pi allowed for capturing the crop field and monitoring live events (Krishna *et al.*, 2017). Recently, to optimize water use for chestnut irrigation, soil moisture content (SMC) was monitored during the vegetative stage. Irrigation was initiated when the sensor at a soil depth of 30–60 cm recorded values exceeding 100,000 Pa, ensuring optimal water conditions for the trees (Mota *et al.*, 2018). The mentioned systems effectively monitored the sensed parameters, but water use efficiency has yet to be assessed. An IoT-based automated irrigation system, using soil, temperature, and humidity sensors, demonstrated a 92% increase in efficiency compared to traditional methods. Over two months, a 600 m² crop field required 341 m³ of water with traditional irrigation, whereas the automated system used only 29 m³ (Rajalakshmi & Mahalakshmi, 2016). SMS-based drip irrigation systems have been shown to save water compared to traditional methods. In a study of banana irrigation, SMS-based systems used 20% less water than manual drip irrigation (Panigrahi *et al.*, 2019). Another study found a 39% water savings compared to timer-based irrigation (Grabow *et al.*, 2013). More recently, SMS-based irrigation in pear orchards resulted in a 50% reduction in water usage while maintaining high crop quality and production (Hamouda *et al.*, 2021). Rajaram and Sundareswaran (2020) used SMS for precision irrigation of brinjal plants. The required water quantity was calculated using temperature and humidity data from probes. The study found that SMS-based irrigation saved 53% of water compared to traditional methods.

The volumetric moisture content (VMC) threshold plays a crucial role in developing an effective irrigation schedule using soil moisture sensors (SMS). In a study by McCready *et al.* (2009), two sensor systems, the Acclima Digital TDT RS500 (Acclima Inc., Meridian, ID) and the LawnLogic LL1004 (Alpine Automation, Inc., Aurora, CO), were used for smart irrigation of St. Augustine grass. Three VMC threshold levels—low, medium, and high—were established. The medium threshold setting was found to save 74% of water while maintaining good plant quality. Similarly, in a study on walnut irrigation, soil moisture data were used to determine water volume based on the crop's growth stage, managed through software compatible with iOS/Android. The system automated irrigation by adjusting according to seasonal water needs (Işık *et al.*, 2017).

In a greenhouse tomato cultivation experiment using an automatic drip irrigation system, a wireless soil moisture sensor (SMS) was installed across a 0–100 cm soil profile. The system utilized the spatiotemporal characteristics of soil moisture distribution to estimate dynamic plant water uptake depth. This data was processed by a central irrigation regulator to ensure precise irrigation depth for each cycle. The water use efficiency for tomato irrigation reached 41.23 kg/m³, showing a significant improvement over the 31.58 kg/m³ achieved with conventional irrigation methods (Liao *et al.*, 2021).

On the other hand, the use of ZigBee wireless network technology in smart irrigation systems for monitoring soil moisture content (SMC) has garnered considerable research interest (Saraf & Gawali, 2017). In this system, a node equipped with sensors measures temperature, humidity, and soil moisture, comparing these values against predefined thresholds. The wireless network, designed to continuously monitor and control water pump valves, operates through the ZigBee protocol (Rasin *et al.*, 2009).

In a study conducted in Algeria, an irrigation system was remotely managed using a 6LoWPAN (Renesas Electronics Co. USA) wireless sensor network, which integrated the ZigBee network with the internet. In this system, soil moisture values from SMS were transmitted via a ZigBee mesh network to a smart gateway, then sent through a mobile data network to a web service for evaluation and automated response (Khelifa *et al.*, 2015). Similarly, ZigBee wireless technology was effectively used in an IoT-based system to monitor soil moisture, temperature, and nutrients in citrus farming. Soil moisture was tracked at depths of 20 cm, 40 cm, and

60 cm, resulting in a 20% savings in water and fertilizer resources (Zhang *et al.*, 2017).

To address the limitations of fixed sprinkler systems, a model based on the ZigBee (Chengdu Ashining Technology Co., Ltd. China) strategy was developed for an adaptive sprinkler irrigation machine (Bodunde *et al.*, 2019). In this system, the ZigBee XBee module, configured as a transmitter, along with a microcontroller and moisture sensor, was placed in the irrigated area. The system can alert the farmer to manually water the plants when necessary. Integrating IoT with this robotic design presents a promising advancement for agriculture. Additionally, ZigBee technology combined with a soil moisture prediction algorithm can forecast soil moisture levels based on sensor data from the field and weather forecasts. The proposed algorithm demonstrated high accuracy, with an R^2 value of 0.96 (Goap *et al.*, 2018).

Fuzzy logic systems have been utilized in various studies to assist farmers in making informed decisions regarding irrigation needs (Anand *et al.*, 2015; Kia *et al.*, 2009). As a proof of concept, a fuzzy logic control system incorporating IoT was proposed to calculate input parameters such as temperature, soil moisture, and humidity, producing motor status outputs. This system was evaluated for water use efficiency against drip irrigation and manual flooding methods over three days. The findings revealed that the smart system pumped water over a span of 7 hours, while the other two methods required between 12 to 20 hours for irrigation (Krishnan *et al.*, 2020). However, a significant limitation of automated irrigation using fuzzy logic is that the water requirements may vary among different plants, necessitating slight adjustments in the fuzzy logic parameters (Sudharshan *et al.*, 2019).

Blockchain tools are crucial for providing scalability, privacy, and reliability in IoT-based smart irrigation systems (Bodkhe *et al.*, 2020; Lin *et al.*, 2020). A sophisticated watering system was designed with blockchain security and a fuzzy decision support system, which demonstrated effective communication among various components, including smart tools, soil moisture, temperature, and humidity sensors, actuators, cloud storage, and users and networks (Munir *et al.*, 2019).

ET controller-based irrigation management

In addition to using soil moisture sensors (SMS) for irrigation monitoring, evapotranspiration (ET) estimates have been utilized to schedule irrigation and are regarded as a promising water-saving technology (Davis & Dukes, 2009; Seagraves *et al.*, 2010). This approach provides irrigation based on the crop's ET requirements. Crop evapotranspiration (ET_c) represents the evaporation from the soil surface and the transpiration from plant canopies. ET_c is calculated as the product of reference evapotranspiration (ET_o) and the crop coefficient (K_c), which varies according to the crop type, growing environment, and developmental stage (Davis *et al.*, 2007). The crop water requirement (CWR) refers to the volume of water necessary to compensate for evapotranspiration (ET). Several factors influence the water needs of a specific crop (ET_{crop}), including weather parameters such as temperature, relative humidity, and wind speed, as well as crop factors like the type of crop and management and environmental factors such as soil fertility (Kisekka *et al.*, 2010b). Controllers that utilize weather data to estimate ET are known as ET controllers (Isaya *et al.*, 2009). ET controllers are classified into three main categories based on how they receive evapotranspiration (ET_o) information: (1) standalone controllers, which obtain climatic variables from on-site sensors to measure ET_o; (2) signal-based controllers, which gather ET_o data and rainfall information through wireless communication from weather stations (using satellite signals); and (3) historical-based controllers, which depend on monthly historical ET_o data for the specific area (Riley, 2005). It is important to note that the accuracy of ET_o estimation can significantly impact the effectiveness of ET-based smart controllers. For instance, research indicated that the ET-based group consumed about 11% more water than the timer-based group due to controllers overestimating ET_o (Grabow *et al.*, 2013). Generally, three primary controllers have been utilized for ET-based smart irrigation: WeatherMatic (Weathermatic, Inc., Dallas, TX; a standalone controller), Toro (Toro Company, Inc., Riverside, CA), and ETwater (ETwater Systems LLC, Corte Madera, CA; signal-based controllers) (Davis & Dukes, 2012).

Case studies using ET controllers

In Las Vegas, signal-based ET controllers were found to reduce water application by approximately 20% compared to control sites (Devitt

et al., 2008). In Valdebebas, Madrid, Spain, irrigation scheduling in gardens was effectively managed using ET controllers based solely on climatic conditions, achieving water savings of up to 35% (Canales-Ide *et al.*, 2019). A study by McCready *et al.* (2009) on the irrigation of St. Augustine grass, which utilized two types of ET controllers, revealed water savings ranging from 25% to 62% (McCready *et al.*, 2009). Similarly, the Toro Intelli-Sense controller (Toro Company, Inc., Riverside, CA) achieved water savings of 59% compared to standard timer-based scheduling while still ensuring good turfgrass quality (Shedd *et al.*, 2007). ET controllers like the Weathermatic SL1600 with SLW15 weather monitor, Toro Intelli-Sense, and ETwater Smart Controller 100 have the potential to generate annual water savings of 42% when compared to conventional irrigation practices. These controllers can effectively replace net irrigation needs without a rain switch while maintaining good plant quality (Davis *et al.*, 2009).

ET controllers were evaluated against a theoretically derived soil water balance model during the winter, spring, and summer seasons. The Weathermatic and Toro controllers delivered 3%–26% and 27%–31% less water than theoretically needed in the winter and spring seasons, respectively. However, in the summer, the Toro controller resulted in 4% overirrigation, attributed to its rain sensor (RS) only bypassing irrigation in cases of extreme rainfall. For ET water treatment, the controller applied 46% and 10% less than the theoretical requirement in the spring and summer seasons, respectively. The integration of rain sensors is crucial for the effectiveness of ET controllers (Davis & Dukes, 2010). In addition to soil moisture sensors (SMS) and rain sensors (RS), the seasonal average irrigation adequacy rating for all treatments reached up to 99% (McCready & Dukes, 2011). The combination of rain switch and rain pause features on the Toro Intelli-Sense controller resulted in a 41% reduction in irrigation for St. Augustine grass compared to using no rain features. Therefore, it is recommended to utilize both the rain switch and rain pause functions to effectively interrupt irrigation events on the Toro Intelli-Sense controller (Rutland & Dukes, 2012).

The smart irrigation technology described earlier, combined with soil moisture-based controllers, has been adopted to promote water conservation in turf and landscape irrigation for residential properties. Experiments utilizing soil moisture sensors (SMS) demonstrated water

savings of 44%, while the ET group reported a 20% reduction in water usage (Nautiyal *et al.*, 2010). Similarly, research focused on papaya irrigation indicated successful management with impressive water savings of approximately 65%, achieved through soil water monitoring or historical ET data, without adversely affecting the plants' physiological and production traits (Migliaccio *et al.*, 2010). Similarly, ET-based irrigation controllers have been implemented for managing the irrigation of wheat and tomatoes. This system includes digital electronic controllers, ET sensors, and various modules. The system automatically calculates crop evapotranspiration (ET_c) for the local microclimate using a modified Penman equation, with a scientific program developed and uploaded to the controller. Consequently, irrigation run times can be adjusted to replace only the amount of water lost by the plants. The results showed that this system could achieve water savings of 27% (Al-Ghobari & Mohammad, 2011).

Results from irrigation experiments in woody fruit orchards indicated that ET-based irrigation systems, utilizing either real-time or historical weather data, applied over 70% less irrigation water compared to time-based treatments (Kisekka *et al.*, 2010a). More recently, ET-based irrigation systems for mustard greens, using either public weather forecasts or microclimatic weather stations, demonstrated water savings of around 71% compared to manual irrigation, without negatively impacting crop growth (Cruz *et al.*, 2020). Additionally, soil moisture probes are useful for verifying the accuracy of irrigation schedules (Widyanto *et al.*, 2014). As a proof of concept, the management of wheat irrigation in In Salah, Algeria, revealed that the practical ET_c applied based on soil moisture data reduced irrigation water usage by 5% compared to theoretical estimates derived from meteorological data (Debauche *et al.*, 2020).

RS-based irrigation management

Rain sensors (RS) are recognized as one of the most straightforward irrigation-sensing strategies and have demonstrated effectiveness in achieving water savings at a relatively low cost (Cardenas-Lailhacar & Dukes, 2008). These sensors can postpone or halt scheduled irrigation cycles when a specific amount of rainfall is detected, effectively disabling the solenoid valves until the sensor dries out (Dobbs *et al.*, 2013). RS should ideally be installed in open spaces to ensure they are exposed to unobstructed rainfall (Dukes & Haman, 2002). The use of RS can help

minimize runoff and deep percolation, decrease weed pressure and disease risks, and eliminate unnecessary irrigation events. Additionally, RS are designed for longevity, with a lifespan of over 10 years, according to the manufacturer, and they typically come with a 5-year warranty (Cardenas-Lailhacar & Dukes, 2008; Dukes & Haman, 2002).

Water savings achieved through the use of rain sensors (RS) ranged from 19% to 34% during standard rainfall occurrences in central Florida (Cardenas-Lailhacar *et al.*, 2008; Haley & Dukes, 2007). A study evaluating the Mini-Clik RS (Hunter Industries, Inc., San Marcos, CA) at two rainfall set points (3 mm and 6 mm) and three different irrigation frequencies (1, 2, and 7 days per week) found that RS with varying set points and irrigation schedules resulted in water savings between 7% and 30%, while maintaining acceptable turfgrass quality (McCready *et al.*, 2009). Furthermore, the study revealed that the RS treatment with a 7-day/week irrigation frequency using a 6-mm set point applied less water per irrigation event compared to the soil moisture sensor (SMS) treatment (McCready & Dukes, 2011).

In a separate study, two types of rain sensors (RS)—Mini-Clik and wireless Rain-Clik—were assessed for their water-saving potential, with the wireless Rain-Clik demonstrating the highest potential for water conservation at 44% (Cardenas-Lailhacar & Dukes, 2008). Similarly, RS-based irrigation systems for Bahia grass achieved water savings of up to 49% compared to conventional irrigation methods, with an irrigation depth of 32 mm and a frequency of 2 days per week. Additionally, the use of RS also facilitated the management of leachate nitrogen forms, specifically NO₃-N and NH₄-N (Dobbs *et al.*, 2014). To monitor real-time rainfall, rain sensors (RS) were connected to an ARM7 microcontroller (Shenzhen Leadwon Electronic Technology Co., Ltd., China), allowing for the determination of soil water content based on rainfall data. The sensor data was used to monitor the irrigation pump motor, and this information was transmitted to the farmer's smartphone via GSM (Global System for Mobile Communications) technology. The results of the system, tested on tomato cultivation, indicated water savings of up to 50% during the germination stage and over 30% during the ripening periods, compared to traditional drip irrigation methods (Barkunan *et al.*, 2020). The same smart irrigation system was also utilized for monitoring paddy irrigation, resulting in water savings of 41.5% compared to conventional flood

irrigation and 13% compared to traditional drip irrigation methods (Barkunan *et al.*, 2019).

Optical sensors: Plant-based irrigation management

The sensors used in precision irrigation depend on specialized hardware for wired and wireless connections to the buried sensors, which may suffer from signal loss due to connection issues (Al-Naji *et al.*, 2021). To eliminate the need for soil-buried soil moisture sensors (SMS), innovative methods have been implemented to manage irrigation using optical sensors, including drones, UAVs, and red/green/blue (RGB) cameras (Ajith *et al.*, 2018).

UAV-based remote sensing is a groundbreaking technology widely used in smart irrigation on a large scale due to its cost-effectiveness, simple setup, ease of transportation, flexibility, short operational cycles, and relatively high resolution (Boursianis *et al.*, 2020; Shi *et al.*, 2019). Compared to satellite imagery, UAV-derived crop canopy data have shown a stronger correlation with in-field assessments (Khaliq *et al.*, 2019). A common approach involves using a histogram of canopy temperature from UAV thermal infrared images to estimate the Crop Water Stress Index (CWSI), which enhances irrigation water use efficiency (Bian *et al.*, 2019).

Various types of sensors can be integrated into UAVs, such as visual, thermal, and multispectral sensors (Mwinuka *et al.*, 2021). In the context of water-saving irrigation, UAVs equipped with RGB cameras have been successfully used to capture images of rice fields, estimating rice plant height with a high correlation coefficient (Yang *et al.*, 2020). Similarly, UAVs have been utilized to monitor soil moisture levels in tea plantations. High-definition cameras mounted on UAVs were used to evaluate tea leaf deficiency and soil conditions, significantly reducing water wastage in the irrigation process (Jia *et al.*, 2019).

Recently, in a semi-arid climate, a six-band multispectral camera mounted on a multirotor UAV was employed to capture images at 50 meters above ground level during the cotton flowering and boll-forming stages. This approach was used to monitor and determine plant water content. The experiment extracted 13 vegetation indices from the camera data, and the results demonstrated that crop water content can be effectively retrieved by combining crop canopy temperature with UAV

multispectral data (Chen *et al.*, 2020). Similarly, a technique for designing trajectories for precision crop irrigation using UAVs was developed based on a Crop Water Stress Index (CWSI) image. This method allowed for spatially variable irrigation, leading to water savings of up to 123% per segment (Albornoz & Giraldo, 2017).

Similarly, multispectral images captured by UAV cameras equipped with a Sony IMX 219 CMOS sensor were integrated with a decision support system to estimate the normalized difference vegetation index (NDVI) map for the precise management of a linear sprinkler device used for tomato irrigation. The results showed that higher water savings could be achieved by combining the NDVI index with the decision support system (Aleotti *et al.*, 2018).

In other studies, multispectral images obtained from Red Edge (Parrot Co. Ltd, Paris, France) and MCA-6 (Mini-MCA-6 Tetracam, Inc., Chatsworth, CA, USA) camera-mounted UAVs were used to predict the spatial variability of water status in maize and grapevine (Baluja *et al.*, 2012; Poblete *et al.*, 2017; Romero *et al.*, 2018). These UAV-based systems demonstrated superior capabilities in assessing field variability in crops and soil compared to traditional on-site measurements.

Bellvert and his team conducted measurements using UAV-based irrigation management and found that the crop water stress index (CWSI) maps generated from airborne thermal imagery were effective in assessing the spatial variability of water stress in vineyards (Bellvert *et al.*, 2014). For precision viticulture, a multisensor UAV system capable of flying at 70 m above ground was employed, integrating three sensors simultaneously: a multispectral camera, a thermal camera, and a high-resolution RGB camera. This system successfully identified 80% of the total missing plants (Matese & Di Gennaro, 2018).

In southwestern Spain, UAVs equipped with thermal cameras were deployed over a commercial drip-irrigated orchard consisting of almond, apricot, lemon, orange, and peach trees to monitor water-stressed areas and establish crop water stress index (CWSI) thresholds. The research identified CWSI thresholds for initiating irrigation at 0.27 for apricot, 0.31 for almond, and 0.37 for peach (Gonzalez-Dugo *et al.*, 2013).

Smart Irrigation System Monitoring

To enhance water use efficiency, it is crucial to monitor specific factors that affect plant development and growth. Contextual monitoring in intelligent irrigation systems requires collecting real-time data on soil conditions, plant health, and climatic variables within the cultivated area using advanced communication technologies (Abioye *et al.*, 2020). The integration of IoT, AI, cloud computing, and edge computing is crucial in improving agricultural land productivity and irrigation efficiency. Technologies such as IoT-based crop and soil monitoring, AI-driven data analysis for decision-making, automated irrigation systems, and weather forecasting are in high demand to enhance crop quality and detect plant and insect diseases. These advancements not only increase crop efficiency but also significantly reduce farmers' dependence on manual labor. Sensors and IoT devices monitor the plant field, while edge computing collects sensor data from the field, which is then sent to the cloud for processing and analysis. Based on this analysis, optimal actions are determined, leading to improved crop production with reduced use of water, fertilizers, and pesticides (Pandey *et al.*, 2022). Wireless Sensor Networks (WSN) are an innovative and crucial technology that has seen significant advancements in recent years. WSNs are applicable across various fields, with agriculture being one of the sectors where they are extensively utilized and have been successfully implemented (Oussama *et al.*, 2022, Singh *et al.*, 2022 and Angelis *et al.*, 2022). Soil quality (SQ) evaluation is essential for monitoring changes in soil performance due to management practices. Measuring soil quality provides early warnings of potential long-term impacts from various land use activities. It also helps identify whether soil quality is declining over time and what factors contribute to soil degradation. This information is crucial for guiding sustainable soil management practices in the future.

Soil Moisture Monitoring

Soil moisture refers to the temporary storage of water in the shallow layers of the earth's surface, and it plays a crucial role across various spatial scales, including agriculture, hydrology, and weather forecasting. It is vital for detecting water stress and managing irrigation, and soil moisture data can be utilized to predict natural disasters such as droughts and floods, as well as environmental changes like sandstorms and erosion. However, accurately estimating soil moisture through in situ

measurements is costly due to the need for repeated sampling to track changes over time. Since soil moisture is highly variable both temporally and spatially, continuous monitoring is essential. There are several methods available to assess the moisture content of soil. Each of these methods for measuring soil moisture has its own advantages and disadvantages, and they should be applied judiciously based on the specific requirements and demands of the project. (Sharma *et al.*, 2018). The accuracy of this method is influenced by weighing precision, although these errors are minimal compared to the variability of soil in the field. While the technique is relatively accurate, it presents practical challenges, such as the delay in obtaining results—typically requiring at least 48 hours after sampling. This limitation makes it unsuitable for real-time irrigation scheduling. Consequently, due to the non-instantaneous nature of soil water content estimations, this method is primarily employed as a guideline (Li *et al.*, 2018). Farmers often employ the feel method to assess soil irrigation by relying on the texture and appearance of the soil. Experienced individuals can make fairly accurate judgments, offering guidance on when to schedule irrigation events. However, this method lacks precision regarding how much water to apply and when to irrigate. As a result, while it is not highly accurate, it remains useful in the absence of alternative options.

The direct method involves collecting soil samples from the field, weighing them, and then drying them in an oven at 105 °C to determine soil moisture content. The total soil water content is calculated based on the mass difference between the wet and dry soil samples. This technique is commonly referred to as the Thermo Gravimetric or Gravimetric method. Additionally, the bulk density of the soil can be used to convert weight-based estimates of soil water content into volumetric assessments (Li *et al.*, 2018).

Volumetric techniques indirectly measure soil moisture content by assessing specific variables within the soil profile. Consequently, these methods are more suited for making real-time irrigation management decisions. They can be categorized into two broad classifications based on their underlying principles: (i) Dielectric sensors and (ii) Neutron moderation.

(i) Dielectric sensors function by measuring the soil's dielectric constant, which reflects a nonconductive material's ability to transmit

electromagnetic waves or pulses. Since the dielectric constant of dry soil is lower than that of water, even minor changes in soil moisture significantly impact the electromagnetic properties of the soil. Dielectric sensors generate an alternating electric field in the surrounding medium, and by monitoring the currents and voltages affected in the measuring rods by this field, they determine the cumulative complex electrical impedance of the medium. The shape and volume of the electric field are primarily influenced by the design and dimensions of the sensor electrodes.

Dielectric sensors are further classified into several types based on their output signals, including Time Domain Reflectometry (TDR), Capacitance or Frequency Domain Reflectometry (FDR), Time Domain Transmission (TDT), Amplitude Domain Reflectometry (ADR), and Phase Transmission sensors (PT). Each type varies in terms of usage, maintenance, measurement requirements, accuracy, and cost (Vera *et al.*, 2018).

(ii) Neutron moderation techniques involve two methods for monitoring soil water content. The first method, known as neutron scattering, relies on the interaction of high-energy (fast) neutrons with the nuclei of hydrogen atoms in the soil. The second method measures the attenuation of gamma rays as they pass through the soil. Both approaches utilize portable devices to gather measurements at fixed monitoring sites and require precise calibration, ideally conducted with the specific soil type where the devices will be deployed (Vera *et al.*, 2018). When properly calibrated, neutron probes offer high accuracy in measuring soil moisture. They are not influenced by soil salinity, have a large measurement radius, and can assess moisture content at various depths. However, these probes are quite expensive and present radiation hazards, necessitating the presence of certified personnel for their operation. Additionally, they can be challenging to calibrate and install. Tensiometric sensors measure the potential of soil matrices, with several common types including tensiometers, electric resistance sensors, thermal conductivity sensors, and psychrometers. Among these, electric resistance sensors and tensiometers are the most widely used. A tensiometer consists of a water-filled tube designed to simulate the movement of plant roots. At one end, it features a porous cup that is buried in the soil and maintains a negative pressure (vacuum). As the soil dries, water is drawn out of the tensiometer, leading to a decrease in pressure reading, which indicates a reduction in soil

moisture. Conversely, when the soil is irrigated, water returns to the tensiometer, and the pressure increases. Tensiometers are responsive to conditions within a large volume of soil and are relatively easy to install and maintain.

Recent advancements in technology have led researchers to capture, represent, and discuss several innovative techniques in soil moisture measurement, as outlined below. Most of these techniques are highly advanced and applicable across various scales.

(i) **Temperature Distribution:** This method utilizes fiber optics to assess changes in soil thermal conductivity related to soil moisture and ambient temperature. Cao *et al.* (2018) employed the active distributed temperature sensing (A-DTS) method to enhance ground heat transfer efficiency by detecting soil moisture through thermal behavior induced by an active electrical charge. This approach established a correlation between thermal conductivity and soil water content across different soil types, including silt, clay, natural soil, and sand.

Additionally, Lagos *et al.* (2020) introduces a novel approach for determining underground water evaporation rates that combines the actively heated fiber-optic (A-HFO) technique with the vadose zone method, keeping the evaporation front at the soil surface. The A-HFO technique yielded assessments of soil moisture characteristics with a spatial resolution of 6.5 mm and an accuracy of 0.026 m³/m³. The calculated soil moisture profile differed somewhat from the measured profile, with the most significant variations occurring near the soil surface.

(ii) **Microwave Moisture Monitoring:** Monitoring moisture content in high-water-content agricultural products has been challenging. According to Zhang *et al.* (2020) a new microwave detection system was developed using a multi-frequency sweeping technique, built from off-the-shelf components. This system was applied to collect moisture data from sweet corn. To gather adequate moisture data, a frequency-swept signal was utilized, covering 41 frequencies between 2.60 and 3.00 GHz, which served as the initial detected signal.

Table 1. Comparison between different of irrigation

	Drip Irrigation	Surface Irrigation			Sprinklers Irrigation		
		Basin Irrigation	Border Irrigation	Furrow Irrigation	Spray type sprinklers	Rotor type sprinklers	Rotate Nozzles
Soil Type	Most of the soil types.	It mainly depends on the crops.	Preferred clay soils with medium infiltration rates or deep homogenous loams.	Most of soil types	Sandy soils with increased flow rates, though adaptable to most soil types.		
Suitable slopes	Can be adapted to any farmable slope.	Flatter land surfaces are easier to construct basins.	Suitable slopes have to be uniform slopes 0.05%: 2% to avoid soil erosion.	Uniform-flat or the tiny slopes with a max slope of 0.5%,	Any farmable slope, whether flat or rippling.		
Crops	Row crops (vegetables, soft fruit), tree and vine crops are all suitable.	Suits many field crops as paddy rice	More suitable with close-growing crops like alfalfa or pasture.	Many types of crops, especially the row crops and the growth of the tree crops.	Field, and tree crops. And water can be sprayed over or under the crop canopy.		
Suitable Water	The irrigation water should be free of any sediments.	Two methods: Direct method, Cascade method.	Normal water like the traditional irrigation systems	The irrigation water should be clean and free of sediments to avoid any problems in the sprinkler nozzle.			
System Layout	Pump unit, Control head Main and sub-main lines emitters, drippers, or laterals	The dimensions and the shape of basins, borders, or furrows depend on the stream size, soil type, slopes, irrigation depth, and other parameters such as the farm size.		Pump unit Mainline or sub mainlines, Laterals			

Table 2. Volumetric soil moisture sensors

Types of sensors	pros.	cons.
TDR	Independent of soil texture temperature or salt content.	<ul style="list-style-type: none"> • Small sensing volume. • Requires soil calibration. • High cost.
FDR	<ul style="list-style-type: none"> • Can determine water content at any depth. • Can provide the exact soil water content. 	<ul style="list-style-type: none"> • Small sensing sphere. • Require perfect conduct with soil to get accurate results.
Resistive sensor	<ul style="list-style-type: none"> • Can provide the exact soil water content • High precision when the soil's ionic concentration doesn't change 	Calibration is required as soil, and ionic concentrations change.
ADR	<ul style="list-style-type: none"> • Because of standard circuitry, it is inexpensive. • With proper calibration, it is accurate. 	<ul style="list-style-type: none"> • Small sensing volume, • Soil specific calibration, • Measurement affect of air gaps and stones
TDT	<ul style="list-style-type: none"> • Accurate with large scale • Because of standard circuitry, it is inexpensive. 	Soil disturbance during installation necessitates permanent installation.
PT	<ul style="list-style-type: none"> • Inexpensive • Accurate with large scale • Accurate with soil specific calibration 	Need to permanently installed Soil specific calibration
Neutron moderation	<ul style="list-style-type: none"> • Water can be measured • at any phase • Accurate with large volume at any depth 	<ul style="list-style-type: none"> • High cost • Hazard radiation • Insensitivity to small variation
Gamma attenuation	Can measure mean water content with depth as well as moisture content	<ul style="list-style-type: none"> • High cost and difficult to use, • Measurement in highly stratified

	changes over time	soil produces large errors • Changes in soil bulk density have an impact.
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Conclusion

Water management is set to become one of agriculture's most significant challenges as global water resources face increasing pressure. Precision irrigation is seen as a critical solution, utilizing cutting-edge technologies such as IoT, wireless sensor networks, and cloud-based systems to optimize water use. These systems offer real-time insights into soil moisture levels, weather patterns, and crop conditions, enabling farmers to provide the precise amount of water needed at the right time. This minimizes water waste, improves crop health, and enhances overall agricultural efficiency. As the demand for food grows and water becomes scarcer, precision irrigation helps ensure that farming remains productive while conserving vital resources. By integrating these smart technologies, farmers can make data-driven decisions, promoting not only water conservation but also environmental sustainability. This approach helps protect ecosystems, reduce the carbon footprint of agricultural practices, and build long-term resilience to climate change. Ultimately, the widespread implementation of precision irrigation is essential for creating a sustainable and efficient agricultural future capable of meeting the world's growing food and water needs.

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CHAPTER - 22

PRECISION FARMING IN AGRICULTURE: INNOVATION AND APPLICATIONS

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Abstract

Precision farming is a cutting-edge approach to agriculture that leverages advanced technologies to optimize crop yields, reduce waste, and promote sustainable farming practices. The idea of precision farming, its essential elements, and its uses in contemporary agriculture are examined in this chapter. It explores how data-driven decision making and precision farming techniques are made possible by digital technologies, satellite imagery, and Geographic Information Systems (GIS). The chapter also looks at the advantages and difficulties of implementing precision farming, as well as how it might revolutionize the agricultural sector and guarantee food security worldwide.

Keywords

Remote sensing; Satellite imaging; Crop monitoring; Artificial intelligence; IoT; Machine learning

Introduction

Precision farming, also known as smart farming, focuses on achieving precise results in agriculture. It uses site-specific data to control agricultural inputs, and the application of microprocessors and computers in various fields maximizes yield. The earliest GPS satellites were launched in the 1950s and 1960s, but farmers began using precision agriculture technologies in the 1980s and 1990s due to satellite images and user-friendly GPS devices. India, the world's largest private industry, faces

challenges in achieving sustainable food security and market economy due to globalization. To address this, the government has implemented policies focusing on small farming communities. Despite the devastating Bengal famine in 1942-1943, India has made significant progress in food production, with a record yield of 212.85 million tons in 2003-04. However, the country faces challenges in meeting the demand for food grains and farm products. Recently, there has been a global push for smart or precision farming, which uses technologies like greenhouses and surface cover cultivation, horticulture, agroforestry, aquaculture, soilless or hydroponic crop culture, tissue culture and other biotechnology, organic and biodynamic agriculture with eco-friendly practices, weather forecasting, plasticulture, satellite and aerial remote sensing, etc. The post-green revolution in India is characterized with the problems of stagnation in production and productivity growth rates of major food grain cereals, dwindling natural resources and increasing production costs due to decline in productivity. With the advent of new technology like sensors, drones, and driverless cars, as well as developments in data management and analysis tools, precision agriculture has since continued to grow and change. Farmers across the world are already using precision agriculture to increase the sustainability, productivity, and efficiency of their operation (Jana, B.L.,2005).

Technologies Used in Precision Farming

1.Global Positioning System (GPS) and Geographic Information System (GIS)

The Global Positioning System (GPS) and Geographic Information System (GIS) plays a vital role in precision farming by providing accurate location information and enabling farmers to manage their crops and resources more efficiently. Here are some ways GPS and GIS are used in precision farming:

1. Field Mapping: GPS is used to create detailed maps of fields, including soil type, moisture levels, and crop yields. Software standards, including Object Architectures COM, NET, Java, XML, and SOAP, provide the foundation of ArcGIS. It offers a lot of assistance for universal standards, flexibility in the suggested solutions, and chances for involvement. ArcGIS 9 can be utilized in the "field," on servers, web browsers, and desktop computers.

- 2. Crop Monitoring:** GPS-enabled sensors and drones monitor crop health, growth, and development, allowing farmers to identify issues early.
- 3. Precision Planting:** GPS guides planting equipment to optimize seed spacing, depth, and orientation, reducing waste and improving yields.
- 4. Precision Irrigation:** GIS is used to optimize irrigation systems, reducing water waste and improving crop yields.
- 5. Variable Rate Application:** GPS controls the application of fertilizers, pesticides, and water, ensuring the right amount is applied in the right place.
- 6. Yield Mapping:** GPS tracks crop yields, enabling farmers to identify areas of high and low productivity and make data-driven decisions.
- 6. Autonomous Farming:** GPS enables autonomous farming equipment, such as tractors and drones, to navigate and perform tasks without human intervention.
- 7. Soil Sampling:** GPS guides soil sampling equipment to collect accurate and representative soil samples.
- 8. Farm Planning:** GIS is used to plan farm operations, including crop rotation, planting, and harvesting.

2. Remote Sensing and Satellite Imaging

Remote sensing technology uses photography to collect and interpret data, eliminating the need for physical interaction between the object and measuring device. It uses unique vegetation characteristics to improve crop yield by introducing more cultivation regions, boosting productivity and cropping intensity. This technology is essential for sustainable agriculture, promoting efficient monitoring and management of natural resources, and promoting sustainable agriculture through various applications.

- Crop health monitoring
- Crop production forecasting
- Command area management
- Water availability monitoring
- Watershed management
- Damage assessment
- Wasteland mapping
- Monitoring in-season agricultural operations

- Assessment of droughts and floods in the country

Drones and Unmanned Aerial Vehicles (UAVs)

Modern technologies like photogrammetry and remote sensing are being used in precision agriculture to improve crop quality and yield, reduce farmers' workload, and spray pesticides and fertilizers. UAVs, equipped with sensors and cameras, track crop height and condition, allowing farmers to take necessary actions at the right time. The multispectral camera scans the entire crop field, while actuation drones locate insect and pest hotspots. Low altitude remote sensing offers high resolution for picture acquisition, ease of construction, and superior mobility. Both biotic and abiotic variables affect crop quality and yield.

Sensor Technologies

Sensors play a vital role in precision farming by providing real-time data on various parameters such as soil moisture, temperature, humidity, and crop health. These sensors enable farmers to monitor and manage their crops more efficiently, optimizing irrigation, fertilization, and pest control. By using sensors, farmers can reduce waste, improve crop yields, and promote sustainable farming practices.

Here are the types and application of sensor technologies in precision farming:

Types of Sensor Technologies

1. **Soil Sensors:** Measure soil moisture, temperature, pH, and nutrient levels.
2. **Weather Stations:** Monitor temperature, humidity, wind speed, and precipitation.
3. **Crop Sensors:** Detect crop health, growth stage, and yield potential.
4. **Irrigation Sensors:** Monitor soil moisture and adjust irrigation schedules accordingly.
5. **GPS Sensors:** Provide location-specific data for precision farming applications.
6. **Infrared Sensors:** Measure crop temperature and detect heat stress.
7. **Hyperspectral Sensors:** Analyze crop health and detect nutrient deficiencies.

8. Acoustic Sensors: Monitor soil moisture and detect water stress.

Applications of Sensor Technologies

- Optimize irrigation schedules based on soil moisture levels.
- Detect crop health issues and apply targeted treatments.
- Create detailed soil maps to optimize fertilizer application and reduce waste.
- Use sensor data to predict crop yields and optimize harvest planning.
- Integrate sensor data with autonomous farming systems to optimize farm operations.

Automation and Robotics

Automation and robotics are transforming precision farming by increasing efficiency, reducing labor costs, and improving crop yields. Here are some examples of automation and robotics in precision farming:

Autonomous Tractors and Equipment

- 1. Autonomous tractors:** Equipped with GPS, sensors, and AI, these tractors can plant, spray, and harvest crops without human intervention.
- 2. Autonomous farming equipment:** Robots and drones can automate tasks such as pruning, weeding, and crop monitoring.

Robotics Farming

- 1. Robotic farming systems:** Integrated systems that combine robotics, AI, and IoT to automate farming tasks, such as planting, harvesting, and crop monitoring.
- 2. Robotic weeding and pruning:** Robots equipped with computer vision and machine learning algorithms can identify and remove weeds, and prune crops with precision.
- 3. Robotic harvesting:** Robots can automate the harvesting process, reducing labor costs and improving efficiency.

Greenhouse

As they offer a regulated environment for crop growth and development, greenhouses are important to precision farming. Precision

farming makes use of greenhouses in the following ways:
Greenhouses' Advantages for Precision Farming

1. **Climate Control:** By precisely regulating temperature, humidity, and light, greenhouses maximize crop development and growth.
2. **Year-Round Production:** Regardless of the outside weather, greenhouses provide for the year-round production of crops.
3. **Higher Yields:** Since greenhouses provide ideal growth conditions, crop yields can rise by as much as 30%.
4. **Water Conservation:** With accurate irrigation systems, greenhouses can minimize water use by up to 90%.
5. **Control of Pests and Diseases:** By offering a regulated environment, greenhouses lower the risk of pests and diseases.

Technologies for Precision Farming in Greenhouses

- **Sensor Systems:** Keep an eye on CO₂, light, humidity, and temperature.
- **Automated Irrigation Systems:** Eliminate waste and maximize water use.
- **LED Lighting:** For ideal crop growth, provide a precise spectrum and intensity of light.
- **Climate Control Systems:** Manage humidity, airflow, and temperature.
- **Data analytics:** To maximize crop growth and development, examine data from sensors and other devices

Types of Precision Farming Greenhouses

- **Glass Greenhouses:** Conventional glass greenhouses.
- **Poly greenhouses** are composed of film made of polyethylene or polypropylene.
- **Tunnel Greenhouses:** These are straightforward greenhouses with a tunnel shape.
- **Multilevel greenhouses** for optimal space efficiency are known as vertical farming greenhouses.
- **Smart Greenhouses:** Equipped with cutting-edge technologies like IoT and AI.
-

Hydroponics

Hydroponics is a method of growing plants in a nutrient-rich solution rather than soil, allowing for precise control over nutrient levels and optimal growing conditions. This soilless cultivation technique enables faster growth rates, increased crop yields, and reduced water usage. Hydroponics also allows for year-round production and can be used to grow a wide variety of crops, making it a popular choice for precision farming and urban agriculture (Kanwalpreet Kour *et al.*,2022)

Types of Hydroponic Systems Used in Precision Farming

1. Nutrient Film Technique (NFT): Plants are grown in long, narrow channels with a continuous flow of nutrient-rich solution.
2. Ebb and Flow (Flood and Drain): Plants are grown in a tray or bed that is periodically flooded with nutrient-rich solution.
3. Drip Irrigation: Plants are grown in a medium, such as rockwool or coco coir, and nutrient-rich solution is delivered directly to the roots.
4. Aeroponics: Plants are grown in the air, with their roots suspended in a nutrient-rich mist.
5. Vertical Hydroponics: Plants are grown in vertically stacked layers, often using a trellis system.

(Jayant P. Mehare *et al.*,2022)

Precision Farming Technologies Used in Hydroponics

1. Sensor Systems: Monitor pH, EC, temperature, and nutrient levels in real-time.
2. Automated Nutrient Delivery Systems: Optimize nutrient levels and reduce waste.
3. LED Lighting: Provide precise spectrum and intensity of light for optimal crop growth.
4. Climate Control Systems: Regulate temperature, humidity, and air circulation.
5. Data Analytics: Analyze data from sensors and other systems to optimize crop growth and development.

(Carlos Cambra *et al.*,2022)

Aquaculture

Aquaculture is the management and propagation of aquatic animals and plants for research, commerce, and recreation. It involves breeding marine and freshwater species to augment natural supplies, providing feedstocks to industries, stocking sport fisheries, providing aquatic bait animals, and providing food and industrial products. Aquaculture has rapidly expanded due to the cultivation of expensive species like oysters, trout, salmon, prawns, crayfish, and shrimp. However, the production of low-energy species like tilapia, carp, and catfish is also increasing. Aquaponics, a hybrid system combining aquaculture with hydroponic plant growing, uses some freshwater fish waste.

Government ocean ranching aims to replenish lakes and oceans by raising fish in controlled environments. Common species include mussels, scallops, oysters, tilapia, carp, trout, and catfish. Lobster aquaculture gained economic success in the late 20th century. Population growth, nutritional changes, and technological advancements have led to global aquaculture expansion. The limited natural ocean resources have increased demand for fish and shellfish, highlighting the importance of aquaculture (James S. Diana,2009).

Benefits and advantages of precision farming

Precision farming significantly improves crop yields and reduces waste by leveraging advanced technologies such as GPS, mapping, and sensor systems. Optimized planting patterns, variable rate application of fertilizers and water, and regular crop monitoring enable farmers to identify issues early and take corrective action. (Balogh *et al.*, 2021). Additionally, precision irrigation systems and targeted application of inputs minimize waste and environmental impact. (Zhang *et al.*, 2021)

By automating systems and using data-driven decision making, farmers can optimize resource allocation, reduce labor costs, and increase efficiency. Overall, precision farming leads to increased efficiency and productivity, improved crop yields, and reduced waste, making it a valuable approach for modern agriculture.

Challenges and Limitation in Precision Farming

Additional expenses, including initial investment, yearly subscription, maintenance, and operational expenditures, are associated

with the implementation of PA technology (Griffin *et al.*, 2018). Perceived profitability was identified as a major predictor of adoption across studies in an ameta-analysis of PA adoption (Tey & Brindal, 2022). When weighed against the profits, however, many farmers felt that the initial PA expenditures were excessive (Pedersen & Lind, 2017; Weersin *et al.*, 2018). Adoption may be hampered by the high initial cost, particularly for farmers with limited resources. The majority of creative enterprises are also severely constrained by financial considerations (Balogh *et al.*, 2021). For farmers, issues of data ownership and privacy present difficulties. The data produced when PA techniques were originally implemented belonged to farmers. Since the advent of the big data era, information from numerous farms has been combined and used to produce services, products, and analyses without the awareness of farmers (Sykuta, 2016). This indicates that if farmers give technology providers too much information, they may be at a disadvantage (Linsner *et al.*, 2021). Farmers' worries regarding the abuse of digitally collected information by commercial service providers were also brought to light by Shang *et al.* (2021). (Castle *et al.*, 2015). Data privacy is a legitimate concern because using PA equipment or services frequently requires producers to consent to data sharing.

Adoption decisions made by farmers are influenced by knowledge. Good information service and training are essential for handling PA equipment and software successfully (Reichardt *et al.*, 2009). Many farmers struggle with data interpretation and analysis, which makes it difficult to use the data and make management decisions based on it. Furthermore, a bad user experience, restricted access to information, and a lack of technical support can all hinder adoption (Zhang *et al.*, 2021). Furthermore, farmers' adoption decisions are greatly influenced by demonstration and exhibition events (Tamirat *et al.*, 2018). To comprehend the advantages, farmers must observe effective PA implementations on properties similar to their own (Balogh *et al.*, 2021).

Future Direction and Trends in Precision Farming

Farmers are using aircraft data and AI-enabled drones to monitor their farms, utilizing deep learning and computer vision algorithms to analyze data collected by drones. AI agriculture bots can pick crops faster and in larger quantities than human workers, and are more accurate in weed identification and elimination. Chatbots are also being used by farmers for advice and guidance on specific agricultural problems. While autonomous machines can perform some tasks, they prevent agriculture from operating

without human intervention. AI is ideal for small-scale farmers, providing information about planting details and density. Smart farms also consider the Internet of Things (IoT) for information on density and nutritional status.

Conclusion

Precision farming is revolutionizing the agricultural industry by leveraging cutting-edge technologies such as IoT, AI, and machine learning. By utilizing cutting-edge technology like IoT, AI, and machine learning, precision farming is transforming the agriculture sector. Farmers can use precision agriculture techniques to maximize crop yields, cut waste, and advance environmentally friendly farming practices. Farmers can respond to shifting climatic conditions and make well-informed judgments because of data-driven decision making made possible by the combination of digital tools, satellite imaging, and GIS. Precision farming will be essential for maintaining food security, reducing the impact on the environment, and fostering a more sustainable agricultural future as the world's population continues to rise.

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CHAPTER - 23

EMERGING TRENDS IN AGRICULTURAL EXTENSION

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ABSTRACT

India's economic structure is primarily agricultural with over 50 percent of the population relying on this sector for income and providing food security and a large share of rural employment. However, a rapid transformation of the sector is being hindered by outdated farming techniques, limited access to markets, fragmented globalization, inefficient use of resources and growing prospects of climate change. For these gaps in the sector, farmers have been empowered with knowledge by establishing agricultural extension services which connect researchers and farmers. Recently, factors like increasing globalization, technological innovations, and policy reforms have changed Indian agricultural extension significantly. This paper identifies key trends that are transforming the policy and practices of agricultural extension services in India namely, use of information and communication technology in extension services, strengthening of public private partnerships and establishment of farmer producer organizations. The goal is to complement all of these policies with knowledge and therefore the government seeks to build an extension system that incorporates agriculture, health and rural development areas. The paper stresses the need for a shift from classical agriculture extension approaches to a more farmer driven modern agricultural extension system. These trends not only improve productivity and incomes, but also promote environmental sustainability and socio-economic inclusion. The changing landscape of agricultural extension services is crucial in ensuring food security for India in the long term, promoting rural growth, and adapting to the risks posed by climate change and global market volatility.

Introduction

Agriculture is regarded as one of the most important sectors in India responsible for the sustenance and growth of the economy. In India over fifty percent of the population is involved in agriculture directly or indirectly. There are several issues that the sector has to contend with such as the use of rudimentary farming methods, inadequate resource optimization, adverse weather conditions, and restricted access to markets. In this respect, agricultural extension services, which assist farmers with relevant knowledge, resources, and aid are essential in narrowing the existing gaps between theoretical agricultural practices and farmers. In India, there has been a change in the philosophy of providing agricultural extension services as a result of technological innovations, transformation in the socio economic environment, and new environmental factors. The provision of extension services in India is progressively changing from traditional to digital methods enabling farmers to access timely and affordable services.

The transition from traditional, in-person interactions to digital platforms, mobile applications, and teleconsultations marks a significant change in the delivery of agricultural advice and support. Additionally, public-private partnerships (PPPs), Farmer Producer Organizations (FPOs), and the embrace of climate-smart agriculture are reshaping the landscape of agricultural extension services in India. These advancements not only equip farmers with the knowledge needed to enhance crop productivity but also help them address the challenges posed by climate change, access modern technologies, and adopt sustainable farming practices. This paper explores the emerging trends in agricultural extension, examining their impact on productivity, sustainability and the socio-economic inclusion of farmers throughout India.

Emerging Trends in Agricultural Extension in India

Agricultural extension in India is experiencing a major transformation, influenced by technological advancements, shifts in farming practices, and changing market needs. As the country faces challenges such as climate change, resource depletion and rural poverty, agricultural extension is crucial in connecting farmers with contemporary agricultural methods.

1. Digitalization and Information and Communication Technologies (ICT) in Agricultural Extension

a. Mobile Applications for Agricultural Support:

The increasing availability of mobile phones and affordable data plans has created new opportunities for agricultural extension services in India. Farmers can now easily access information on weather forecasts, crop advisories, market prices, and pest control methods through various mobile applications. Apps such as Kisan Suvidha, iKisan, and AgriApp deliver real-time, localized information, allowing farmers to make informed decisions throughout the farming cycle. This shift towards digital solutions lessens reliance on traditional extension services and equips farmers with essential knowledge right at their fingertips.

b. E-Extension and Online Platforms:

E-Extension involves utilizing digital tools like websites, webinars, online training modules, and video resources to share agricultural knowledge. The Indian government and numerous NGOs have created platforms where farmers can find information on government schemes, educational resources, and even expert advice. For instance, the eNAM (National Agriculture Market) initiative consolidates information on commodity prices, availability, and market connections, helping farmers make more informed selling choices. These platforms offer a wide range of information, significantly cutting down the time and costs associated with traditional extension methods.

c. Tele consultation and Virtual Advisory:

Telecommunication tools, especially voice and video calls, are increasingly being used to provide expert advice. Remote consultations have made it easier for farmers in rural and remote areas to access agricultural experts. Through tele consultations, farmers can get guidance on pest control, crop diseases, or input usage without the need to travel long distances. Both government programs and private companies are now frequently offering these services.

Public-Private Partnerships (PPPs)

a. Role of Private Sector in Extension Services:

Alongside government-led extension services, private companies in the agri-input sector such as those dealing with fertilizers, seeds, machinery, and agrochemicals—are becoming key contributors to agricultural extension. Through PPPs, these companies provide specialized guidance on how to effectively use their products. For example, major corporations like Bayer and Syngenta are advocating for sustainable farming practices and crop-specific technologies to boost productivity.

b. Corporate Farming and Agri-Tech Startups:

Agricultural startups are increasingly vital in enhancing market connections and offering technology-driven solutions. Digital platforms such as BigHaat, AgriBazaar, and Ninjacart are establishing direct-to-market links for farmers, allowing them to avoid intermediaries. These platforms frequently give farmers access to high-quality seeds, machinery, and other essential resources, leading to improved productivity and income. Through these partnerships, farmers benefit from enhanced access to technology, resources, and markets, which promotes greater efficiency in agricultural production.

3. Farmer Producer Organizations (FPOs)

a. Collective Action through FPOs:

Farmer Producer Organizations (FPOs) are being promoted as a way for smallholder farmers to tackle issues related to accessing resources, markets, and technology. By coming together, farmers can collectively purchase inputs such as seeds and fertilizers, secure credit, and negotiate better prices. Extension services are now focusing on training FPOs in cooperative management, leadership skills, and marketing strategies to help farmers build strong collective groups.

b. FPOs and Technology Dissemination:

FPOs act as platforms for sharing new technologies and agricultural practices. Extension services are increasingly targeting these

organizations to effectively reach a larger number of farmers. By collaborating with FPOs, extension agents can introduce innovative agricultural practices, improved seed varieties, efficient irrigation methods, and pest management techniques to a wide range of farmers.

4. Climate-Smart Agriculture (CSA) Practices

a. Water Management and Conservation:

In light of the increasing challenges posed by water scarcity, agricultural extension services are advocating for water-use efficiency. Techniques such as drip irrigation, rainwater harvesting, and micro-irrigation are being introduced to farmers, enabling them to use water more effectively and ensure sustainable crop production. By training farmers on efficient irrigation systems, agricultural extension services help optimize water usage, resulting in enhanced productivity in areas facing water shortages.

b. Soil Health Management:

Soil degradation and erosion are major concerns in Indian agriculture. Extension services are now emphasizing sustainable soil management practices like crop rotation, organic farming, and integrated nutrient management (INM) to enhance soil health. Soil testing is being encouraged to help farmers apply the appropriate type and amount of fertilizers, reducing reliance on chemicals while boosting soil fertility.

c. Climate-Resilient Crop Varieties:

As temperatures rise and rainfall patterns become more erratic, the need for crop varieties that can withstand drought, flooding, and extreme temperatures is increasingly important. Agricultural extension services are actively promoting the use of climate-resilient crops, assisting farmers in adapting to these changing climatic conditions.

5. Use of Drones and Remote Sensing Technologies

a. Precision Agriculture and Drones:

The advent of drones and remote sensing technologies has transformed how agricultural extension services gather and analyze data

from the fields. Drones equipped with high-resolution cameras and sensors can monitor crop health, assess soil conditions, and identify pest problems. This information is crucial for precision farming, where resources like fertilizers, pesticides, and water are applied based on immediate needs, leading to better resource management and higher yields.

b. Geographic Information System (GIS) for Crop Management:

GIS technologies are employed to collect detailed spatial data regarding crop conditions, field variability, and environmental influences. This information enables the targeted application of inputs, which not only cuts costs but also reduces environmental impact. By utilizing GIS-based analysis, extension services can suggest tailored interventions to boost crop productivity across various regions.

6. Knowledge Sharing and Capacity Building

a. Farmer Field Schools (FFS):

Farmer Field Schools (FFS) have become a popular extension method in India. These schools offer a space for farmers to come together, observe demonstrations, and discuss best practices in agriculture. Topics include crop management, pest control, organic farming, and the latest technologies. This hands-on approach fosters better learning and encourages the adoption of innovative farming techniques.

b. Peer-to-Peer Learning Networks:

Peer-to-peer learning is becoming an increasingly popular trend in agricultural extension. Through networks such as farmer clubs, cooperatives, and online forums, farmers are actively sharing knowledge, innovations, and practical advice. These networks help to reduce feelings of isolation and build a sense of community among farmers, promoting the exchange of effective practices and solutions to common challenges.

7. Inclusive and Gender-Sensitive Extension Services

a. Empowering Women in Agriculture:

A significant focus of new agricultural extension trends is the involvement of women farmers in decision-making processes. Given that

women make up a substantial part of India's agricultural workforce, there is a growing acknowledgment of the importance of gender-sensitive extension services. Training programs are designed specifically for women farmers, equipping them with agricultural skills as well as leadership, entrepreneurship, and financial management abilities.

b. Marginalized Communities and Social Inclusion:

Extension services are increasingly being crafted to be inclusive, reaching out to marginalized communities, including Scheduled Castes (SCs), Scheduled Tribes (STs), and other rural poor. These services are customized to ensure that these communities receive the necessary support, including access to technology, inputs, and financial resources.

8. Agri-Entrepreneurship and Value Chain Development

a. Encouraging Agricultural Entrepreneurship:

Agricultural extension is now placing a strong emphasis on transforming farmers into agri-entrepreneurs. By facilitating the establishment of agribusinesses such as seed production, food processing, and agricultural marketing, extension services are assisting farmers in diversifying their income streams. This approach is particularly important in rural areas where relying solely on agriculture may not yield enough income.

b. Developing agricultural value chains:

Developing agricultural value chains—from production to processing, storage, packaging, and marketing—is a crucial part of agricultural extension. Extension services assist farmers in enhancing their post-harvest practices and engaging in value-added sectors. This not only boosts income but also minimizes waste. For instance, by encouraging value-added initiatives such as dairy processing, poultry farming, or organic farming, agricultural extension services play a vital role in strengthening rural economies.

9. Precision Agriculture and Data-Driven Decision Making

a. Smart Farming Solutions:

Precision farming is a growing trend where extension services are introducing farmers to technologies like Internet of Things (IoT) devices, sensors, and artificial intelligence (AI). These smart farming solutions enable farmers to monitor soil moisture, temperature, and crop health in real time, enhancing their decision-making capabilities. This results in a more efficient use of resources such as water, fertilizers, and pesticides.

b. Big Data and Predictive Analytics:

The application of big data and predictive analytics is becoming increasingly important in agriculture. Extension services are guiding farmers in utilizing large datasets to forecast weather patterns, pest outbreaks, and potential crop diseases, enabling them to take proactive measures. With sophisticated forecasting tools, farmers can organize their farming activities more effectively and mitigate the risks linked to crop failures.

10. Policy-Driven and Farmer-Centric Agricultural Extension

a. Government Schemes and Subsidies:

The Indian government has introduced several policies aimed at supporting farmers, including the Pradhan Mantri Fasal Bima Yojana (a crop insurance scheme), Pradhan Mantri Kisan Samman Nidhi (which provides direct income support), and the Soil Health Card scheme. Agricultural extension services play a crucial role in keeping farmers informed about these initiatives, helping them navigate the process of accessing subsidies and benefits.

b. Integrated Agricultural Extension System:

There is a growing emphasis on an integrated extension system that merges agricultural practices with rural development and health initiatives. By bringing together these different fields, extension services assist farmers in adopting methods that enhance not only their crop yields but also their overall health, nutrition, and financial well-being.

Importance of New Trends in Agricultural Extension

Increased Productivity and Efficiency: New trends often incorporate modern technologies and innovative practices. These advancements can boost productivity, enabling farmers to produce more food while using fewer resources. This is particularly important in a world where the demand for food continues to rise.

Adaptation to Changing Conditions: Agriculture faces various challenges, such as climate change, water scarcity, and evolving market demands. New trends in extension programs assist farmers in adapting to these changes by equipping them with knowledge and tools to manage risks and make informed choices.

Sustainability and Conservation: Many new trends highlight sustainable farming practices that help preserve natural resources like soil and water. By promoting methods such as precision agriculture, organic farming, and integrated pest management, extension programs support long-term environmental sustainability.

Resilience to Climate Change: Climate-smart practices, which are a vital part of new trends, enable farmers to build resilience against the unpredictable effects of climate change. These practices help farmers manage water resources more effectively, choose climate-resistant crops, and adjust their planting and harvesting schedules.

Improved Livelihoods: Integrating value chain development, agri-preneurship, and market access into extension programs can significantly enhance farmers' incomes. New trends empower farmers to participate in higher-value activities and establish direct connections with consumers, reducing reliance on middlemen.

Youth and Gender Empowerment: New trends emphasize engaging youth and addressing gender inequalities in agriculture. By attracting young individuals to farming through technology adoption and entrepreneurial opportunities, and by ensuring equal access to resources for all genders, extension programs promote social inclusivity and rural development.

Technological Adoption: As technology continues to evolve at a rapid pace, it is essential to integrate digital tools and precision techniques into

agriculture. Extension programs play a crucial role in assisting farmers to understand and effectively adopt these technologies, which leads to better farm management and informed decision-making.

Global Food Security: With the global population expected to rise, ensuring food security is a significant challenge. Emerging trends in agricultural extension are vital for boosting food production, minimizing post-harvest losses, and creating efficient supply chains, all of which are critical for maintaining global food security.

Capacity Building and Knowledge Transfer: Agricultural extension programs act as a vital link between research institutions and farmers. By sharing research-based knowledge and providing training, these programs empower farmers with the skills and insights necessary to adopt best practices.

Rural Development: Agriculture serves as the foundation for many rural economies. By encouraging modern practices, enhancing the value of agricultural products, and linking farmers to markets, extension programs play a key role in rural development, job creation, and poverty alleviation.

Environmental Stewardship: Many recent trends emphasize reducing the negative environmental effects of agriculture, such as soil degradation and water pollution. Extension programs that advocate for eco-friendly practices enable farmers to become responsible caretakers of the land.

Conclusion

The changing trends in agricultural extension in India reflect a significant shift towards more inclusive, technology-driven, and sustainable farming practices. The use of ICT-based solutions, including mobile apps, e-extension platforms, and teleconsultations, is helping farmers make informed decisions and access essential agricultural knowledge in real-time. This digital transformation has made agricultural extension services more accessible and efficient, particularly for farmers in remote and underserved regions. Public-private partnerships and the emergence of agri-tech startups are crucial in improving market access and encouraging technological adoption among farmers. Initiatives like Farmer Producer Organizations (FPOs) allow farmers to unite, share resources, and strengthen their collective bargaining power, leading to increased productivity and income.

The focus on climate-smart agriculture, precision farming, and resilient crop varieties is essential for tackling the intertwined challenges of food security and environmental sustainability. Additionally, prioritizing gender-sensitive and inclusive extension services ensures that marginalized groups, including women and tribal farmers, are empowered to engage in agricultural decision-making. As India's agricultural landscape evolves, extension services must adapt to these new trends, equipping farmers not only with tools to boost productivity but also with the skills to navigate the complexities of modern agriculture. By creating an environment that promotes knowledge sharing, technological innovation, and inclusive development, agricultural extension can serve as a vital driver for rural development and enhance the resilience of Indian agriculture against global challenges like climate change and market fluctuations.

CHAPTER – 24

BLENDING TRADITION AND TECHNOLOGY: THE ROLE OF ITK IN SUSTAINABLE FARMING

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Agriculture is the backbone of human civilization, providing food, livelihoods, and economic stability. However, the sector is increasingly under strain due to environmental challenges, resource depletion, and the pressures of feeding a growing global population. As the demand for sustainable practices intensifies, the integration of Indigenous Technical Knowledge (ITK) and modern technology offers a promising pathway to balance productivity with environmental stewardship. Global agriculture is at a crossroads, facing unprecedented challenges that threaten food security and ecological balance. In Soil Degradation, continuous monocropping overuse of chemical fertilizers, and deforestation have led to the depletion of soil organic matter and nutrients. Approximately 33% of the world's soils are moderately to highly degraded, according to the Food and Agriculture Organization (FAO). For water scarcity, Agriculture accounts for nearly 70% of global freshwater withdrawals, yet inefficient irrigation practices result in significant wastage and Groundwater depletion and erratic rainfall patterns, exacerbated by climate change, further complicate water management. Rising temperatures, altered rainfall patterns, and increased frequency of extreme weather events impact crop yields and agricultural livelihoods. Agriculture is both a victim and a contributor to climate change, with significant greenhouse gas emissions from conventional practices. These pressing concerns underscore the need for a paradigm shift towards sustainable agriculture, where productivity and environmental conservation go hand in hand.

Understanding Indigenous Technical Knowledge (ITK)

Indigenous Technical Knowledge (ITK) refers to the cumulative body of knowledge, practices, and beliefs developed by local communities over generations through interaction with their environment. Rooted in

cultural traditions, ITK is often passed down orally, through observation, or via practice. It represents a practical and context-specific understanding of agricultural, ecological, and natural systems.

Key characteristics of ITK

- Localized
- Eco-friendly
- Dynamic
- Community-based
- Holistic

Historical Significance and Evolution in Agriculture

ITK has played a foundational role in agricultural development, forming the basis for traditional farming systems that have sustained societies for centuries. Its historical significance lies in the following areas:

Adaptation to Local Conditions

Communities developed ITK practices to suit specific soil types, rainfall patterns, and climatic zones. For example, terraced farming in the Himalayan region evolved as a solution to cultivate steep slopes and prevent soil erosion.

Cultural Integration

ITK is deeply embedded in the cultural fabric of societies, often reflected in rituals, festivals, and folklore related to farming. Practices such as rainwater harvesting or seed preservation are often tied to cultural beliefs and traditions.

Sustainability Before Modern Inputs

Before the advent of chemical fertilizers and pesticides, ITK ensured soil fertility and pest management using organic and natural methods. Practices like crop rotation and intercropping maintained soil health and minimized pest outbreaks.

Knowledge Transfer

ITK has been transmitted across generations, ensuring the continuity of sustainable practices and a deep understanding of local ecosystems. This oral tradition has preserved a wealth of knowledge, though it is at risk of being lost in the face of modernization.

Sustainable Agriculture: Challenges and Necessities

Environmental Challenges in Modern Farming

Modern farming faces numerous environmental challenges that threaten the long-term viability of agricultural systems. Overuse of chemical fertilizers and pesticides has degraded soil health, reducing its organic matter and fertility. Intensive irrigation practices have led to groundwater depletion and salinization, exacerbating water scarcity. Climate change has further compounded these issues, with rising temperatures, unpredictable rainfall patterns, and extreme weather events affecting crop yields and the stability of farming systems. Monocropping, a hallmark of industrial agriculture, has also diminished biodiversity, making ecosystems more vulnerable to pests and diseases. These environmental challenges highlight the urgent need to transition to sustainable agricultural practices that conserve natural resources while maintaining productivity.

Economic and Social Implications of Unsustainable Practices

Unsustainable agricultural practices have significant economic and social repercussions. Farmers often face increased input costs due to dependency on synthetic fertilizers, pesticides, and hybrid seeds, which can lead to financial distress. Soil degradation and declining water availability further reduce yields, making farming less profitable. In many regions, rural communities face displacement as land becomes unsuitable for cultivation, exacerbating poverty and migration to urban areas. Additionally, unsustainable farming contributes to environmental pollution, impacting public health and increasing healthcare costs. Socially, the erosion of traditional knowledge and practices undermines community resilience, disconnecting people from their cultural and agricultural heritage. Addressing these issues requires a holistic approach that balances economic viability, social well-being, and environmental sustainability.

The Role of ITK in Addressing Sustainability Issues

Indigenous Technical Knowledge (ITK) offers practical, eco-friendly solutions to the challenges of sustainable agriculture. ITK practices, such as crop rotation, intercropping, and organic composting, improve soil health, enhance biodiversity, and reduce dependence on chemical inputs. Traditional water conservation methods like step wells, rainwater harvesting, and zai pits help manage water resources effectively

in regions facing scarcity. ITK also fosters community involvement and knowledge sharing, promoting resilience and self-reliance among farmers. By integrating ITK with modern technologies, such as precision farming and AI-driven decision-making tools, agricultural systems can achieve greater sustainability. Recognizing the value of ITK not only supports environmental conservation but also preserves cultural heritage and empowers rural communities.

Core Contributions of ITK to Sustainable Farming

Soil Health Management: Indigenous Methods for Maintaining Soil Fertility

Indigenous Technical Knowledge (ITK) has long provided effective methods for maintaining soil fertility and health, crucial for sustainable farming. Practices such as crop rotation and intercropping enhance soil structure and nutrient availability while minimizing erosion. The use of organic manures like farmyard compost, green manure, and bio fertilizers enriches the soil with essential nutrients and improves microbial activity. ITK also incorporates methods like mulching with natural materials to retain moisture and prevent soil degradation. These practices are eco-friendly, cost-effective, and adaptable to local conditions, reducing dependency on synthetic fertilizers and safeguarding soil for future generations.

Water Conservation Techniques: Traditional Irrigation and Water Harvesting

Water conservation is a cornerstone of ITK, particularly in regions prone to droughts or water scarcity. Traditional water harvesting systems such as step wells, tanks, and ponds have been ingeniously designed to store and manage water effectively. In arid areas, techniques like zai pits and contour bunding help capture and retain rainwater for crop use. Indigenous irrigation systems, such as the phad system in Maharashtra and the kul irrigation canals in Himachal Pradesh, optimize water distribution while minimizing wastage. These time-tested methods ensure efficient water use, enhance groundwater recharge, and provide sustainable solutions for water management in agriculture.

Crop Protection: Natural Pest Control and Disease Management

ITK offers a wealth of knowledge for natural pest control and disease management, reducing reliance on chemical pesticides that harm

the environment. Farmers use biopesticides prepared from locally available materials, such as neem leaves, garlic, and chili, to deter pests effectively. Companion planting, where specific crops are grown together to repel pests or attract beneficial insects, is another widely practiced ITK method. Ash application and fermented plant extracts are used to manage diseases without compromising soil and crop health. These natural approaches ensure long-term pest control, reduce input costs, and preserve the ecological balance of farming ecosystems.

Biodiversity Conservation: Role of ITK in Preserving Genetic Resources

Indigenous practices play a crucial role in conserving biodiversity by maintaining diverse crop varieties and local livestock breeds. Farmers traditionally save and exchange seeds of native crops that are well-adapted to specific climatic and soil conditions, ensuring resilience to environmental changes. Agroforestry systems, which integrate trees, crops, and livestock, create habitats for various species and enhance ecosystem services. ITK also emphasizes sustainable harvesting of wild plants and medicinal herbs, preserving genetic resources and traditional knowledge for future use. This biodiversity conservation not only strengthens agricultural systems but also supports broader environmental sustainability.

Synergizing ITK with Modern Technology

Integrating Indigenous Technical Knowledge (ITK) with modern agricultural technology offers a sustainable, inclusive, and efficient approach to farming. ITK provides centuries of practical wisdom and ecological balance, while modern technology adds precision, scalability, and automation, creating complementary strengths.

Contextual Adaptation

ITK offers localized insights into soils, crops, water, and climate, enhancing the effectiveness of modern tools. For instance, integrating green manuring with precision farming or combining traditional water conservation techniques with IoT-based monitoring optimizes resource management.

Boosting Technology Adoption

Farmers are more likely to adopt technologies aligned with their traditions. Pairing drones with ITK-based solutions like neem biopesticides bridges the gap between innovation and cultural relevance.

Sustainability and Ecology

ITK's natural practices, such as biodiversity conservation and pest management, complement modern tools like AI and drones, ensuring productivity without compromising environmental health.

Empowering Farmers

Incorporating ITK makes modern technologies more accessible, affordable, and user-friendly, particularly for small-scale farmers. Apps that combine traditional planting calendars with weather updates and market insights exemplify this synergy.

Fostering Innovation

ITK inspires new tools and techniques, such as optimizing intercropping with AI algorithms. Collaborative research involving ITK and modern technology fosters innovation and knowledge exchange.

Building Resilience

Blending ITK with modern technology creates climate-resilient farming systems by combining adaptive strategies, like planting drought-resistant crops, with advanced climate prediction tools.

Success Stories and Case Studies

Role of ITK in Zero Budget Natural Farming (ZBNF)

Example: Andhra Pradesh, India

ZBNF integrates traditional farming techniques with natural inputs to reduce costs and enhance sustainability. The use of ITK in Andhra Pradesh, especially practices like Panchagavya (a concoction made from cow dung, urine, milk, curd, and ghee) for soil fertility and pest management, has proven successful. This method, combined with modern technologies like soil health monitoring, has helped farmers achieve higher yields while maintaining low input costs.

Successful ITK Integration in Organic Farming

Example: Sikkim, India

Sikkim, India's first fully organic state, demonstrates successful integration of ITK in organic farming. Farmers use traditional crop rotation, organic manure, and indigenous pest control methods alongside modern organic certification practices and market linkage technologies. This holistic approach has significantly increased soil health, reduced chemical pesticide usage, and improved crop yields while preserving local biodiversity.

Community-led Initiatives in Preserving ITK While Adopting Technology

Example: Araku Valley, Andhra Pradesh

In Araku Valley, tribal farmers have successfully integrated ITK with modern farming technologies. The community uses organic farming methods, such as composting and intercropping, alongside digital tools like mobile apps for weather forecasting and crop monitoring. This combination has helped increase productivity and income while preserving traditional farming practices and enhancing ecological sustainability.

Conclusion

Blending Indigenous Technical Knowledge (ITK) with modern agricultural technologies presents a transformative approach to achieving sustainable farming. While ITK offers a deep understanding of local ecosystems, biodiversity, and cultural practices, modern technology provides precision, scalability, and data-driven solutions. Together, they can optimize resource use, enhance productivity, and reduce environmental impact. The synergy between tradition and technology not only preserves cultural heritage but also addresses contemporary challenges like climate change, soil degradation, and water scarcity. Successful case studies, such as those seen in Zero Budget Natural Farming and organic farming systems, demonstrate that this integrated approach fosters resilience, innovation, and inclusivity in agriculture. Incorporating ITK alongside advanced technologies empowers farmers, especially smallholders, and ensures agricultural systems remain adaptive and sustainable. Ultimately, the fusion of these two powerful approaches holds the key to a more sustainable, efficient, and equitable future for global agriculture.

CHAPTER - 25

COLLECTION AND MOLECULAR SEQUESTRATION OF *Bipolaris maydis* CAUSES MAYDIS LEAF BLIGHT IN MAIZE (*Zea mays* L.)

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Introduction

Maydis leaf blight (MLB), caused by the fungal pathogen *Bipolaris maydis*, poses a significant threat to global maize (*Zea mays* L.) production. This fungal disease not only reduces yield but also affects grain quality, threatening food security in maize-dependent regions. Understanding the pathogen's biology and its interaction with maize is essential for developing effective management strategies. This chapter discusses the comprehensive approach for the collection, isolation, and molecular characterization of *Bipolaris maydis*. Additionally, it highlights its pathogenicity mechanisms and potential strategies for disease control.

1. Collection of *Bipolaris maydis* Samples

1.1 Field Sampling Techniques

The collection of *Bipolaris maydis* involves sampling maize plants exhibiting symptoms of Maydis leaf blight from diverse agro-climatic zones. Symptoms typically include tan, elliptical lesions with dark brown margins, often leading to severe blighting in advanced stages. The steps involved include:

- **Selection of Sampling Sites:** Sampling is conducted in fields representing varying climatic conditions, maize genotypes, and farming practices to capture a wide range of pathogen variability.

- **Symptomatic Leaf Collection:** Leaves displaying characteristic lesions are carefully removed and labeled with details such as location, date, and maize variety.
- **Sampling Asymptomatic Leaves:** To detect latent infections, some asymptomatic leaves are included in the collection.

1.2 Preservation and Transport

Maintaining sample integrity during transport is crucial for accurate pathogen isolation. Methods include:

- Storing leaf samples in sterile paper envelopes or polythene bags.
- Using ice boxes or coolers to maintain low temperatures and prevent fungal overgrowth during transit.

2. Isolation and Morphological Characterization of *Bipolaris maydis*

2.1 Fungal Isolation Procedures

The isolation of *Bipolaris maydis* from infected leaf samples involves the following steps:

- **Surface Sterilization:** Symptomatic leaf sections are surface-sterilized using 70% ethanol followed by rinsing in sterile distilled water to eliminate surface contaminants.
- **Culture Media:** Sterilized leaf sections are plated onto potato dextrose agar (PDA) medium, which supports fungal growth. Plates are incubated at 25°C for 5-7 days.
- **Single-Spore Isolation:** Pure cultures are obtained by transferring single spores to fresh PDA plates, ensuring the removal of contaminants and mixed cultures.

2.2 Morphological Identification

- **Colony Characteristics:** Colonies of *Bipolaris maydis* typically appear grayish-brown to black with a velvety texture.
- **Microscopic Features:** Conidia are observed under a microscope. They are curved, multicellular, and exhibit transverse septations, distinguishing them from other fungal pathogens.

3. Molecular Sequestration and Characterization

3.1 DNA Extraction

High-quality genomic DNA is essential for molecular studies. DNA is extracted from pure fungal cultures using protocols such as:

- **CTAB Method:** A widely used technique involving cetyltrimethylammonium bromide to lyse cells and purify DNA.
- **Commercial Kits:** Ready-to-use kits provide efficient and consistent DNA yields.

3.2 Polymerase Chain Reaction (PCR) Amplification

PCR is employed to confirm the identity of *Bipolaris maydis* using specific primers targeting conserved regions:

- **Internal Transcribed Spacer (ITS) Regions:** ITS1 and ITS4 primers amplify fungal ribosomal DNA, providing species-specific identification.
- **Housekeeping Genes:** Genes such as actin or beta-tubulin are also used for phylogenetic studies.

3.3 Sequencing and Phylogenetic Analysis

- **Sequencing:** Amplified PCR products are sequenced to obtain nucleotide data.
- **Bioinformatics Tools:** Sequences are analyzed using tools like BLAST and aligned with reference databases. Phylogenetic trees are constructed to determine evolutionary relationships among isolates.

4. Pathogenicity Testing

4.1 Koch's Postulates

Koch's postulates are fulfilled to confirm the pathogenicity of *Bipolaris maydis*:

- **Inoculation:** Pure fungal cultures are inoculated onto healthy maize plants under controlled conditions.
- **Symptom Observation:** Inoculated plants are monitored for typical Maydis leaf blight symptoms.
- **Re-Isolation:** The pathogen is re-isolated from infected plants to confirm its identity.

4.2 Screening for Virulence

Virulence assays involve inoculating maize genotypes with *Bipolaris maydis* isolates to:

- Evaluate the aggressiveness of different isolates.
- Identify resistant and susceptible maize varieties.

5. Insights into Host-Pathogen Interaction

5.1 Mechanisms of Infection

Bipolaris maydis employs several strategies to infect maize, including:

- **Direct Penetration:** The fungus penetrates the cuticle or stomata to invade host tissues.
- **Secretion of Toxins:** The production of host-specific toxins (HSTs), such as T-toxin, disrupts mitochondrial functions in susceptible maize genotypes, leading to cell death.

5.2 Molecular Basis of Susceptibility

- **Cytoplasmic Factors:** Maize genotypes with T-cytoplasm are highly susceptible to T-toxin-producing isolates.
- **Defense Gene Expression:** The expression of genes related to plant immunity, such as pathogenesis-related (PR) proteins, plays a critical role in resistance.

6. Implications for Disease Management

6.1 Resistance Breeding

- **Genotype Screening:** Identification of resistant maize genotypes through phenotypic screening and molecular markers.
- **Genetic Improvement:** Incorporating resistance genes into commercial hybrids using marker-assisted selection (MAS).

6.2 Integrated Pest Management (IPM)

Effective management of Maydis leaf blight requires a combination of approaches:

- **Cultural Practices:** Crop rotation, residue management, and timely planting reduce disease pressure.
- **Chemical Control:** Fungicides, such as triazoles and strobilurins, are effective when applied at critical growth stages.
- **Biological Control:** Beneficial microorganisms like *Trichoderma spp.* and *Pseudomonas fluorescens* suppress *Bipolaris maydis* growth and enhance plant defense.

Conclusion

The collection, isolation, and molecular characterization of *Bipolaris maydis* are pivotal for understanding its epidemiology and devising effective management strategies. By integrating molecular tools with traditional practices, sustainable solutions can be developed to mitigate the impact of Maydis leaf blight, ensuring stable maize production and food security.

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