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ADVANCES IN AGRICULTURE SCIENCES
VOLUME I

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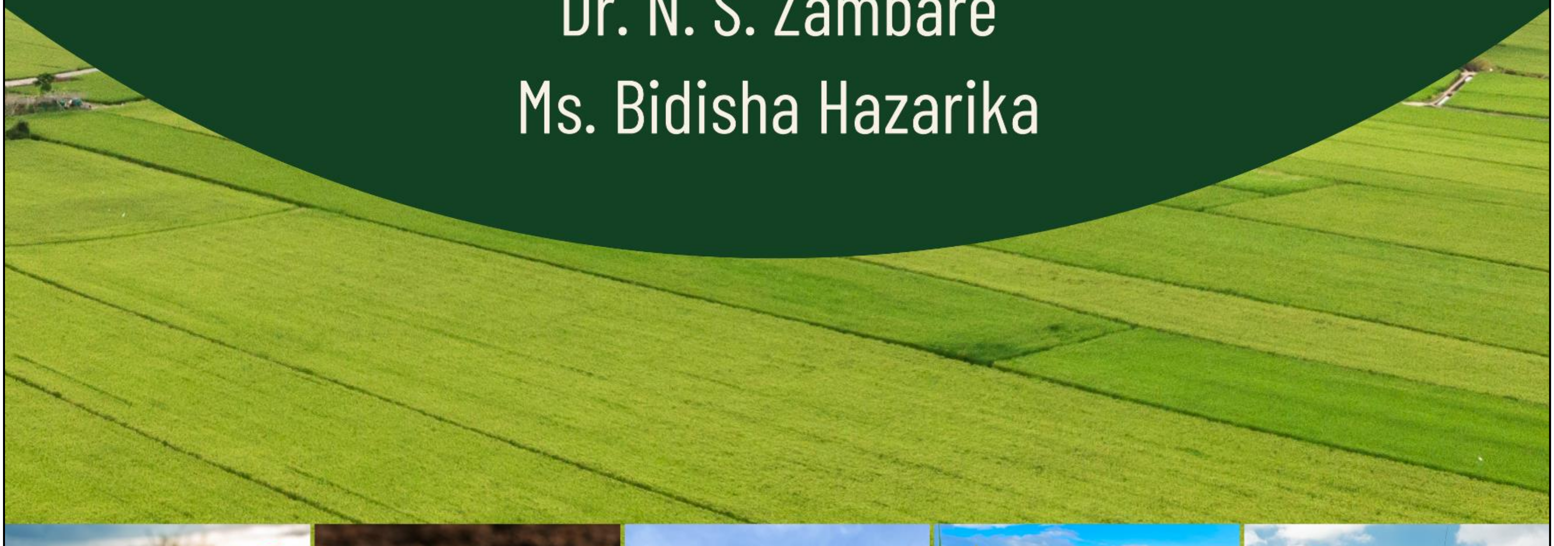

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Advances in Agriculture Sciences Volume I

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PREFACE

Agriculture, being the cornerstone of human civilization, has undergone remarkable transformations over centuries. However, in today's rapidly changing world, the challenges facing agriculture are more complex and multifaceted than ever before. From feeding a growing global population to mitigating the impact of climate change, the demands placed upon the agricultural sector are immense.

In response to these challenges, scientists, researchers, and practitioners from around the globe have been tirelessly working to push the boundaries of agricultural knowledge and practice. Their relentless pursuit of innovation has led to remarkable discoveries and novel solutions that hold the potential to revolutionize the way we produce food, manage resources, and safeguard the environment.

"Advances in Agriculture Sciences" serves as a testament to the dedication and ingenuity of these individuals. Through a collection of insightful chapters, this book offers a comprehensive overview of cutting-edge research and emerging trends across various domains of agricultural science. From precision farming and biotechnology to sustainable practices and digital agriculture, each chapter delves into the latest developments and their implications for the future of farming.

Moreover, this book aims to foster interdisciplinary collaboration and knowledge exchange among researchers, practitioners, policymakers, and stakeholders in the agricultural community. By bringing together diverse perspectives and expertise, we hope to inspire dialogue, spark innovation, and drive positive change across the agricultural landscape.

As we navigate the complexities of the 21st century, the importance of agricultural science in addressing global challenges cannot be overstated. It is our sincere hope that "Advances in Agriculture Sciences" will serve as a valuable resource for anyone seeking to deepen their understanding of the dynamic field of agriculture and contribute to its continued advancement.

We extend our heartfelt gratitude to all the authors who have contributed their expertise and insights to this book. Their contributions have been instrumental in shaping this endeavor and enriching the discourse on agricultural innovation.

Editors

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SOIL POTASSIUM AND ITS MANAGEMENT STRATEGIES IN INDIAN AGRICULTURE

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Abstract:

This chapter explores soil potassium (K) management in Indian agriculture, addressing the prevalent challenges of K deficiency in diverse agro-climatic zones. Fertilizer application, particularly with potassium-based fertilizers tailored to specific crops and soils, is a primary strategy. Precision agriculture techniques, such as soil testing, guide optimal fertilizer use. Organic amendments, including compost and manure, contribute to long-term K enrichment and improved soil structure. Effective crop residue management enhances K recycling and boosts organic matter content. Sustainable practices like crop rotation and cover cropping further diversify nutrient sources, promoting balanced soil health. By integrating these strategies, this review underscores the significance of a comprehensive and sustainable approach to soil potassium management for ensuring enhanced agricultural productivity in India.

Keywords: Indian agriculture, Nutrients, Potassium, Soil fertility

Introduction:

In India, intensive agriculture involving exhaustive high-yielding varieties has led to heavy withdrawal of nutrients from the soil. The challenge in current agriculture is not only to produce more food to feed the rapidly growing population but also to maintain soil health and quality. N, P and K are the major nutrients required by plants in large amount. Constant increasing cost of chemical fertilizers creating economic problems to the small and marginal farmers and on the other hand soils are becoming ill due to imbalance in utilization of chemical fertilizers. Potassium is important for activation of several enzymes in plants, involving in photosynthesis, protein synthesis, stomatal regulation, water relations, translocation of assimilates, and improvement of crop quality. Potassium plays a crucial role in antagonistic and synergistic interaction with other essential nutrients (Arjun *et al.*, 2018). The current N:P:K use ratio in India is 7.7:3.1:1 which is growing wider from the ideal ratio of 4:2:1. The all India consumption of potassic fertilizer was at 2.53 million tonnes during 2021-22. Cropping systems like rice-wheat, maize-wheat, potato-wheat and sugarcane demands immediate attention to correct the imbalances in nutrient consumption. It is a great threat to Indian agriculture that large K mining is happening and K reserves are depleting.

Potassium is derived from English word "Pot-ash" which means "ash prepared in pots" Refers to the practices of using the leachate of wood ash (5-25 %) as a source of potassium. In 1807, metallic potassium was first isolated by Sir Humphry Davy (British scientist) by the method of electrolysis of molten caustic potash (KOH). It was the first metal isolated by electrolysis. It is the 7th most abundant metal on earth crust. Potassium is denoted as "K" which means Kalium word given by German chemist Martine Heinrich. Potassium is highly mobile in plant and less mobile in soil so potassium deficiency symptoms appears at lower part of the plants. The potassium ion (K^+) is actively taken up soil solution by plant roots. The concentration of K^+ in vegetative tissue ranges from (1-4 %) on dry matter basis. Potassium is involved in many metabolic pathways that affect crop quality; it is often called as quality element (Basha *et al.*, 2019).

Role of potassium in plants

- Increases root growth and improves drought resistance.
- Maintains turgor; reduces water loss and wilting.
- Aids in photosynthesis and food formation.
- Reduces respiration, preventing energy losses.
- Enhances translocation of sugars and starch.
- Produces grain rich in starch.
- Increases plants protein content.
- Builds cellulose and reduces lodging.
- Helps retard crop diseases.
- Potassium activations of more than 60 enzymes in plant sys
- Preventing the lodging in cereals
- Maintain the water balance in plant system

Table 1: Impact of potassium application on quality attributes of various crops

Crop	Crop quality attributes with K application
Rice	Increased protein content
Potato	Early vegetative growth and bulkiness of tuber
Sugarcane	Increases cane girth, height and number of millable canes
Cotton	Increases fiber fineness, strength
Maize	Increases chlorophyll (Chl a + Chl b) content
Pearl millet	Increases carotenoids
Mustard	Increases oil content
Banana	Increases sugars and fruit size
Turmeric	Increases curcumin content

Forms of potassium

There are mainly four forms of potassium

1. Water soluble form
2. Exchangeable form
3. Non-exchangeable form
4. Mineral or Lattice form

1. Water soluble potassium

- Potassium present in soil solution under normal field moisture condition and relatively unbound by cation exchange forces is termed as "water soluble potassium".
- Water-soluble K (WS-K) in soils vary from 1 to 10 ppm.
- WS-K in mineral soil is about 1 per cent of exchangeable K.
- Water soluble K constituted 0.1 to 0.2 per cent of total K in surface soils indicating almost negligible contribution to the total potassium of soils (Divya *et al.*, 2016).
- It is the form most subjected to leaching in soils.

2. Exchangeable potassium

- Potassium adsorbed on the soil colloidal surface and which is replaceable within a short period by other cations is termed as "exchangeable potassium".
- Exchangeable K is electrostatically bound as an outer sphere complex to the surface of clay minerals and humic substances.
- Exchangeable K in soils vary from 40 to 600 ppm.
- It is constituting about nearly >90 per cent of the available K present in exchangeable form and it contributes 1 per cent of total K.

3. Non-exchangeable potassium

- The soil potassium excluding water soluble and exchangeable forms represent non-exchangeable potassium. It is held between adjacent tetrahedral layers of clay minerals.
- It is slowly available form of K.
- Potassium becomes fixed because the binding forces between K and the clay surfaces are greater than the hydration forces between individual K ions (Kumar *et al.*, 2017).
- Non-exchangeable K in soils vary from 50 to 750 ppm.
- Inherent K status of a soil depends upon the rate and amount of non-exchangeable K.

4. Mineral or lattice potassium

- Major portion of soil K exists as part of mineral structure and in a fixed form.
- Structural K is regarded as covalently bonded within the crystal structure of various K bearing minerals like feldspars and micas.
- It accounts more than >90 per cent of the total K in the soils.
- Mineral K in soil vary from 5000 to 25000 ppm.
- The amount of K in minerals depends on the type of parent materials and the age of soil.
- The mineral K was found to be less in surface soils than the sub-surface soils.

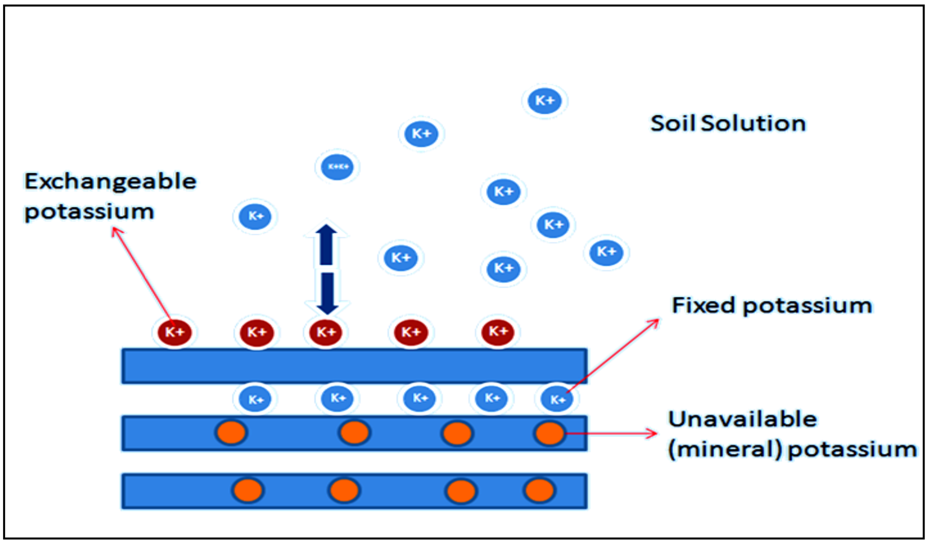


Fig. 1: Location of different forms of potassium

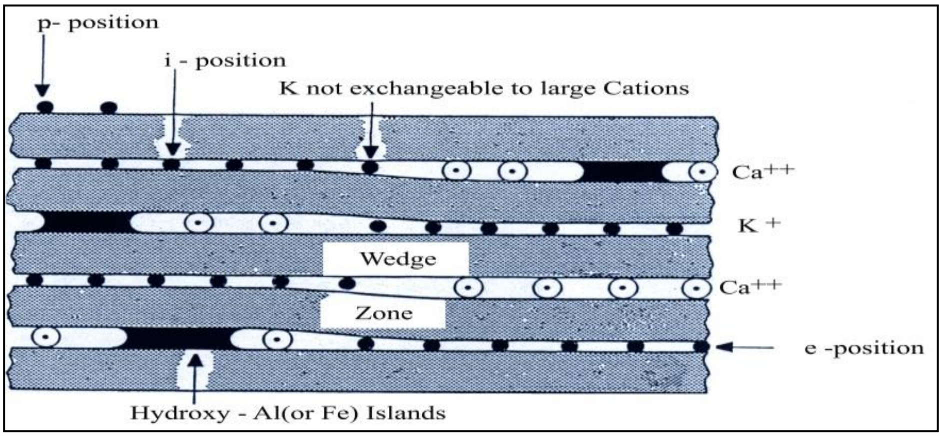


Fig. 2: Potassium fixation

Factors affecting potassium fixation in soil

1. Charge density
2. Extent of the interlayer wedge zone
3. Nature and concentration of competing cations in the surrounding medium
4. Solution K concentration
5. Moisture content

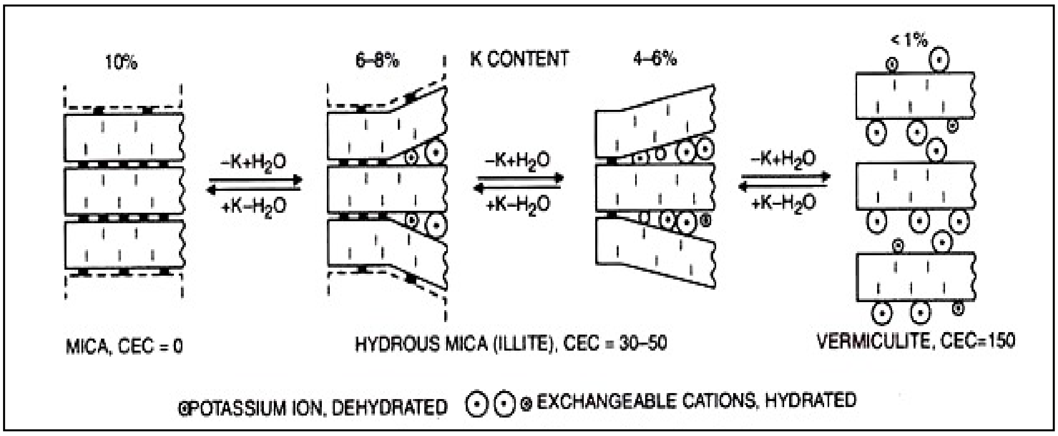


Fig. 3: Potassium release

- ✓ Phenomena of both the fixation of exchangeable and release of non-exchangeable K play an important role in the dynamics of soil potassium.
- ✓ The gradual release of K from trapped positions in the mica lattice to form illite and eventually vermiculite with gain of water and swelling of K lattice.
- ✓ The 2:1 type of clay minerals are capable of both fixing and releasing K.

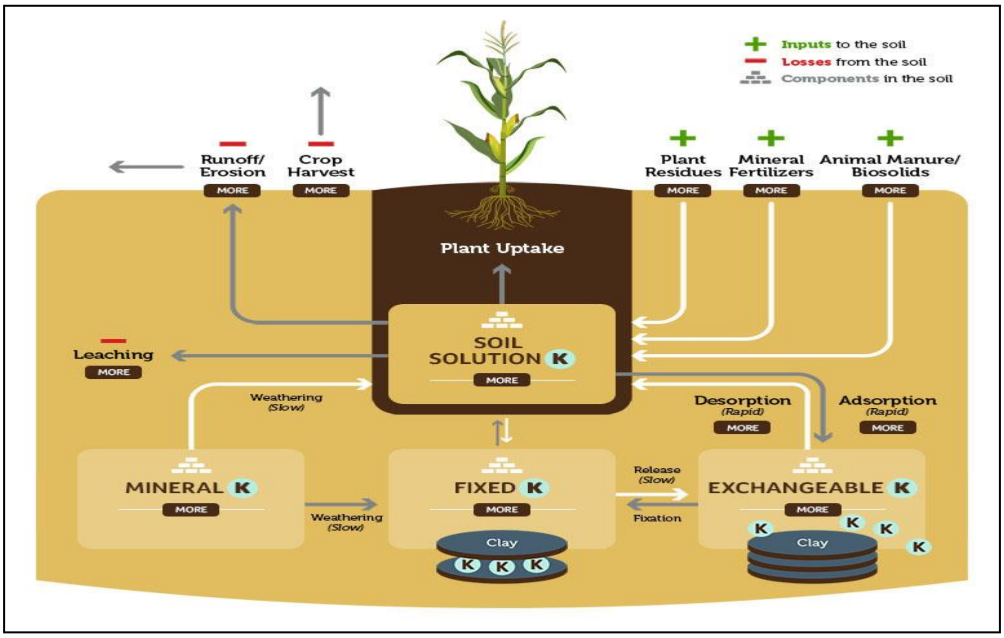


Fig. 4: Potassium cycle

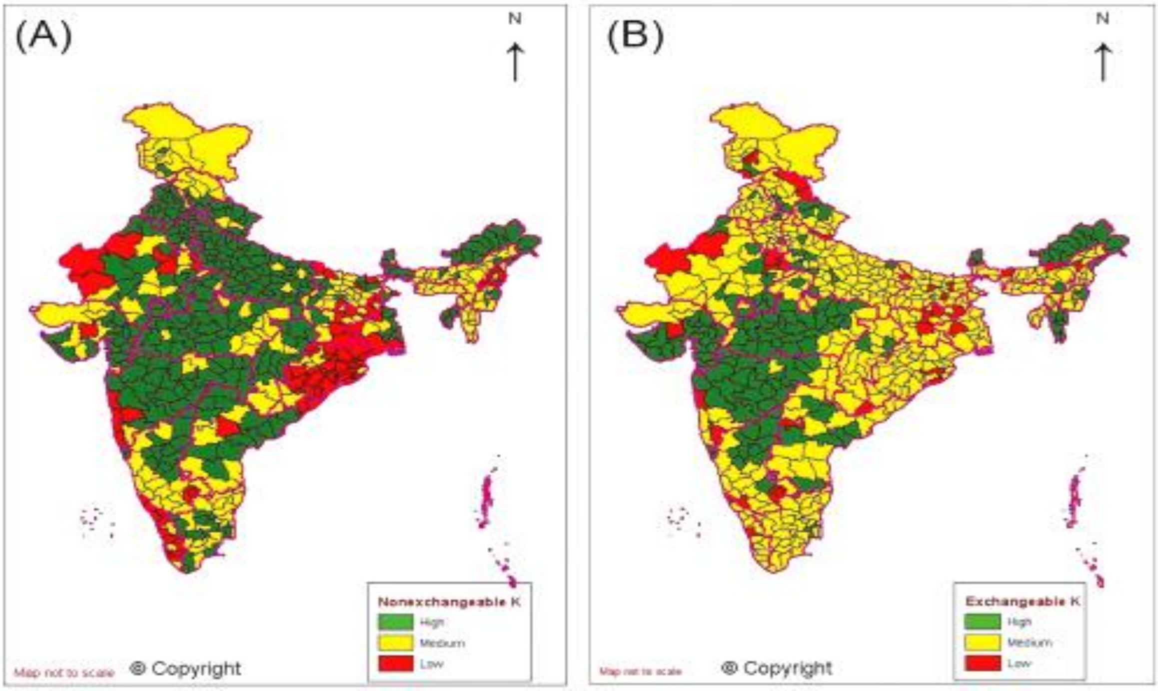
Potassium in soil can be thought of as existing in four pools according to the availability of the K for uptake by plant roots. It is present dissolved in the soil water, adsorbed onto particles of clay and organic matter and held within the crystal structure of clay particles.

Potassium bearing minerals

➢ Muscovite	➢ Sylvite
➢ Langbeinite	➢ Carnallite
➢ Niter	➢ Orthoclase
➢ Biotite	➢ Feldspar

In India districts were classified into three categories: low, medium and high for both exchangeable K and non-exchangeable K. Exchangeable K was categorized as low (<50 mg kg^{-1}), medium (50-120 mg kg^{-1}) and high (>120 mg kg^{-1}) and for non-exchangeable K, the categories used were low (<300 mg kg^{-1}), medium (300-600 mg kg^{-1}) and high (>600 mg kg^{-1}). Exchangeable soil K (available K) superimposed on non-exchangeable soil K in a district-level map of India; priority districts of India and agriculture ecosystems were identified to utilize imported K fertilizer more efficiently. GIS-based maps of exchangeable K, non-exchangeable K (Fig. A and B), and an overlay of exchangeable K and non-exchangeable K were developed for spatial identification of different categories.

The average contents of various forms of potassium in red, black, laterite and alluvial soils of Karnataka were worked out and correlation coefficients were calculated. The variation in the distribution of potassium depends upon the mineral present, particle size and degree of weathering. Correlations between potassium fixation capacity of the soils and various soil parameters were worked out.



CRIDA, Hyderabad **Srinivasarao *et al*. (2022)**

Fig. 5: Non-exchangeable and Exchangeable K status of Indian Soil

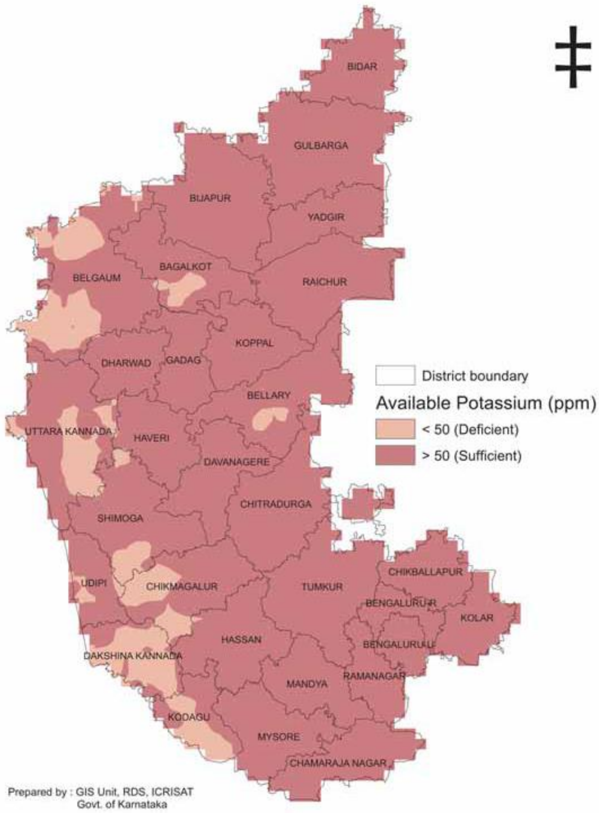


Fig. 6: Available potassium status of Karnataka soils

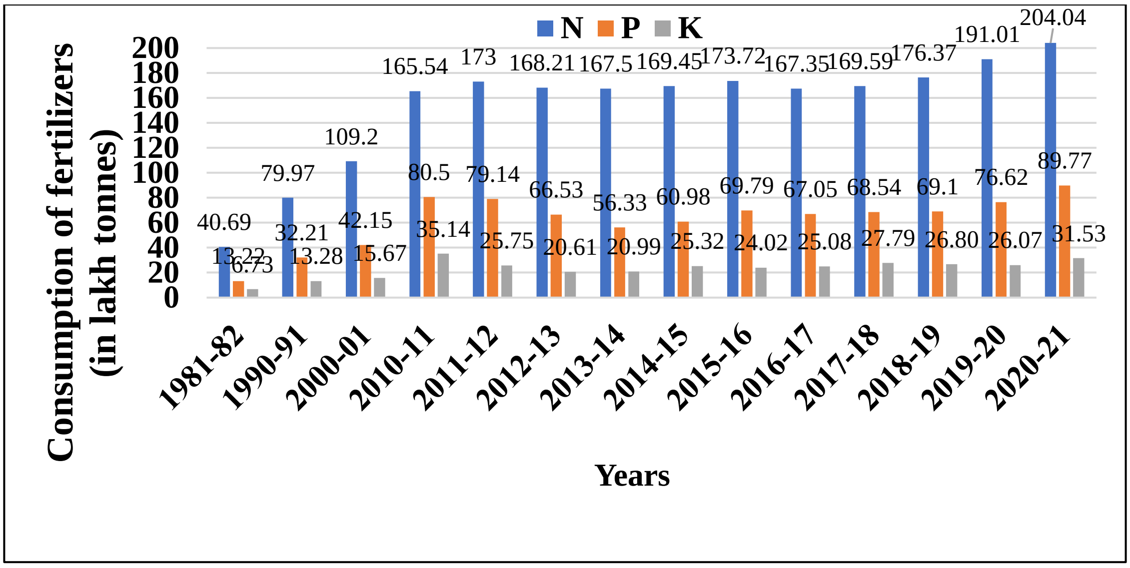


Fig. 7: Consumption of fertilizers in India

From 1981 to 2021 nitrogenous fertilizer consumption rate increases but potassium consumption rate is more or less static. It might be due to low cost of nitrogenous fertilizer than the potassic fertilizer and also misconception by the farmers was that nitrogen will increase the yield but reality is it will provide luxurious growth to the plants and Inadequate application of K in crops and cropping systems leads to yield losses. Negative K balance (input-output) in many regions is pointing toward large scale mining of native K. Depletion of soil K adversely affects future food security in India. Thus, it is highly essential to increase K fertilizer input in India to bridge the yield gaps.

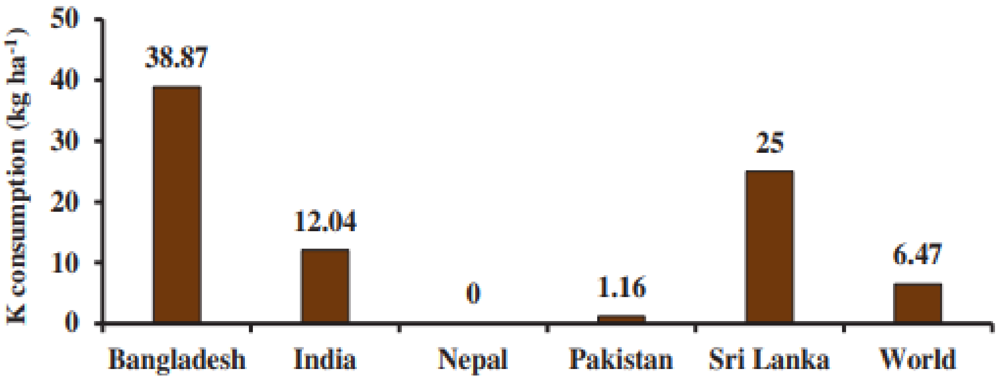


Fig. 8: Potassium fertilizer consumption in agriculture in South Asian countries

The importance of K fertilization is underestimated due to lack of awareness among farmers. Generally, farmers overlook the benefits of K application because its effectiveness is visible only after the maturity stage, largely in the form of product quality. But in comparison, the effectiveness of N and P fertilization is visible immediately after their application. The cost and availability of fertilizers also play a key role in purchasing fertilizers. Total K fertilizer consumption in kg per ha of agricultural land in South Asian countries in descending order are 38.87, 25, 1.16, while the world average is 6.47 and 12.04 in Bangladesh, Sri Lanka, Pakistan and India respectively.

Table 2: Potassium balance sheet in different states

State	**Nutrients (‘000 t) Addition (A)**	**Removal (‘000 t) (R)**	**Balance (‘000 t)**	**Mining index (R/A)**
Alluvial Soils				
Punjab	18.7	763.5	- 744.8	40.7
UP	113.6	1777.2	-1663.6	15.6
Haryana	4.6	490.1	-485.5	105.7
Black soils				
Maharashtra	196.9	2095.9	-1899.1	10.6
MP	24.1	848.8	-824.7	35.2
Red soils				
Karnataka	216.1	603.6	-387.5	2.8
Lateritic Soils				
Kerala	87.3	175.6	-88.3	2.0
Desertic Soils				
Rajasthan	7.0	1068.0	-1061.1	152.7
All India	**1454.2**	**11656.5**	**-10202.3**	**8.0**

NBSS&LUP, Bangalore **Ramamurthy *et al*. (2017)**

The nutrient addition, removal, balance and nutrient mining index for India and for different states covering alluvial, black, red, lateritic and desertic soil regions indicated that K removal by crops far exceeded than the K addition through fertilizers. At national level, the K depletion was about 10.2 m t year^{-1} and mining index for K was 8.0. In all the soil regions, K balance was negative. The K mining index was highest in Rajasthan (152.7) followed by Haryana (105.7) Punjab (40.7), Madhya Pradesh (35.2) and least in Kerala (2.01) and Karnataka (2.79) which indicated K depletion in all soil types.

Removal of K in proportion to N is rather high in cropping systems, particularly in those involving cereal and fodder crops due to its high mobility. Crops take up far more K than they remove with the harvested produce. An adequate replenishment of soil K reserves is required by external application of K to sustain crop productivity. Split application K reduces the leaching losses in coarse-textured and high rainfall associated soils, as it provides an adequate amount of K to crop and replenishes soil K reserves. K removal by important crops and cropping systems in SA countries

Table 3: Potassium removal by important cropping systems of India

Cropping system	K Removal (kg ha^{-1})
Rice-Wheat	280
Rice-Wheat-Green gram	256
Maize-Wheat	206
Maize-Wheat-Green gram	232
Maize-Indian Rapeseed-Wheat	200
Soybean-Wheat	170
Pigeonpea-Wheat	168
Pearl millet-Wheat-Green gram	284

Table 4: Categorization of Indian soils based on both exchangeable and non- exchangeable K and suggested management for each category

Category	Exchangeable K (mg kg^{-1})	Non-exchangeable K (mg kg^{-1})	Number of districts	Suggested K management
I	Low	Low	15	K in fertilization is a must
II	Low	Medium	18	K fertilization is essential
III	Low	High	2	K additions at critical stages of crops improve yield levels
IV	Medium	Low	58	Continuous cropping needs K addition at critical stages as non-exchangeable K fraction does not contribute to plant K nutrition substantially
V	Medium	Medium	115	Maintenance doses of K may be required for intensive cropping systems
VI	Medium	High	172	Crops may not need immediate K additions
VII	High	Low	1	Long-term cropping would need K additions after few years
VIII	High	Medium	24	K application is not required immediately
IX	High	High	129	K application is not required

CRIDA, Hyderabad **Srinivasarao *et al*. (2022)**

Based on the status of exchangeable K and non-exchangeable K (low, medium and high), districts were grouped into nine categories. District-wise classification allows for prioritization of districts for K fertiliser application so as to maximize yields and K use efficiency, thereby enabling the most profitable use of imported K fertiliser.

- Under this grouping, there were 15 districts where both exchangeable and nonexchangeable K is low (Category I). Soils in this category represent mostly red, lateritic soils, light textured and shallow soils. Since both the K fractions are low, regular application of K fertiliser is absolutely essential. The amount of K-fertiliser to be applied should be based on recommendations specific to crops, varieties, climate and management practices.
- Eighteen districts are categorized under Category II where exchangeable K is low and nonexchangeable K is medium. These soils also represent light textured and acidic alluvial soils. These soils also require regular additions of adequate amounts of K-fertiliser.
- In the two districts under Category III, where exchangeable K is low and non-exchangeable K is high, soil K supply may not match crop requirements, especially during stages of rapid K uptake, and therefore K addition at critical crop stages is required to obtain good yields.
- Category IV covers 58 districts where exchangeable K is medium and non-exchangeable K is low. These districts represent light textured alluvial, red and lateritic, acid sulphate and sandy soils. These soils need considerable attention from K management point of view. Continuous cropping on these soils can result in depletion of soil reserve K, especially if K-intensive cropping systems like rice-wheat, sunflower, potato and other tuber crops, banana, high yielding fodders and vegetables are grown. Regular additions of K at critical stages are essential in these districts.
- Category V covers 115 districts of India, where both exchangeable and non-exchangeable K fractions are medium. These regions represent various types of soils from acid to alkaline, red, medium to deep black and alluvial. As both the fractions are medium, K additions are required for high value (tobacco) and K exhaustive (sugarcane, potato, etc.) crops.
- A maximum of 172 districts falls under Category VI, where exchangeable K is medium and non-exchangeable K is high. These districts represent a variety of soils including heavy textured red soils, medium to deep black soils, heavy textured alluvial soils, and high organic carbon Mollisols. Crops may not need immediate application of K unless specific K loving crops like banana and potato are grown.
- Only one district (Jaipur) falls under Category VII, where exchangeable K is high and nonexchangeable K is low. This district represents medium deep alluvial soils with less K bearing minerals. Long-term intensive cropping would need some maintenance application of K.
- Category VIII with high exchangeable K and medium non-exchangeable K covers 24 districts. These districts represent medium to deep black soils, fine textured alluvial and red soils with K rich minerals. Potassium application is not required immediately in these soils.

- Category IX represents 129 districts where both exchangeable and nonexchangeable K are high. These soils represent deep black and fine textured alluvial soils and show higher long-term K supplying power and do not require K application

Sources of potassium

- Potassium chloride (muriate of potash) KCl: 60 % K_2O, 40-45 % Cl
- Potassium sulphate (Sulphate of potash) K_2SO_4: 50 % K_2O, 45 % SO_4
- Potassium nitrate (Nitrate of potash) KNO_3: 46 % K_2O, 13 % N
- Sylvinite (crude potassium salts): 21 % K_2O, 26 % Na_2O
- Kainite (crude potassium salts): 11 % K_2O, 27 % Na_2O
- Potassium schoenite K_2SO_4 $2MgSO_4$: 22-23 % K_2O, 10-11 % MgO, 21-22 % SO_3

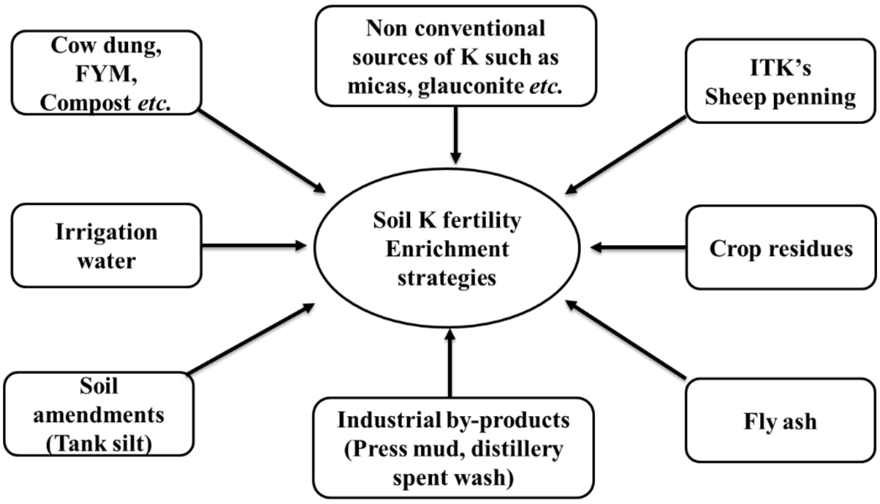


Fig. 9: Soil K fertility management through various strategies

Apart from fertilizer and soil potassium (both exchangeable and reserve); there are a various potassium rich sources that can be effectively utilized to enrich potassium in soil. Crop residues of cereals accumulate approx. 70-75% of the absorbed potassium by leaves, straw and stover (Sarma *et al.*, 2015). In Indo-Gangetic plain, Rice-wheat cropping system is most prevalent, therefore, a huge crop residue biomass generated and most of farmers prefer burning of crop residues in the field to get early vacant field for succeeding crop. For overcome this problem, conservation agriculture become a better strategy and core principle of conservation agriculture to retain crop residues within field after harvesting of economic yield. As, the crop residues are rich in potassium, this may add potassium to soil apart from improving soil physically, chemically and biologically. The incorporation of potassium exhaustive crop like sugarcane, rice, wheat, maize, pulses etc. in the soil to preventing potassium loss and improved the potassium status. In dryland region, soil sedimented in tank is better amendments approach to improve the water holding capacity of dryland soil as well as also supply certain amount of nutrients (Sharma *et al.*, 2018).

The industrial by-products like fly ash, press mud and distillery spent wash that can be better used in agriculture to enhance the potassium status. Fly ash, press mud and distillery spent wash contain significant amount of potassium and act as excellent source of potassium for crop production *i.e.*, 0.15-3.5%, 0.30-1.80% and 222 mg per litre respectively.

Conclusion:

The present nutrient use trend in India is not balanced and has led to widespread deficiency of various mineral nutrients in soil. All fractions of K in soil should be taken into consideration while planning for nutrient management strategies. Careful understanding of different forms of K in the soil has great relevance in assessing the long-term K supplying power of soil to crops and is important in formulating a sound fertilizer program for a given set of soil and crop. A future study on clay mineralogical make-up of the soils may help calibrating the reserve pool of K and the extent of its mining. The soil potassium can be managed through application of crop residues, soil amendments, foliar spray, fertigation and split application of potassic fertilizer. This may help the planners to formulate an effective K fertilizer program for the soils of the region.

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BIOCHAR: A VERSATILE CARBON SOLUTION FOR SUSTAINABILITY AND ENVIRONMENTAL ENHANCEMENT

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Abstract:

This book chapter provides a comprehensive exploration of biochar, a carbon-rich material produced through the pyrolysis of organic biomass. It covers various aspects of biochar, including its production methods, environmental benefits, agronomic and horticultural applications, environmental remediation potential, integration into livestock farming and its role in energy and biomass systems. Biochar demonstrates immense potential in addressing environmental challenges and promoting sustainability. It offers significant carbon sequestration benefits, mitigating climate change by capturing and storing carbon in a stable form. The addition of biochar to soils enhances soil fertility, nutrient retention and water management, leading to improved crop productivity and reduced environmental impacts. Furthermore, biochar can remediate contaminated soils by immobilizing or reducing the bioavailability of pollutants, making it a valuable tool for environmental remediation efforts. In the realm of livestock farming, biochar aids in waste management, odour reduction and nutrient retention. Its integration into animal systems supports animal health and welfare while mitigating greenhouse gas emissions. Moreover, biochar plays a role in energy and biomass systems as a co-product of bioenergy generation and a renewable energy source. It contributes to carbon sequestration and offers opportunities for sustainable resource utilization. Despite its potential, there are challenges to address and future directions to explore. These include technology development, feedstock sustainability, standardization and certification, risk assessment, knowledge dissemination, integration with sustainable agricultural systems and continuous research and innovation. By addressing these challenges and pursuing future directions, biochar can be further optimized and harnessed to its full potential. Its adoption and utilization across various sectors can significantly contribute to a more sustainable and resilient future. Biochar offers a pathway towards mitigating environmental challenges, improving soil health, promoting sustainable agriculture, remediating contaminated sites and supporting renewable energy generation.

Introduction:

Biochar, a term derived from the fusion of "bio" and "charcoal," represents a promising and innovative approach to address some of the pressing challenges faced by our society today.

With its roots dating back centuries to ancient civilizations, biochar has gained significant attention in recent years as a sustainable solution for various environmental and agricultural issues. This chapter aims to explore the multifaceted aspects of biochar, ranging from its production methods and properties to its wide-ranging applications and potential implications.

At its core, biochar is a carbon-rich material produced through the process of pyrolysis, which involves the thermal decomposition of organic biomass in the absence of oxygen (Dar *et al.,* 2019). This transformational process converts organic feedstocks such as agricultural waste, forestry residues and animal manure into a stable form of charcoal-like substance. The resulting biochar exhibits unique physical and chemical properties that set it apart from other organic materials.

Biochar holds immense promise as a powerful tool in the realm of environmental sustainability. One of its primary benefits lies in its capacity to sequester carbon dioxide from the atmosphere, thereby mitigating climate change. By locking away carbon in a stable form for potentially hundreds or thousands of years, biochar contributes to reducing greenhouse gas emissions (Das *et al.,* 2021). Furthermore, the incorporation of biochar into soils offers numerous advantages including improved soil fertility, enhanced water retention and increased nutrient cycling. These characteristics make biochar a valuable asset in efforts to combat food insecurity, promote sustainable agriculture and restore degraded lands.

Beyond its agricultural applications, biochar has also demonstrated its potential for environmental remediation. Its ability to immobilize heavy metals and organic pollutants in contaminated soils and sediments makes it a promising tool for soil remediation projects and the restoration of polluted sites (Murtaza *et al.,* 2023). Additionally, biochar's utilization in wastewater treatment systems has shown promise in improving water quality and reducing the presence of contaminants (Enaime *et al.,* 2020).

The use of biochar extends beyond the agricultural and environmental realms. Its integration into livestock farming practices presents an opportunity to manage animal waste more effectively, reducing odours and emissions while simultaneously improving nutrient management. Furthermore, biochar can be co-produced alongside bioenergy generation, offering an additional renewable energy source and potential revenue stream.

While biochar exhibits great promise, it is crucial to consider the challenges and potential risks associated with its widespread adoption. Technological barriers, economic viability and potential environmental impacts must be thoroughly evaluated to ensure the responsible and sustainable deployment of biochar in various applications.

In this chapter, we will delve deeper into the world of biochar, exploring its production methods, environmental benefits, agronomic and horticultural applications, environmental remediation potential, implications for livestock farming, integration into energy and biomass systems and the challenges and future directions for this innovative field. By comprehensively examining the diverse aspects of biochar, we hope to shed light on its transformative potential and inspire further exploration and utilization of this remarkable substance.

Biochar production

Biochar production involves the conversion of organic biomass into a stable carbon-rich material through the process of pyrolysis. Pyrolysis is a thermochemical decomposition process that occurs in the absence of oxygen, preventing the complete combustion of biomass and resulting in the formation of biochar (Yaashikaa *et al.,* 2020).

Types of feedstock: Various types of feedstock can be used for biochar production, including agricultural waste, forestry residues, wood chips, crop residues and animal manure (Gabhane *et al.,* 2020). The choice of feedstock can impact the characteristics of the resulting biochar, such as its elemental composition, porosity and nutrient content.

Pyrolysis process: Pyrolysis involves heating the biomass at high temperatures (typically between 350°C and 700°C) in an oxygen-limited environment (Kan *et al.,* 2016). The absence of oxygen prevents complete combustion and leads to the formation of biochar. The pyrolysis process can be divided into three main stages:

1. Drying and Degassing: Initially, the biomass undergoes drying during which moisture is removed. As the temperature increases, volatile components such as water, methane, carbon dioxide and other volatile organic compounds are released as gases.
2. Pyrolysis: At higher temperatures, thermal decomposition of the biomass occurs, resulting in the formation of biochar. The composition and properties of the biochar are influenced by the temperature, heating rate and residence time during this stage. Higher temperatures generally yield biochar with greater carbon content and improved stability.
3. Cooling and Collection: After the pyrolysis process, the biochar is cooled and collected to prevent further chemical reactions. The biochar is then typically crushed or ground to achieve the desired particle size for specific applications.

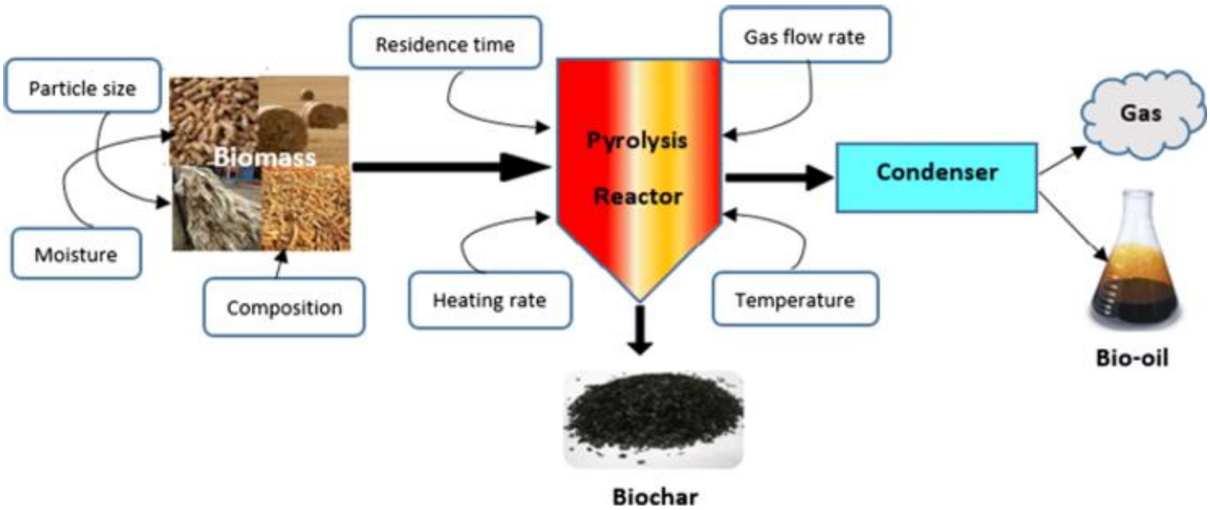

Fig. 1: Biochar Process (Sakhiya *et al.,* 2020)

Production techniques: Several production techniques are employed to generate biochar, including:

1. Slow Pyrolysis: This method involves heating the biomass at a relatively slow rate (typically less than 100°C per minute). Slow pyrolysis promotes the production of higher

biochar yield. It is often used in small-scale operations or in traditional kilns (Qambrani *et al.*, 2017).

2. Fast Pyrolysis: In fast pyrolysis, the biomass is rapidly heated at high temperatures (up to 1,000°C) within seconds. This process produces a higher yield of liquid byproducts, known as bio-oil, along with biochar and combustible gases.
3. Torrefaction: Torrefaction is a mild pyrolysis process carried out at temperatures between 200°C and 300°C. It primarily aims to improve the fuel properties of biomass, producing a solid product called torrefied biomass. While torrefied biomass shares similarities with biochar, it is distinct in terms of its intended use as a renewable energy source.

Factors influencing biochar production: Several factors influence the production of biochar, including:

1. **Feedstocks:** Biomass is a complex solid material derived from living organisms, divided into woody and non-woody biomass. Woody biomass has attributes like low dampness, debris and voidage, while non-woody biomass has high debris, dampness and voidage. Moisture content significantly impacts biomass formation, with higher moisture content inhibiting char formation and increasing energy needed for pyrolysis. Low moisture content is preferable for biochar formation due to reduced heat energy and reduced time needed for pyrolysis.
2. **Carbonization temperature:** Pyrolysis is a popular method for exchanging biomasses for biochar with three classifications: slow, moderate and quick. Pyrolysis temperature affects physicochemical properties and structure of biochar including elemental components, pore structure, surface area and functional groups.
3. **Residence time:** Extended residence time at low pyrolysis temperature (300 ℃) led to a decrease in biochar yield, pH and iodine adsorption, where in high temperature (600 ℃) had minimal impact.
4. **Pre-treatment of biomass:** Pre-treating biomass before pyrolysis affects biochar characteristics, with methods like immersing raw materials in solutions and reducing particle size resulting in higher yields. Pre-treatments like nitrogen and metal doping, solution pre-treatments like soaking or steaming and baking can affect the elemental composition and properties of biochar.

Environmental benefits of biochar

Biochar offers a range of environmental benefits that make it a valuable tool for addressing pressing global challenges. From mitigating climate change to improving soil fertility and water quality, biochar demonstrates significant potential for fostering environmental sustainability. Some of the key environmental benefits of biochar are given below:

1. **Carbon sequestration and climate change mitigation:** Biochar plays a crucial role in carbon sequestration by capturing and storing carbon in a stable form. During the pyrolysis process, carbon dioxide (CO_2) is released as a byproduct, while biochar retains a significant portion of the carbon from the original biomass. This carbon remains locked

away in the biochar, with the potential to remain sequestered for extended periods, thus reducing CO_2 emissions into the atmosphere. By incorporating biochar into soils, carbon is effectively stored in a long-term reservoir, mitigating climate change by reducing greenhouse gas concentrations.

2. **Soil fertility enhancement:** The addition of biochar to soils can improve soil fertility and overall soil health. Biochar acts as a soil amendment, enhancing nutrient availability and retention. Its porous structure and high surface area provide a habitat for beneficial soil microorganisms, promoting microbial activity and nutrient cycling (Deem & Crow, 2017). Biochar also improves soil structure, enhancing water infiltration, reducing erosion and increasing soil moisture retention. These soil fertility benefits contribute to increased agricultural productivity, reducing the need for synthetic fertilizers and their associated environmental impacts.
3. **Reduction of greenhouse gas emissions from soils:** Biochar application to soils has the potential to reduce greenhouse gas emissions, particularly nitrous oxide (N_2O) and methane (CH_4). Nitrous oxide is a potent greenhouse gas emitted from agricultural soils, primarily as a result of microbial processes involved in nitrogen cycling. Studies have shown that biochar amendments can reduce N_2O emissions by altering soil conditions and microbial activity (Harter *et al.,* 2014). Similarly, biochar amendments can reduce CH_4 emissions by creating a more oxygenated soil environment, which inhibits methanogenic bacteria (Nan *et al.,* 2022).
4. **Water quality improvement:** Biochar has shown promise in improving water quality and reducing water pollution. When applied to agricultural fields, biochar can reduce the leaching of nutrients, such as nitrogen and phosphorus into water bodies. This reduction in nutrient runoff helps to prevent eutrophication, a process that leads to the depletion of oxygen in aquatic ecosystems. Additionally, the porous structure of biochar acts as a filtration medium, trapping and immobilizing pollutants, such as heavy metals and organic contaminants, in soils and sediments, thereby preventing their migration into water sources.
5. **Restoration of degraded lands:** Biochar application can contribute to the restoration and reclamation of degraded lands. By improving soil fertility, water retention and microbial activity, biochar aids in rehabilitating soils affected by erosion, mining, or other forms of degradation. Biochar amendments promote the establishment of vegetation, enhance nutrient cycling and increase the overall resilience of degraded ecosystems.
6. **Enhanced waste management:** Biochar can be produced from a variety of organic waste streams, such as agricultural residues, forestry byproducts and animal manure. By converting these waste materials into biochar, it offers a sustainable waste management solution, reducing the release of greenhouse gases that would occur through conventional waste disposal methods such as open burning or landfilling.

Agronomic and horticultural applications of biochar

Biochar has gained considerable attention for its applications in agriculture and horticulture. Its unique properties make it a valuable tool for improving soil health, enhancing crop productivity and promoting sustainable farming practices.

Soil amendment and nutrient retention: One of the primary applications of biochar is as a soil amendment. When incorporated into soils, biochar enhances soil fertility by improving nutrient retention and availability. Its porous structure and high surface area act as a reservoir for essential nutrients, such as nitrogen, phosphorus and potassium, preventing nutrient leaching and making them more accessible to plants. Biochar also promotes the growth of beneficial soil microorganisms, which aid in nutrient cycling and contribute to plant health.

Soil structure improvement and water management: Biochar has the ability to improve soil structure, particularly in compacted or degraded soils. Its addition helps to increase soil porosity, promoting better water infiltration and reducing the risk of soil erosion. Biochar's high surface area and porous nature enhance water-holding capacity, allowing soils to retain moisture for longer periods. This can be particularly beneficial in arid or drought-prone regions, as it reduces water requirements and enhances crop resilience to water stress.

pH adjustment and soil stabilization: Biochar can be used to adjust soil pH, making it a versatile tool for addressing acidic or alkaline soil conditions. Acidic biochar can be applied to lower the soil pH (Shetty & Prakash, 2020), while alkaline biochar can help raise pH levels (Geng *et al.,* 2022). This pH adjustment can benefit specific crops that thrive in particular pH ranges. Furthermore, biochar can stabilize soils by improving their cation exchange capacity (CEC) and reducing nutrient leaching, ensuring better nutrient availability for plants.

Crop yield and productivity enhancement: Numerous studies have shown that biochar amendments can enhance crop yield and productivity. The improved soil fertility, nutrient retention and water management provided by biochar contribute to healthier plants with increased biomass and higher yields (Ding *et al.,* 2016). Biochar's ability to promote beneficial microbial activity in the soil also aids in nutrient cycling and plant nutrient uptake, further boosting crop productivity.

Disease and pest management: Biochar can play a role in disease and pest management in agriculture and horticulture. It has been shown to suppress certain soil-borne pathogens, such as fungi and nematodes, reducing disease incidence and severity (Iacomino *et al.,* 2022). Additionally, biochar amendments can enhance the activity and abundance of beneficial soil microorganisms, which contribute to natural pest control mechanisms. These effects can lead to reduced reliance on chemical pesticides and contribute to more sustainable pest management practices.

Horticultural and urban greening applications: Biochar finds applications in horticulture and urban greening initiatives. It can be incorporated into potting mixes or growing media for container plants, providing improved water retention, nutrient availability and root aeration. Biochar-amended substrates enhance plant growth and development, making it an attractive option for greenhouse production and urban gardening projects. Biochar can also be used in green roof systems and urban soil remediation efforts, contributing to sustainable urban greening and biodiversity conservation.

Environmental remediation with biochar

Biochar has emerged as a promising tool for environmental remediation, offering effective and sustainable solutions for addressing various forms of pollution and contamination. Its unique properties make it well-suited for mitigating environmental challenges and promoting ecosystem restoration.

Soil remediation: Biochar can remediate contaminated soils by immobilizing or reducing the bioavailability of pollutants. Its high surface area and porous structure provide binding sites for heavy metals, organic pollutants and other contaminants, preventing their migration into groundwater or uptake by plants (Guo *et al.,* 2020). Biochar amendments can significantly reduce the mobility and toxicity of contaminants, promoting soil health and minimizing the risks associated with contaminated land.

Water treatment: Biochar has the ability to adsorb a wide range of pollutants in water systems, including heavy metals, organic compounds and nutrients. When used as a filtration medium, biochar traps and removes these contaminants from water, improving its quality (Jagadeesh & Sundaram 2022). Its adsorption capacity can be further enhanced by modifying biochar properties or coupling it with other treatment techniques. Biochar-based filtration systems offer a cost-effective and sustainable approach to water treatment, particularly for small-scale or decentralized applications.

Phytoremediation support: Phytoremediation, the use of plants to remediate contaminated sites, can be enhanced by incorporating biochar into the soil (Bousdra *et al.,* 2023). Biochar amendments improve soil fertility, water retention and nutrient availability, creating favourable conditions for plant growth and root development. Biochar also helps to sequester contaminants in the rhizosphere, minimizing their uptake by plants and reducing the potential for contaminant transfer to the food chain. By supporting phytoremediation processes, biochar contributes to the successful restoration of polluted ecosystems.

Carbon sequestration and climate change mitigation: Biochar's carbon sequestration potential has implications for mitigating climate change and reducing greenhouse gas emissions. When applied to contaminated or degraded land, biochar not only aids in remediation efforts but also sequesters carbon in a stable form and it effectively acting as a long-term carbon sink. By combining environmental remediation with carbon sequestration, biochar offers the dual benefit of addressing pollution while contributing to climate change mitigation.

Mitigation of air pollution: Biochar can play a role in mitigating air pollution by capturing and adsorbing pollutants from the atmosphere. It has shown effectiveness in reducing the levels of volatile organic compounds (VOCs), odours and certain gases, such as ammonia and hydrogen sulphide (Maurer *et al.,* 2017). Biochar-based filters or barriers can be used in industrial settings, livestock facilities, or urban areas to improve air quality and minimize the impact of air pollution on human health and the environment (Gwenzi *et al.,* 2021).

Ecological restoration and land reclamation: The use of biochar in ecological restoration and land reclamation projects helps to rehabilitate degraded or disturbed ecosystems. By improving soil fertility, water retention and nutrient cycling, biochar enhances the establishment and growth of vegetation in such areas. This aids in stabilizing soil, reducing erosion and promoting biodiversity and finally contributing to the overall recovery and resilience of the ecosystem.

Biochar and livestock farming

Biochar presents opportunities for improving various aspects of livestock farming, ranging from waste management to animal health and environmental sustainability. Its unique properties and applications offer potential benefits for both animal welfare and farm operations.

Manure management and odour reduction: One significant application of biochar in livestock farming is in the management of animal waste, such as manure. Adding biochar to manure storage facilities or directly to bedding materials helps to absorb moisture and reduce odour emissions. Biochar's porous structure acts as a filter, trapping and retaining odorous compounds such as ammonia and sulphur compounds. By mitigating odour issues, biochar contributes to creating a more pleasant and healthier environment for both animals and farm workers.

Reduction of greenhouse gas emissions: Livestock farming contributes to greenhouse gas emissions, particularly in the form of methane (CH_4) from enteric fermentation and manure management. The addition of biochar to livestock waste management systems can help in mitigating these emissions. Biochar's presence in manure alters the microenvironment, reducing the production and release of methane by methanogenic bacteria. By minimizing methane emissions, biochar contributes to the overall reduction of greenhouse gas footprints associated with livestock farming operations.

Animal health and welfare: Biochar shows potential for improving animal health and welfare on livestock farms. The addition of biochar to animal feed has been found to have positive effects on digestion, nutrient utilization and overall gut health. Biochar's adsorption properties can bind certain mycotoxins, reducing their potential negative impact on animal health (Osman *et al.,* 2022). Additionally, biochar-amended bedding materials can provide a drier and more comfortable environment for animals, reducing the risk of bacterial infections and improving animal welfare.

Soil fertility and forage production: Biochar-amended manure can be beneficial when used as a soil amendment for pasture and forage production. The addition of biochar helps to enhance soil fertility, nutrient availability and water retention, promoting the growth of healthy and nutritious forage crops. Improved forage quality can positively impact animal nutrition, leading to better animal performance and productivity.

Carbon sequestration and renewable energy generation: The production of biochar from livestock waste offers opportunities for carbon sequestration and renewable energy generation. By converting animal waste into biochar, carbon is effectively sequestered in a stable form, reducing greenhouse gas emissions. Additionally, biochar production can be integrated with bioenergy generation, creating a renewable energy source and a potential revenue stream for livestock farms.

Biochar in energy and biomass systems

Biochar holds potential as a valuable component in energy and biomass systems, offering opportunities for renewable energy generation and sustainable resource utilization. Its unique properties and production methods make it suitable for integration into various energy production processes.

Co-product of bioenergy generation: Biochar can be produced as a co-product alongside bioenergy generation processes such as biofuel production, biomass combustion or anaerobic digestion. During these processes, biomass is converted into energy-rich products like biofuels or biogas. The solid residue left after energy extraction can be transformed into biochar through pyrolysis, providing an additional value stream and contributing to the overall sustainability of the bioenergy system.

Renewable energy source: Biochar itself can be used as a renewable energy source. Through gasification, biochar can be converted into syngas, a gas mixture primarily composed of hydrogen and carbon monoxide (Hofstrand, 2010). Syngas can be utilized for heating, electricity generation, or as a feedstock for biofuel production. The combustion of biochar in specialized burners or boilers can also produce heat energy. By harnessing the energy potential of biochar, renewable energy systems can be diversified, contributing to a more sustainable energy mix.

Carbon negative energy systems: The combination of bioenergy production and biochar sequestration can result in carbon negative energy systems. These systems capture more carbon from the atmosphere during biochar production and energy generation than they release, effectively removing carbon dioxide from the atmosphere. By operating carbon-negative energy systems, it becomes possible to offset carbon emissions from other sectors, contributing to overall carbon neutrality and climate change mitigation.

Waste biomass valorization: Biochar offers a solution for the valorization of waste biomass. Biomass residues that would otherwise be discarded or left to decompose can be converted into biochar, reducing waste and utilizing biomass resources more efficiently. By converting waste biomass into a valuable product like biochar, energy and biomass systems contribute to a circular economy and resource sustainability.

Challenges and future directions

While biochar holds great promise as a sustainable solution with numerous applications, there are several challenges and areas for future development that need to be addressed to maximize its potential.

Technology and scalability: One significant challenge is the development of cost-effective and scalable biochar production technologies. Existing pyrolysis systems can be energy-intensive and have high capital costs, limiting their widespread adoption. Research and innovation are needed to optimize pyrolysis processes, reduce energy requirements and develop efficient and affordable production systems that can accommodate different feedstocks and production scales.

Feedstock availability and sustainability: The availability of suitable biomass feedstocks for biochar production is a critical factor. Sustainable sourcing of feedstocks is essential to prevent competition with food production, land-use conflicts and deforestation. Identifying and utilizing waste biomass streams, such as agricultural residues and forestry byproducts, can help ensure the sustainability and environmental integrity of biochar production.

Standardization and certification: The establishment of standards and certifications for biochar is essential for ensuring quality, consistency and safety. Developing internationally recognized guidelines for biochar production methods, properties and applications can promote confidence among users and facilitate market adoption. Standardization efforts should also consider the potential environmental impacts of biochar production and application to ensure its overall sustainability.

Environmental considerations and risk assessment: While biochar offers several environmental benefits, potential risks and unintended consequences need to be thoroughly evaluated. Long-term impacts on soil microbial communities, soil fertility dynamics and water quality should be investigated to assess any adverse effects. Comprehensive risk assessments are necessary to ensure responsible and safe biochar application in various contexts.

Knowledge and education: Increasing awareness and knowledge about biochar among farmers, policymakers and the general public is crucial for its widespread adoption. Educational initiatives, training programmes and outreach efforts can help bridge the knowledge gap and promote understanding of biochar's potential benefits, proper application methods and best management practices. Collaboration among researchers, industry stakeholders and agricultural communities is vital to facilitate knowledge exchange and promote evidence-based decision-making.

Integration with sustainable agricultural systems: The integration of biochar into sustainable agricultural systems and land management practices is an important future direction. Understanding the synergies and interactions between biochar and other sustainable practices, such as conservation agriculture, organic farming and agroforestry, can help to optimize biochar's effectiveness and maximize its benefits. Integrated approaches that consider biochar as part of a holistic system offer the potential for enhanced sustainability and resilience in agricultural and land management systems.

Multi-disciplinary research and innovation: Biochar research should continue to be multi-disciplinary, involving collaboration among scientists, engineers, agronomists, environmentalists and other relevant disciplines. This collaborative approach can lead to innovative solutions, advanced production methods and an improved understanding of biochar's effects on soil, plants, water systems and the environment. Encouraging research into novel feedstocks, production techniques and biochar applications will further expand the knowledge base and foster continuous innovation.

Conclusion:

In conclusion, this chapter has explored the multifaceted world of biochar, covering its production methods, environmental benefits, agronomic and horticultural applications, environmental remediation potential, its role in livestock farming and its integration into energy and biomass systems. Biochar offers a range of opportunities and benefits across these domains, contributing to environmental sustainability, resource efficiency and improved agricultural practices.

Through its carbon sequestration potential, biochar helps mitigate climate change by capturing and storing carbon in a stable form. Its addition to soils enhances soil fertility, nutrient retention and water management, leading to improved crop productivity and reduced environmental impacts. Biochar also plays a vital role in environmental remediation by immobilizing contaminants in soils and water systems, contributing to the restoration of degraded lands and the improvement of water quality.

In the context of livestock farming, biochar aids in waste management, odour reduction and nutrient retention. It supports animal health and welfare while mitigating greenhouse gas emissions associated with animal agriculture. Biochar's integration into energy and biomass systems offers opportunities for renewable energy generation, carbon sequestration and resource utilization, thereby promoting sustainable and climate-friendly energy production.

However, several challenges and future directions should be considered for the effective and responsible implementation of biochar. These include technology development, feedstock sustainability, standardization and certification, risk assessment, knowledge dissemination, integration with sustainable agricultural systems and continuous research and innovation.

By addressing these challenges and pursuing future directions, biochar can be further optimized and harnessed to its full potential. Its adoption and utilization in various sectors have the potential to significantly contribute to a more sustainable and resilient future, mitigating environmental challenges, improving soil health, promoting sustainable agriculture and supporting renewable energy generation.

As we continue to explore and advance our understanding of biochar, it is essential to remain proactive, collaborative and adaptive. By incorporating biochar into our practices and systems, we can strive towards a more sustainable and harmonious relationship with the environment, fostering a greener and more resilient planet for generations to come.

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CLIMATE-SMART AGRICULTURE ADAPTATION STRATEGIES FOR COTTON CULTIVATING MARGINALIZED FARMERS

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Abstract:

The climate change impacts on cotton cultivating marginalized farmers in central India was carried out in winter 2020. For this purpose, 70 marginalized farmers were identified from Amravati, Wardha and Yavatmal districts of Maharashtra. The climate change impacts were assessed with the aid of a specially designed and developed questionnaire. The major impacts include soil fertility reduction (84.28%), increase in insect/pest attack (91.42%), production cost increase (100%), and monsoon season has adverse impacts on livestock (96.66%). To enhance the resilience capacity of this group of farmers climate-smart agriculture adaptation strategies have been identified and described. These strategies include bio-priming of seeds, rice husk as biochar, urea deep placement, push-pull technology, bio-fumigation, custom-hiring of farm implements etc. For climate-smart agriculture to work in addition to these adaptation strategies other supportive mechanisms such as national-level policy, financial allocation, institutional arrangement, capacity development and enhancement will pave the way for sustainable farming which will ensure livelihood security for this group of farmers and will transform from subsistence farming to sustainable farming.

Keywords: Agriculture, Climate change, Climate-smart agriculture, Cotton, Marginalized farmer

Introduction:

Climate change according to the Inter-governmental Panel on Climate Change (IPCC) is defined as identifiable changes in the climate based on statistical tests, changes in the properties, and this is observed over a prolonged period typically decades. Considerable changes were reported by IPCC in its report regarding temperature, precipitation, and the number of extreme weather events. Of the various environmental problems society is facing today, climate change probably is the most dynamic and complex one. Furthermore, climate change is recognized as a potential threat to agriculture and food security (Rama Rao *et al*., 2016). The climate change projections for India towards 2050s indicate an increase in 9-16% precipitation and temperature by 1-4^{o}C (Krishna Kumar *et al*., 2011). This climate change will result in increase in the number of extreme weather-based events such as cyclones, floods, droughts, aridity which will have adverse impacts on agriculture (Rama Rao *et al*., 2016).

Of the various counties in the world developing countries particularly India will be at receiving end due to climate change because of their greater reliance on smallholding agriculture, technology and infrastructure limitations, lack of financial and institutional resources (Shirsath *et al*., 2017). Agriculture is the backbone of the Indian economy which contributes to one-sixth of gross domestic product and provides employment to 56% of the workforce. Of the net cultivated area in India (142 million hectares), 54% depends on rainfall (Sikka *et al*., 2016). Of the different farmers' groups in India, small (2.0 ha/<5.0 acres) and marginal (1.0 ha/<2.5 acres) groups contribute about 80% (Dev, 2012).

In the year 2019-20 cotton production from India was the highest in the world (29.5 million bales/6423 metric tonnes) (United States Department of Agriculture). The cotton cultivation area for India is provisionally estimated as 12.58 million hectare and production is 36.00 million bales which are about 486 kg/ha for 2019-20 (Cotton Advisory Board). Maharashtra has a maximum (4.25 million hectare) cotton cultivation area with the second largest production (8.2 million bales) (Cotton Corporation of India). The Vidarbha region is the maximum cotton cultivating region of India (30%) (Cotton Advisory Board).

The small-scale farmers considered cotton as an important cash crop and essential for economic development particularly in developing countries (Mohapatra, 2002). The water requirement of the cotton is relatively high 7,000-29,000 litres/kg of cotton and thus it is considered as a water-intensive crop (Soth, 1999). The Indian cotton requires 15,198 m^3/tonne of rainwater and 5,019 m^3/tonne irrigation water for the production of cotton lint. The water resource use by cotton in India is about 15% (Jasserina, 2007). The insect infestation in cotton is a common problem in India. This causes damage to 50% of the crop as compared to the rest of the world which is 25%. In addition, pesticide use by cotton in India, which only takes up 5% of the arable land, accounts for 54% of the total use and is estimated to be US$ 344. The rate of pesticide application in cotton is about 1 kg/ha (Jasserina, 2007).

The favourable environmental conditions particularly light, temperature, and soil moisture are required for cotton cultivation. An increase of 1-4°C in ambient temperature will result in the decrease in cotton yield by hampering fruit formation. Even though cotton can survive in hot climates, its ability to survive in elevated temperatures largely depends upon water availability and weather patterns. The cotton crop is sensitive to frost and needs a dry season for bolls to dehiscence properly (Ton, 2011). The increase in rainfall intensity during the monsoon will have additional problems for cotton. The climatic variability resulting in flooding and drought will affect Maharashtra's rainfed cotton production (Hebbar *et al*., 2013).

Cotton is an important crop in the world and India. Climate change's impacts will reduce crop quantity and quality. In the light of future climate change projections in India, this crop will face adverse impacts. Moreover, marginalized farmers due to their limited resilience will be at receiving end. Print and online literature review revealed that no study was carried out on climate-smart agriculture strategies for cotton cultivating marginalized farmers in India. Thus, this is the identified gap in this subject domain. This study was carried out to assess the climate change impacts and climate-smart agriculture adaptation strategies of cotton cultivating marginalized farmers of central India. This study outcome will add a new understanding of climate change impacts on cotton cultivating marginalized farmers and climate-smart agriculture strategies to be adopted by this group of farmers. Furthermore, the initiatives have to be taken at the national/regional level to enhance the resilience of these farmers thus paving the way for sustainable agriculture leading to livelihood security.

Study area:

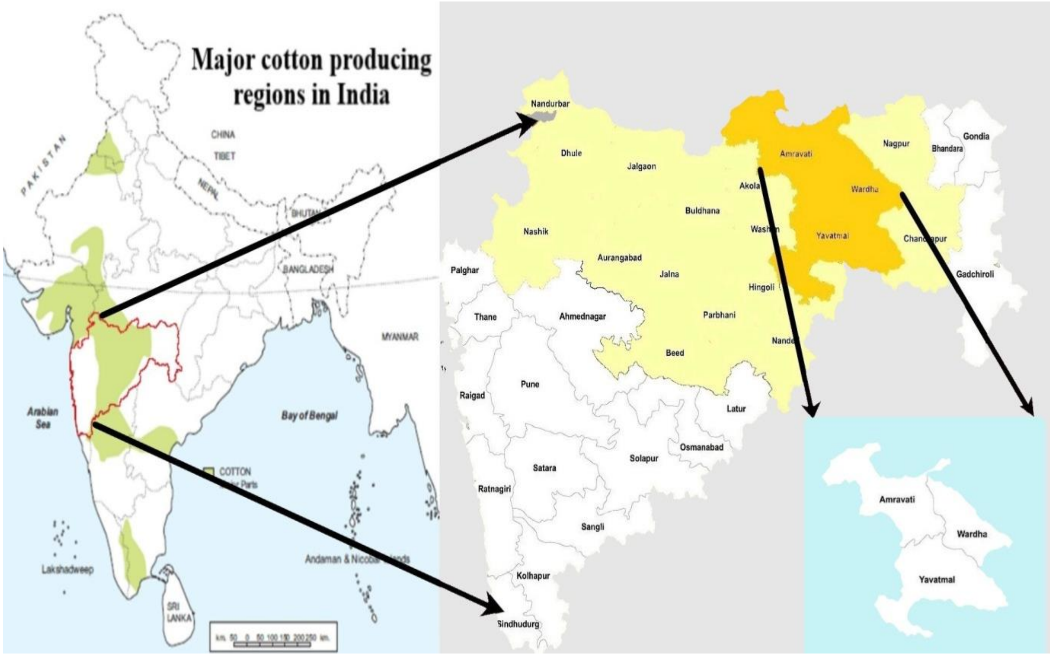

Fig. 1: Cotton cultivating study area

The study was carried out in three districts of the Vidarbha region of Maharashtra state. The description about the location, temperature, precipitation, soil, and cropping pattern of the study area is as follows:

The Amravati district (Figure 1) is situated between 20°32' N to 21°46' N latitudes and 76°37' E to 78°27' E longitudes and has a geographical area of 12,212 sq km. The summer recorded maximum temperature up to 47^{o}C whereas, the minimum temperature in winter (5-9^{o}C). The district receives rainfall from the southwest monsoon and has an average annual rainfall of 700-800 mm. In the district, 91.50% area is exclusively under rainfed cropping. The total area under Kharif crops is 6,83,700 ha, while 1,06,200 ha is under Rabbi crops. Cotton is the main cash crop of the district; covering an area of 3,27,901 ha (34.60% of the total cropped area).

The Wardha district (20°15'N to 21°21'N latitudes and 78°30'E to 79°15'E longitudes) (Figure 1) has a geographical area of 6,309 sq km and the total population is 1.3 million of which 73.70% of population live in rural areas (Census of India, 2011). The district has a hot summer and general dryness throughout the year except during the southwest monsoon season. In summer temperatures can go up to higher than 46°C and in winter the temperature drops to 9^{o}C. The average annual rainfall is 1090.3 mm out of which rainfall during the period from June to September contributes to about 87% and July being the wettest month. Black soil is the predominant soil type in this district. The important crops grown in the Kharif season are cotton, sorghum, and pulses, and since the mid-1980s, cotton and soybean have become an extremely important Kharif crop in the district. Of the total cropping area, cotton covers an area of 1,48,000 ha.

The Yavatmal district is located between 19°26’ N to 28°42’ N latitudes and 77°18’ E to 79°18’ E longitudes (Figure 1) and covers an area of 13,582 sq km. According to the Census of India 2011, the district had a population of 2.77 million. The climate of the district is hot and dry and in summer, the maximum temperature of the district goes up to 45.6°C and the temperature drops to a minimum 5.6°C in winter. The district receives an average annual rainfall of 911.34 mm from the southwest monsoon season. In general, all types of soils are observed in this district. The district has a cotton cultivated area of 4,05,000 ha (40.28%) out of 10,05,265 ha of total cultivable land available for agriculture.

Methodology:

The study area was selected based on cotton as the main crop. To assess the marginalized farmers’ climate change impacts on cotton the inclusive criterion for the study was those farmers who have agricultural land ≤ 1.0 ha (≤ 2.5 acres) and those engaged in the agricultural activity for >15 years. Three villages from each district and more than 25 marginalized farmers in each district were randomly selected. In total nine villages were selected for data collection through the field survey. The villages covered under the study include Bhatkuli, Sayat, and Antapur from Amravati district; Sindi, Palasgaon, and Hiwra from Wardha district and Murli, Nukti, and Belora from Yavatmal district. Purposive sampling was used to identify the sample population. A total of 70 marginalized farmers as a sample population were selected for this study. The study was carried out in February and March 2020. The quantitative approach was used for data collection.

The primary data was collected by eliciting the information from these identified marginalized farmers in a specially designed and developed questionnaire that emphasized climate change impacts assessment during sowing, crop growth, post-harvest, livestock, and adaptation strategies used and planned to execute in the future. The Likert scale was used for the responses of the questions to get quantitative and comparable responses. The secondary data viz. study area, climate, rainfall, demographic profile, etc. were gathered from government databases such as Census of India, government district data, and India Meteorological Department.

Furthermore, climate-smart agriculture adaptation measures for cotton were identified from the online and print literature on the subject topic. For this purpose, online databases such as Science direct, Indian Science Abstract, Krishikosh, etc. were referred. A total of 126 research papers on the concerned topic from national (n = 24) and international (n = 102) were referred. In addition, several books (n = 87) including scientific & technical reports on climate change, climate-smart agriculture, sustainable agriculture and allied topics were consulted. The identified climate-smart agriculture adaptation measures were classified according to the crop growth stages.

Results and Discussion:

The climate change impacts on cotton during sowing, crop growth, harvest, and livestock are presented in Table 1. These impacts are arranged according to the descending order of farmers' responses. From the table, it can be seen that soil fertility reduction (84.28%) is the major impact during sowing followed by more rounds of sowing due to seed loss (72.84%). In the case of crop growth, insect/pest attacks increased (91.42%) and were closely followed by new types of insects affecting crops (89.99%). During harvesting, production cost has increased (100%) followed by late harvesting blackens the cotton (88.57%) are major impacts of climate change. The climate change impacts on livestock revealed fodder production from farms reduced (96.66%) and monsoon season has adverse impacts (96.66%). Other additional problems include hail storm damage cotton buds, discolouration of the cotton due to uneven rainfall during harvesting etc.

Table 1: Climate change impacts on cotton marginalized farmers

Sowing
Soil fertility reduced (84.28)
More rounds of sowing due to seed loss (72.84)
Shift in crops (70)
Higher temperature makes the cotton buds and plants dry (68.57)
Irrigation water scarcity (65.71)
Crop growth
Insect/pest attack increased (91.42)
Cost of pesticide/insecticide use in farm increased several folds (91.42)
New types of insects affecting crop (89.99)
Productivity reduced due to less water for irrigation (65.71)
Harvest
Production cost increased (100)
Late harvesting blackens the cotton (88.57)
Climate change affecting ready harvesting crop (85.71)
Per acre farm yield from last 5 yrs. Reduced (71.42)
Not getting maximum selling price (71.42)
Profit received from the farm decreased (71.42)
0-20% of yield reduced in last five year (55.71)
Livestock
Fodder production from farm reduced (96.66)
Monsoon season has adverse impacts (96.66)
Summer season has adverse impacts on livestock (90)
Vector borne diseases increased (80)
Livestock production reduced (66.66)
Heat stroke (66.66)

(Values in parenthesis indicates percentage)

Climate-smart adaptation strategies for cotton cultivation

To overcome these climate change impacts on cotton cultivating marginalized farmers from the study area climate-smart agriculture adaptation strategies for the reported problems were identified from the literature and the same has been described below.

Bio-priming of seeds

Bio-priming is a process of biological seed treatment of seed hydration and inoculation with beneficial organisms. Selected funguses are used against soil and seed-borne pathogens. In this method seeds have to be pre-soaked in the water for 12 hours. The formulated products of bioagents (*Trichoderma hazzianum* and *Pseudomonas fluorescens*) have to be mixed with the pre-soaked seeds at the rate of 10 g per kg of seed. Treated seeds are placed as a heap and to be covered with a moist jute sack to maintain high humidity for about 48 hours at 25-32^{o}C to incubate. The bioagent adhered to the seed grows on the seed surface under the moist condition to form a protective layer all around the seed coat. The seeds thus bio primed with the bioagents protect seed and soil-borne pathogen, improved germination and seedling growth. Flavio *et al*., (2011) reported buffering against biotic stress in cotton on the use of bacillus as a bio-priming agent.

Rice husk as biochar

Rice husk is hard protective coverings of rice grains that are separated from the grains during the milling process. The biochar is prepared from it by adopting the pyrolysis method. During its production, a large fraction of the carbon in the original organic residue is retained in the crystalline structure. The use of biochar in the soil will increase crop productivity and also improves soil tilth, fertility, water holding capacity, reduces the risk of soil erosion and the need for fertilizer inputs. Biochar has the potential to trap atmospheric carbon dioxide in the soil (Kohli, 2019).

Urea deep placement

To increase the fertilizer, use efficiency deep placement of fertilizer has been recognized as a potential method. This method involves the placement of urea (1-3 g as a granule) at the soil depth of 7-10 cm. This method increases the percentage of nitrogen that is absorbed by the crops by double and reduces the nitrogen loss in the air and to surface runoff. This method can increase the cotton yield and further reduces urea use (FAO, 2011).

Push-pull technology

Push-pull is an innovation that holistically combines multifunctional resource-conserving Integrated Pest Management and Integrated Soil Fertility Management approaches while making efficient use of natural resources to increase farm productivity by addressing most aspects of smallholders' constraints (Cook *et al*., 2007; Hassanali *et al*., 2008). Push-pull technology has been potentially used for the management of stem borers and parasitic weeds by using repellent intercrops. In this strategy, repellent intercrops are used for driving stem borers away ('push'), and attractive trap crops are used in the crop border to attract female moths ('pull') to lay eggs. Besides controlling stem borers, Molasses grass enhances the natural enemy population (*Cotesia* sp.), when intercropped with maize (Khan *et al*., 1997). The intercrop *Pennisetum purpureum* secretes a gummy substance that restricts larval development, causing few to survive (Khan *et al*., 2006). Furthermore, it improves soil health and conserves soil moisture.

Bio-fumigation

Bio-fumigation is an agronomic practice that releases volatile bio-toxic compounds into the soil atmosphere during the decomposition of organic amendments. During the breakdown of the Brassica isothiocynates (ITCs) produced which is highly toxic to pathogens. The myrosinase enzymes at neutral pH hydrolyze glucosinolates to release ITCs following tissue damage. Glucosinolates that are produced as secondary metabolites by Brassica are responsible for providing resistance against pathogens. Black mustard (*Brassica nigra*) and Indian mustard (*Brassica juncea*) can provide substantial quantities of ITCs and could be utilized in a bio-fumigation cropping system (Tollsten and Bergström, 1988).

Custom-hiring of farm implements and machines

To carryout, various agricultural-related activities number of farm tools and implements are required. To have these tools and implements is not possible for smallholder/marginalized farmers thus, to overcome this situation farm tools and implements can be procured and made accessible at a central location in the village called a custom hiring centre. This centre will be under the supervision and management of the village committee. These machines/implements can be used by any farmer by paying usage charges. The amount collected by this can be utilized for the maintenance and purchase of new machines/implements. The procurement of the new machines will be carried out by the village committee with a priority to tillage, sowing, weeding, spraying, harvesting and post-harvesting operations. Furthermore, to carry out special operations such as transplanting of seedlings, breaking up of hardpans under the plough layer etc. needs to be procured (Srinivasa Rao, 2016).

Mulching and no-tillage

Mulching technology involves the use of a biotic or abiotic material to cover soil. In this technology plant residue viz. dried leaves, straw is used along with plastic sheets to cover soil. Mulch on the soil surface conserves the soil moisture by reducing evaporation and thus reducing the quantity of irrigation water requirement. Moreover, mulches keep soil temperature lower during the day and higher at night. Zero tillage reduces the soil moisture loss during the subsequent stage of the crop. The early establishment of the crop and minimising tillage retain as much residual soil moisture as possible (Kohli *et al*., 2019).

Proper housing for livestock

Designing free-stall barns that allow for maximum natural airflow during the summer will reduce the effects of heat stress. Open sidewalls, open roof ridges, correct sidewall heights and the absence of buildings or natural features that reduce airflow increase natural airflow. Adequate ventilation to maintain air quality should be provided during the winter months while ensuring protection from cold stress.

To disseminate summer heat and to ensure adequate barn environment measures such as sprinkling water and misting inside the barn, as well as applying lime and sprinkling water on the roof can be attempted. In addition, vegetable creepers over the sheds, hanging green mat for reducing direct sun rays and heat waves and hanging wet gunny bags against the direction of the wind are some methods that can be adopted during high-thermal stress periods (Ambazamkandi *et al*., 2015).

For rearing goats, slatted floors from locally available wooden planks with the proper roofs can provide shelter to tackle heat stress during summer and rainstorms during monsoon. A gap of one inch must be maintained between each slat so that the urine and faecal material could be collected from the bottom of the floor. Bamboo can be used for making the roof and is covered with either thatched material or coarse crop residue.

Fodder management

Improved quality of feed reduces the emissions of greenhouse gases from livestock (especially methane). To develop the feed banks rangeland can be explored as they will act as a carbon sink. Grazing and fodder lands can also be conserved through reforestation, enclosures and zero grazings. Grazing lands can also be rehabilitated by planting improved grass and fodder trees.

The substitution of conventional protein sources by *Acacia colei* seeds in the diet of broilers can replace 50% of the protein source of chicken rations. Corn straw, after treatment using silage technology, can help to improve feed digestibility and reduce methane production. With an identical ratio of fine feed to coarse feed, methane emission decreased by 30% by feeding silage rather than dry corn (Pasternak *et al*., 2005).

The fodder bank consists of the planting of high-quality fodder species which can provide high biomass in a short time and bridge the forage scarcity during the annual dry seasons (Bayala *et al*., 2014) and also during the long dry spells within the growing season. Planting of high biomass yielding and fast-growing grasses and shrubs suitable for fodder not only increases fodder availability but also reduces erosion and landslides that originate in these areas. These fodder banks also help in the preservation and storage of surplus fodder, availability of nutritious fodder during the period of fodder scarcity, and enhance the nutritive value of crop residue and other cellulosic waste for animal feeding (Dhyani *et al*., 2013). Fodder banks do not meet 100% of feed requirements but supplement the available dry season forage.

Short and medium-duration fodder cultivars of several crops that can withstand up to 2-3 weeks of exposure to drought in rainfed areas should be cultivated. These include sorghum, bajra, and maize. These cultivars can be sown immediately after the rains under rainfed conditions in arable lands during the Kharif season and are ready for cutting by 50-60 days (Prasad *et al*., 2014).

Conclusions:

Climate change has pronounced effects on cotton cultivating marginalized farmers. These effects are different in various crop growth stages. Owing to the poor socio-economic condition, resource constrains, technology know how this group of marginalized farmers are vulnerable to climate change. To enhance the resilience capacity of these farmers' climate-smart agriculture adaptation strategies need to be adopted. To make climate-smart agriculture to work additional supportive mechanisms are needed which include mainstreaming climate-smart agriculture into national policies and programmes, priority and constraint analysis, diversification of options, time-bound goals and targets, awareness and access to information, financing, capacity development, institutional arrangement and safety nets. In addition, these options have to be divided into short, medium and long term measures for effective implementation of them. Furthermore, a pan-India study will enhance the understanding of the various dimension of this subject.

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ORGANIC FARMING: FUTURE OF AN INDIAN AGRICULTURE TOWARDS HEALTHY NATION

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Abstract:

Organic farming, as a sustainable alternative to conventional agriculture, deliberately abstains from synthetic fertilizers, pesticides, and growth regulators, opting instead for eco-friendly practices like crop rotations, animal manures, and biofertilizers. This system addresses the environmental, ecological, social and health issues associated with conventional farming methods. India, with its historical roots in organic agriculture, is witnessing a surge in the domestic market for organic food, propelling the adoption of this environmentally conscious approach. The advantages of organic farming extend beyond its protective measures for the environment and human health, encompassing improved soil fertility, enhanced water quality, erosion prevention, and the creation of rural employment opportunities. This article delves into the significance of organic farming in fostering a sustainable agro-ecosystem, emphasizing its relevance, challenges, and constraints within the Indian context, all aimed at enhancing the well-being of both humanity and the planet.

Keywords: Organic farming, Soil, Human health, Environment, India

Introduction:

Organic farming is an agricultural production system that refrains from the use of synthetic compounds like fertilizers, pesticides, fungicides, growth regulators and livestock additives. Instead, it focuses on utilizing crop residues in the field to enhance soil fertility, provide balanced nutrients to plants, and improve soil microbial activity. This method not only reduces production costs but also mitigates environmental pollution in an eco-friendly manner, fostering sustainable agriculture for guaranteed food production. By relying on locally available natural resources, organic farming promotes self-sufficiency and employs an eco-friendly strategy to safeguard biodiversity, reduce fossil energy use, and offer farmers opportunities for satisfactory livelihoods, ultimately contributing to the overall health of the nation by Shukla *et al*. (2011).

Rembialkowska (2007) reported the food quality and safety have become paramount concerns for the general public due to growing environmental awareness and the rise of various food hazards such as dioxins, bovine spongiform encephalopathy, and bacterial contamination. The decline in consumer trust towards conventional farming methods, which can introduce contamination into the food chain, has prompted a quest for safer and more ecologically produced foods. In response to these concerns, there is a rising preference for organically grown food and products, which are perceived to meet the demand of safer and more authentic food options.

Over recent years, organic farming have gained popularity as a cultivation process, Dangour *et al*. (2010). Organically grown foods are increasingly regarded as a top choice for both consumers and farmers, aligning with a "go green" lifestyle. The burgeoning interest in organic farming raises the question of what exactly is meant by this term, Chopra *et al*. (2013).

The term "organic farming" was coined by Lord Northbourne in 1940, but the roots of the organic movement has extended back to the early 1800s. The evolution of organic farming, based on theoretical works of Rodale in the United States, Lady Balfour in England, and Sir Albert Howard in India during the 1940s, has now encompassed approximately 23 million hectares of land worldwide. Sir Albert Howard's influential work, 'An Agricultural Testament,' holds particular significance in India as it analyzes the centuries-old environmentally friendly farming practices in the country. In 1840, Justus Von Liebig developed a theory of mineral plant nutrition, proposing that certain mineral salts could directly substitute manure (Filipovich, 2020).

According to Winter and Davis (2006), organic farming is characterized by minimal use of off-farm inputs and management practices aimed at restoring, maintaining, and enhancing ecological harmony. Organic produce, as outlined by Winter and Davis, is cultivated without the use of synthetic pesticides, antibiotics, growth hormones, genetic modification techniques (such as genetically modified crops), sewage sludge, or chemical fertilizers.

In contrast, Worthington (2001) stated the conventional farming involves the application of synthetic pesticides and chemical fertilizers to achieve higher crop yields and profits. In this approach, synthetic pesticides and chemicals are employed to eliminate insects, weeds, and pests, while growth factors such as synthetic hormones and fertilizers are used to accelerate growth rates

Organic farming in India

Ever increasing population as opposed to an ever decreasing supply of living resources like food and water has made it necessary to create more agricultural production and stabilize it in a viable and feasible manner. The benefits of Greeen Revolution credited to Dr. M. S. Swaminathan have now reached a plateau and with diminishing return it has become necessary to devise alternate technique. In addition, the excess use of fertilizer and artificial growth regulators has results into to an issue called pollution. The need of the hour is a natural balance between life and property for existence. Keeping in view the fact that fossils and fuels are on their way of extinction and are non-renewable, organic, nature friendly ways of farming and agriculture has gained importance (https://www.farmingindia.in/organic-farming).

Status of organic farming in India:

Land under organic farming- The data suggested by IFOAM and Research Institute of Organic Agriculture (FiBL), can be termed as mere god gifted to the nations with higher land mass and lower population.

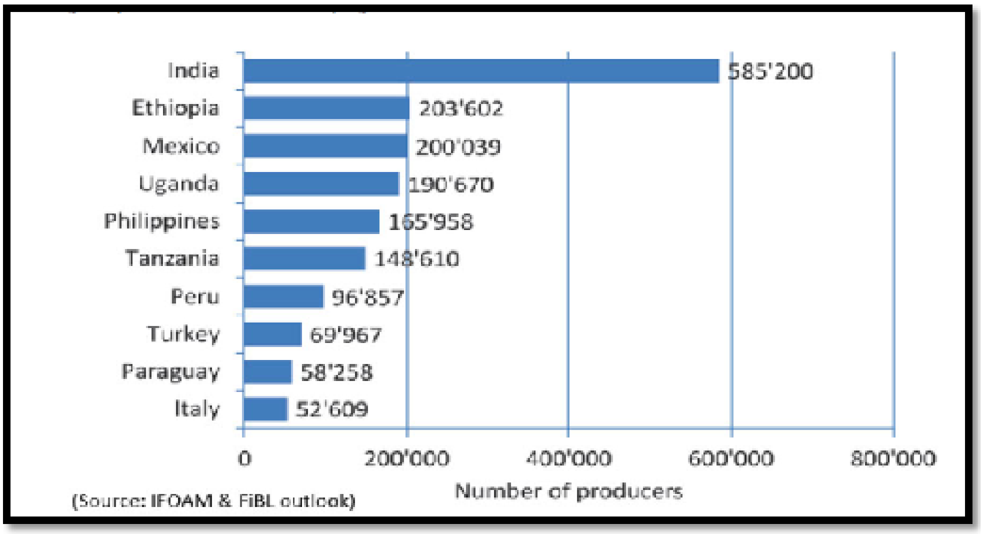
India ranks 1st in number of organic farmers and **9th** in terms of area under organic farming.

First fully organic state: Sikkim became the 1st State in the world and to become fully organic state and other States including Tripura and Uttarakhand have set similar targets.

Organic cultivation in North-Eastern region

(In hectares)

State	Area	In conversion
Sikkim	74,094	1,982
Meghalaya	2,580	37,756
Assam	9,883	18,129
Nagaland	3,526	5,314
Arunachal	51	6,129
Manipur	158	5,240
Tripura	204	2,048
Mizoram	0	999
Total	90,496	77,597



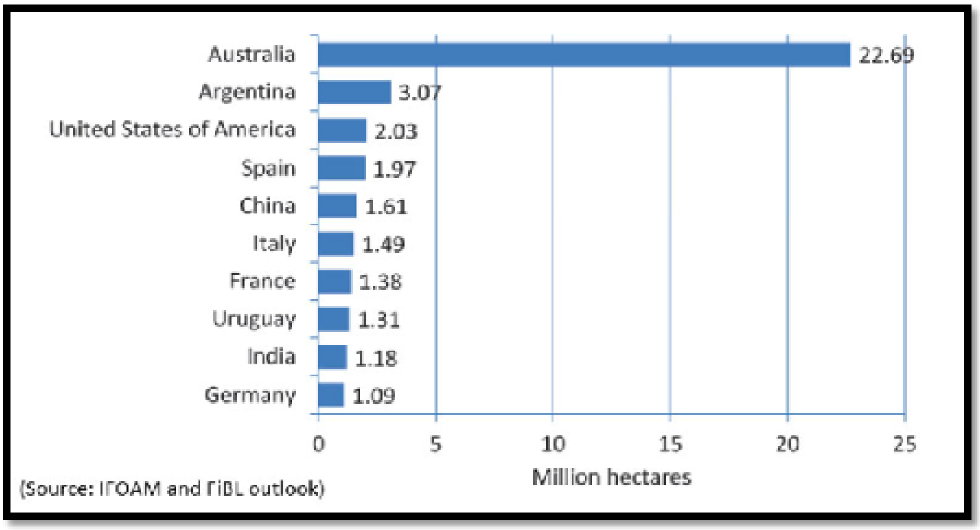


Fig. 1, 2, 3: Area under organic farming as data suggested by IFOAM and Research Institute of Organic Agriculture (FiBL) in India

Government initiatives:

- In 2015, two programs were launched to support farmers in adopting organic farming and improving earnings through premium prices: Mission Organic Value Chain Development for North East Region (MOVCD) and Paramparagat Krishi Vikas Yojana (PKVY).
- The Agri-export Policy 2018 aims to position India as a major player in global organic markets, with significant organic exports including flax seeds, sesame, soybean, tea, medicinal plants, rice, and pulses leading to a nearly 50% increase in organic exports in 2018-19.
- Certification is crucial for customer confidence, and both PKVY and MOVCD promote certification under Participatory Guarantee System (PGS) and National Program for Organic Production (NPOP) for domestic and export markets.
- The Food Safety and Standards (Organic Foods) Regulations, 2017, align with NPOP and PGS standards. Consumers are advised to look for logos of FSSAI, Jaivik Bharat / PGS Organic India on produce to verify its organic authenticity. PGS Green certification is granted to chemical-free produce transitioning to 'organic,' a process that takes three years.
- Strengthening the organic e-commerce platform, such as www.jaivikkheti.in, facilitates direct links between farmers and both retail and bulk buyers.

Minimum requirements for organic farming include considerations for mixed farming, cropping patterns, planting, and manurial policies.

Need for organic farming

- The Green revolution in the late 60’s aimed at increasing food production in India by introducing plant nutrition-responsive crop hybrids, synthetic agrochemical’s, farm mechanization, and improved cultural practices.
- Initially successful, the Green revolution led to a 3-4 fold increase in crop productivity, achieving crop and environmental security by Sinha (2008) and Gahukar (2011).
- In recent years, the promised more crop production has been disappointing due to factors such as reduction or stagnant crop productivity, soil salinity/alkalinity, decreasing soil fertility, and increased susceptibility to insect pests and diseases (Gahukar, 2010a)
- Biswas (2011) reported the less external inputs sustainable agriculture, emphasizing organic farming, results in crops being least attacked by pests and diseases, with lower disease incidence in soil enriched with antagonists like *Trichoderma* spp. and *Pseudomonas fluorescens.*
- Despite some disadvantages, organic farming addresses environmental problems, reduces the risk to human health, and aligns with increse consumer preference for organic foods free from artificial additives and contaminants.
- For the initial 3-4 years, organic farming may not be cost-effective, but it later reduces production costs by 25-30% while enhancing or maintaining soil fertility and preventing soil erosion, Chandra *et al*. (2007).
- The positive impacts of organic farming extend to the ecosystem, promoting wildlife survival in lowlands and providing pasture for grazing animals. Cultural practices like crop

rotations, intercropping, symbiotic associations, cover crops, organic fertilizers, and minimum tillage are central to organic farming.

- As climate change becomes more problematic, organic farming is perceived as crucial for environmental conservation and biodiversity, contributing to the mitigation of greenhouse gases and global warming by sequestering carbon in the soil reported by Gahukar (2010b).
- Preference for local genotypes/cultivars in organic farming is due to the resistance to insect pests, diseases, and resilience to climatic stress, aligning with findings reported by Kasturi (2007) and Lotter (2003).

Impact of organic farming

1. **Environmental impact**

Organic farming emerges as a key player in environmental conservation, presenting a less harmful alternative to conventional agriculture by avoiding synthetic pesticides. Extensive studies by Oquist *et al.* (2007) highlight the superior biodiversity and good soil properties associated with organic practices, including higher organic matter, biomass, enzyme activity, stability, and enhanced water capabilities. This sustainable method not only reduces water and wind erosion but also proves efficient in resource utilization, consuming less energy and generating minimal waste per unit area or yield reported by Hansen *et al.* (2001). Moreover, organically managed soils exhibit enhanced quality and water retention, leading to increased yields, even in drought years, showcasing the resilience and eco-friendly nature of organic farming, Pimentel *et al.* (2005).

2. **Socioeconomic impact**

Organic cultivation yields significant socioeconomic benefits by generating more income-generating jobs per farm, driven by its heightened labor demand. Winter and Davis (2006) note that organic products typically cost 10%-40% more than conventional crops, influenced by various factors in both input and output aspects. Factors such as the high cost of organic certification, field manpower expenses, and the absence of subsidies on organics in India contribute to the higher prices reported by Mukherjee *et al.* (2018). Despite this, consumers are able to pay a premium due to increasing health awareness. Some organic products face high demand and short supply, leading to increased costs. Thompson and Kidwell (1998) reported the Locally produced biofertilizers and pesticides contribute to lower yearly inputs for farmers, while working in organic farms enhances occupational health by reducing exposure to agricultural chemicals. The longer shelf life of organic food, attributed to lower nitrates and higher antioxidants, adds economic value. The profitability of organic produce has fueled the expansion of the organic farming sector, attracting a growing interest from farmers towards organic agriculture reported by Shreck *et al.* (2006).

Advantages of organic farming- According to Yadav (2017):

1. Improvement and maintenance of the natural landscape and agro-ecosystem.
2. Avoidance of overexploitation and pollution of natural resources.
3. Minimization of the consumption of non-renewable energy resources.
4. Exploitation synergies that exist in a natural ecosystem.
5. Maintenance and improve soil health by stimulating activity or soil organic manures and avoid harming them with pesticides.

6. Optimum economic returns, with a safe, secure, and healthy working environment.
7. Acknowledgement of the virtues of indigenous know-how and traditional farming system.

Disadvantages of organic farming:

1. It requires knowledge of making and using effectively organic manures.
2. More time is required to obtain results of organic farming
3. Reduction in crop yield.
4. It requires more workers for managing the organic farming

Constraints:

1. Quality and certification credibility pose significant challenges in organic farming.
2. Issues related to food safety, resistance to change from traditional farming methods and contamination from genetically modified (GM) crops are major concerns.
3. While urban consumers are able to pay higher premiums for organically produced commodities, rural populations may find it economically challenging to do so.
4. Incentivizing production alone is insufficient; there was need to create market demand for organic products.
5. Initial crop yields are relatively less, requiring skilled labor with higher wages.
6. Organic manures are costly and not easily accessible, further contributing to the financial burden.
7. The cost of certification is often unaffordable for small-scale farmers.
8. Difficulty in obtaining non-treated seeds, as many states mandate the use of seeds treated with synthetic insecticides, botanicals and fungicides for sale.
9. With the increasing prevalence of transgenic crops in conventional agriculture, ensuring that organic fields remain GM-free is challenging due to its gene transmission through pollen.
10. Transparency in the supply chain system is very crucial, necessitating organization among farmers in groups or associations, such as the Organic Farming Association of India and the Institute of Natural Organic Agriculture (Kulkarni, 2011).

Perspectives:

1. Organic farming, despite its labor-intensive nature, presents an opportunity for rural employment and long-term improvement in natural resources. Integrating animal husbandry into organic farming offers a sustainable source of manure and organic materials. Policymakers should actively promote organic farming to enhance the quality of life, restore soil health, boost the national economy, and create a healthier environment, aligning with Indian farming conditions.
2. Providing subsidies to encourage farmers and establishing attractive premiums for organic products and other commodity through contract farming can incentivize the adoption of organic practices reported by Gahukar (2007).
3. In areas experiencing water pollution, promoting the traditional/conversion to organic farming can serve as a restorative method/measure.
4. Conducting systematic research on organic technology for various crops, including the development of suitable varieties/hybrids, plant nutrition, and integrated pest management techniques, can contribute to demand for organic produce in both retail and export markets.

5. Utilizing waste and fallow lands distributed under the "Bhudan Movement" for organic crop cultivation can increase the area and production of organic food crops. Introducing separate MSP for organic produce and establishing organic zones for isolation, particularly in seed production, can motivate farmers.
6. Regularly revising Indian standards to align with global/world standards ensures that organic produce from India meets the criteria of importing countries. Strengthening labeling for organic produce is essential, similar to the approach taken for genetically modified crops by Kulkarni (2011).
7. Encouraging farmers to participate in the "Participatory Guarantee System," a farmer-centric certification system, has led to significant growth in organic farming in India. Continued development and awareness-building efforts are crucial for unlocking the future market potential of organic farming.

Conclusion:

With a focus on raising awareness and empowering producers, Indian organic farmers are on track to establish a more prominent presence in the global agricultural trade. This effort aligns with India's overarching goals of eliminating hunger, ensuring food security, enhancing nutrition, and fostering sustainable agricultural practices. In conclusion, the imperative to transition towards organic farming is evident, serving as a crucial step to safeguard plant, environmental, and human health in the pursuit of a more sustainable and resilient agricultural system. **"Let's get on organic farming and food, which gives us a healthy and prosperous life……"**

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PRO-SOCIAL BEHAVIOR AND FIELD EXTENSION WORK

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Abstract:

Pro-social behaviours are ones that are intended to uplift other people. The propensity for empathy and concern for others, as well as taking actions to support or benefit others, are characteristics that might be described as pro-social. It's evident in day-to-day living that some people are more pro-social than others. Pro-social children and adults are more likely to have empathy for other people. Pro-social behaviour seems to be consistent starting at a relatively young age. Pro-social behaviour is defined in terms of our own feelings as well as the wellbeing of others and ourselves. Additionally, it addresses how we wish to live pro-social lives. The primary objective of the current presentation is to explore pro-social activity, emphasising how it differs from altruistic behaviour and what it actually means. Pro-social behaviour is heavily influenced by the situations and experiences one has had. A person must exhibit pro-social behaviour in order to carry out field extension work that has the potential to empower agricultural households in our nation and improve their financial circumstances and farm output, as well as their prior experiences. It was discovered that a person's pro-social behaviour is also influenced by their experiences.

Keywords: Pro-social, Behaviour, Social Psychology, Experiences, Field extension Work

Introduction:

Pro-social behavior

Pro-social behaviour is the term used to describe acts of kindness that benefit others without directly benefiting the giver. Empathy, or other people-focused emotional reactions such as feelings of compassion, sympathy, and concern, can improve helping. Four different theories explain the origins of Pro-social behaviour: the empathy-altruism hypothesis, which motivates us to help those in need; the negative state relief hypothesis, which motivates us to help others in need in order to lessen negative feelings in ourselves; the empathy joy hypothesis, which motivates us to engage in pro-social behaviour in order to positively impact others; and the self-efficacy hypothesis, which is dependent on an individual's level of competence. Pro-social behaviour serves a variety of purposes and is motivated by a variety of factors. This implies that people give to others for valid causes. A common reason for inaction is the conviction that someone else will handle it. When confronted with an emergency, one must recognise that something strange is occurring, classify the situation as an emergency, take ownership of the situation and decide whether or not to offer assistance based on knowledge or abilities. The decisions made at these five critical stages influence one's propensity to assist or not assist. Not every person has the same inclination to assist others. In actuality, it is greatly impacted by feelings, empathy, and several personality traits. Helping those with similar characteristics is more likely than helping those who are not. It has been discovered that a variety of situational factors can have an impact on pro-social activity, both positively and negatively. One of the key factors influencing helpful behaviour is empathy. Helping is also influenced by several psychological traits, such as low egocentrism, social responsibility, internal centre of control, and belief in a just world. Individuals offer long-term volunteer assistance for a variety of self-serving and altruistic reasons. Volunteering is a common way for people to express or live out their values, learn more about the world, advance cognitively, get experience relevant to their careers, fortify social bonds, and lessen bad emotions, among other reasons when given the option to choose between comparatively moral and comparatively immoral choices, people can be distinguished based on their fundamental motivation. Self-interest, moral integrity, and moral hypocrisy are the three motivating factors.

Definition and description

Pro-social behaviour is a voluntary behaviour intended to benefit another person (Staub,1979). "Voluntary" highlights the pro-social behaviour and factors contributing to pro-social behaviour actor's spontaneous initiative as opposed to professional assistance (e.g., physicians or nurses). A few examples of pro-social activity are lending, sharing, consoling, and assisting. (Bierhoff, 2002). Pro-social behaviour is defined as "any act performed with the goal of benefiting another person" (Aronson *et al.*, 2004). Pro-social is voluntary made with the intention of benefiting others (Eisenberg and Fabes, 1998). The advantages that the pro-social behaviour may have for the individual executing it are highlighted in this definition. However, actions that help others but have self-interest as their primary objective (such as cooperatives meant to acquire shared resources) are usually not seen as pro-social. Volunteering, sharing food or toys with friends, providing costly assistance (such as putting one's own life in danger to save another person), and providing emotional support to those in need (such as consoling a peer after a disappointing experience or tending to an ailing person) are typical examples.

Origin of pro-social behaviour

The origin of pro-social Behaviour includes three different views i.e., empathy-altruism hypothesis that leads us to help others in need, negative state relief hypothesis that leads us to help others in need to reduce negative feelings in ourselves and empathy joy hypothesis that leads us to engage ourselves in pro-social behaviour to have a positive impact on others.

- **Negative-state relief hypothesis:** According to the Negative State Relief Model, sympathetic concern is accompanied by depressive emotions that the helper attempts to alleviate by providing assistance to someone in need. The goal of pro-social activity in this case is to improve the welfare of the helper and the aided. The negative state relief model has three main characteristics: (1) helper feel sympathetic concern; (2) these feelings are accompanied by feelings of sadness and (3) helpers want to alleviate these feelings by providing assistance to others (Smith *et al.*, 1989).
- **Empathy–altruism hypothesis:** The empathy-altruism theory holds that when one feels empathetic towards someone in need, one is motivated to act altruistically to meet that need. The altruistic motivation increases with the degree of empathy. The empathy-altruism hypothesis states that sympathetic concern encourages providers to improve the well-being of individuals in need as opposed to avoiding the circumstance (Batson, 2002).
- **Empathic-joy hypothesis:** According to this theory, a helper's general sensitivity to a victim's emotional state and their increased sensation of vicarious delight and relief when the recipient's needs are met are the foundations of their empathic care. The empathic-joy hypothesis has three main features: 1) helpers feel empathic concern; 2) this concern stems from their sensitivity to another's needs; and 3) knowing that another person is relieved of their distress encourages the helper to feel joy and relief of their own empathic concern.
- **Self-efficacy hypothesis:** According to this theory, one's degree of competency in a certain ability can affect one's willingness to assist, particularly when someone is in need. When someone is competent, they are more likely to be helpful because they are more assured of what to do, less anxious about making a mistake, and less stressed out about the issue (Staub, 1979).

Pro-social behaviour and altruism

Pro-social activity frequently has social and psychological benefits for the individual exhibiting it. People can gain over time from being in a community that values pro-sociality (Hall, 1999). It has been challenging for studies to pinpoint acts of pure altruism that solely benefit the recipient and not the giver. Generally speaking, altruism is any voluntary action done with the intention of helping someone else without expecting anything in return. (Smith & Mackie, 2000). The French sociologist Auguste Comte have coined the term altruism when he stated that people are naturally inclined to act empathetically towards others (Lee and Kang, 2003). Altruism, however, does not equate to pro-social behaviour. Helping another person with the intention of benefiting oneself is referred to as pro-social behaviour (Aronson *et. al.*, 2004). Donors to the tsunami relief fund, for example, might not necessarily be unselfish. Donations made with the intention of avoiding taxes are not considered to have an altruistic purpose (Akert and Fehr, 2004). The primary distinction between pro-social activity and altruism is that the former lacks the element of self-interest (Myers, 1996).

Perspectives of pro-social behavior

A. Evolutionary perspective

According to Charles Darwin's Theory of Evolution, any physical characteristic or feature that an individual possesses that is dictated by their DNA and aids in their survival will be passed on to subsequent generations. He concluded that the assumption "If an organism acts altruistically, it may decrease its own reproductive fitness" was flawed in light of altruistic behaviour. This is referred to as the 'Paradox of Altruism'

Theories under evolutionary perspective

- **Theory of group/multilevel selection:** By taking into account the effects of natural selection on groups rather than individuals, it explains how altruism evolved. According to the theory of group selection, a group consisting primarily of selfish members will lose out to a group with a substantial proportion of altruists if the two groups are directly competing. Better cooperating groups thrive because they are naturally selected for.
- **Kin selection theory/inclusive fitness theory:** It claims that people have evolved to give preference to those who resemble genes. Because aiding blood relations increases the likelihood that the helper's genes will be passed on to subsequent generations, this leads to a preference for doing so. More support is given to relatives than to non-relatives, particularly when the assistance is costly (e.g., kidney donation).
- **Reciprocal-altruism theory:** This idea states that people are more willing to assist strangers if they know that they will be expected to pay back them in the future. Reciprocal altruism should make reproduction more likely for those who practise it than for those who do not.

B. Developmental perspective

From this perspective, people typically grow more altruistic as they get older, and throughout this time, their motivation shifts from extrinsic to intrinsic. Altruism develops in 6 stages.

Stage 1: Children assist when they follow rules and obey clear consequences or rewards.

Stage 2: Although obedience to authority still motivates helping, tangible benefits are no longer required.

Stage 3: While they are still capable of being motivated by tangible rewards, children are starting to assist more out of internal motivation.

Stage 4: Social standards and the lack of tangible rewards encourage children to serve others.

Stage 5: Children provide assistance to others by assimilating the concepts of mutual behavioural trade.

Stage 6: Youngsters provide a helping hand because they want to serve others and don't wait for anything in return. At this point, altruism is assisting, that is:

1. Self-selected as opposed to selected in deference to other authority
2. Reinforced inside as rather than externally

C. Socio-psychological perspective

This emphasizes a relationship between a person and society. An individual aspires to fulfil the demands of society, and society assists him in realising his objectives. An individual's personality is shaped by this interaction. Theories under this perspective are: 1. Norm theory and 2. Social exchange theory

1. Norm theory

Social norms are the expectations and guidelines that a society uses to direct its members' behaviour. Social norms have the potential to significantly influence behaviour since they cause people to behave both in accordance with and against their own interests.

- **Norm of social responsibility:** It says that when someone is dependent on us and in need, we should assist them. Consequently, adults take responsibility for children's health and safety, and educators feel obligated to their students. But because they believe that we should give others what they deserve, many selectively apply this standard.
- **Norm of reciprocity:** We believe that we have a moral duty to assist those who assist us, meaning that we should be compensated for any services rendered. This standard contributes to the development of "social-capital", or the cooperative relationships, mutual trust, and support that maintain communal well-being.
- **Norm of social justice:** It indicates that one should only lend a hand when one feels that the other person deserves it. Either by having socially desirable personality traits or by acting in ways that are desired by others, people might earn the rightful title. (If moral people find themselves in difficult situations, we owe it to them to support them.)

2. Social exchange theory

- According to this theory, people are more inclined to lend a hand if their expenses are kept to a minimum and their gains are maximized.
- The expenses of providing assistance could include: Time, effort, loss of resources, risk of danger, negative emotional reaction, and others.

Pro-social behaviour in emergency situations

There are five step response in emergency situations (Darley & Latane, 1969), which include the following:

1. Noticing the emergency: People need to become aware that an emergency has happened before they may offer assistance. Occasionally, seemingly insignificant factors, like someone's level of urgency, might blind them to the fact that someone else is in danger. According to research by Darley and Batson (1973), seminary students who were rushing to deliver a sermon on campus were far less likely to assist a seemingly hurt confederate who was moaning in a doorway than those who weren't rushing.

2. Interpreting an emergency as an emergency: Whether or not the onlooker perceives the situation as an emergency determines whether they will assist next. Ironically, people tend to think an emergency is nothing serious when they see other onlookers around. People get this pluralistic ignorance because they see other people's responses (informational impact); if they notice that everyone else is acting normally, they presume there is no danger (Latane and Darley, 1970).

3. Assuming that it is your responsibility to help: Someone has to assume responsibility as the next necessary step in order for assisting to happen. Diffusion of responsibility is a phenomenon that occurs when there are numerous witnesses; that is, as the number of witnesses rises, so does each bystander's sense of obligation to assist. Because everyone believes that someone else will step forward to assist, nobody actually does.

4. Knowing what to do: One needs to know what kind of help to offer, even if all the prerequisites are satisfied. If not, they won't be able to assist.

5. Making the decision to help: Lastly, even if you are aware of the kind of assistance that would be appropriate, you may choose not to take action because you see yourself as unqualified to assist or because you are too scared of the consequences to yourself (Markey, 2000).

Determinants of pro-social behaviour

A. Social determinants
B. Personal determinants
C. Cultural determinants
D. Situational determinants
E. Other determinants

A. Social determinants

1. **Social environment –** The current physical and financial environments.
2. **Social reinforcement –** The control of behaviour through outside stimuli like a smile, a pat on the back, some simple praise, acceptance, and sincere attention.
3. **Social responsibility –** The duty to act in society's best interests and welfare.
4. **Social justice –** Just and equitable interactions with society, including social equity, equal opportunity, and economic distribution.
5. **Social norms-** Unwritten standards that direct people's behaviour.
6. **Reciprocity-** The practice of returning favours received by an individual
7. **Social exchange-** It is the interchange of at least two people's activities, whether they are material or immaterial and rewarding or not.
8. **Socioeconomic status-** Individuals from lower socioeconomic backgrounds exhibit more sociable behaviour.

B. Personal determinants

1. **Empathy-** The capacity to comprehend and experience another person's feelings is known as empathy. It is the cornerstone of pro-social conduct.
2. **Moral reasoning-** Thinking process to evaluate the correctness or incorrectness of any notion
3. **Mood-** A broad psychological condition connected to feelings
4. **Emotions-** A consciously felt, stimulus-induced, subjectively felt emotional state that is relatively intense.

5. **Gender-** Pro-social behaviour is more common in women than in men, according to assessments from peers, parents, and teachers. Furthermore, observational studies have shown that when it comes to sharing and cooperating, females are more probable than males to do so (Burford *et al.*, 1996).
6. **Physical attractiveness-** Physical attractiveness or the appealing qualities of a person's behaviour or actions are considered forms of attractiveness (DeVito, 1976). Those who are physically appealing are more likely to get assistance than those who are not (Harrell, 1978). The argument is that, whether intentionally or unintentionally, society tends to regard attractive people differently and expects them to have better lives (Berscheid *et al.*, 1973). Physical attractiveness plays a significant role in a child's development of pro-social behaviour (Cohen, 2006).
7. **Internal joy and satisfaction-** The emotional state of happiness and excitement.
8. **Personal experience-** A large body of research examines at how one's own experiences influence self-protective behaviour. According to Christy and Voigt (1994), people who said they had experienced abuse as children were more inclined to step in and help if they witnessed a kid being harmed than people who had never experienced abuse.

C. Cultural determinants

1. **Cultural norms and tendencies (Individualistic and collectivistic)-** Members build up socialization techniques through reinforcement and observation, which control their cultural behaviour.
2. **Cultural values-** The standard used to determine if a concept or action is just and equitable, beneficial or harmful, or right or wrong (children from pro-social households tend to be more inclined towards pro-social behaviour)
3. **Cultural dimensions-** The unspoken or unwritten limits that society has set on how people should act or behave.
4. **Cultural adaptation-** The process of successfully assimilating into a different culture.
5. **Residential status (Rural or urban)-** The likelihood of assistance from rural as opposed to urban individuals is higher (Schroeder *et al.*, 2015).
6. **Religion-** People who are religious are reported to be more involved in charity and volunteer work, regardless of demographic characteristics like political inclination and money (Monsma, 2007)

D. Situational determinants

1. **Kinship-** People are more inclined to act pro-socially towards others who are similar to them or whom they find likeable as well as towards those who are regarded as near, particularly kin (Graziano *et al.,* 2007). Aside from genetic relatedness, pro-social action towards family members most likely entails affective bonds, reciprocity, and a sense of duty. Victims who are members of their in-group receive greater sympathy than those who are members of their out-group. (Flippen *et al.,* 1996). Similarities in attitude function as a heuristic cue indicating

kinship, which can inspire kin-recognition reactions (such as pro-social activity) even in the case of strangers (Park and Schaller, 2005).

2. **Situational motivators-** The circumstances-specific traits that encourage pro-social behaviour in people.

3. **Bystanders effect-** The more people there are, the less likely it is that someone in need of assistance would get help. This phenomenon is known as the "bystander effect." If there are few or no other witnesses during an emergency, observers are more inclined to act.

4. **Situational behavior-** Pro-social behaviour is greatly influenced by an individual's behaviour by the circumstances.

5. **Situational cues-** Pro-social behaviour is also determined by the signals that a circumstance generates, such as resemblance, need, appearance, need for assistance, etc.

E. Other determinants

1. Victim's perspective: Understanding a situation from the perspective of a victim involves empathizing with their experiences and considering the emotional, physical, and psychological impact of their ordeal. It's important to approach this with sensitivity and respect for the individual's feelings and autonomy. Empathy and support are crucial when considering the victim's perspective. Acknowledging their experiences, providing a safe space for them to share their feelings, and offering practical assistance can contribute to their recovery. It's important to be aware that each person's experience is unique, and responses to trauma can vary widely.

2. Identifiable victim effect: Prior studies have demonstrated that individuals tend to donate more to victims who can be identified than to those who are statistically or unidentified (Small *et al.,* 2006). Pro-social behaviour is also increased by other identifying characteristics, such as displaying a victim's face or being in proximity to them (Bohnet and Frey, 1999). In their advertising campaigns, charities do frequently describe or feature photos of specific victims to entice potential contributors; nevertheless, it appears that these initiatives are more about capitalising on the identifiable victim effect than they are about fostering a sense of "friendship" between donors and victims.

3. Attributions concerning victim's responsibility: Additionally, victims who are seen as "deserving," or whose needs originate from outside sources rather than from within, receive greater donations from the public. Therefore, it is decided that disabled children are worthy, while healthy unemployed men are not (Schmidt and Weiner 1988). Subsequently, sympathy acts as a mediator between deservingness and pro-social action, indicating that decisions are not made only on the basis of rational calculations (Weiner, 1980). According to a study conducted within New York, people were more willing to assist "blind" confederates who had fallen than "drunk" ones (Piliavin, 1969).

4. Positive friend influence: Pro-social behaviour can be significantly influenced by friends in particular. In terms of how much they exhibit pro-social behaviour and how driven they are to do so. Pro-social behaviour is more common among adolescents with friends than it is in those without. (McGuire & Weisz, 1982).

5. Age: Pro-social principles were less important to older adolescent boys than they were to younger adolescent boys. Additionally, significant age group differences were found in a study of the behaviours of teenage football players, who were recruited from age groups of under 13, under 15, and under 17. The oldest group showed more frequent antisocial behaviour and less frequent pro-social behaviour in comparison to the younger groups. (Kavussanu *et al.*, 2006).

6. Personality: Although certain pro-social activities may require a combination of additional attributes, such as perceived self-efficacy in the case of helping, individual differences in pro-sociality are linked to sociability, low shyness, extroversion, and agreeableness (Penner *et al.*, 2005). It is probable that pro-social behaviour is influenced by both contextual factors and personality traits. For instance, those who were agreeable were more likely than those who were not to assist an outgroup member; but, agreeableness was not linked to aiding an ingroup member (Graziano *et al.*, 2007).

7. Effects of positive moods: Feel good, do good: People are more likely to help others when in a good mood for a number of other reasons, including doing well on a test, receiving a gift, thinking happy thoughts, and listening to pleasant music. Good moods can increase helping for three reasons: (1) good moods make us interpret events in a sympathetic way; (2) helping another prolongs the good mood, whereas not helping deflates it; (3) good moods increase self-attention, and this in turn leads us to be more likely to behave according to our values and beliefs (Tarrang and Hargreaves, 2004)

Importance of pro-social behaviour for field extension work

- A shift from top-down to bottom-up approach, where bottom-up approach will focus more on involving the farmers in the decision- making process.
- Coordination among different stakeholders is very important for the regular supply of inputs and for creating effective marketing linkages
- Link between research institutions and the farmers because the extension agent has the work of feedforward and feedback for which extension agent requires pro-social behaviour
- Nowadays, more focus on group-led extension which involves the mobilization and organizing farmers into different groups
- Feedback for farmer-driven research-which is essential for the development of research agenda for the socio-economic development of farmers
- The basic function of extension is to bring changes in knowledge, attitude and skill of a farmer, for which pro-social behaviour is required both at extension end and farmers end
- The main aim of extension is to Help people to help themselves
- Principle of cultural difference says that to avoid the negative effects of cultural difference between extension agent and farmer we have to respect their culture and we have to behave like them while we are attending them.

Ways to inculcate pro-social behaviour

- Sensitizing them about the real condition of farmers through field visits, meetings, etc.

- Imparting them with the skills like conflict resolution, leadership etc, through training and workshop
- Inculcating it in the curriculum of students
- Encouraging institutions/individuals by offering some incentives for that pro-social behaviour
- For making field extension work successful, the extension professional and the other stakeholders should be pro-social
- Understanding the psychology behind antisocial behaviour and trying to address it
- Use social skills building apps
- Highlight individual Pro-social strengths and build upon them
- Increasing empathy
- Reducing Bystander effect

ICAR-initiatives during COVID-19 (An Act of pro-social Behaviour)

Case Study: KVK Ernakulam of ICAR-CMFRI, Kerala

Context

Hon'ble CM of Kerala urged to commence farming as lockdown activity. Whereas lack of access to seed, feed and technical support was a constraint to farmers during lockdown. KVK could not continue its regular supply of Pearl spot and carp fish seeds on first Saturday of every month (average 10,000 numbers) due to lockdown. Every month otherwise KVK used to supply to 50-70 farmers.

Intervention

Commenced farm delivery of fish seeds and feed from KVK's Satellite seed production units. Farmers registered in KVK WhatsApp number (8281757450) by hearing repeated announcements through All India Radio. Online class was delivered on 15th April 2020 by way of facebook live by SMS (Fisheries) delivered 15,000 seeds and 200 kg feed worth 1.72 lakhs during the lock down period to 46 farmers. Payment received online to KVK account at SBI, Perumpilly, Narakkal Branch

Conclusion:

Pro-social behaviours are voluntary behaviours made with the intention of benefiting others. Pro-social behaviour is often accompanied with psychological and social rewards for its performer. In the long run, individuals can benefit from living in a society where pro-sociality is common. Altruism is generally defined as any form of voluntary act intended to favour another without expectation of reward. There are various factors that affect the pro-social behaviour e.g. (i) Noticing the emergency, (ii) Interpreting an emergency as an emergency. (iii) Assuming that it is your responsibility to help, (iv) Knowing what to do, (v) Making the decision to help. Amongst the various factors affecting helping behaviour, we saw that (i) Physical attractiveness, (ii) Similarity and kinship, (iii) Religiosity, (iv) Victim's perspective, (v) Personal experience, (vi) Gender, (vii) Age, (viii) Personality etc. Pro-social behaviour is heavily influenced by the situations and experiences one has had. A person must exhibit pro-social behaviour in order to carry out field extension work that has the potential to empower agricultural households in our nation and improve their financial circumstances and farm output, as well as their prior experiences.

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HARMONIZING NATURES SYMPHONY: TREES, AGROFORESTRY AND SOIL MICROBES IN SUSTAINABLE AGRICULTURE

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Introduction:

In this chapter, we'll delve into the interconnectedness among trees, agroforestry and soil microbes, forming an ecosystem symphony where each element plays a crucial role in supporting the others. This intricate dance nurtures fertile soils and assists farmers in their pursuit of sustainable agriculture. The soil, a dynamic and indispensable resource, holds a central position in global biogeochemical cycles, ecosystem health and the production of sustainable food. However, severe degradation affects numerous farmlands (Du *et al.,* 2012), impacting soil health, which is crucial for sustaining plant life, animals and human sustenance. Soil's capacity to enhance agricultural productivity, sequester carbon, reduce nutrient loss and preserve biodiversity contributes to its overall health, encompassing the range of services it provides to ecosystems. Dryland rangelands, less productive rainfed arable lands and substantial areas of irrigated arable lands-approximately 73%, 47% and more, respectively face degradation (Gisladottir and Stocking, 2005).

Agroforestry emerges as a practical agro-ecological method guided by ecological principles and approaches in its design and management. It involves complex interactions between trees and crops, recognized as a potential avenue for bolstering agricultural sustainability (Preety, 2018). The interdependence among trees, agroforestry and soil microbes forms a symbiotic relationship that underpins a healthy ecosystem. This intricate interplay sustains soil fertility, enriches biodiversity and encourages sustainable agricultural practices.

- **Trees as stewards of soil health:**

Trees, with their extensive root systems, play a pivotal role in maintaining soil stability and preventing erosion. Their roots anchor the soil, reducing the risk of nutrient runoff and soil degradation. As trees shed leaves and other organic matter, they contribute to soil organic content, fostering a fertile environment for microbial life.

- **Microbial marvels in soil:**

Soil microbes, encompassing an array of bacteria, fungi and other microorganisms, are the unsung heroes of the underground world. They break down organic matter, decompose plant material and recycle nutrients, contributing to soil fertility. Furthermore, certain microbes form symbiotic relationships with plants, aiding in nutrient uptake and enhancing their resilience to stressors.

- **Agroforestry: Bridging the gap:**

Agroforestry, the intentional integration of trees into agricultural systems, bridges the gap between trees, soil microbes and farming practices. By planting trees amidst crops, farmers create a diverse and dynamic environment that supports a rich microbial community. This diversity enhances nutrient cycling, improves soil structure and increases water retention, benefitting both crops and soil health.

- **The symbiotic web:**

The relationship between trees, agroforestry and soil microbes forms a complex web of interactions. Trees provide shelter and resources for a diverse range of soil microbes, while these microbes, in turn, aid in nutrient cycling, enhancing tree and crop health. This symbiosis fosters a resilient ecosystem where each component reinforces the other, creating a self-sustaining cycle of growth and regeneration.

- **Sustainable agriculture and beyond:**

Understanding and harnessing this symbiotic relationship holds immense promise for sustainable agriculture. It reduces reliance on external inputs like fertilizers and pesticides, promotes soil health and fertility and enhances the resilience of farming systems to climate change and environmental stressors. Beyond agriculture, this harmony between trees, agroforestry and soil microbes contributes to ecosystem health, carbon sequestration and biodiversity conservation.

In essence, the symbiotic relationship between trees, agroforestry and soil microbes underscores the interconnectedness of nature. Recognizing and nurturing this relationship holds the key to building resilient, productive and sustainable ecosystems that support both human needs and the health of the planet. By stabilizing soil, promoting the formation of aggregates, storing carbon, improving nutrient availability and nurturing a healthy soil ecosystem, agroforestry can rejuvenate soil health. While agroforestry has been advocated for achieving carbon neutrality, several hurdles need addressing (Pan *et al.*, 2022).

1. The microbial universe beneath our feet

Beneath the surface of the earth lies a bustling metropolis teeming with life, unseen yet profoundly impactful-the realm of soil microbes. These microscopic organisms, including bacteria, fungi, protozoa and nematodes, form the foundation of healthy soil ecosystems. They are the unsung heroes responsible for nutrient cycling, soil structure maintenance and even plant health. Beneath the unassuming surface of the earth lies a thriving, bustling metropolis, hidden from our eyes but vital for life as we know it-the microbial universe. This microscopic realm is a tapestry of countless organisms, a rich and diverse community of bacteria, fungi, protozoa, nematodes and other microorganisms that form the foundation of healthy soil ecosystems. Due to various human activities in recent decades, soil fertility has deteriorated. Disruption of the natural fallow cycle due to population growth and subsequent reduction in available land per person has contributed to this decline. When natural land in temperate climates is converted to farmland, around 60% of soil organic carbon is lost, while in tropical regions, this loss can exceed 75% (Lal, 2004).

1.1.The unseen ecological marvel:

The soil, often overlooked, harbors an astonishingly diverse ecosystem. Microbes in the soil perform an array of essential functions that are integral to the health of our planet. They break down organic matter, recycle nutrients and contribute to the formation and maintenance of soil structure.

1.2.A symphony of interactions:

Within this microbial universe, a complex web of interactions thrives. Bacteria aid in decomposing organic matter, releasing nutrients essential for plant growth. Fungi form intricate networks, connecting plants and facilitating nutrient exchange, while also serving as the internet of the soil world, transmitting signals between organisms.

1.3. Guardians of soil fertility:

Soil microbes are the guardians of soil fertility. They play a critical role in the nitrogen cycle, converting atmospheric nitrogen into forms usable by plants. Some microbes form symbiotic relationships with plant roots, aiding in nutrient absorption and increasing the plants resilience to stressors such as drought or disease.

1.4. Resilience and sustainability:

The health and diversity of these microbes are indicative of soil vitality. A thriving microbial community leads to fertile soil, capable of supporting robust plant growth. Moreover, healthy soils with rich microbial life are more resilient to environmental changes, such as climate variations or disturbances.

1.5. Understanding and cultivating:

Appreciating this microbial universe is crucial for sustainable land management and agriculture. Practices that disrupt these delicate ecosystems, such as excessive tillage or overuse of chemical inputs, can harm these microbial communities, leading to degraded soil health.

In essence, the microbial universe beneath our feet is a testament to the complexity and resilience of nature. Understanding, respecting and nurturing this hidden world is key to fostering healthy soils, sustainable agriculture and a thriving planet for generations to come. Studies have demonstrated that the selection and combination of tree species within various agricultural systems, such as agroforestry systems, have an impact on multiple soil functions, termed as soil multi-functionality (SMF) (Nair *et al.*, 2009; Feliciano *et al.*, 2018).

2. Trees: Guardians of the soil

Trees, with their sprawling roots and diverse canopy, are nature's guardians of the soil. Their roots delve deep into the earth, creating a complex network that provides stability and prevents soil erosion. But it is beneath the ground where their true magic lies. Through a symbiotic relationship with mycorrhizal fungi, trees exchange nutrients, primarily carbon, for vital minerals like phosphorus and nitrogen. These fungi form vast underground networks, connecting trees and facilitating the transfer of nutrients across species.

In the intricate tapestry of nature, trees stand tall not just as majestic beings reaching toward the sky but as steadfast guardians of the soil beneath our feet. Their silent, steadfast presence embodies resilience, providing invaluable support to maintain the very foundation of our ecosystems—healthy soil. For decades, agroforestry methods have gained advocacy in both tropical and temperate regions worldwide. These practices are believed not only to enhance soil quality but also to offer various additional ecosystem services (Jose, 2009). Trees contribute to increased soil organic matter on farms, leading to heightened cation exchange capacity in soils. This capacity enables soils to retain applied nutrients more effectively and resist nutrient leaching (Young, 1989).

2.1. Rooted stability:

Trees, with their extensive root systems, anchor the soil, preventing erosion and land degradation. Their roots delve deep into the earth, intertwining and creating a complex network that holds the soil in place, especially in vulnerable areas like hillsides or near water bodies. This prevents soil loss due to water or wind and maintains the integrity of the landscape.

2.2. Organic matter contributors:

As trees shed leaves, twigs and other organic matter, they contribute to the soil's richness. This continuous supply of organic material adds to the soil's humus content, fostering a fertile environment for microbial life. Gradually, this organic matter breaks down, enriching the soil with nutrients and enhancing its ability to retain moisture.

2.3. Nutrient exchange and mycorrhizal relationships:

Trees engage in fascinating relationships with soil microbes, particularly mycorrhizal fungi. These fungi form partnerships with tree roots, extending their reach and aiding in the absorption of nutrients—such as phosphorus and nitrogen—from the soil. In return, trees provide these fungi with sugars, creating a mutually beneficial exchange that supports both parties.

2.4. Climate and water regulation:

Beyond their direct impact on soil health, trees play a pivotal role in regulating climate and water cycles. Their transpiration—where they release water vapor through their leaves—affects local humidity and precipitation patterns. Additionally, the shade provided by tree canopies helps regulate soil temperature, reducing moisture loss and preventing excessive evaporation.

2.5. Sustainable land management:

Recognizing trees as guardians of the soil is crucial for sustainable land management. Incorporating trees into agricultural landscapes or implementing reforestation efforts can significantly enhance soil health. Agroforestry systems, for instance, blend tree cultivation with agriculture, optimizing soil fertility, reducing erosion and promoting biodiversity. By emulating natural woody perennial ecosystems, agroforestry holds promise for sustaining agriculture. Furthermore, through its role as a significant source of organic matter in soil, agroforestry profoundly influences the physical, chemical and biological qualities of soil, fostering plant growth (Du *et al.*, 2012).

In essence, trees are not merely solitary entities but integral components of a thriving ecosystem. Their role as guardians of the soil underscores the profound impact they have on soil health, biodiversity and the overall well-being of our planet. Nurturing and preserving these arboreal guardians is fundamental for a sustainable and resilient future. Research by Ma *et al.* (2020) indicated that incorporating multiple tree species in agroforestry systems might enhance nutrient utilization efficiency and net primary production compared to systems involving a single tree species. Therefore, any alterations in agroforestry practices could significantly influence soil multi-functionality.

3. Agroforestry: A marriage of agriculture and trees

Agroforestry, the deliberate integration of trees into agricultural landscapes, harnesses the benefits of both trees and crops. This practice isn't just about maximizing yields; it's a harmonious relationship that nurtures soil health. By planting trees alongside crops, farmers create microhabitats that foster a diverse array of soil microbes. The presence of trees enhances soil organic matter, improves water retention and reduces soil erosion, all while providing shade and shelter for crops and livestock.

Agroforestry, the fusion of agriculture and forestry, epitomizes a forward-thinking approach to land use—one that harmonizes productivity with environmental stewardship. This innovative practice capitalizes on the benefits of trees within agricultural systems, fostering a multitude of advantages that extend far beyond the farm gate. Diversifying crops within agroforestry systems leads to higher yields of crops, timber, or fodder compared to monocropping the same species. However, the benefits of agroforestry for food systems and soil health, in contrast to tree-focused systems for biomass or lumber production, require more extensive research (Eddy and Yang, 2022).

3.1. Biodiversity and habitat creation:

One of the standout features of agroforestry is its ability to create diverse habitats. By intermixing trees with crops or livestock, it mimics natural ecosystems, fostering a rich biodiversity of plants, insects, birds and other wildlife. This diversity promotes ecological resilience, providing habitats for beneficial insects, pollinators and other organisms that contribute to pest control and ecosystem balance.

3.2. Soil health and fertility enhancement:

Agroforestry stands as a steward of soil health. Trees, with their deep-reaching roots, enhance soil structure and stability, mitigating erosion and improving water infiltration. Their leaf litter and root systems contribute organic matter to the soil, enriching it with nutrients and fostering microbial activity, thereby increasing fertility and enhancing crop productivity.

3.3. Climate resilience and carbon sequestration:

In an era marked by climate change concerns, agroforestry emerges as a climate-smart solution. Trees act as carbon sinks, absorbing atmospheric carbon dioxide and storing it in their biomass and the soil. This not only mitigates climate change by reducing greenhouse gas concentrations but also contributes to climate resilience by stabilizing local microclimates and water cycles.

3.4. Sustainable yield and economic viability:

Agroforestry systems often yield multiple products simultaneously. While crops provide short-term returns, trees offer long-term benefits such as timber, fruits, nuts, fodder, medicinal plants and other non-timber forest products. This diversification of products ensures economic stability for farmers, reducing dependency on single crops and potentially volatile markets.

3.5. Water management and erosion control:

The presence of trees in agroforestry systems aids in water regulation. Their root systems enhance soil water retention and reduce runoff, minimizing soil erosion. This aspect is particularly crucial in regions prone to drought or experiencing erratic rainfall patterns.

3.6. Cultural and social significance:

Beyond its environmental and economic benefits, agroforestry holds cultural significance in many communities. Traditional agroforestry practices often embody indigenous knowledge and local wisdom, preserving cultural heritage while providing sustainable solutions to modern challenges.

Agroforestry is not merely a marriage of convenience between agriculture and trees; it's a strategic alliance that generates a multitude of benefits. By leveraging the synergy between trees and crops, agroforestry systems offer a blueprint for sustainable land use—one that promotes biodiversity, enhances soil health, mitigates climate change, secures livelihoods and contributes to the well-being of both ecosystems and communities. As the world grapples with pressing environmental and agricultural challenges, agroforestry stands as a beacon of hope—a versatile, resilient and promising pathway towards a more sustainable future.

4. Soil microbes: Unsung heroes of farming

In sustaining life on Earth, soil plays a crucial role, particularly for organisms in terrestrial biomes and ecosystems. Its multifaceted functions, including supporting food production and serving as a reservoir for preserving drinking water, hold significant relevance to human existence (FAO and ITPS, 2015). The impact of soil microbes on farming cannot be overstated. They act as nature's recyclers, breaking down organic matter into essential nutrients that plants can readily absorb. Nitrogen-fixing bacteria convert atmospheric nitrogen into a usable form for plants, reducing the need for synthetic fertilizers. Mycorrhizal fungi form mutualistic relationships with plant roots, extending their reach for nutrients and enhancing plant resilience to stress. Within cropping systems, trees notably boost soil organic matter by 50-100% in numerous instances, facilitated by processes such as pruning, litterfall, root slough and exudates (Young, 1989). This surge in microbiological activity further stimulates the mineralization and decomposition of nutrients. Consequently, it facilitates easier nutrient absorption by plants from the soil, resulting in increased uptake of nutrients by plants (Paudel *et al.*, 2011).

Soil microbes, the invisible workforce beneath our feet, are the unsung heroes of farming and the linchpin of healthy ecosystems. These microscopic organisms, including bacteria, fungi, protozoa and nematodes, form a complex and diverse community that plays a pivotal role in soil fertility, plant health and ecosystem sustainability.

4.1. Nutrient cycling and decomposition:

Soil microbes are nature's recyclers, breaking down organic matter such as dead plants, leaves and animal remains. Through a process called decomposition, they convert complex organic compounds into simpler forms, releasing essential nutrients like nitrogen, phosphorus and potassium. These nutrients are then made available for uptake by plants, forming a vital part of the nutrient cycle.

4.2. Symbiotic relationships with plants:

Certain soil microbes form symbiotic relationships with plants, creating mutually beneficial interactions. Mycorrhizal fungi, for instance, form associations with plant roots, extending their reach into the soil and enhancing nutrient uptake, especially phosphorus and micronutrients. Additionally, nitrogen-fixing bacteria form nodules on legume roots, converting atmospheric nitrogen into a usable form for plants, reducing the need for synthetic fertilizers.

4.3. Soil structure and aggregation:

Microbes contribute significantly to soil structure and aggregation. Their secretions and activities bind soil particles together, creating aggregates that improve soil structure and porosity. This enhances water infiltration and retention while preventing soil erosion, crucial for maintaining fertile and healthy soils.

4.4. Disease suppression and pest control:

Some soil microbes act as natural protectors, suppressing soil-borne diseases and controlling pests. They compete with pathogenic organisms for resources, produce antibiotics, or induce systemic resistance in plants, contributing to disease suppression and reducing the need for chemical interventions.

4.5. Carbon sequestration and climate regulation:

Soil microbes play a vital role in carbon cycling. They decompose organic matter, releasing carbon dioxide through respiration, but they also contribute to carbon sequestration by storing organic carbon in the soil. This process helps mitigate climate change by removing carbon dioxide from the atmosphere and storing it in stable soil organic matter.

4.6. Importance for sustainable agriculture:

In the realm of agriculture, understanding and harnessing the power of soil microbes is crucial. Practices that support microbial communities, such as reduced tillage, cover cropping and organic matter addition, promote soil health and fertility while reducing reliance on synthetic inputs like fertilizers and pesticides. Healthy microbial populations contribute to resilient and productive agricultural systems.

4.7. Future directions and research:

Ongoing research into soil microbiology continues to unveil the intricate web of interactions between microbes, plants and the environment. This understanding paves the way for innovative agricultural practices that leverage microbial communities to improve crop productivity, enhance soil health and address sustainability challenges.

Through roots, litterfall and root exudates in the rhizosphere, trees contribute organic matter to the soil system (Bertin *et al.*, 2003). While nearly 50% of branches' dry weight and 30% of foliage consist of carbon (C), a significant portion of C sequestration (approximately two-thirds) takes place underground. This process involves living biomass like roots and other belowground plant components, soil organisms and carbon stored in different soil layers (Nair *et al.*, 2010). In essence, soil microbes are the unsung heroes that form the backbone of agricultural productivity and ecosystem health. Recognizing their pivotal role and fostering conditions that support diverse and thriving microbial communities is fundamental for sustainable farming practices, food security and the overall health of our planet.

5. The farmer's benefaction

For farmers, this interconnected web of life holds immense promise. Healthy soil teeming with diverse microbes translates to increased crop productivity and resilience. Reduced dependency on external inputs like fertilizers and pesticides not only cuts costs but also mitigates environmental impact. Moreover, agroforestry systems offer additional income streams through timber, fruits, nuts and medicinal products, diversifying and stabilizing farm incomes.

While crop diversification within agroforestry systems leads to higher yields of crops, timber, or fodder compared to monocropping the same crops, research on the benefits of agroforestry for food systems and soil health is less extensive in comparison to tree-focused systems for biomass or lumber production (Eddy and Yang, 2022). Agroforestry has gained recognition as an effective approach to address land degradation and aid in its restoration. Unlike monoculture systems, agroforestry integrates a variety of plant species to create a biodiverse agricultural landscape. Typically, these systems encompass a diverse blend of trees, crops, herbs and forage species, with trees as a fundamental component. This diverse composition enhances biodiversity, local ecosystem functions and services, contributing to sustainable rural development and offering numerous environmental and economic advantages. However, farmers may perceive tree planting negatively due to concerns about land occupation and the reduction of space available for food production (Leakey *et al.*, 2015).

Agroforestry, the intentional integration of trees into agricultural systems, offers multifaceted advantages that make it highly beneficial to farmers in numerous ways:

5.1. Diversified income streams:

Agroforestry systems allow farmers to cultivate a variety of products simultaneously. Trees can provide timber, fruits, nuts, fodder, medicinal plants, or other non-timber forest products. This diversification reduces reliance on a single crop, thereby stabilizing income and mitigating risks associated with market fluctuations or crop failures. Agroforestry enables farmers to cultivate multiple products simultaneously. Trees provide a range of products such as timber, fruits, nuts, fodder, medicinal plants, or other non-timber forest products. This diversification reduces dependency on a single crop and creates additional revenue sources, spreading income risk.

5.2. Improved soil health:

The presence of trees contributes organic matter to the soil through leaf litter and root systems, enhancing soil fertility and structure. This organic matter increases soil moisture retention, promotes beneficial microbial activity and improves nutrient cycling—all of which boost crop yields and reduce the need for chemical fertilizers.

5.3. Erosion control and land stabilization:

Tree roots help bind soil particles, reducing erosion and improving land stability. This is especially beneficial in hilly or sloping terrains where erosion is a significant concern. Agroforestry mitigates soil loss, preserving topsoil and maintaining fertile land for sustainable farming.

5.4. Climate resilience:

The presence of trees in agroforestry systems helps regulate microclimates, providing shade and shelter to crops. This shelter can mitigate temperature extremes, protect against wind damage and reduce evaporation, supporting crop resilience to climate variations. Additionally, trees contribute to carbon sequestration, aiding in climate change mitigation.

5.5. Enhanced biodiversity and pest control:

Agroforestry systems foster diverse ecosystems that support a range of wildlife, insects and beneficial organisms. This biodiversity contributes to natural pest control, reducing the need for chemical pesticides. Predatory insects and birds attracted to these systems help manage pests that might otherwise damage crops.

5.6. Water management:

Tree roots facilitate better water infiltration and retention in the soil, reducing runoff and enhancing water availability for crops. This is particularly advantageous in regions experiencing water scarcity or erratic rainfall patterns, as agroforestry systems can improve water-use efficiency.

5.7. Long-term sustainability:

Agroforestry embodies a sustainable approach to farming that prioritizes ecosystem health. By integrating trees with crops, farmers contribute to biodiversity conservation, maintain soil fertility and create resilient farming systems that are less vulnerable to environmental shocks.

5.8. Cultural and social significance:

Agroforestry often aligns with traditional knowledge and local practices, preserving cultural heritage while providing sustainable solutions to modern farming challenges. Additionally, these systems can offer social benefits by creating employment opportunities and strengthening community resilience.

In essence, agroforestry represents a holistic and forward-thinking approach to farming that maximizes land use efficiency, improves productivity and promotes environmental sustainability—all of which are crucial for the long-term success and resilience of farmers and agricultural systems. Nair (1984) highlighted the potential of agroforestry, agri-horticultural and agri-pastoral systems in mitigating erosion and runoff. Moreover, these systems have the capability to preserve soil organic matter, enhance soil physical characteristics, boost nitrogen fixation and facilitate effective nutrient cycling.

Also, agroforestry offers various economic benefits to farmers, contributing to increased profitability and long-term financial stability. Here's a breakdown of how agroforestry proves advantageous from an economic standpoint:

- **Long-term investment and asset creation:**

Trees in agroforestry systems are long-term investments. As they mature, they can generate significant value through timber sales or high-value products. This allows farmers to establish valuable assets that appreciate over time, contributing to generational wealth and providing financial security.

- **Reduced input costs:**

Agroforestry practices often lead to reduced input costs. Trees contribute to improved soil fertility, reducing the need for synthetic fertilizers. Additionally, the ecosystem created by agroforestry supports natural pest control, reducing pesticide expenses.

- **Improved land utilization and efficiency:**

By integrating trees with crops or livestock, farmers maximize land use efficiency. Agroforestry optimizes available space, allowing farmers to utilize marginal or previously underutilized land. This maximization of land use results in higher productivity per unit area.

- **Increased resilience to market fluctuations:**

The diverse products from agroforestry systems offer a degree of resilience to market fluctuations. While market prices for one product may vary, the diversity of products ensures a steady income stream, reducing vulnerability to price volatility.

- **Environmental stewardship incentives:**

In some regions, governments or organizations provide financial incentives or subsidies for implementing agroforestry practices. These incentives aim to promote sustainable land use and conservation efforts, offering financial support to farmers adopting such methods.

- **Cost savings on external inputs:**

Agroforestry systems reduce dependency on external inputs like fertilizers, pesticides, or irrigation, leading to cost savings. By promoting natural processes such as nutrient cycling, soil improvement and pest control, farmers minimize the need for expensive external inputs.

- **Increased value-added products:**

Agroforestry systems allow for value addition through processing of tree products. For example, fruits can be processed into jams, nuts into value-added snacks, or medicinal plants into herbal products, increasing the value of the produce and fetching higher prices.

A smaller yet still substantial portion of agricultural land, about 160 million hectares, boasts over 50% tree cover. Recognizing the potential of trees to enhance nutrition, income, housing, health, energy provision and environmental sustainability within agricultural landscapes has steered ICRAF's mission. Trees stand as the central element in the concept of "evergreen agriculture" (WAC, 2008). Agroforestry presents farmers with diverse economic opportunities. It not only generates additional income streams but also contributes to cost savings, asset creation and resilience in the face of market fluctuations, making it an economically sound and sustainable farming practice.

Conclusion: Cultivating harmony for a sustainable future

The interconnected dance of soil microbes, trees and agroforestry illustrates the blueprint for sustainable agriculture. It's a harmonious synergy that, when leveraged, cultivates robust ecosystems benefitting both the land and livelihoods. Recognizing this interdependence opens pathways to resilient agriculture, thriving ecosystems and a balanced relationship with nature. By embracing this symbiotic relationship, we pave the way toward a future where agriculture harmonizes with nature's rhythms, fostering resilient soils, abundant harvests and thriving ecosystems in perfect balance. This journey towards sustainability signifies humanity's ability to thrive in harmony with the natural world, acknowledging that our well-being is deeply intertwined with the health of our planet.

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APPLICATION OF UNMANNED AERIAL VEHICLE (UAV) IN SMART AGRICULTURE

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Introduction:

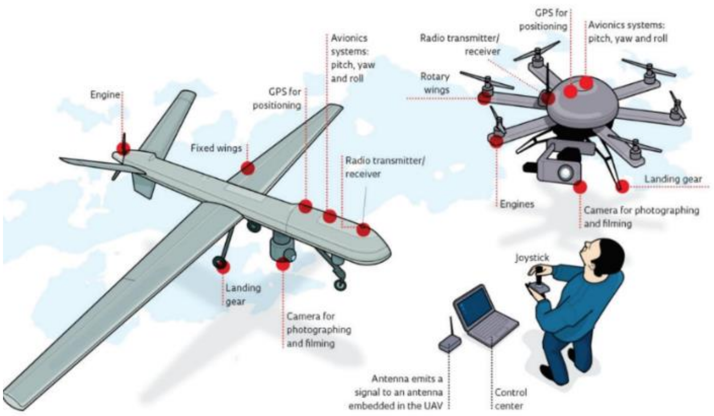
Unmanned aerial vehicle (UAV), popularly known as drone is an unpiloted, autonomous aircraft that can be operated either remotely or autonomously flown based on pre-programmed flight plans or more complex dynamic automation systems. Drones typically fly at low altitudes to acquire the remotely sensed data. For low altitude remote sensing, the most agricultural drones are mini model fixed-wing airplanes or rotary-winged helicopters of low cost, low speed, low ceiling altitude, light weight, low payload weight capability, and short endurance (Huang *et al.*, 2013). Besides fixed-wing airplanes or rotary helicopters, remote controlled kites, balloons, gliders, and motorized parafoils have been used for agricultural imaging as well (Pudelko *et al.*, 2012). The distinct feature of this drone is that it must be equipped with a low-cost imaging system, automated flight, stabilized by inertial navigation sensors that include global positioning system (GPS) that is able to geocode aerial photographs. The desirable resolution is about 1–2 centimeters, a relatively better image resolution than that of any satellite-based images (Yusof *et al.*, 2006).

Historically drones are better known for their role in defense operations due to their ability to be customized and their remote capabilities. Drone technology is rapidly developing in marine and under water work and research environments, such as automated under water vehicles (AUVs), possess technology to capture pictures of the seabed, fish and surrounding areas to help researchers in oceanography or habitat research. Similarly, AUVs are also used in the in the oil and gas industry to carry out inspection activities and by defense for search operations.

However, automated drone technology is in relatively infantile in agriculture, but some automated drones are being used for data collection, automated seeding and pollination without the need of operators. Drone applications have been attempted for animal tracking and monitoring on farming, such as domestic livestock management, pasture utilization, livestock behavior, and grazing distribution monitoring. In addition, farmers will also be assisted in livestock theft or death detection. In global scenario, the application of drone technology in modern agriculture is gaining importance and so is the case in India. In our country, drones have recently become the subject of several studies to evaluate their applicability for precision agriculture applications. Several successful drone studies have been reported using small, lightweight cameras on board, performing spraying, sowing operations, surveying, mapping etc. Hence, the focus of this article is to present an overview of the structure of drone technologies and its applications in agriculture, which will be useful to various stakeholders in adopting precision agriculture.

Drone types

Drones are generally classified into three main categories, which are the fixed wing, rotary wing and hybrid vertical take-off and landing (VTOL) drone. Fixed wing drones have the advantage of being able to fly at high speeds for long duration with simpler structure. These drones have the disadvantage of requiring a runway or launcher for takeoff-landing and not being able to hover. On the other hand, rotary wing drones have the advantage of being able to hover, takeoff and land vertically with agile maneuvering capability at the expense of high mechanical complexity, low speed and short flight range. This makes them the perfect instrument for detailed inspection work or surveying hard-to-reach areas. The structure of the fixed and rotary wing drones is presented in Fig. 1a. Drones with combined features of fixed wing type and rotary wing type are known as VTOL drone (Fig. 1b). VTOL drones are like multi-rotor systems in terms of takeoff efficiency. VTOL drone is used for surveying and mapping, agricultural monitoring, disaster management, traffic handling, wildlife and forest cover, and military uses.



(a) fixed and rotary wing

(b) hybrid- vertical take-off and landing drone

Fig. 1: Drone types

Classification of drone based on all-up weight

Table 1. Classification of drone based on its all up weight (Anonymous, 2021).

Types of drones	Weight	Remote Pilot license
Nano	≤ 250 g	Not required
Micro	250 g to 2 kg	Not required for non-commercial use and required for commercial use
Small	2to 25 kg	Required
Medium	25 to 150 kg	Required
Large	> 150 kg	Required

Drones can be classified as nano, micro, small, medium, and large drone based on the all-up weight including payload (Anonymous, 2021, Table 1). As per the guidelines of directorate general of civil aviation, GOI, it is mandatory to have remote pilot license for the person who wants to operate drones of higher weight than nano drones (more than 250 g).

Basic components of a drone

Components of a drone have been shown in Fig. 2 and discussed in following subsections:

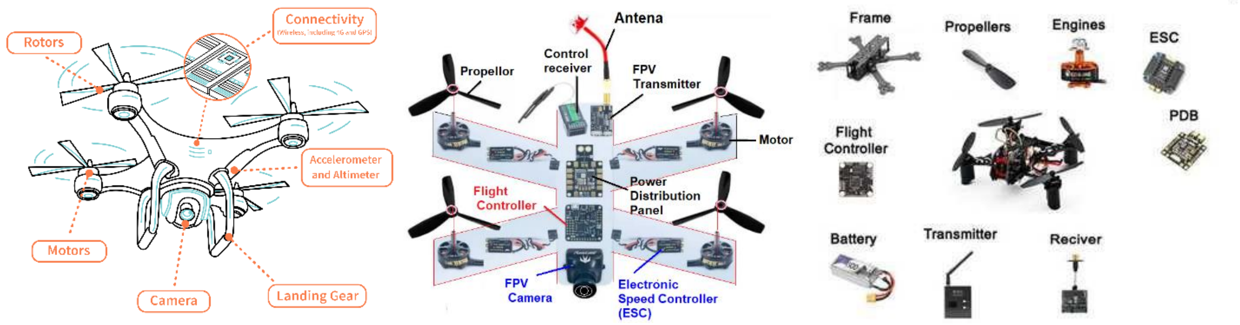


Fig. 2: Components of drone.

Frame: The skeleton of a drone is the frame (chassis), motors, propellers etc. are attached to the chassis. Frames come in a variety of sizes and weight ratings. The most common one is X shaped frame.

Motor: The motors (4 nos. in Quad copter) are provided to spin the propellers. The higher the kV, the faster the motor can spin. However, faster is not always better. A fast motor spin requires much more power from the battery, causing the flight times to decrease. More rpm also decreases the life of the motor over long run.

Propeller: A quad copter has four propellers, two propellers at the front that spin counterclockwise, and two propellers ate the back that spins clockwise. The front propellers pull the quad copter through the air like a tractor. Hence, these propellers are called “Tractor” propeller. The propellers at the back side push the UAV forward, hence the name “Pusher” propeller. Most drone propellers are made of plastic or carbon fiber.

Flight controller: It is the ‘Brain’ of the quad copter. The flight controller interprets input from receiver, GPS module, battery monitor, inertial measurement unit (IMU) and other onboard sensors. It regulates motor speeds, *via* ESCs, to provide steering, as well as triggering cameras or other payloads. It controls autopilot, waypoints, failsafe, and many other autonomous functions.

Radio transmitter and receiver: To control the drone by the operator, ground control station (GCS) is used by the radio transmitter and receiver. The receiver in the flight controller receives signals from the transmitter. Minimum of 4 channels is required to operate any function of the drone. The 4 channels means that there are 4 channels on the GCS (remote) that control the motion of the helicopter as: up/down (channel 1), turn left/right (channel 2), forward/back (channel 3), and left/right lean aka aileron (channel 4). In the marker we can have more channel GCS according to the use.

Battery and charger: Lithium ion/Lithium polymer (LiPo) batteries are mainly used to supply power to the UAV. Because, it has high energy density, power density, and lifetime. For getting the longer duration operation, a high capacity (in terms of mAh and C rating) battery is required, but it causes the increase of load in quad copter due to its weight. Hence, optimum selection of battery capacity is very important.

Camera: For recording video and taking hyperspectral and multispectral images, a good quality camera is provided. The latest drones are all in one, which come with an integrated gimbal and camera. These cameras and lens are specifically designed for aerial filming and photography.

Sensors: Different types of sensors like thermal sensor, collision avoidance sensors, terrain following sensor obstacle detection sensor and many other types of sensors being mounted onto drones and being used in a wide variety of sectors according to specific application.

GPS module: GPS is an important requirement for waypoint navigation and many other autonomous flight modes like return to home (RTH), GPS coordinates for spraying particular area, measuring /surveying of area etc.

Application of drone technology in agriculture

Applications of high-resolution aerial sensing in agricultural field

Drone with suitable sensors for remote sensing of plant responses (to induced abiotic and biotic stress) and performance (yield) in field conditions have several benefits. The integrated system can provide (i) better access to the field, (ii) high-resolution data (1–2cm depending on flying altitude), (iii) timely data collection (even under cloudy conditions), (iv) quick evaluations of the field growth conditions, (v) simultaneous image acquisition, (vi) self-automated flights for monitoring the plots at regular periods in a given growing season; and (vii) low operational costs. Sensors such as thermal cameras, hyperspectral camera, multispectral camera, and Light Detection and Ranging (LIDAR) systems can be used for measuring crop growth and development (Tiwari *et al.,* 2019). The sensors can be based on spectral interactions between object and the electromagnetic spectrum such as reflectance or emission in visible and infrared regions or time-of-flight of sound/light signals. The applications of time-of-flight based sensors are commonly used for evaluating physical/morphological plant characteristics such as plant growth, height, and canopy volume/vigor. In regard to the spectroscopic and imaging techniques, a number of plant phenotypes such as disease susceptibility, susceptibility to drought stress, chlorophyll content, nutrient concentrations, growth rates, and yield potential can be evaluated (Zhang and Kovacs, 2012). The plant trait can be related to wavelength of spectral radiation and amount of light energy emitted/absorbed, as sensed by the detector in the sensing module. Fluorescence, visible, near infrared, multi/hyperspectral, and thermal spectroscopic techniques work on these principles, although each have their unique characteristics. Figure 3 shows different kind of sensor used on drone.

There are several remote sensing applications in precision agriculture using small UAVs (Sahni *et al.,* 2018). Some of those include: weed detection, aerobiological sampling, leaf area index estimation, soil characterization, water status, diseases, pest management and yield estimation. Table 2 show the different sensors and its characteristics which can be mounted on UAV and data can be collected.

Fig. 3: Sensors integrated with Drone (Khot, 2017)

Mapping of crop health using drone surveillance

Drones carrying high-resolution multi-spectral, hyper-spectral and thermal cameras are being used to develop monitoring systems to help growers assess the health of their crops. Monitoring and mapping of horticulture crop health, one of which targets water stress in fruit trees and grape vines. Water stress causes trees and vines to shut down their transpiration systems, which normally help keep them cool, in order to conserve water. As a result, the temperature in the plant canopy rises, and this can be captured by the thermal cameras on drones flying overhead. The thermal data is used to generate a water stress map of the crop, at a pixel resolution of 10 cm, within an hour. Water stress is otherwise measured tree-by-tree, with tests that take about 30 minutes each. This system has the potential for widespread horticultural application as both drone and sensor technology become more affordable, and software is developed to automate the collection and interpretation of thermal data. For orchardists and vineyards, maintaining a slight water stress helps to increase the sweetness – and the value – of their fruit.

Disease identification of agricultural crops

Drones have been utilized in agriculture in cooperation with image processing technologies for phenotyping and vigor diagnosis. One of the problems in the utilization of UAVs for agricultural purposes is the limitation in flight time. It is necessary to fly at a high altitude to capture the maximum number of plants in the limited time available, but this reduces the spatial resolution of the captured images. It is essential to assess crop health and spot bacterial or fungal infections on trees/plant. By scanning a crop using both visible and near-infrared light, drone-carried devices can identify which plants reflect different amounts of green light and NIR light. This information can produce multispectral images that track changes in plants and indicate their health. A speedy response can save an entire orchard. In addition, as soon as a sickness is discovered, farmers can apply and monitor remedies more precisely. These two possibilities increase a plant's ability to overcome disease. And in the case of crop failure, the farmer will be able to document losses more efficiently for insurance claims.

Judicious and precise application of agrochemicals

Researchers estimated that aerial spraying can be completed up to five times faster with drones than with traditional machinery. Some of the aspects that give drones a competitive edge over manned crop dusters are their relative ease of deployment, reduction in operator exposure to pesticides, and potential reduction of spray drift. Drones are capable of spraying 1.15 and 1.08 hectares per hour for groundnut and paddy crop, respectively. Spraying the pesticide with drone from 3.5 m height gives higher droplets coverage rate and uniformity on wheat canopy than ground spraying. Use of drones to spray pesticides can save about 80% of operating time, 90% of water consumption and 50% of pesticide use (Varma *et al.,* 2022). This technology helps in utilizing water economically because it uses ultra-low volume (ULV) spraying technology. Foliar application of nutrient, plant protection chemicals and fertilizers with precision on taller trees (litchi, mango, guava, sapota, jackfruit etc.) and field vegetable crops. With the use of drones, over and under use of agrochemicals can be checked and target application of these can be ensured.

Horticulture and plantation crop management

This includes applying fertilizer at the appropriate time, inspecting for insects, pests and monitoring the impact of weather conditions. A combination of drones equipped with multi-spectral sensors and satellite based remote sensing platforms can be used to estimate area under different horticultural crops in the region. Spread of water bodies and area under makhana, singhara and other water loving crops for proper planning and management. It also helps in water resource mapping at villages or watershed scale.

Crop and weed species distribution and mapping

The use of UAV's equipped with advanced cameras and sensors capable of detecting specific weeds. More precise weed management planning can improve the effectiveness of mechanical methods and reduce herbicide application. It can also delay the emergence of weed resistance.

Seed sowing

A seed dropping mechanism using drone, seeds are dispersed upon reaching the predetermined positions, with maximum capacity of 60 seeds per minute and also capable of dropping 28800 seed balls in 8 hours (Ghazali *et al.*, 2022). Start-ups have developed drone seeding/planting systems that achieve an uptake rate of 75% and decrease sowing costs by 85%.

Mapping and soil analysis

Compared to terrestrial mapping, drone mapping has a lower implementation cost, about 68 times faster, and requires low manpower (Ghazali *et al.*, 2022). It is also helpful in acquiring information such as pH level, soil type, and chemical contents in the soil. Drone in combination of ortho photos, multispectral images, and digital surface model data produced the most accurate classification, with accuracy rate near 90%.

Restrictions of using drones in agriculture

Drones have many restrictions such as standards, cost, payload, operation and reliability for practical applications in agriculture. There is no standard protocol for any single project both technically and economically. Although the costs of the aircraft and the camera could be minimized, the assembly and integration require significant labor and time even for highly skilled technicians and engineers which may increase total cost. Lightweight done payload is the most important limitations in agricultural applications. For the users and designers of UAV systems choosing the optimum payload for the mission requirements is of prime importance (Torun, 2000). Payload design, mechanical, and electrical accommodation for drones are critical concepts for successful agricultural applications. Drones can be operated both automated and manually. GPS based autonomous flight is a highly desirable component for practical use of drones in agriculture. Crashes and component failures are driving up the cost of drones and limiting their availability for agricultural operations. Researchers in the field believe the low-cost requirements are causing designers to limit safety requirements, and that increased safety and reliability is needed to ensure UAVs are trusted to perform tasks (Bhamidipati and Neogi, 2007).

Future Scope:

From the future perspective, agriculture drone can assist farmers to reduce excessive use of water and will contribute to reducing the chemical load on the environment by spraying on the plant that requires attention. It also used sowing for both crops and reforestation in both plane and difficult areas within no time. Therefore, in future this can be called a green-tech tool. Drones are not only confined to the agriculture sector but can be successfully used across several industries. Governments of developed countries is focusing on setting out the favorable strategy for enhancing the use of such drones by increasing the funding and commercializing agriculture technologies.

Conclusions:

The precise soil and plant properties can be determined by image processing methods such as historical yield maps, core and leaf samples, aircraft, and satellite imagery. However, image resolution is one of the most important problems in these methods. Also, these methods often can be incomplete or time consuming, and when data is collected it can take a long time to process and analyze. Today, one of the most popular methods to identify soil and plant properties is low altitude aerial images. For this purpose, drone is the most popular vehicle. Drones provide real time and high-quality aerial imagery compared to satellite imagery over agricultural areas. Also, applications for localizing weeds and diseases, determining soil properties, detecting vegetation differences and the production of an accurate elevation models are currently possible with the help of drones. Drones will enable farmers to know more about their fields. Therefore, farmers will be assisted with producing more food while using fewer chemicals. UAVs might involve fleets, or swarms, of autonomous drones that could tackle agricultural monitoring tasks collectively, as well as hybrid aerial-ground drone actors that could collect data and perform a variety of other tasks.

Variable rate spray technology is the core of precision UAV based spraying. An economical and user-oriented system is needed that could process spatially distributed information and apply only the necessary amounts of pesticide to the infested area efficiently and to minimize environmental damage. As drone based aerial spraying application with high-degree atomization of spray liquid, droplets easy to drift, in order to ensure the effective application supporting technologies for such as R&D technologies for nozzle, chemical agent and adjuvant, etc., which have a huge research potential. In which, these nozzles may include the electrostatic nozzle, the adjustable spray nozzle for droplet size and spray flow, chemical agent for aerial spraying by UAV may include the ultra-low-volume liquid the nano biological agent, chemical adjuvant for aerial spraying by drone. The development and application of these technologies will provide a strong guarantee for precision agricultural aviation application by effectively reducing drift and loss of droplets and promoting the absorption of the active ingredients in crop.

The vast application of drones in agriculture can transform the traditional method of farming into smart farming. Drone technology implications in agriculture not only improve the crop production but also transforms the farmer to protected scenarios. According to the various reports and documents, in the Indian context, these technologies have very limited application. But this may be increased in near future for various application such as efficient water management, characterizing water bodies, planting, livestock monitoring, soil health monitoring, disease, and pest control and vice versa, from farm to household for multiple uses. It has numerous advantages; save about 80% of operating time, 90% of water consumption, 50% of pesticide use, decreasing fertilizer costs and increasing yield, decrease planting costs by 85% and so on. In Indian context, both federal and state governments are trying to popularize this advance technology through various policies and scheme in agriculture through SAUs, KVKs, government and private institutions and agri- industries.

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HYBRIDIZATION IN CROSS POLLINATED CROPS: AN OVERVIEW

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Hybridization in cross pollinated crops

Pollination plays an important role in the life cycle of a plant and as per its types the crop plants are called self pollinated crops (same flower) and cross pollinated crops (different flower). Breeding in self pollinated crops has been described.

In cross pollinated crops the pollination occurs by transfer of pollens from an anther in the flower of one individual to the stigma of a flower present on another individual. The common example of cross pollinated crops are maize, bajara, sugarbeet and many forage or fodder grasses like Anjangrass, Bermuda grass, Bunch grass and Sudan grass. In cross pollination pollinated crop plants the floral structure and mode of pollination exhibit considerable variations. Therefore these crop plants require specific and different methods for breeding.

The cross pollination crop species are highly heterozygous as well as homozygous. The breeding methods selected for cross pollinated crops are therefore essential to remove the inbreeding to keep inbreeding depression. The common method areuse for cross pollinated crops are divided into two categories. i) for population improvement ii) for hybrid and synthetic varieties. The two important features of cross pollinated crops are increasing depression and heterosis i.e. hybrid vigour. The inbreeding depression can be kept a minimum by population improvement method but they are not useful for heterosis. The hybrid varieties are generally developed to get maximum hybrid vigour but under certain condition they are only methods which can be used to get increase in the yield. In India all most all maize varieties under cultivation in different regions are hybrid vigour or systematic varieties. The method are used only for production of hybrid and systematic varieties in cross pollinated crops.

The hybrid varieties are the first generation (F_1)from crosses between two purelines, inbreed, open pollinated varieties, clones or other population that are genetically dissimilar. In the present only inbreed lines and hybrid varieties development from inbreed have been described.

Inbreeds lines

The inbreeding means mating of individual more closely related by ancestry and it is responsible for loss of vigour. An inbreeds nearly homozygous line obtained by continuous inbreeding of cross pollinated species with selection accompanying inbreeding perfably by self pollination so inbreed line can be defined as a nearly homozygous line developed by contained inbreeding usually selfing accompanied by selection. To induce the hybrid vigour and improve the nature of the inbreed crossing between two inbreeds is carried out and for this crossing different methods are fallowed. In these crossing methods when two inbreeds say A and B are crossed to produce the hybrid (A X B) it is known as single cross when two single crosses say (A X B) and (C X D) are crossed the resulting hybrid (A X B) x (C X D) is known as double cross. A three way cross is a cross between a single cross (A X B) and an inbreed (C) to yield (A X B) x (C). When an inbreeds is crossed with an open pollinated variety it is known as an inbreed variety cross or top cross.

Development of inbreed lines

The inbreeds lines are developed from a genetically variable population by continuous interbreeding and then selfing of individual. The population from which the inbreed lines are developed and isolated is called source population. The source population is generally on open pollinated variety but sometimes it may develop from a synthetic cross or single cross or double cross variety. The inbreed isolated from source population but not used for population improvement. The development of first cycle inbreeds which are generally used for different types of crosses require a suitable system of close inbreeding. The system should include self pollination as it is essential to increase homozygosity and homogenous nature of inbreeds require for successful crossing. The system generally used for the development and isolation of inbreeds show the following steps.

1. Step-1-First year: The individual are vigorous, disease free and with other desirable characters are selected from source population and allowed to undergo self pollination.

2. Step-1-Second year: About 30 to 40 plants are with sufficient space in between using seeds obtained from each of the selected individual in step-I. From these plants the best individual in different rows are selected and are again allowed to undergo self pollination.

3. Step-3-Third year to sixth year: During these years the process at step-2 is repeated and plants are allowed to undergo only self pollination with increasing self pollination individual become more and more homozygous. By very critical selection out standing individual are selected.

4. Step-4- seventh year: At this stage all the selected individuals are almost homozygous. These inbreed are maintained by Sib pollination instead of self pollination. These inbreeds lines are then used for different crosses in hybrid seed production programme.

Use of inbreeds in crosses for production of hybrid:

The selected inbreed are combined by any one of the following methods for crossing 1. Single cross 2. Double cross and 3. Top cross.

1. Single cross: When a cross is made in between two inbreeds such as AXB and CXD it is called single cross. This was initially proposed by Shull in 1909. The product of this crop is hybrid which is given to farmer for cultivation. When single cross is to be made two rows of female parents alternate with one row male parents are planted. By this planting method about two third of the available field area can be utilized for production of hybrid seeds.

The product of each single cross is a hybrid and it is with maximum hybrid vigour. It produces plants with maximum uniform characters due to which years in crops like Bajara, Jowar and Maize etc. are of uniform nature. TheF_1 plants produce better yield than the parents but this character does not remain in further generation the farmers have to use fresh hybrid seeds to grow the crop. The single cross are commercially required as foundation hybrid for double crosses and three way crosses. The single crosses can predict the performance of a double cross. To get maximum success in single cross the made sterile inbreed is used as a female parent.

Example: Sorghum variety CSH-1 is produced by single cross between (A) Kharif 60 Ms x B yellow endosperm variety. This sorghum variety is with early to medium maturity creamy white seeds and gives higher yield than local varieties.

2. Double cross: The cross between the product of two single crosses (A X B) x (C X D) involving four inbreed is called double cross, for the double cross when inbreed are selected the care is taken to avoid the repeatation of inbreed line in both the single crosses i.e. in all the inbreeds be four and not less in number. Normally for single cross the closely inbreeds are selected but in case of double cross the inbreeds should be with variation and distantly related. In double crosses the inbreeds which are involved can include male sterile line if required.

The double cross hybrid seeds are developed using hybrid individual of one single cross i.e. A x B as a female parents and the other i.e. C x D as a male parents. The double cross is produced by alternate with one row of male plants. This 4:1 female: male ratio is useful to utilize the 80 % available land for production of hybrid seeds.

Application of double cross

The double crosses are widely used for production of commercial hybrid seeds of many varieties of crops. All maize hybrid distributed to farmers in the different regions for cultivation are produced from double crosses. In maize the single cross hybrid seeds are usually small in size irregular in shape and their yield is very low. All the double cross hybrid seeds are high yielding larger uniform in shape and can be cultivated without any increase in the cast of production. As these seeds can be produced in large quantities because of high yielding nature they can meet the demands of farmers at relatively low cast. The double cross seeds in maize and other crops exhibits greater variability than the single cross seeds and this variability is useful for wider adaptation.

Examples: 1. Maize: Ganga this hybrid is produced from two single cross hybrids (CM 109 X CM 110) X (CM 202 X CM 111). 2. Pearl Millet (Bajara): a) HB-1 (Tift-23 A x BIL-3 B) b) NGB-5 (MS-5071-A x K 559).

3. Three way cross: The three way cross from its name indicates the involvement of three inbreed lines. When this single crosses parent used is a product of single cross i.e. with two inbreed lines. When this single crosses parent (AxB)is crossed with another inbreed lines (C) the product obtained is the mixture of three inbreed lines. The involvement of the third inbreed line in the form of male parent make the three way cross. The third inbreed line selected is usually high yielding variety. This parent in the cross increase the probability of combining the desirable characters from another good inbreed line.

For the three way cross the single crossed variety and the inbreed line are planted in the same way as the inbreeds in the single cross. The main advantage of three way is the utilization of the hybrid vigor in the single cross first generation (F_1) in the form of female parent in order to get maximum yield of hybrid seed as well as the normal size and uniform shape in the seeds. In case of maize the single cross produces small irregularly shaped seeds with relatively low crop yield. The disadvantages can be removed by three way cross using suitable additional inbreed line in the form of male parent. The three way cross was initially used to obtained good seeds in sweet corn variety of maize in U.SA.

The three way cross produces a maize efficient mating system for obtaining varieties with improved performance. In this cross the selection and choice of the third inbreed line is very important because the contribution of this time (C) in the form of male parent in the genetic make up of hybrid seed is about 50 % while the contribution of remaining two inbreed lines (A) and (B) involved in the original single cross will be 25 % each. The important observed in the three way cross is obtained high production of pollen from inbreed line in the form of male parent. The nature of the hybrid seeds obtained from three way cross is more or less intermediate between single and double crosses as for as characters genetic variance and the yield are concerned.

Example: Maize-Ganga Safed, Hybrid makka-2, Hi-starch hybrid makka.

Top cross or inbreed variety cross (A x Variety): This is the cross between an open pollinated variety and inbreed line. This can also be defined as the progeny from out crossed seeds of selection or lines or clones to a common pollen parent heterozygous possessing wide genetic base.

The top cross are not used for hybrid seed production but they are mainly used for testing combining ability of inbreed lines. The cross method allows not only testing of large number of inbreed lines of once but also provides basis for discarding more than 50 % of the tested lines. The early testing method of inbreed lines save considerable time. Tenkins in 1935 suggest this method. It consists of derivation of inbreed lines by inbreeding and their top cross testing both carried out simultaneously.

Early identification S_1 (F_1 generation of selfing) lines with superior combining ability plays an important role in the success breeding programmes. This method of testing for combining ability is profitable where material has previously been selected visually for desirable characteristics like vigor, stalk strength etc. The early testing method in such condition is appropriate for isolating families of high combining abilities better character select and poor are eliminated during inbreeding.

Top cross testing is regarded as the earliest and quickest method of eliminating bulk of poorly combined inbreeds line. It measures the ability of inbreed to produced superior hybrids in combination with other inbreeds. This testing should be done for these inbreed lines which are acceptable on agronomic standards. Selection based on top cross performance gives the best general combines.

Synthetic cross: In this cross number of inbreed lines, clones or sibbed lines are crossed to utilize the desirable characters from different success. Synthetic varieties may be mixture of seed harvested from few carefully selected plants. Also genotypes having good combining ability are selected and crossed in all possible combination. Usually a number parental lines that enter in a synthetic variety may range from 5 to 10. The methodology for evolving synthetic variety essentially consists of 1. Hybridization of several tested good combining inbreeds. 2. Allowing natural cross pollination in them for number of cycle until the variety shows homozygosity in its phenotype.

The synthetic varieties are used for the improvement of forage crops, sugar beets and maize etc. In forage crops where floral structure more difficult in artificial pollination, synthetic cross proved to be useful. Many new varieties of forage are being developed by mixture together seeds of individuals plants into a synthetic variety. The synthetic varieties are reconstructed at frequent intervals if they show signs of loss of vigor. The compounding of compound strains into synthetic varieties is totally depend upon their combining ability. Synthetic varieties of maize of superior to open pollinated varieties form which inbreeds lines were derived but they show low yield as compared to best F_1 hybrid formed by crossing inbreeds lines.

As natural pollination is allowed in synthetic crosses there is no necessity of producing seed in isolated plots. The utility of synthetic variety over double crosses is not from the view point of superior quality but for its cheaper cost of seed production. Further they can be used for a number of generation. Unlike hybrid variety. The second merit of synthetic cross over the open pollinated varieties is the existence of hybrid vigour (heterosis) in them. The synthetic varieties are more flexible than double crosses. They get adapted to the flexible growing condition of different areas.

Examples: As the welsh plant breeding station a large number of superior strains were produced by synthetic cross method in several forage crops. Multiple strain variety developed in U.S.A. is Ranger leucern was synthesized seeds of 5 strains.

Heterosis or hybrid vigor: Hybrid vigor or heterosis can be defined as the increased vigor or desired like growth, size, yield of a hybrid progeny F_1 over the parents (P_1P2) which is resulted from cossing the genetically unlike organism or it can also be defined as the increase in vigor or growth of hybrid progeny in relation to the average of parents. Thus the hybrid vigor is the result of hybridization. The terms heterosis and hybrid vigor used as Synonyms but heterosis is in a fact a phenomenon and hybrid vigor its result.

Hybrid vigor was by Koelreuter as early as 1763 in Tobacco whereas the hybrid plants exhibit luxurious growth. The report of more productivity of hybrid maize than the parents came from Bael in 1880 Dr. G. H. Shell in 1940 observed that after self pollination the inbreed lines under go loss in vigor but when inbreed line were crossed the vigor was completely recovered. The yield comparison was between pure strains and hybrids.

Example of hybrid vigor: The effect of hybrid vigor are expressed in the following ways. i. Increase in plant size. ii. Height of the plant iii. Size of the leaves root system and iv. Size and number of grains. In self pollinated crops hybrid vigor is obtained by producing F_1 progeny in sufficient quality to be grown on field scale. This method is used in vegetable crops such as tomato and cucumber which set large number of seeds from single pollination.

In maize the cross pollination crop thee hybrid vigor utilization has proved to be the most beneficial process of data selling during early days and use of male sterile lines in relatively recent period has early boosted the hybrid seed production in maize and also other cross pollinated crops like sorghum and sugar beet etc. The supply of quality seed i.e. seed showing full vigor health and high yield is the main aim of hybrid seed production which is obtained through hybrid vigor.

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TRAPS IN AGRICULTURE SERVE AS ADAPTIVE TOOLS FOR MONITORING INSECT POPULATIONS, ASSESSING DIVERSITY, AND PLAYING AN INTEGRAL ROLE IN INTEGRATED PEST MANAGEMENT (IPM)

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Abstract:

Monitoring insect pest activity in agricultural ecosystems is one of the requirements for farmers to anticipate any risks to their field crops. It is well knowledge that artificial light sources attract moths and other evening arthropods, such as various types of moths and beetles. In order to capture pests that are active during the day, farmers often utilize colored traps, such as yellow pan traps or yellow sticky traps. When attempting to forecast when aphids will begin to spread, a yellow pan trap is very useful. The yellow pan trap works very well for predicting outbreaks of aphids. Traps may be used with or without attractant signals, and to increase their specificity and efficacy, they combine chemical (food/host, pheromone, Para pheromone, oviposition), visual (color, light, and form), and auditory stimuli. A good way to prevent infestations of insect pests is to inspect grain kept in bins every two weeks. This process aids in identifying early signs of infection or degeneration. There are several tools available for grain sampling and insect detection, giving farmers a wide range of choices for efficient pest control. Technological innovations have led to the development of automated monitoring systems that send data to an offsite station on trap catches. The effectiveness of pest control programs is increased by this real-time data transfer, which offers precise and timely insights for well-informed decision-making. In conclusion, different trapping methods, frequent monitoring, and insect traps are essential elements of insect pest control systems. They support the preservation of agricultural productivity and preventive pest management.

Introduction:

Integrated Pest Management (IPM) is a comprehensive approach to pest control that aims to manage pests in an environmentally responsible and sustainable manner. One crucial component of IPM is the use of traps, which serve a multifaceted role in this integrated strategy. Traps are tools designed to capture or monitor specific pest species, and they play a pivotal role in pest detection, population management, and the reduction of the reliance on chemical pesticides. Their role in IPM encompasses not only targeted pest control but also the minimization of environmental impacts, cost-efficiency, and the promotion of more sustainable agricultural and pest management practices. Finding early signs of illnesses and insects pest as well as prospective biocontrol strategies in real-life situations is the aim of pest monitoring.

Monitoring of insect pest activities in Agricultural ecosystems is one of the prerequisites for farmers to predict the pests that will be likely to occur in their field crops. Traps are helpful for the farmers to decide on methods/or times of plant protection interventions including pre or post-infestation measures to be executed. Traps are 'Farmer's Eco-friendly Tools' to monitor and mass trapping of insect pests which envisages the ways to maintain the infestation below the economic threshold level, besides safeguarding the environment, natural resources, and non-target organisms. Some of such kinds of traps are

A trap is a device that impedes or stops the progress of an organism. These traps provide valuable information on the insect population fluctuations and their peak period of emergence as well as their activities. Traps are also useful in mass trapping and killing insects. The various types of traps have been developed based on factors like physical (light and sticky traps), chemical (pheromone and bait traps), and mechanical (suction, pitfall, and emergence traps). Currently, they are employed by entomologists in the integrated pest management of many agricultural insect pests.

Why traps are useful

In addition to providing a relative estimate of insect density, trap captures may alert people to the presence of pests, hot areas, insect movement, and activity. Assessments of the numeral of adult pests caught on sequential sampling dates may indicate whether the pest density in crops is changing or remaining relatively constant over the long term (Gillespie and Quiring, 1987; Higgins, 1992). Evaluating trap catches can help in determining the need for treatment, the timing of applications, and the effectiveness of previous control actions. Growers can identify the direction from which insects are migrating by clustering two or more traps near entrances, air vents, and both inside and outside of growing areas. They can do this by orienting each trap in a different direction and comparing the proportion of pests caught on trap surfaces facing different directions. In this context, traps are indispensable instruments that help growers and pest management professionals make informed decisions while safeguarding ecosystems and ensuring food security.

1.0. Light trap

The attraction of moths and other nocturnal insects to light is a well-known phenomenon and has been used for collecting nocturnal insects since the beginning of the eighteenth century. Many kinds of moths and beetles, which are nocturnal arthropods, become attracted to artificial light sources (Nag and Nath, 1991; Axmacher and Fiedler, 2004). The first purpose-built devices termed light traps were used by the Romans in the first century AD (Morge, 1973; Beavis, 1995). Light-trapping refers to all methods of attracting and/or capturing nocturnal insects with lamps or artificial light sources that usually have a strong emission in the ultraviolet range of the spectrum, whether they are connected to a trap or just being operated in front of walls or other reflective surface.

1.1. Light Sources:

Electric:

Incandescent (tungsten filament): Good for leafhoppers, gall midges, and paddy pests.

Mercury vapor lamps (MV): Efficient for attracting most insects, including Lepidoptera and Coleoptera.

Compact fluorescent lamps (CFL): Energy-efficient alternative to MV lamps.

Ultraviolet (UV) lamps: Highly effective for diverse insects, primarily used in developed countries.

Non-electric:

Kerosene and LPG gas lamps: Affordable alternatives where electricity is unavailable.

Carbide (acetylene) gas lamps: Powerful light source but potentially explosive.

Oil torches: Eco-friendly option using waste oil.

Mode of action

Various light sources provide visual cues to the insects and attract light by stimulating the compound and simple eyes of the insects.

Time of operation

Between 7 pm to 11 pm; to be installed at the inception of crops

Recommendation

One light trap with 220 W mercury lamp/1 ha. Some traps may be changed according to the light sources.

All available models of light traps use one of the above lamps as a source of attraction. The various models of light traps available are grouped according to the sources of light used: incandescent light, mercury vapor light, and black light trap (UV light trap). Black light tubes made of fluorescent material, incandescent bulbs, mercury vapor black light lamps, and LED black light bulbs are possible forms of it.

1.2 Types of light traps

Incandescent light traps:

Primitive models: Simple designs like the Montana Light Trap using lanterns (e.g., for cutworms).

Simple models: Reflector with lamp and water pan for capturing larger insects.

Low-intensity models: Designed for capturing smaller, delicate insects like rice gall midges.

Mercury light trap models:

Robinson Trap: Basic model with an inverted cone and vanes, effective for noctuids and other nocturnal insects.

Muguga Trap: Like Robinson but with a metal cone and rain protection, uses a powerful 500W mercury bulb.

Rothamsted Trap: Uses a roof to focus light beam, suitable for various moths(Taylor and Brown, 1972).

Black light trap models:

Black Light Insect Survey Trap: Standard design with baffles, funnel, and collection container, useful for diverse insects (Harding *et al.*, 1966).

Electric Grid Traps: Flat or cylindrical grids surrounding the lamp to kill attracted insects, used for specific pests(Heinton, 1974).

Electrocute Grid Traps: Commonly called "grid traps," used for nuisance insect control near living areas and businesses.

Considerations:

Each type of trap has different strengths and weaknesses in terms of target insects, effectiveness, and ease of use. Light source choice (incandescent, mercury, black light) impacts trap attractiveness to different insect species. Additional factors like trap placement, environmental conditions, and time of operation can influence capture success.

It consists series of adjacent wires insulated from each other and connected to opposite polarities of a low current high voltage transformer. The assembly of charged wire is most frequently made in the form of a flat panel or circular case with the provision for an attractant lamp. An insect flying between the wires draws an arc that passes through its body usually causing death (Mitchell *et al.*, 1974).

1.2.3.4 Light trap with provisions for timely automatic separation of insects

An automatic device for dividing and packaging light trap insect catches according to time intervals of as little as 5 minutes has been developed by Hartstack and Hollingsworth, (1968) for overall insect survey. Insects collected in the gravity tape trap move from the killing chamber into a paddle wheel compartment which deposits them between sheets of rolled plastic film where they are retained until the package is opened for identification.

Fig. 1: Solar light trap, Sticky trap, Pheromone trap

1.3. Solar Light Trap

The solar panel absorbs the sunlight available during the daytime and is stored in the battery. Later during the night, the UV LED uses this energy to emit light which attracts insects. The light emitted by the UV LED attracts most of the nocturnal insects at a particular wavelength. An automatic dusk-to-dawn system is installed which helps to automatically switch on the device during the night and switch off during the day. The insects attracted to the UV LED light are captured in a liquid medium inside the basin. Insect pests in agricultural areas will soon be effectively controlled by the solar light trap technology. Government and non-government organizations may utilize this as an IPM tool (Bera, 2015).

Limitations

- Insects see green, blue, and near ultraviolet (UV) light very well, but they see yellow and orange light poorly and cannot see red or infrared light.
- Light-trapping is still a selective method, and not all taxa of a given group (family, genus) are attracted to light with the same efficiency, and females of many species are less attracted than males or not at all.
- It is less effective when there is brilliant moonlight, next to fresh water, or near bright artificial lights.
- This method requires a source of electric power.
- Too close to large rivers and lakes because of the enormous numbers of freshwater insects encountered

1.4. The following insect orders regularly come to light:

Caddisflies (Trichopteran)—both marine and freshwater species, Stoneflies (Plecopteran)—genera—Stenoperla and—Megaloptera, Dobsonflies (Megaloptera), Mayflies (Ephemeroptera), Lacewings (Neuropteran), Wasps (Hymenoptera)—particularly Ichneumonidae, Moths (Lepidoptera)—Geometrid, Noctuid, Crambid, Tortricid, and Hepialids, Beetles (Coleoptera): longhorns, scarabs, and click beetles, Flies (Diptera): several families, Bugs (Hemiptera): backswimmers, water boatmen, and praying mantids (Mantoidea).

1.5 Target pests

Leafhoppers, planthoppers, bugs, chaffer beetles, dung roller, rice leaf folder, stem borer, cotton bollworm, red hairy caterpillars, store grain pests, etc.

1.6 Operation of light trap

Moths are impacted by lighting in a variety of ways, including flying, navigation, vision, dispersion, migration, egg-laying, mating, eating, and camouflage. The sum of these many impacts has a significant influence.

Light traps also attract many beneficial and non-target insects like parasitoids and predators. To avoid the loss of such insects, light traps must be operated during peak periods of activity of harmful insects. For example, in the rice ecosystem, maximum numbers of insect pests are caught between 8 pm - 12 midnight. The operation of light traps during this period will minimize the attraction of beneficial insects. In sorghum, the peak period of attraction of *Chilo partellus* is between 8-11 pm.

1.7. Yellow fluorescent lighting in the orchard at night

Fruits are harmed by fruit-piercing moths like *Oraesiae marginata* Fabricius and *Eudocima tyrannus* Guenee. By using yellow fluorescent lights in the orchard at night, fruit damage may be avoided (Nomura, 1967; Nomura *et al.,* 1965). This method is based on the finding that when moths are exposed to light above a certain brightness at night, their compound eyes become as used to light as they are during the day (MeyerRochow, 1974; Walcott, 1969). The light adaption suppresses the activities of flying, drinking fruit juice, and mating that occur at night.

1.7.1. Reflective mulching films inhibiting flying

It is well known that the use of light-reflecting mulching films in open agricultural fields inhibits the entry of alate aphids.

2.0. Attraction of insects to color plates

At night, light sources can attract certain insects that are diurnal. But during the day, artificial light sources are less effective—or completely ineffective—at controlling pests because of how intense the sunshine is. It is good knowledge that colored traps, such as yellow pan traps, or yellow sticky traps, can be used to catch daytime pests. A yellow pan trap can also be used to predict aphid outbreaks. Important agricultural pests like planthoppers, leafhoppers, aphids, whiteflies, thrips, and leaf miner flies are among the insects drawn to these yellowish gadgets (Esker *et al.,* 2004; Mainali and Lim, 2010; Vaishampayan *et al.,* 1975). According to Tokimura *et al.,* (2009), yellow sticky plates or rolls have become crucial instruments for the physical control of these pests. The yellow color is thought to mimic the color of flowers, which are a natural food source for many insects. Additionally, the ultraviolet reflectance of yellow is attractive to some insects, as it is associated with sunlight and potential food sources.

These sticky trap models include simple rectangular galvanized sheets, plastic jars or tin boxes, cylindrical tubes, etc. over which the sticky adhesive materials are applied. Generally, different colors are painted on the trap depending upon the preference of various insects to colors are used as coloured sticky traps. To enhance the number of insects captured, models that include the sticky trap and water pan have also been created. Typically, pheromones are utilized with sticky traps (Mohan *et al.,* 1994).

White-coloured traps are most effective in attracting the pigeon pea fly, *Melanagromyza obtusa* yellow colour attracts cotton white fly, *Bemesia tabaci*, cotton aphids, *Aphis gossypi*, and green house white fly, *Trialeurodes vaporariorum* (Bhatnagar and Davies, 1979; Gillespie and Quiring, 1987).

Brinjal - White flies and Hoppers @ 5 traps/ acre.

Bhendi - White flies and Aphids @ 5 traps/ acre.

Cotton - Bollworms, White flies, and Tobacco caterpillar @ 5 traps/ acre.

Install blue-colored sticky traps @ 20 / acre for thrips management

2.2. The insect attraction may depend upon the color of the material that has been used. Here are some examples:

Red sticky trap - Apple maggots

White sticky trap - Weevils

Yellow water pan - BPH and WBPH

2.3. Scouting technique

Yellow sticky traps are a common method for monitoring many pests, including aphids, whiteflies, and leaf-miner adults. Use of yellow sticky traps in seedling production areas at the rate of 1–2 traps/50–100m2 can trap significant numbers of whiteflies. Lu et al. (2012) showed that yellow sticky traps significantly suppressed the population increase of adult and immature whiteflies in greenhouses. Similarly, thrips are highly attracted to the bright blue color; blue sticky traps can be set up every 2–3m2 in a greenhouse for effective control (Murai, 2002)

Advantages:

- ✓ Non-toxic: Sticky traps are non-toxic and do not use chemicals, making them a safer option for both humans and pets. This aligns with the principles of IPM, which prioritize the use of least-toxic methods.
- ✓ Easy to use: Sticky traps are simple to set up and require minimal maintenance. They can be deployed by anyone, making them accessible for home use as well as professional pest management.
- ✓ Monitoring: Sticky traps are useful for monitoring pest populations. By inspecting the traps regularly, you can get a sense of the pest activity and determine whether further control measures are needed.
- ✓ Cost-effective: Sticky traps are generally inexpensive and can be a cost-effective method for managing pests, particularly for monitoring purposes.

Disadvantages:

- ✓ Selective effectiveness: Sticky traps are most effective for certain types of pests, primarily those that are small and have limited mobility, like flies, fruit flies, or crawling insects. They are less effective for pests that fly and are not attracted to the trap's visual or chemical cues.
- ✓ Non-selective: Sticky traps are not selective, meaning they can capture beneficial insects or even non-target species. This could harm the ecosystem and disrupt the natural balance of pests and their predators.
- ✓ Inhumane for larger pests: For larger pests, such as rodents or larger insects, sticky traps can be inhumane and cause unnecessary suffering. The captured animals may die slowly, which is considered cruel by animal welfare standards.
- ✓ Limited control: While sticky traps can reduce pest numbers, they are typically not sufficient for complete pest control. They are best used in conjunction with other IPM methods for a comprehensive approach.

- ✓ Aesthetic issues: Sticky traps with captured pests can be unsightly, which may not be suitable for all environments, such as public spaces or homes. The sight of trapped pests can also be unpleasant for some people.

3. Pheromone trap

One of the main elements of the IPM programme is the usage of pheromone traps. Pheromone traps, which provide an efficient, non-toxic way to monitor and manage pest populations, are an essential component of the pest control landscape. The use of pheromone traps and lures guaranteed that pesticides were applied sparingly and only when necessary, as opposed to on a calendar-based and preventative basis. Traps were set up at 2-3 per acre, one metre above the typical crop canopy. There is no attraction interference between the two traps; the distance between them is 40 ± 5 M.

Pheromones are used in IPM programs for,

a) Population density surveys

b) Forewarn regarding outbreaks of important insect pests

c) Male confusion – Mating disruption

Pheromones have greater direct behavioral control usefulness in surveys to determine the presence/abundance of insect species so that other control measures can be exercised. Several models of pheromone applications and traps are available.

3.1. Mode of action

A specific species' male adults are drawn to sex pheromone traps under the false impression that the female adult is present for mating. Because there aren't enough male adults to support the mating, fertilisation, creation, and depositing of viable eggs by virgin females, these attractive male adults get imprisoned and die. When placed in small and big quantities, it serves as a mass-trapping and monitoring tool, respectively.

Recommendation * 5 traps/ac for monitoring; 12 traps/ac for mass-trapping

3.3. Types of Pheromone Traps:

1. Delta trap: It is a sturdy, inflexible plastic trap with a detachable adhesive insert. Its top insert is made of an adhesive that doesn't dry out. One end of the trap needs to be opened in order to remove it. The adhesive insert is centred with pheromone lures. It is not necessary to disassemble the trap in order to inspect the catch. Every six weeks, the dispensers and adhesive inserts need to be changed. Inspections of traps should be done once every two to three weeks.

2. Funnel trap: Sturdy plastic trap with a detachable cover, a broad base, and a pheromone dispenser within. To help with control, K can be given an optional insecticidal strip as a killing agent, or an insecticidal spray can be used inside the trap. The pheromone attractant entices flying insect pests into the trap. After entering the trap, insects are exposed to the insecticidal strip and are unable to escape.

3. Probe trap: Grain storage silos employ this. The upper two thirds of the acrylic cylindrical tube are pierced with tiny, slanted perforations. A detachable collection tube is located in the lowest section of the tube. There are two holes at the top of the trap where a card can be passed to fix a marker that is above the grain. The tap is 0.5 to 1 m below the grain surface, vertically buried in the grain. Keep the trap between 10 and 35 metres away. Through holes in the tap, the crawling insects enter, and through the funnel, they fall into the specimen tube. There is a coating on the collection tube that keeps insects from scuttling out.

4. Omni directional pheromone trap: It is exclusively used for monitoring Earias. It consists of an aluminum vessel of 30 c m diameter. Holes are provided on the sides of vessels. The trap contains a septum on the inner side and hangs in the field.

3.4. Purpose

Monitoring: To know the pest incidence and intensity in fields based on several males caught, the timing and frequency of control measures can be determined.

Mass trapping: As a result of mass trapping of insect males, most females remain unmated and are not able to produce fertile eggs.

Mating disruption: The widespread application of synthetic pheromones in the field made the insects unable to locate their mates.

3.5. Available lures:

Sl.No	Crop	Insect pests	Name of lure
1.	Paddy	Yellow stem-borer	Scirpo lure
2.		Leaf folder	Cnaphalo lure
3.	Vegetable & flower crops, oilseeds, pulses, chickpeas, soybean, cotton, sunflower.	Tobacco cutworm	Spodo lure/ Litlure.
		Gram pod borer	Heli lure
4.	Brinjal	Shoot and fruit borer	
5.	Okra	Shoot and fruit borer	
6.	Sweet potato	Weevil	Aggregation pheromone lure
7.	Tomato	Leaf miner and fruit borer	
8.	Cotton	Pectinophora gossypiella	Pectino lure/ Gossyplure
9.	Cotton	Spotted bollworms	Ervit lure and Ervin lure
10.	Coconut	Red palm weevil	Ferro lure/ferrugineol
11.	Coconut	Rhinoceros beetle	Rhino lure
12.	CBHC	*Opisina arenosella*	CBHC Lure
13.		*Aphis gossypii*	Alarm pheromone β Farnescene (EBF)
14.	White grubs or root grubs	*H. consanguinea*	Methoxybenzene aggregation pheromone
15.	Crucifers	Diamondback moth	DBM lure
16.	Sugarcane	*Scirpophaga excerptalis*	STB lure

17.	Inter node	*Chilo saccariphagus indicus*	INB Lure
18.	Stalk Borer	*Chilo auricilius*	SSB Lure
19.	Early Shoot Borer	*Chilo infuscatellus*	ESB Lure
20.	Striped Stem Borer	*Chilo suppressalis*	SSB Lure
21.	Maize	*Spodoptera frugiperada*	FAW lure
22.	Litchi Fruit Borer	*Conopomorpha sinensis*	LFB lure
23.	False Codling Moth	*Thaumatotibia leucotreta*	FCM lure
24.	Black Cutworm Lure	*Agrotis ipsilon*	BC Lure
25.	Potato Tuber Moth Lure	*Phthorimaea operculella*	PTM lure
26.	Beet Armyworm	*Spodoptera Exigua*	Beet Armyworm Lure
27.	Almond Moth	*Ephestia cautella*	Almond Moth Lure

Examples of male sex pheromones

Cotton boll weevil, *Anthonomas grandis*, Coleoptera

Cabbage looper, *Trichoplusia ni*, Lepidoptera

Mediterranean fruitfly, *Ceratitis capitata*, Diptera.

4.0. Storage entomology

Monitoring bin-stored grain every two weeks to detect early signs of degradation or infestation is one of the most effective approaches to prevent insect infestations. This section describes various tools for sampling grain and inspecting it for insects.

During food grains' storage, insects are a primary source of biotic and abiotic agents that cause degradation, resulting in losses that are both quantitative and qualitative. Because insects in store houses are usually only observed while they are hovering or flying around, the number of insects may have decreased significantly as a result. It is common knowledge that no granary can hold grains without insects, since harvested food always contains eggs, larvae, or pupae due to field carryover infection, which is inevitable in developing countries such as India. Thus, in order to quickly identify insects in stored produce and to plan appropriate countermeasures, fundamental technologies are required. To battle stored grain insects, many technologies have been developed; some of these are often used in homes, farms, and godowns throughout the Nation.

Fig. 2: Insect probe trap, pitfall trap, wo-in-one Model, Indicator Device

4.1. Probe sampling and trap method

Challenges of traditional methods:

Probe sampling and sieving are laborious and time-consuming.

Manual inspection of probes is difficult and inefficient.

Innovative traps developed by TNAU: (Mohan *et al.,* 1994), (Mohan, 2007; Mohan and Rajesh, 2016).

- ✓ Two-in-one probe trap: combines probe and pitfall trap, highly effective for pulse beetles.
- ✓ Indicator device: uses a sticky surface to attract and trap insects.
- ✓ TNAU automatic insect removal bin: removes and crushes insects and eggs, reducing grain damage.
- ✓ UV light traps: attract and trap various stored grain insects.

These traps are useful in the trapping of a variety of stored grain insects including lesser grain borer (*Rhyzopertha dominica* F.), rice weevil (*Sitophilus oryzae* L.), red flour beetle (*Tribolium castaneum* Herbst), saw-toothed grain beetle (*Oryzaephilus surnamensis*) etc. (Mohan and Rajesh, 2016).

Benefits of using traps:

- Timely detection and monitoring of insect infestation.
- Reduced reliance on manual inspection methods.
- Increased efficiency and effectiveness of pest control.
- Reduced grain damage from insects.

Overall, it seems like these traps offer a promising solution for improving pest management in stored grains. They address the limitations of traditional methods and provide more efficient and effective ways to detect, monitor, and control insect infestations.

4.2. Visual lures and pheromones

The potential of light in detecting, monitoring, and managing insects in stored food grains. You are right that it offers a clean and potentially effective alternative to traditional methods (Shimoda and Honda, 2013). using light for insect management in stored grains holds promise as a clean, versatile, and potentially effective approach. Combining light with other methods:

Pheromone traps: Using light traps alongside pheromone traps can enhance the attraction and capture rates of targeted pests.

Monitoring data: Light trap data can be combined with other monitoring methods (e.g., probe sampling) to provide a comprehensive picture of the insect population and optimize control strategies (Laopongsit and Srzednicki, 2010).

5.0. Various kinds of traps are employed for insects that travel through the air, such as flying or wind-borne insects, as well as for insects that walk or dwell on the ground, are subterranean, or are aquatic. Several of these are detailed below.

Traps for flying insects and wind-blown insects Interception traps. Interception traps and their applications in both ecological studies and pest management. Here are some key points I found:

Interception traps:

Simple design: Usually a suspended net with a funnel leads to a collection container.

Exploit insect flight behavior: Traps are placed in known insect flight paths, particularly at habitat edges or gaps in vegetation.

Examples: Malaise traps (modified tent) and window traps (vertical barrier with gutter).

Applications:

Ecological studies: Monitoring insect diversity and abundance, studying insect movement patterns.

Pest management: Interception and control of specific pest species in targeted areas.

Advantages of interception traps:

Passive: No lures or attractants needed, minimizing environmental impact.

Effective: Can capture a wide variety of flying insects, depending on trap design and placement.

Non-lethal: Modified traps can collect live insects for further study or release.

Challenges to consider:

Species specificity: Trap effectiveness varies depending on insect species and flight behavior.

Environmental factors: Wind, temperature, and light can affect insect activity and trap efficiency.

Collection and analysis: Sorting and identifying captured insects can be time-consuming.

Overall, interception traps offer a valuable tool for both understanding insect ecology and managing pest populations. Their low environmental impact, passive approach, and diverse applications make them a versatile and effective option for insect studies and pest control.

Sticky traps: The most common traps for faunal surveys in agricultural studies are likely panels, cylinders, or spheres coated in sticky substance. In their most basic configuration, these may be transparent panels covered in a substance that captures insects that are blown upon or fly into the panel. Panels can also be utilised with a chemical attractant combined with a colour, shape, or both.

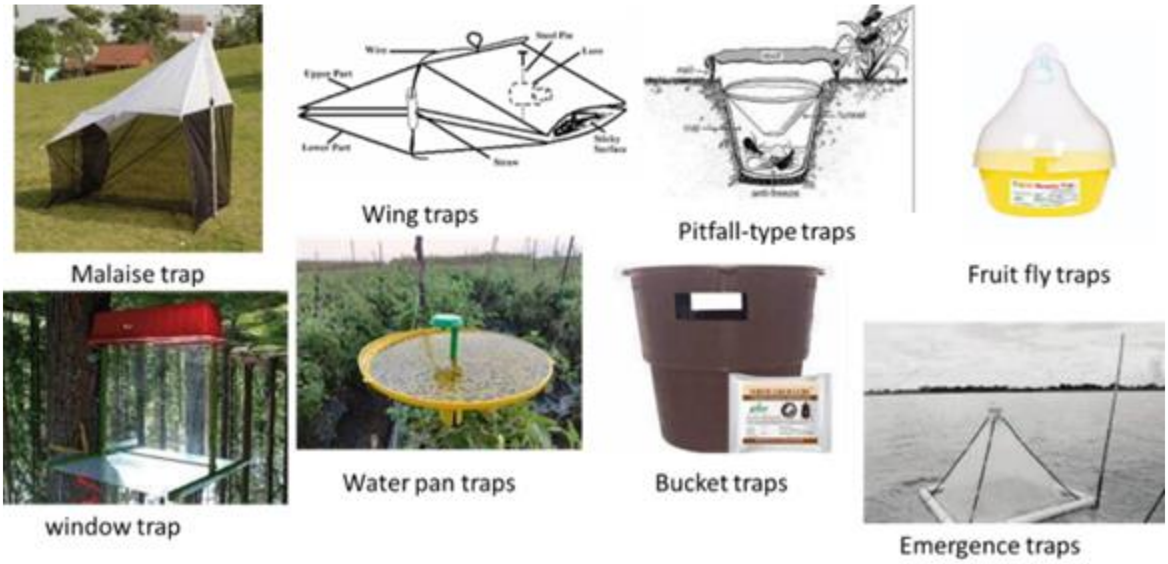

Fig. 3: Different types of traps

Three-dimensional triangular traps, diamond traps, and wing traps: This group consists of additional low-cost traps that are employed in conjunction with an attractant. These are sticky traps that are either disposable or use a sticky component that is changed out during servicing. The sticky surface of the trap is covered on the inside. Delta traps are tiny, lightweight, triangular traps with a tent-like design that are convenient to carry and hang from trees. The Jackson trap is a delta trap that is used to catch a variety of tropical tephritid fruit flies. It features a replaceable, sticky-coated removable base that can be used for sampling.

Diamond traps: These are shaped like diamonds and are employed to keep an eye out for indoor pests in public spaces like supermarkets and shops. For Lepidoptera pests, wing traps, which consist of a floor and a roof, are commonly employed. Compared to delta traps, these are larger and less manoeuvrable, but the larger surface area makes them more appropriate for larger pest moths. Compared to water pan traps, they are less vulnerable to dust and grime since the sticky surface is enclosed within the trap, and they also catch fewer non-target insects.

Water pan traps: A water pan trap is an easy way to gather aphids and other flying insects. Flying over the traps, insects are drawn to the water's shiny surface and end up trapped. The traps are built from dishwashing pans, storage containers, or rectangular baking pans that have been partially filled with aqueous soap or automotive anti-freeze solutions. Since these traps are open, there can be issues with movement in the wind, evaporation in dry spells, or overflowing in times of intense rain.

Bucket traps: A bucket trap is an additional easy-to-use and affordable trap. The bucket trap can be used as a closed container with openings on the top or sides for insects to enter, or it can be used without a lid. To let trapped water escape, small drainage holes can be positioned close to the trap's bottom. Two types of bucket traps that are translucent closed containers with entrance holes around the edge are the Nadel trap and the Mis-Sion trap. The top of the corn rootworm trap is formed like a big funnel, and there is a space between it and the container.

A variety of retention devices can be used with bucket-type traps. A pesticide such as dimethyl 2,2-dichloro vinyl phosphate (DDVP. mothballs) can be used inside, but if the concentration is too high it may prevent insects from entering. Aqueous solutions of soap, car antifreeze, or surface- tents such as triton may also be used.

Bucket traps with funnels: Combinations of bucket traps and funnels are arguably the most widely used traps in agriculture. The McPhail trap, a bell-shaped invaginated glass trap designed to catch tephritid and drosophilid fruit flies, is one example. The original McPhail-type trap was constructed of glass, but there are now a number of plastic variations available, such as dome traps, International Pheromones McPhail traps, and Multilure traps, which are characterised by a clear top and a yellow base. A wasp trap, like the Victor yellow jacket trap, is another illustration. Another bucket trap design with a funnel is the boll weevil trap, however this one has the funnel fixed on a cylinder.

Cone traps: In essence, cone traps are bucket traps with funnels attached, but the funnel is much bigger than the bucket or collecting tube. These are employed with the funnel's big mouth facing downward and its top pointing in the direction of a container. Heliothis traps and butterfly bait traps are two types of these traps.

5.2. Traps for walking arthropods and soil-dwelling insects

Pitfall-type traps: When gathering insects and other arthropods that are moving across a surface, pitfall traps come in handy. are frequently employed to calculate the relative abundances and species richness of ground-active insects. When baits or lures are placed inside or near traps, a lot of insects are drawn to them. These can be made either "specific," which is made for a particular target, or "generic," which attracts a lot of insects. The efficiency of pitfall traps, which catch a variety of moving ground insects, can be enhanced by baiting.

Grain probe traps: A unique kind of a pitfall trap designed for use with stored grain is the grain probe trap. An extended cylinder with holes bored into the sides above a funnel and insect receptacle makes up a grain probe trap. An early model of the trap had a hollow cylinder manufactured from a sheet of 14-gauge brass and was machined from solid brass. Afterwards, a perforated section of tubular polyethylene and clear poly-carbonate (Lexan) plastic were used to create probe traps. When the traps are employed at the grain surface, they are simple to service since the apertures can be blocked by webbing made by the larvae of lepidopteran grain pests like the Indian meal moth, which makes the traps useless.

Shelter traps: When it's desired for the trap to be undetectable, shelter traps come in handy for insects that like a dark harborage. These often contain tiny apertures that entice insects to enter the trap and are used to catch insects as they move across a surface. The most well-known types of these traps are roach motels. The cone-shaped bottom of the PC floor trap has been swapped out for a flat container, enabling it to be hung on a wall or set on the ground. This modification makes the PC floor trap suitable for use as a shelter trap.

Swarm traps are shelter bees used to detect swarms of Africanized honey bees encroaching and to catch undesired swarms of domestic honey bees. These are big, bucket-shaped traps that are hung at least a metre above the ground, constructed of moulded fibre material, and have a single entrance hole. They give bees a place to nest, and when they are caught, they can be recognised and eliminated as pest bees or maintained alive and transferred to regular hives to produce honey.

Emergence traps: Cone traps or "emergence traps" are a particular kind that are used to catch adults that are in the ground during their larval or pupal stages. These traps are constructed from funnel-shaped aluminium screens, with a top aperture that connects to a vial or collecting tube. To seal the trap to the earth, it is positioned flush with the ground and the soil is pushed up around its perimeter. When adults come out of their underground stages, they climb up into the trap and are trapped in the collecting tube.

Solar bait stations: The aforementioned traps are effective for capturing subterranean insect stages above ground; on the other hand, solar bait stations are useful for capturing below ground stages of wireworms (Elateridae) and fake wireworms (Tenebrionidae). These are employed in the estimation of wireworm populations and in the determination of whether to treat or not treat seeds. These insect groups' larvae can be focused by producing microenvironments with ideal levels of moisture, warmth, and food. A handful of grains, such as wheat, is buried a few inches below the soil's surface. A roughly eighteen-inch-tall mound of earth coated in clear plastic encases the bait. Soil should be applied to the plastic's edges to keep them from blowing away. Stations should be constructed in the fall before soil freezes, and they can be examined in the spring before planting time. Surveyors' flags can be used to mark sites for easy location.

5.3. Traps for aquatic insects

Interception traps. Interception traps capture aquatic insects moving through the water and are generally like interception traps used for wind-borne insects. These traps tend to be tapered nets with either round or rectangular openings which either can be fixed to sample insects in moving water or pulled through the water manually. The size of the mesh governs the size of insects retained, but the use of too fine a mesh may impede the movement of water through the trap and retain too much debris.

Emergence traps. Floating emergence traps are used to capture insects with aquatic larval stages as they emerge as adults. Construction and use are like that for emergence traps used for soil-dwelling insects.

Lindgren funnel traps:

These traps consist of many black funnels that are hung between two trees, one on top of the other with the use of a rope. On the funnel's bottom side is a jar filled with ethanol, an ethanol/propylene glycol mixture, or another preservative. The wood-boring beetles are drawn to them because they resemble upright trees. Another factor that draws bugs in is the aroma of ethanol. There are numerous additional insects in the collection as well.

5.4. Automated monitoring systems

Information technology advancements are expanding the field of precision agriculture, i.e., using computers to support managerial decisions. Precision agriculture relies heavily on the capacity to transfer data from traps quickly into computer databases or spreadsheets, which will help with timely decision-making on pest management. In order to reduce the amount of data entering required for trap type, position, and other details, bar codes can be placed to traps and a bar code scanner can be brought to the field. This will leave only bug counts to be manually recorded. Data from traps is directly recorded into a computer as the next stage of automation.

Conclusion:

Traps stand as a linchpin in the framework of Integrated Pest Management, offering a multifaceted approach to pest control that is both ecologically and economically sound. Their role extends beyond mere pest capture, encompassing pest monitoring, early detection, and targeted control. By facilitating informed decision-making, minimizing the need for chemical pesticides, and reducing environmental impacts, traps promote a sustainable and environmentally responsible approach to pest management. In doing so, they help safeguard ecosystems, conserve resources, and secure food production, making traps an indispensable tool for modern agriculture and pest control. As we continue to confront the challenges of pest management in an increasingly interconnected and environmentally conscious world, the role of traps in IPM remains pivotal for a more sustainable and secure future.

The prospects for the role of traps in Integrated Pest Management (IPM) are promising and hold great potential for advancing sustainable agriculture and pest control. Here are some key aspects of the bright future of traps in IPM:

1. Technology Integration: Advancements in technology, such as the use of sensors, data analytics, and remote monitoring, will enhance trap efficiency and data collection. Smart traps will provide real-time data, enabling more precise and timely pest management decisions.
2. Innovative Trap Designs: Ongoing research and development will likely lead to more effective and specific trap designs. These innovations will cater to a broader range of pests and environmental conditions, ensuring a higher success rate in pest control.
3. Reduced Pesticide Dependency: As traps continue to prove their efficacy in pest monitoring and control, their adoption will further reduce the reliance on chemical pesticides. This shift aligns with the growing demand for reduced chemical use in agriculture.

4. Environmental Sustainability: The environmental and ecological benefits of traps will continue to be recognized, fostering the adoption of IPM practices. This trend will contribute to reduced harm to non-target species and ecosystems, supporting biodiversity and long-term environmental sustainability.
5. Global Adoption: IPM, including trap usage, will gain prominence worldwide as a response to the need for sustainable agriculture. This will lead to more widespread adoption of traps, benefiting both developed and developing agricultural regions.

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BIOCHEMISTRY OF PROTEIN AND AMINO ACID

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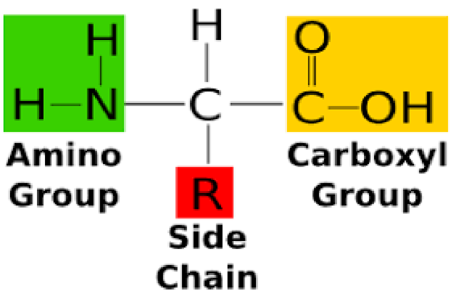
Abstract:

Proteins are made up of hundreds or thousands of smaller units known as amino acids. There are 20 different kinds of amino acids that are linked together by peptide bond to make a protein molecule. The sequence of amino acids determines each protein's unique 3-dimensional structure and its specific function such as catalysis of biochemical reactions, mechanical support and immune protection, movement, transport of ligand, transmits nerve impulses, and control growth and differentiation. The amino acids of a protein have been classified as polar, nonpolar, hydrophilic, hydrophobic, acidic, basic, aliphatic and aromatic. A protein can acquire a regular secondary structure for instance α-helix, β-pleated sheet, β-turn, and coils. The secondary structures are further folded leading to the formation of higher order structure namely, tertiary structure which is stabilized mainly by hydrogen-bonding, electrostatic interactions, hydrophobic interactions and van der Waals interactions. Proteins are not entirely rigid molecules. They undergo conformational changes upon ligand binding. For instance, myoglobin and hemoglobin undergo conformational changes when they bind oxygen, therefore they can transport oxygen to the different tissues and lungs respectively.

Amino acids

Amino acids are the building block of proteins. Amino acids are important organic compounds that contain amine ($-NH_2$) and carboxyl (-COOH) functional groups, along with a side-chain (R group) that is specific for each amino acid. Twenty different amino acids are commonly found in proteins. All of these 20 common amino acids are α-amino acids except proline and their general structure is shown below. They have a carboxyl group and amino group which are covalently bonded to a α-carbon atom. They differ from each other in their side chain R groups. Since, the remaining structure are same therefore properties of these amino acids are primarily determined by the side chain groups. The nature of these side chain maybe polar, nonpolar (aliphatic), hydrophilic, hydrophobic, acidic, basic and aromatic.



Structure of amino acid containing R side chain

Classification

The 20 amino acids have been classified using different criteria by different scientists. For instance, they have been classified as polar, nonpolar, hydrophilic, hydrophobic, acidic, basic, aliphatic and aromatic. Here, we have classified all of these 20 common set of amino acids into six distinct classes. They have also been classified based on nutritional aspects as Essential (His, Ile, Leu, Lys, Met, Phe, Thr, Trp, Val) and Non-essential (Ala, Arg, Asn, Asp, Cys, Glu, Gln, Gly, Pro, Tyr, Ser). Among these amino acids some amino acids are conditionally essential (Arg, Cys, Gln Gly Pro, Tyr). Monoaminodicarboxylic acids and diaminomonocarboxylic acids are acidic (Asp, Glu) and basic (Arg, His, Lys) amino acids respectively.

Amino acid	Three -letter abbreviation	One letter symbol
Alanine	Ala	A
Arginine	Arg	R
Asparagine	Asn	N
Aspartic acid	Asp	D
Asparagine or aspartic acid	Asx	B
Cysteine	Cys	C
Glutamine	Gln	Q
Glutamic acid	Glu	E
Glutamine or Glutamic acid	Glx	Z
Glycine	Gly	G
Histidine	His	H
Isoleucine	Ile	I
Leucine	Leu	L
Lysine	Lys	K
Methionine	Met	M
Phenylalanine	Phe	F
Proline	Pro	P
Serine	Ser	S
Threonine	Thr	T
Tryptophan	Trp	W
Tyrosine	Tyr	Y
Valine	Val	V

Nonpolar (Aliphatic) amino acids

The R side chain in this class of amino acids including alanine, valine, leucine and isoleucine are hydrophobic in nature therefore they stabilize the protein structure through hydrophobic interactions. Glycine is also classified as nonpolar amino acids, but it has very small side chain. Therefore, it does not contribute to hydrophobic interactions. Glycine has the simplest structure. The side chain of proline has a distinctive cyclic structure which is an imino group held in a rigid conformation, therefore it reduces the structural flexibility of particularly that regions of polypeptide chain where it occurs.

Aromatic amino acids (Phenylalanine, Tyrosine and Tryptophan)

The side chain of aromatic amino acids contains an aromatic ring which are relatively nonpolar (hydrophobic) in nature. These amino acids can participate in hydrophobic interaction. Tyrosine and tryptophan are much more polar than phenylalanine owing to their hydroxyl and nitrogen indole ring respectively. These amino acids show light absorption in the ultraviolet range due to the presence of conjugated double bond-single bond system.

Polar, uncharged amino acids

This class of amino acids includes serine, threonine, cysteine, asparagine and glutamine. The R group of these amino acids are more soluble in water or more hydrophilic than those of nonpolar amino acids because they contain functional groups (OH, SH, $CONH_2$) that form hydrogen bonds with water. The polarity of serine and threonine is contributed by their hydroxyl groups, and that of cysteine and tryptophan by sulfhydryl and indole ring respectively which is weakly hydrogen bonded with oxygen and nitrogen respectively. Furthermore, polarity of asparagine and glutamine is contributed by their amide group.

Acidic amino acids

These amino acids contain two carboxyl groups, one α- carboxyl and other β- or γ-carboxyl group. Since they contain two acidic groups (one α-carboxyl group + one β or γ-carboxyl group) and one basic group (α-amino group), the net charge of these amino acids is therefore acidic and they are negatively charged at physiological pH.

Peptides bond:

The amide bond which covalently link two amino acids to form a dipeptide is termed as peptide bond or peptide link. This link forms between the carbonyl group of an amino acid and the nitrogen of the next amino acid by removing one water (H_2O) molecule.

Characteristics of the peptide bond:

The peptide bond is rigid and planar: The peptide bond has a partial double bond character –that is, it is shorter than a single bond **[**i.epeptide bond is intermediate in bond length (0.132 nm) between a single bond (0.147 nm) and a double bond (0.123 nm)] and is, therefore, rigid and planar.

This prevents free rotation around the bond between the carbonyl carbon and the nitrogen of the peptide bond. The rigid peptide bonds limit the number of conformations by polypeptide chains.

Gramicidin

Gramicidin is a circular or cyclic decapeptide containing ten amino acid residues that are linked to each other through peptide bonds. Besides containing amino acids, it has two non-amino acid residues of D-phenylalanine and two residues of L-ornithine (a non-protein amino acid). The structure of gramicidin is depicted below. Gramicidin is an antibiotic.

Protein

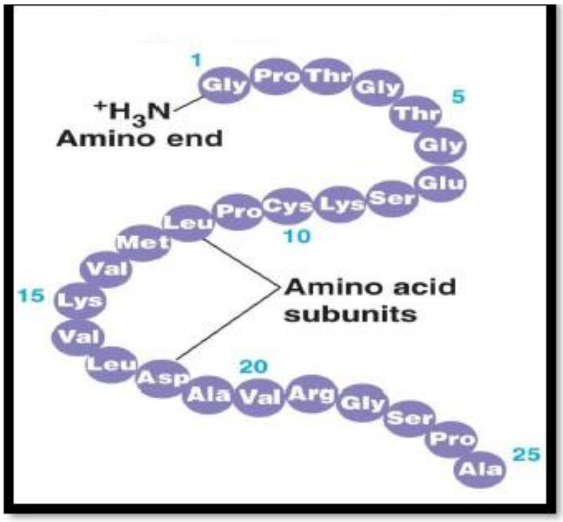
"Protein are complex organic nitrogenous compound, which is made up off amino acids, and each amino acid are joint by peptide bonds". They are made up of C, H, N, O and one or more chain of amino acids. Protein were first described by the Dutch chemist ***Gerardus Johannes Mulder*** in **1838**.

Proteins are polymers of amino acids linked via α- peptide bonds. They can be represented as primary, secondary, tertiary, and even quaternary structures, but from a nutritional viewpoint only the primary (amino acid) sequence is of interest. Similarly, although there are many compounds in the body that can be chemically defined as amino acids, we are only concerned with the 20 canonical amino acids encoded in DNA, plus 5 others—ornithine, citrulline, γ -aminobutyrate, β-alanine, and taurine—that play quantitatively important roles in the body. We consume proteins, which are digested in the gastrointestinal tract, absorbed as small peptides (diand tripeptides) and free amino acids, and then used for the resynthesis of proteins in our cells. Additionally, some amino acids are also used for the synthesis of specific (nonprotein) products, such as nitric oxide, polyamines, creatine, glutathione, nucleotides, glucosamine, hormones, neurotransmitters, and other factors. Again, such functions are not quantitatively important for most amino acids, and the bulk of amino acid metabolism is directly related to protein turnover (synthesis and degradation). For an individual in nitrogen balance, an amount of protein equal to that of the daily protein (nitrogen) intake is degraded each day with the nitrogen being excreted as urea and ammonia (with limited amounts of creatinine and uric acid).

The carbon skeletons of the amino acids degraded to urea and ammonia are recovered through gluconeogenesis or ketone synthesis, or oxidized to carbon dioxide. Of the 20 amino acids present in proteins, 9 are considered nutritionally indispensable (essential) in adult humans because the body is not able to synthesize their carbon skeletons. These 9 amino acids are leucine, valine, isoleucine, histidine, lysine, methionine, threonine, tryptophan, and phenylalanine. In addition, 2 others are made from their indispensable precursors: cysteine from methionine, and tyrosine from phenylalanine. Although arginine is needed in neonates, it appears that adults, with the possible exceptions of pregnancy in females and spermatogenesis in males, can synthesize sufficient arginine to maintain a nitrogen balance. The others, glutamate, glutamine, aspartate, asparagine, serine, glycine, proline, and alanine, can all be synthesized fromglucose and a suitable nitrogen source. Under some conditions, glutamine, glutamate, glycine, proline, and arginine may be considered as conditionally indispensable, meaning that the body is not capable of synthesizing them in sufficient quantities for a specific physiologic or pathologic condition. Thus, any discussion of dietary protein must consider not only quantity but also quality (ratio of indispensable amino acids).

Protein structure

The levels of protein structural organization have been divided into four orders, one leading to the other. The sequence of amino acids in its peptide chain is known as primary structure of a protein. It can be well understood from the primary structure of protein that whether all the amino acids are present or not, if so in what concentration as well as the sequence arrangement of amino acids. Primary structure mostly formed by covalent peptide bonds linking the α- carboxyl carbon of each amino acids with α-nitrogen of the next amino acids.



Primary Structure of Protein

The secondary structure consists of the three-dimensional conformation of the protein. Depending on hydrogen bond, amino acid residues close-up, hold and stabilize this three-dimensional form of the protein. Detailed studies in chemistry confirmed three different types of secondary structure of protein viz. α- helix, β-pleated and triple helix.

The α-helix is right-handed, compact and rigid coiling like structure as shown in Fig. Each turn of the helix has a pitch of 540 pm and contains about 3, 6 amino acid residues. The alpha helix is stabilized by a hydrogen bond between the H-atom attached to electronegative nitrogen atom of a peptide linkage and the electronegative carbonyl oxygen atom of the fourth amino acid on the amino-terminal side of that peptide bond. The amount of helix content differs in various proteins.

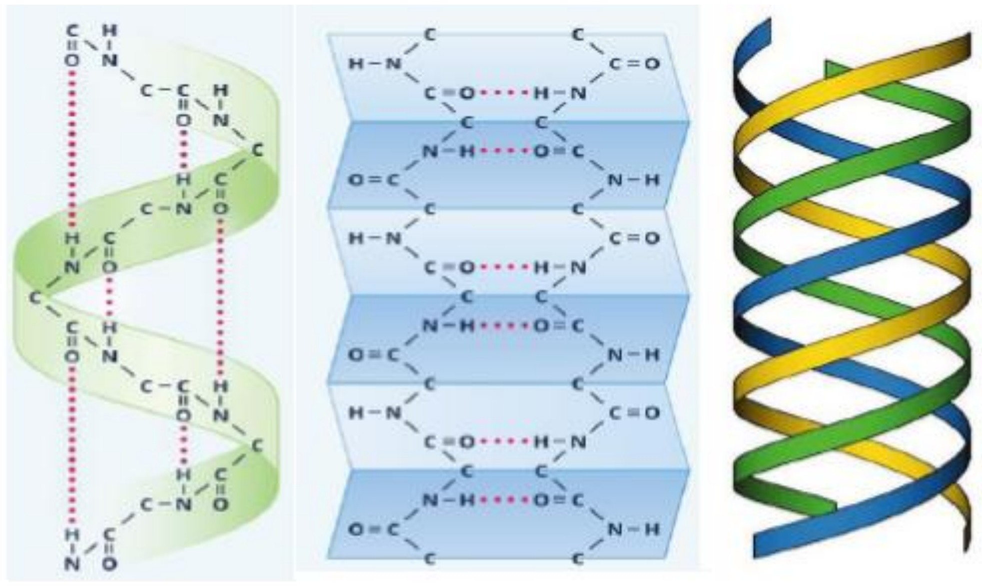
The β-pleated sheet is a less common, nonhelical, fully extended, slightly zig-zag, sheet like structure. It is stabilized by regular hydrogen bonds between α-amide N of a peptide bond of one peptide strand and the α- carbonyl O of another peptide linkage of an adjacent peptide strand.

The triple helix structure is formed by three congruent geometrical helices of polypeptide chains with same axis winding around one another to form a kind of stiff cable like structure. It is also known as super helical structure. Examples of triple helices include collagen like proteins, triplex DNA, triplex RNA. This type of structure is stronger and relatively rigid compared to others.

Secondary structures of protein

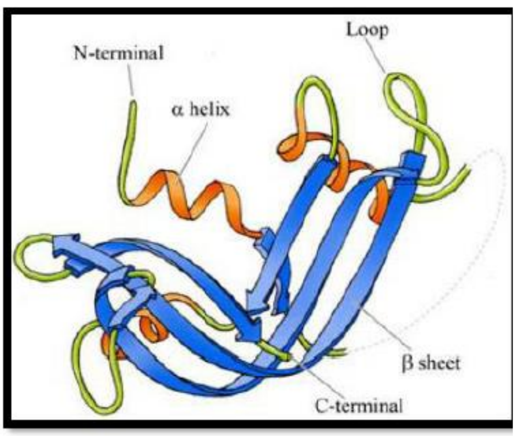
A protein needs to adopt a final and stable 3-dimentional shape in order to function properly. The tertiary structure refers to this configuration of a protein subunit in three-dimensional space. The forces that stabilize the tertiary structure are intermolecular disulfide bonds between cystein residues, electrostatic interactions between ionic groups of opposite charge and also hydrogen bonding.

α- helix **β-pleated** **Triple helix**



Tertiary structure of a protein

Tertiary structure of a protein plays a role in catalytic activity of proteins like enzymes and in how the hormone regulates receptor activation. Physiologic alterations of mature tertiary protein structure occur much more rapidly than does primary sequence. Many proteins consist of more than one polypeptide chain which is known as subunit. Quaternary structure refers spatial arrangement of these subunits of a naïve protein. Due to presence of two or more subunits, it is called as oligomers. The subunits are then held together mainly by hydrogen bonds and ionic bonds between polar amino acid sidechains of surface residues, and some hydrophobic interactions between nonpolar 35 amino acid sidechains of the contact regions. Hemoglobin is the simple example of quaternary structure. It contains two α and two β chains. The four chains are held together to give a globular shape. Quaternary structure allows a protein to have multiple functions and also to undergo complicated conformational changes.



Classification of protein

A-According to their chemical composition:

Proteins can be classified on the basis of their chemical composition into three main classes:

1. Simple Protein
2. Compound pr conjugated Protein
3. Derived Protein

1. Simple Protein

Simple proteins are made up of amino acid subunit joined together by peptide bonds. When hydrolyzed by enzymes, simple protein yield only the amino acids from which they are comprised. Example of simple proteins include albumin, globulins, glutelins and albuminoids.

(a) Albumins

- They are soluble in water.
- They are coagulated by heat.
- They are deficient in Glycine.

(b) Globuline

- They are insoluble in water.
- They are coagulated by heat.
- They are deficient in Methionine.

(c) Prolamin

- They are soluble in water.
- After hydrolysis they produce proline and amide nitrogen.

2. Compound pr conjugated protein

Conjugated proteins are proteins which yield upon hydrolysis amino acids and non-protein part is called the prosthetic group.

Conjugated proteins are classified on the basis of the chemical nature of their prosthetic groups:

a. nucleoprotein
b. Glycoproteins (contains carbohydrate part)
c. Lipoproteins (contains lipid part)
d. Hemoproteins (contains heme)
e. Metalloproteins (contains metal)
f. Phosphoproteins (phosphorylated protein)

Nucleoprotein

Nucleoprotein are the conjugated protein with nucleic acid (either DNA or RNA)

Mucoprotein

They are the proteins that are the building blocks of mucus, which is a protective barrier to the epithelia of cells. They are composed of simple protein with carbohydrate. They produces amino sugar, uronic acis etc.

3. Derived Protein

These proteins are derived by complete hydrolysis of simple or conjugated protein by acid, alkalis and enzymes.

B- According to their shape

Proteins can be classified on the basis of their chemical composition into two main classes:

1-Globular proteins 2-Fibrous proteins

1-Globular proteins:

- They are generally soluble in water.
- The polypeptide chains are tightly folded into a globular shape.

Example: enzymes, hemoglobin, myoglobin.

2-Fibrous proteins:

- They are insoluble in water
- Their polypeptide chains are arranged in long strands (elongated in the form of fibers).

Example: Collagen, elastin, keratin

C-According to their biological function

Proteins can be classified on the basis of their biological function into:

1. Catalytic function (enzymes)
2. Transport function (hemoglobin, albumin, transferrin)
3. Nutrient and storage proteins [e.g., casein & ferritin]
4. contractile or mobile proteins [e.g., actin, myosin]
5. Structural function [Keratin, elastin, collagen]
6. Defense proteins [e.g., immunoglobulins, fibrinogen and thrombin]
7. Regulatory function, some hormones are proteins (Growth hormone [GH, somatotropin])
8. Some toxins are proteins
9. Defense (Antibodies and coagulating factors)

The general properties of proteins

1. High molecular weight substances.
2. It constitutes more than 50% of the dry weight of the cell.
3. It presents in different shapes; fibrous and globular.
4. The globular is soluble in water and diluted salt solution with different degrees
5. The chemical and physical properties depend on the amino acids forming the protein.
6. The biological properties and 3D conformation depend also on the constituting amino acids.
7. All proteins are amphotericcompounds.
8. They precipitate by heat, in alcohols and in their isoelectric point.

Functions of proteins

As mentioned before that protein contributes average 17% of wet cell mass and they are the agents of biological functions. Proteins provide energy like carbohydrate and fat, but its major role as structural component of muscle mass and other tissues. Enormous number of proteins exhibit diversified functions as described here.

The most varied and most highly specialized proteins with catalytic activity are known as enzymes. Each enzyme is very specific in its function and acts only in a particular metabolic reaction. About all the chemical reactions in a living system and every step in metabolism and is catalyzed by enzymes.

A protein that serves the function of moving metal ions, organic molecules or gases like oxygen by binding them referred as transport protein. On the cell membrane different transport proteins are located as they enable transport of nutrients like glucose, amino acids etc across it. Membrane transport proteins take up metabolite molecules on one side of a membrane, transport them across the membrane, and release them on the other side. Each transport protein is designed to transport a specific substance as needed. Examples include actin and myosins are essential for locomotion of the whole organism as they are involved in muscle contraction.

The structural proteins serves as structural component of the body are keratins, collagens and elastins, which form structural framework of various organs and connective tissues and provide strength and mechanical support. Examples include collagen present in tendons and cartilage provides tensile strength and elastin, present in the ligament provides elastic property to organs like uterus, arteries, and lung.

The immunoglobulins or antibodies produced by the lymphocytes of vertebrates acts as protective protein. They specifically recognize and neutralize the invading microorganisms as well as any other intruding antigen.

Specific proteins bind and reservoir specific substances in cells or in extracellular fluid are known as storage proteins. Ferritin acts as a storage protein as it stores iron in spleen and liver cells.

A number of hormones as either peptide or protein in nature regulate metabolic functions of a cell. Proteins also maintain ionic and fluid distribution on two sides of membrane.

Protein synthesis

Protein synthesis is one of the most fundamental biological processes by which individual cells construct their specific proteins. This process of protein synthesis takes place in multiple ribosomes simultaneous and all throughout the cell cytoplasm. This process is very complex and is determined by the genetic information present in the DNA. Through this process biological cells generate new proteins, as well as save loss of cellular proteins via degradation or export. Briefly protein synthesis process is carried out in two steps – Transcription and Translation.

Transcription is the first step in which the pattern of one gene is copied from DNA sequence to RNA sequence. In this process the information in the DNA is transferred to the cytoplasm by way of synthesis of a template called messenger RNA (mRNA) by the enzyme

RNA polymerase. Mainly three steps take place to complete this process. In the initiation step RNA polymerase enzyme binds to a region of a gene called promoter and makes a strand of mRNA with a complementary sequence of base. In the next elongation step addition of nucleotides occurs to the mRNA strand, RNA polymerase reads the unwound DNA strand and builds the mRNA molecule. In the termination step sequence in the gene stops and mRNA detaches from DNA. After leaving nucleus, mRNA undergoes several modifications as removal of introns, adding of an adenine based poly- A tail to protect the ends of the mRNA molecule before translation.

In translation, occurs in cytoplasm, mRNA along with transfer RNA (tRNA) and ribosomes work together to produce proteins. In the initiation step mRNA anchored by ribosomes, which contain ribosomal nucleic acid (rRNA), the translation begins with the reading of the first triplet. Small tRNA molecules bring in the individual amino acids and attach them to the mRNA. In elongation step this pattern continues and forms a chain of amino acids. In termination step, when a stop signal is reached, the entire complex disassociates. Ribosomes, the mRNA, the tRNA and the enzymes are then splits back for another translational event.

The peptide now dissociates may undergo post translational modifications like cleavage of signal peptide, methylation, hydroxylation, glycosilation etc. in the golgi apparatus and finally the protein is either released into the extracellular fluid or stored in granules inside the cell for future release.

Physical and chemical properties of proteins

A. Physical properties of proteins

Physical properties

Major physical properties of proteins include:

Colour and taste: Proteins are usually colourless and tasteless, homogeneous and crystalline.

Shape and size: They range in shape from simple crystalloid spherical structures to long fibrillar structures. Two distinct shapes have been characterized.

A. Globular proteins: They are spherical in shape; examples of globular proteins include pepsin, edestin, insulin, and ribonuclease etc.

B. Fibrillar proteins: These are thread-like or ellipsoidal in shape. Most of the structural studies of proteins have been done using these proteins. Examples of such proteins include fibrinogen, myosin etc.

***MW**: Proteins generally have very high molecular weights ranging between 5x103 and 1x106 daltons.

* **Colloidal nature**: Due to their giant sizes, proteins exhibit many colloidal properties, such as the following:

a) They have extremely low diffusion rates.

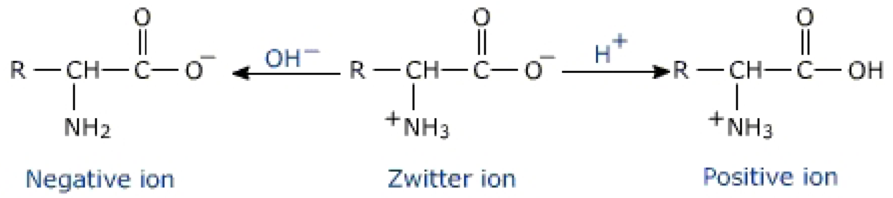
b) They may cause considerable light-scattering in solution, resulting in visible turbidity (Tyndall effect).

Denaturation: This is a process that involves the disruption of the secondary and tertiary structures of the protein, leading to the loss of biological activity. Often, denaturation is followed by coagulation, a process in which denatured protein molecules form large aggregates which precipitate from solution.

Denaturation may be caused by a variety of agents, both physical and chemical. Physical agents include mechanical action (such as shaking), heat treatment, cooling and freezing operations, high hydrostatic pressures, rubbing, UV rays and ionizing radiations such as X-rays, radioactive and ultrasonic radiations, etc.

Chemical agents include organic solvents (acetone, alcohol), aromatic anions (salicylates), some anionic detergents (such as sodium dodecyl sulfate), etc.

Amphoteric nature: Just like amino acids, proteins are amphoteric in nature, i.e. they act as both acids and alkalies. Proteins migrate in an electric field and the direction of migration depends upon the net charge carried by the molecule, which is influenced by the pH value. Each protein has a fixed value of isoelectric point (pI) at which it will not move in an electric field.



Isoelectric point: Isoelectric point (or isoionic point) is the pH value at which the number of cations is equal to that of anions. Thus, at the isoelectric point, the net charge of a protein is always zero. But the total charge (sum of positive and negative charges) is always maximum at this point. Thus, the proteins are dipolar ions or zwitterions at the *pI*.

At pH values lower than *pI*, the protein will have a net positive charge and will migrate towards the cathode and at pH values higher than *pI*, the protein will have a net negative charge and will move towards the anode.

At the isoelectric point, the osmotic pressure and viscosity of the protein solution are at a minimum, Also, at this point, proteins are least soluble and can be precipitated out most readily.

Ion binding capacity: Being amphoteric, proteins can form salts with both anions and cations. A mixture of proteins at a given pH will include both cations and anions and salts of protein-protein combinations will be formed.

Many ions form insoluble salts with proteins and serve as excellent protein precipitating agents. For example, anions of acids such as phosphotungstic, trichloroacetic, and picric acids form insoluble salts with proteins when the latter behave as cations. Heavy metals (Hg, Cu, Ag, Zn) also act as precipitating agents for proteins when the latter behave as anions. Acid dyes may be used as colouring agents for insoluble proteins such as silk and wool through the protein's ion-binding capacity.

Solubility: The solubility of a protein is greatly influenced by pH. Solubility is lowest at the isoelectric point (*pI*) and increases with increasing acidity or alkalinity. This is because, when the protein molecules exist as either cations or anions, repulsive forces between ions are high, as all the molecules possess excess charges of the same sign, positive or negative. Thus, they will be more soluble than when they are at the isoelectric point.

Globulins are hardly soluble in water but their solubility is greatly enhanced by addition of neutral salts such as NaCl. This phenomenon is known as '*salting-in*' effect. Many proteins are precipitated from aqueous solutions by high concentrations of neutral salts, especially sodium sulphate, ammonium sulfate, magnesium salts and phosphates.

This is the '*salting-out*' process. Some proteins such as casein (present in milk) are readily precipitated at or near their isoelectric point. This phenomenon is, therefore, called *isoelectric precipitation*.

Optical activity: All protein solutions rotate the plane of polarized light to the left, i.e. they are levorotatory.

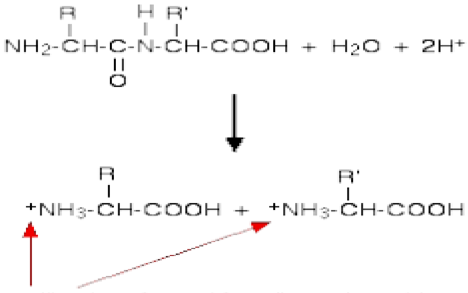
Chemical properties

Let's now discuss the major chemical properties of proteins.

Hydrolysis

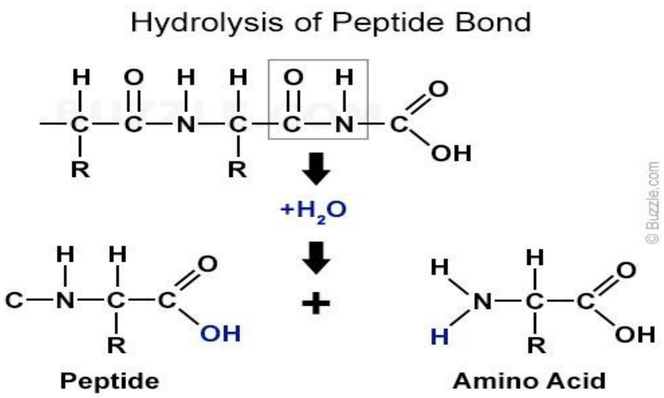
Proteins are hydrolyzed by a variety of hydrolytic agents.

Hydrolysis by acidic agents: Proteins, upon hydrolysis with conc. HCl (6- 12 N, 100-1100C, 6-10 h) yield amino acids in the form of their hydrochlorides.

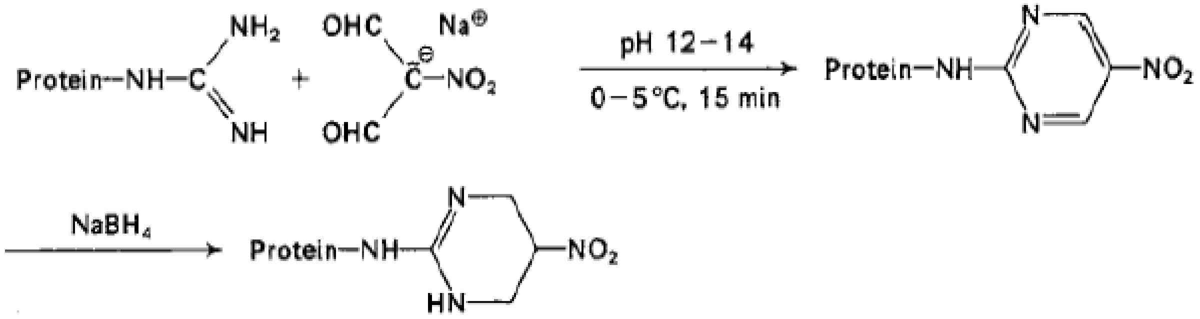


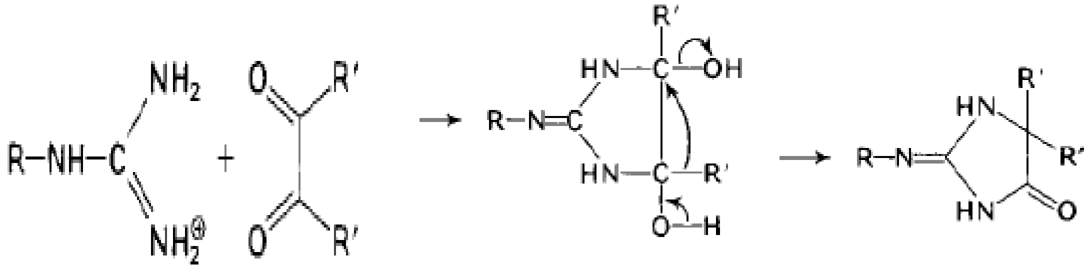
Hydrolysis by alkaline agents: Proteins may be hydrolyzed with 2 N NaOH.

Hydrolysis by proteolytic enzymes: Under mild conditions, certain enzymes such as pepsin and trypsin can hydrolyze the proteins.



Arginine residue -The arginine residue of proteins reacts with α- or β-dicarbonyl compounds to form cyclic derivatives. -The nitropyrimidine derivative absorbs at 335 nm. The arginyl bond of this derivative is not cleaved by trypsin but it is cleaved in its tetrahydro form, obtained by reduction with NaBH4. -In the reaction with benzil, an iminoimidazolidone derivative is obtained after a benzilic acid rearrangement.





Reaction of the arginine residue with 1,2-cyclohexanedione is highly selective and proceeds under mild conditions.

Regeneration of the arginine residue is again possible with hydroxylamine.

Glutamic and Aspartic Acid residues

These amino acid residues are usually esterified with methanolic HCl. There can be side reactions, such as methanolysis of amide derivatives or N,O-acyl migration in serine or threonine residues.

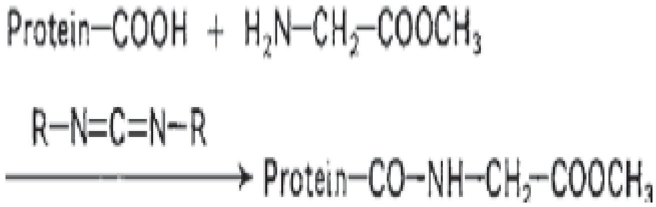
$$\text{Protein—COOH} \xrightarrow[0\,°\text{C}]{\text{CH}_3\text{OH/HCl}} \text{Protein—COOCH}_3$$

Diazoacetamide reacts with a carboxyl group and also with the cysteine residue.

$$\text{Protein—COOH} + \text{N}_2\text{CH—CONH}_2$$

$$\longrightarrow \quad \text{R—COOCH}_2\text{CONH}_2$$

- Amino acid esters or other similar nucleophilic compounds can be attached to a carboxyl group of a protein with the help of carbodiimide.



Hydrolysis: Protein are hydrolyzed by dilute mineral acids, alkaline, enzyme. The end product of hydrolysis is amino acids.

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UTILIZATION OF TECHNICAL TEXTILE IN AGRICULTURAL ADVANCEMENT

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Abstract:

Agro-textile is an expansive and dynamic segment within technical textiles. The applications of agro-textiles are versatile and extend across farming, sericulture, animal husbandry, and horticulture. Agro textile play a crucial role in managing climatic conditions and environmental factors for optimal crop production, silk worm cultivation, cattle farming, horticultural crop yield, as well as post-harvest operations. In the forthcoming future, agro-tech emerges as the predominant strategy for elevating productivity while simultaneously mitigating adverse environmental impacts, including water pollution, soil degradation, water conservation challenges, and the onset of climatic breakdown. The expected increase in market growth of agro textile is closely related to the ever increasing global population.

Keywords: Technical textile, Agro textile, Agriculture, farming

Introduction:

Technical textiles are textile materials and products that are produced more for their technical performance and utilitarian qualities than for their aesthetics or decorative purposes. A textile item created for functional, rather than aesthetically pleasing, reasons is referred to as a technical textile. The Indian textile industry dominates the nation's economic life, according to the Ministry of Textiles' 2012 report. It is not fulfilling basic needs of life but also a major contributor to national industrial production, employment generation and exports. Technical textile is considered to be the fastest growing sector in the textile industry and is engaged in manufacturing high-technology fabrics which is not only beautiful but also provide greater functionality. Moreover, the Textile industry has changed its focus from clothing application to non–clothing applications of textiles referred as technical textiles**.** These technical textiles have grown at twice the rate of clothing textiles and now account for over half of total textile consumption (Chaudhary &Shahid, 2013).

Technical Textile is an investment destination in India because it can give a boost-up to traditional textile industry. According to the most recent figures, it provides roughly 17% to export revenue, 14% to industrial output, and 4% to GDP. Over 35 million individuals, many of whom are women and members of Schedule Castes and Schedule Tribes, have direct work opportunities because of this. Because the textile industry is the second-largest contributor to the nation's economy, its expansion and growth are intimately correlated with the country's economic growth.In their 2007 paper "Technical textile- Functional textiles and apparels," Teli and Kumar discuss the crucial role that functional textiles and apparel play, identifying Meditech and Protech as the two main branches of the Technical textile segment responsible for the substantial growth in rapidly developing nations like China and India. Use of technical textile in farming is not novel; it has been used for thousands of years (Sharma et al, 2022) and has a significant contribution in the protection of crops and sustainable and eco-friendly agriculture. Due to a remarkable growth in consciousness towards sustainable environment and advancements in technology, there has been a substantial shift towards the use of textile fibers in agriculture. (Kasirajan and Ngouajio, 2012). The Agro-textile segment is one of thefastest-growing segments of technicaltextiles. The implementation of agro-textile and agro-technical practices covering livestock, shading, weed &insect control, and extending the growing season of agriculture crops including agro-produce packaging (Chowdhury *et al.,* 2017).

Technical textile and agriculture

Agricultural textiles are one of the growing technical textile and also known as agri-textiles. The technical textiles are considered to the fastest growing sector and are producing advanced, high-performance fabrics that are designed to offer significant value in terms of functionality (Chaudhary and Shahid, 2013).

The rise in population and increasing demand for better and high-gradefruits and vegetables are the crucial factor for the growth of agro-textiles. Fibers for agro-textiles are often selected according to the application area in agro-tech. The fibers like, jute, coir, sisal, and hemp have wide applications in agro-textiles. Today agro-textiles play a significant role to control environment for crop production, eliminate variations in climate, weather change and generate optimum condition for plant growth. Textile structures in various forms are used in shade houses/poly houses, green houses and open fields to control environmental factors such as temperature, water and humidity (Dorugade *et al.,* 2023).

Crop protection and weed control are major challenges facing farmers in the agriculture industry. Agro-textiles like sunscreen, bird net, windshield, mulch mat, hail protection net and harvesting net are used. (Palamutcu and Devrent, 2017).

The surge in demand for food, propelled by an aging population, is composed to be a key driver for the agro-textile market. The continuous growth of the global population deepens the demands on agricultural production, necessitating expansion. Thus, there is an imperative need to enhance the quality and yield of agricultural products while operating within defined constraints of water and space.

To foster robust plant growth and ensure a generous harvest, the utilization of sunscreen nets with open mesh construction becomes paramount. These nets serve as a protective shield, effectively managing the intensity of solar radiation to create an optimal environment within fields and greenhouses. Root ball nets extremely important for safe and speedy growing of young plants that root system is not damaged when they are dug up, transported or replanted. Ground

Cover is an extremely versatile landscape and horticultural fabric for long-term weed control, moisture conservation and separation. It is mainly used in planted areas. Windshields are used in farming to protect fruit plantations from wind and to prevent damage to plants. It also prevents plants being cooled by the wind. Mulch mats are used to suppress weed growth in horticulture applications. It covers the soil, blocking light and preventing the growth of competing wheat around the seed link. This also reduces the need for herbicides needed for weed control.

Leveraging technical textile to reduce health hazards of farmers

Using personal protective equipment (PPE) is essential, for protection of farmers against the health effects of pesticides thereby reducing health expenditures associated with pesticide exposure. The extent of harm caused by pesticides depends on their toxicity and the duration of exposure. Factors such as the chemical composition and formulation of the pesticide determine that how it enters the body and the amount absorbed and how severe the symptoms of pesticide poisoning manifests. However complete elimination of risks is not always possible. In agriculture hazards can take forms including objects, falling objects, sparks, chemicals, noise pollution and other potentially hazardous situations.

Wearing protective equipment (PPE) significantly reduces a wide range of risks. Examples of gear include gloves, steel toed boots, goggles or face shields, earplugs or earmuffs hard hats, respirators and full body suits. By using PPE consistently in settings can effectively minimize skin contact risks as well as inhalation or oral exposures, to pesticides. This greatly reduces the chances of pesticide poisoning occurring.

Review of available statistical data of utilization of technical textile in farming

The demand of agro technical textile in agriculture is increasing rapidly. According to recent report of Compound annual growth rate (CAGR) agricultural textilesmarket is projected to grow from USD 15.9 billion in 2023 an as expected to reached USD 20.2 billion by 2028 globally (textilevaluechain).

Between 2018 and 2022, the technical textile market exhibited substantial growth, and this momentum continued at a robust pace from 2023 to 2033. Improvements in farming methods as well as implementation of technical textiles in agriculture and farming practices targeted at increasing crop yields have significantly contributed to the positive trajectory of the technical textiles market. Demand for protective nets made from agrotech textiles are gaining momentum in the United States, in line with the country's effort to achieve food self-sufficiency and reduce dependence on other countries for food-related needs (futuremarketinsights).

According to insights from the American Farm Bureau Federation, a single farm in the United States currently provides food to nearly 166 individuals. However, with the global population projected to increase by 2.2 billion over the next thirty years, farmers face the imperative task of boosting food production by about 70% from the current rate (America's Diverse Family Farms, 2020 Edition).

According to a report by the IMARCgroup, India's agriculture industry will beworth INR 63,506 billion in 2020. India'sTechnical Textiles Sector has a 12 percentAnnual Average Growth Rate (AAGR), which is nearly three times the globalaverage of 4 percent. (Meena and Surliya, 2022).

Conclusion:

Technical textiles, characterized by their focus on performance properties rather than mere aesthetics, encompass a vast landscape of applications. Within this realm, the domain of agro textiles stands out as a growing and crucial sector. As our world deals with increasing demands for agricultural production due to increasing population, the role of agro textiles is becoming increasingly important. The agricultural and horticultural sectors are adapting to the evolving needs of tomorrow, embracing various technologies to achieve higher overall yields, improved quality, and more flavorful agro-products. The application of agro textiles varies, with some locations utilizing them to shield plantations from excessive sunlight, while others seek protection against the cold. By incorporating high-quality agro textiles, the ability to increase both the quality and yield of agricultural products becomes not just a possibility, but a tangible reality, contributing to a sustainable and resilient future of global agriculture.

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BIOCHEMISTRY OF PESTICIDES AND INSECTICIDES, HISTORY AND CLASSIFICATION

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Abstract:

The use of pesticides and insecticides in agriculture is still essential to achieve adequate control of pests. However, there is an important social pressure towards the development of measures for minimizing the impact of pesticides on the environment and reducing and controlling the risks associated with their application. One way to achieve these goals is the rational application of pesticides and insecticides by properly adjusting the amount of product to the actual needs and specific conditions of the application (pest to be controlled, machinery and pesticide used and vegetation to be treated). However, applying large quantities of product is fairly common, in order to ensure the result, without taking into account that this practice normally entails an excessive release of products that pollute the environment and increases production costs.

Introduction:

Pesticides

Pesticide is any substance or mixture of substances used to prevent, destroy, or control pest including insects, fungus, rodents or, unwanted species of plants causing harm during production and storage of crops. The word "pesticide" is a broad term that includes insecticides, herbicides, fungicides, and rodenticides that may be used to kill some specific pests. Pesticides are classified according to the sources of origin as either being a chemical pesticide or bio pesticides. Biological pesticides are host specific. They are highly specific in the sense that it acts on the target pest and strongly related organisms, whereas chemical pesticides are nonspecific with wide range of activities on a large group of nontarget organisms. Bio pesticides are environmentally friendly because they are less toxic, decomposed easily, and required in small quantities.

Chemical pesticides cause several environmental pollutions because they are quite toxic and may not be biodegradable. More so, bio pesticides are of important advantage being less susceptible to genetic modification in plant populations. This confirms the little chance of pesticide resistance in pests, which is hardly encountered in case of chemical pesticides. Chemical pesticides are further subdivided into organochlorine, organophosphate, carbamate, and pyrethroids. Biopesticides are group of pesticides derived from natural materials such as animal, plant, and microorganism (bacteria, viruses, fungi, and nematodes). They include microbial pesticides, plant incorporated protectants, and biochemical pesticides. Pesticides act through several mechanisms. Some are termed growth regulators as they either stimulate or retard the growth of pest, while repellents are known to repel pests, and attractants attract pests or chemosterilants, which sterilize pests. Pesticides with a wide range of activities and used to control more than one class of pests are difficult to classify. Examples are aldicarb, which is used in Florida citrus production and may be considered an acaricide, insecticide, or nematicide for the reason that it controls mites, insects, and nematodes, respectively. Aside from established chemicals employed as insecticides, other traditional means are also employed to decrease the growth of insect or limit their activities.

History

Ever since ancient times, human civilizations have tried to apply the most effective and less time-consuming approaches for cultivating and preserving their food resources. An actual illustration of this is how they cultivated venomous and nutritious vegetation in the same place due to the shielding effect of toxic plants for insect elimination. Correspondingly, throughout this period, elemental sulfur has also been used. These would be the initial methods for removing pests for several millennia.

Traditional Chinese medicine also uses primitive sulfides. It is likewise interesting to note that Homer's epic work "Odysseus," written around the Natural Remedies for Pest, Disease and Weed Control. Around 1500's, the early stages of the use of the "para-pesticides," namely mercury and arsenic, emerged. These substances were used until the start of synthetic pesticide era (1940 and beyond), initially for the destruction of food reserves during the World War II and later on as precious tools for cultivating processes of foods consumed daily. It is crucial to note that through this time, several scientists have highlighted the adverse effects of pesticides on human health when used for a long time. For instance, the drastic increase in the number of lymphoma patients is a topic that would be discussed until today.

Classification of pesticides

Pesticide may be defined as any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant.

As per the Insecticides Act 1968, any substance which is in the schedule, or such other substances as the central government may, after consultation with the Board, by notification in the official gazette, include in the schedule from time to time or any preparation containing any one or more of such substances is a pesticide.

Pests include insects, plant pathogens, weeds, molluses, birds, mammals, fish, nematodes (roundworms), and microbes that destroy property, spread disease or are a vector for disease or cause a nuisance. Although there are benefits to the use of pesticides, there are also drawbacks, such as potential toxicity to humans and other animals.

Pesticides may be classified in many ways and these classifications can provide useful information about the

1. Use or target pests

2. Mode of Action
3. Toxicity
4. Chemistry/Chemical structure

Classification based on Use or target Pests:

a) **Acaricides:** The substances that are used to kill mites and ticks, or to disrupt their growth or development. Eg: DDT, dicofol, Fenpyroximate

b) **Antifeedants:** The chemicals which prevent an insect or other pest from feeding. Eg: Chlordimeforn, Fentin and Azadirachtin.

c) **Bactericides:** The compounds which are used to kill or inhibit bacteria in plants or soil. Eg: Copper hydroxide, Kasugamycin, Streptomycin, Tetracycline

d) **Fungicides:** The chemicals which are used to prevent, cure eradicate the fungi. Eg: carbendazim, thiabendazole, thiophanate-methyl,

e) **Chemosterillant:** The chemicals that renders an insect infertile and thus prevents it from reproducing. The chemosterillant acts by inhibiings the production of egg, causes death of the eggs or cause lethal mutation on the spam or eggs material Eg: Aziridinyl, Diflubenzuron

f) **Herbicides:** Substances that are used to kill plants, or to inhibit their growth or development. Eg: Paraquat, Glyphosate, 2,4-D

g) **Insecticides:** A pesticide that is used to kill insects, or to disrupt their growth or development. Eg: Monocrotophos, Carbofuran, Lambdacyhalothrin

h) **Nematicides:** The chemicals which are used to control nematodes. Eg: Abamectin, Triazophos

i) **Plant growth regulators:** The substances that alter the expected growth, flowering or reproduction rate of plants. Eg: NAA, Ethephon

j) **Rodenticides:** The substances used to kill rats and related animals. Eg: Zinc Phosphide, Bromadiolane.

Classification based on mode of action:

The classification of pesticides is also done on the basis of mode of action. They are

a) Contact insecticides:

The contact pesticide acts on the pest when the pest comes in to contact are chew the plant material. Entry of pesticide is through dermal contact. Some examples are Endosulfan, Malathion, fenvalerate.

b) Stomach insecticides:

Pesticides that act inside the gut of the target organisms. The main mode of entry for these compounds is through ingestion. Some of the stomach poisons are toxins produced by the bacteria *Bacillus thuringiensis and* rodenticides such as Zinc Phosphide.

c) Systemic:

Systemic insecticides are those in which the active ingredient is taken up, primarily by plant roots, and transported (translocated) to locations throughout the plant, such as growing points, where it can affect plant-feeding pests. Systemics move within the vascular tissues, either through the xylem (water-conducting tissue) or the phloem (food-conducting tissue) depending on the characteristics of the material. Systemic insecticides are most effective on insects with piercing—sucking mouthparts, such as aphids, whiteflies, mealybugs, and soft scales, because these insects feed within the vascular plant tissues. Ex. monocrotophos, carbofuran.

d) Translaminar:

These materials penetrate leaf tissues and form a reservoir of active ingredient within the leaf. This provides residual activity against certain foliar-feeding insects and mites. Insecticides/miticides with translaminar properties include aba-mectin, pyriproxyfen (Distance), chlorfenapyr (Pylon), spinosad (Conserve), and acephate (Orthene). In general, these types of materials are active against spider mites and/or leafminers. Because the active ingredient can move through plant tissues (that is, leaves), thorough spray coverage is less critical when using these materials to control spider mites, which normally feed on leaf undersides.

e) Fumigant:

Fumigants are gaseous pesticides that control pests in agricultural fields, structures like buildings and apartments, storage houses and various other sites. Fumigants are generally volatile in nature with good penetrating power. Aluminium Phosphide, methyl bromide, chloropicrin and iodoform are some of the most popular examples of fumigants. Some of the chemicals have fumigant action apart from either of the above properties, for example DDVP, Lindane, chlorpyrifos.

Insecticides

Introduction:

Based on the molecular structure of a compound, the pesticides are divided into two groups: **organic** and **inorganic**. The earliest chemical pesticides like Sulfur and lime were inorganic. Most of the modern pesticides are organic chemicals. Organic pesticides can be subdivided into two groups: the **natural organics**, and the **synthetic organics**.

Natural organics:

The natural organic pesticides are derived from naturally occurring sources such as plants, microorganisms etc. and may be divided as Microbial bio-pesticides and Botanical Pesticide. Microbes used as bio-pesticides are basically bacteria (Antagonistic and Entomotoxic Bacteria), fungi (Antagonistic and Entomopathogenic Fungi) and viruses (Nuclear polyhydral virus and Baculovirus). Two major botanical pesticides are Azadirachtin and Pyrethrin.

Synthetic organic pesticides are produced artificially by chemical synthesis. This group comprises most "modern" pesticides and subdivided into following groups:

i. Organochlorine Pesticides

ii. Organophosphate Pesticides

iii. Carbamates

iv. Synthetic-pyrethroid

v. Other Insecticides

i. Chlorinated hydrocarbon:

These chemicals are often considered to belong to the group of organochlorine pesticides. These pesticides were commonly used in the past but many have been removed from the market due to their persistence. They are hard to break down in the natural environment and their prolonged use in large quantities lead to environmental pollution and accumulation in mammals, resulting in cumulative poisoning or damage. Termed as Persistent Organic Pollutants (POPs), most of the organochlorine pesticides are banned.

Chemical group	Compounds
Dichlorodiphenylethanes	DDT, Methoxychlor
Hexachlorocyclohexane	Lindane
Cyclodienes	Aldrin, Dieldrin, Endrin, Chlordane, Heptachlor
Chlordecone	Mirex

ii. Organophosphorus Insecticides:

Organophosphorous compounds can kill by contact, systemic or fumigant action or a combination of the three. They affect the nervous system by disrupting an enzyme that regulates acetylcholine, a neurotransmitter. Being a nerve poison they can cause acute toxic reactions in humans.

Based on the chemical structures op's are classified as the following groups

S. No.	Type	Insecticides
1	Pyrophosphates and related compounds	TEPP, Schradan
2	Phosphates	Chlorfenvinphos, Mevinphos, Dichlorvos, Monocrotophos, Tetrachlorvinphos
3	Thiophosphates	Chlorpyriphos, Diazinon, EPN, Ethyl parathion, feniitrothion, Fenthion, Methyl parathion, Primiphosmethyl, Triazophos
4	Dithiophosphates	Dimethoate, Aazinphos-methyl, Malathion, Phorate
5	Phosphonates	Terbufos, Trichorfon
6	Phosphoramidates	Acephate, Tebophos, Methamidophos

iii. Carbamates:

They have systemic and contact in action. They are nerve poison and inhibit acetyl cholinesterase activity at synapse or nerve junctions. They act similar to organophosphorus compounds except for the reversible nature of toxicity. ***Example*:** Carbofuran, Propoxur etc.

iv. Pyrethroids:

Pyrethrum is found in the flowers of plants belonging to the family Compositae and the genus *Chrysanthemum* sp. The pyrethrum compounds found in pyrethrum flowers consist of six esters which are the combinations of three different alcohols (pyrethrolone, jasmolone and cinerolone) with two different acids (chrysanthemic acid and pyrethric acid). Pyrethrums are highly unstable in the presence of light, moisture, and air. The pyrethrins are contact insecticides and have almost no stomach poison action because they are so readily hydrolyzed to nontoxic products. Their primary action is on the insect central nervous system, as shown by the fact that they produce such rapid paralysis. **Synthetic pyrethroids (SPs)** are synthetic analogs and derivatives of the original pyrethrins and include a variety group of about 1,000 insecticides. Though they are analogs of pyrethrins, their production has involved extensive chemical modifications which make them highly toxic and less degradable in the environment. Due to complex chemical structure, the pyrethroids are composed of two, four or eight isomers, and their commercially products may contain a mixture of these various isomers. For increasing the efficiency of the insecticides, the pyrethroids are formulated with compounds like piperonylbutoxide, piperonyl sulfoxide and sesamex, which act as synergists. Pyrethroids are broad spectrum insecticides, effective against a wide range of insect pests of the sucking complex such as aphids, jassids, whiteflies as well as chewing pests such as borers and leaf feeders. Prior to harvest, they are sprayed over edible products to control pests, as grain protectants, veterinary pests and household insecticides.

v. Oher Insecticides:

a) Neonicotinoids insecticides: Neonicotinoids are a new class of insecticides with nicotinic receptor agonist. The neonicotinoid insecticides include imidacloprid, acetamiprid, nitenpyran, dinotefuran, thiamethoxam, thiacloprid and clothianidin. Among these, imidacloprid is most widely used at present.

b) Insect Growth Regulators: Juvenile hormone analogs and mimics when applied to an insect, an abnormally high level of juvenilizing agent will produce another larval stage or produce larval-pupal intermediates. Juvenoid IGRs can also act on eggs, can cause sterilization, disrupt behavior and disrupt diapauses. E Anti-juvenile hormone agents cancel the effect of juvenile hormone, an early instar treated with an anti-juvenile hormone molts prematurely into a nonfunctional adult. Some of the examples are methoprene, kinoprene, hydroprene, pyreproxyfen, fenoxycarb etc. Some examples for ecdysteroids include compunds namely tebufenozide (MIMIC, CONFIRM) halofenozide, methoxyfenozide, chromafenozide, difenolan etc.

c) Chitin synthesis inhibitors: These are chemically diverse compounds that affect reproduction and development of chitin synthesizing organisms (insect and fungi) to varying degrees. Application of chitin synthesis inhibitors typically induces malformations of the cuticle and a significant reduction of chitin amounts. Ex. diflubenzuron, triflumuron, hexaflumuron, novaluron, lufenuron, flufenxuron, teflubenzuron, chlorfluazuron, etoxazole, hexythiazox, clofentazine and buprofezin.

d) Avermectins: Avermectins and milbemycins of compounds which are structurally similar were discovered from *Streptomyces* sp., and are used against worms, ticks, flies and agricultural pests. Abamectin, a commercial product, is a mixture of >80% avermectin B1a and <20% avermectin B1b which are obtained from *Streptomyces avermitilis*, a soil bacterium whereas milbemectin products, is a mixture of ≥70% milbemycin A4 and ≤30% milbemycin A3 obtained from another soil bacterium, *Streptomyces hygroscopicus*subsp. *aureolacrimosus*. Milbemycins and avermectins have the same mode of action which is to potentiate glutamate and GABA gated chloride-channel opening.

e) Spinosyns: Spinosyns are the group of compounds was originally isolated from *Saccharopolysporaspinosa* (actinomycetes). Spinosad is a mixture of at least two major compounds, spinosyn A and spinosyn D, in which spinosyn A is a major constituent. These effects are consistent with the activation of nicotinic acetylcholine receptors by a mechanism. Spinosad is approved for use as an organic insecticide for caterpillars, leaf miners, thrips and foliage-feeding beetle.

f) Botanical Insecticides: Botanical pesticides, in the form of isolated substances or complex mixtures, exhibit a range of biological activities, acting as insecticides, repellents, attractants, fungicides, nematicides, and bactericides. It has been reported that about 17500 aromatic plant species growing worldwide in tropical environments and more than 3000 constituents have been identified to possess significant pesticidal properties.

Neem and azadirachtin A: Neem along with the various species of Meliaceae family namely, *Azadirachtaindica*has emerged as top botanical insecticide with the highest potential. The Meliaceae specially, *A. indica* (Indian neem tree), contains at least 35 biologically active principals of which Nimbin and azadirachtin are the most active insecticidal ingradients. The major active principle, azadirachtin (AZA), a ring C-secotetranortriterpenoid, is the most potent natural insect antifeedant discovered. Azadirachtins obtained from seed kernel of neem, contain numerous structurally similar compounds belongs to limonoid group besides oil but the major bioactive compound for pest control has been identified as azadirachtin A. AZA is dually advantageous as a natural insect control agent because it possesses both protectant (antifeedant) and toxic (insect growth regulatory) properties against insects.

g) Microbial insecticides: Different species and strains and *Bacillus* bacteria are known to affect different groups of insect pests, primarily due to differences in endotoxin receptor sites on the gut wall. The lethal component is crystals of δ-endotoxin. *Bacillus thuringiensis* var. *kurstaki* (Dipel, Javelin) is effective against caterpillars of moths and butterflies.

Definition and concepts of pesticide residue

The **pesticide residue** may be defined as the quantity of pesticide and its derivative or metabolites present in or on any agricultural produce, animal feed, food items of human beings and environment. It is usually expressed as parts per million (ppm) or parts per billion (ppb) or parts per trillion (ppt) on weight by weight basis.

Definition by WHO: "Any substance or mixture of substances in food for man or animals resulting from the use of a pesticide and includes any specified derivatives, such as degradation and conversion products, metabolites, reaction products, and impurities that are considered to be of toxicological significance."

Definition by FAO (1986)**:** Substance(s) which remains in or on a feed or food commodity, soil, air or water following use of a pesticide. For regulatory purposes it includes the parent compound and any specified derivatives such as degradation and conversion products, metabolites and impurities considered to be of toxicological significance.

The pesticides applied on the field crops, horticultural crops and domestic pest control, do under go degradation during the course of time by many ways as follows: Runoff, Leaching, Volatilization, Microbial Degradation, Physical Degradation (Hydrolysis, Photolysis & Pyrolysis). Though all the pesticides were thoroughly tested and evaluated before approval, their residue may be present because of extensive use in agriculture to control pests & improve yields, more than 1000 different active substances are used & most of them are persistent in nature. Sometimes not applied in accordance with intended purpose, Good Agriculture Practice sometimes not respected Accidental contamination.

Dissipation of pesticides

Millions of tons of pesticides are applied annually; however, less than 5% of these products are estimated to reach the target organism, with the remainder being deposited on the soil and non-target organisms, as well as moving into the atmosphere and water. Dissipation of pesticides is defined as loss of pesticide residues from an environmental compartment due to degradation and transfer to another environmental compartment. The dissipation includes various processes like adsorption, transfer, breakdown and degradation.

a) Adsorption

Adsorption is the binding of pesticides to soil particles. It is varying with the type of pesticide, soil, moisture, soil pH, and soil texture. Pesticides are strongly adsorbed to soils that are high in clay or organic matter and not strongly adsorbed to sandy soils. Most soil-bound pesticides are less likely to give off vapours or leach through the soil. They are also less easily taken up by plants.

b) Transfer processes

Volatilization is the process of solids or liquids converting into a gas, which can move away from the initial application site. This movement is called vapour drift. Pesticide volatilization occurs most readily from sandy and wet soils. Hot, dry, or windy weather and small spray drops increase volatilization. Where recommended, incorporating the pesticide into the soil can help reduce volatilization.

c) Spray drift is the airborne movement of spray droplets away from a treatment site during application. It is affected by spray droplet size - the smaller the droplets, the more likely they will drift, wind speed - the stronger the wind, the more pesticide spray will drift, distance between nozzle and target plant or ground - the greater the distance, the more the wind can affect the spray

Drift can damage crops or can contaminate crops ready to harvest. It may also be a hazard to people, domestic animals, or pollinating insects and contaminate water in ponds,

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streams, and ditches and harm fish or other aquatic plants and animals. Excessive drift also reduces the pesticide applied to the target and can reduce the effectiveness of a treatment.

d) Runoff is the movement of pesticides in water over a sloping surface. The pesticides are either mixed in the water or bound to eroding soil. Runoff can also occur when water is added to a field faster than it can be absorbed into the soil. Pesticides may move with runoff as compounds dissolved in the water or attached to soil particles. The amount of pesticide runoff depends on: the slope, the texture of the soil, the soil moisture content, the amount and timing of a rain-event (irrigation or rainfall), the type of pesticide used. Runoff from areas treated with pesticides can pollute streams, ponds, lakes, and wells. Pesticide residues in surface water can harm plants and animals and contaminate groundwater. Water contamination can affect livestock and crops downstream.

Pesticide runoff can be reduced by using minimum tillage techniques to reduce soil erosion, grading surface to reduce slopes and leaving border vegetation and plant cover to contain runoff. Pesticide losses from runoff are greatest when it rains heavily right after spray. It reduces the chances of runoff by watching the weather forecast.

e) Leaching is the movement of pesticides in water through the soil which occurs downward, upward, or sideways. The factors influencing whether pesticides will be leached into groundwater include characteristics of the soil and pesticide, and their interaction with water from a rain-event such as irrigation or rainfall. Leaching can be increased when the pesticide is water soluble, the soil is sandy, a rain-event occurs shortly after spraying and the pesticide is not strongly adsorbed to the soil.

f) Absorption is the uptake of pesticides and other chemicals into plants or microorganisms. Most pesticides break down once they are absorbed. Pesticide residues may be broken down or remain inside the plant or animal and be released back into the environment when the animal dies or as the plant decays. Some pesticides stay in the soil long enough to be absorbed by plants grown in a field years later leaving residues in future crops.

g) Crop removal through harvest or grazing may remove pesticide residues

h) Degradation is the process of pesticide break down after application. This may be due to some physical factors (photo degradation, Pyrolysis), chemical reactions (Hydrolysis) or broken down by microbes and plants enzymatic actions (Metabolism). This process may take anywhere from hours or days to years, depending on environmental conditions and the chemical characteristics of the pesticide. Pesticides that break down quickly generally do not persist in the environment or on the crop. However pesticides that break down too rapidly may only provide short-term control.

i) Chemical breakdown is the breakdown of pesticides by chemical reactions in the soil. The rate and type of chemical reactions depends on the binding of pesticides to the soil, soil temperatures, pH levels - many pesticides, especially the organophosphate insecticides, break down more rapidly in alkaline soils or in spray tank water with a high pH level, soil moisture

j) Photo degradation is the breakdown of pesticides by sunlight which depends on the intensity and spectrum of sunlight, length of exposure, and the properties of the pesticide. Pesticides applied to foliage are more exposed to sunlight than pesticides that are incorporated into the soil. Pesticides may break down faster inside plastic-covered greenhouses than inside glass greenhouses, since glass filters out much of the ultraviolet light that degrades pesticides.

Pyrolysis: Degradation of pesticides due to heat.

Hydrolysis: Degradation of pesticides due to water.

Conclusion:

The application of chemical pesticides has been given a lot of attention and support for the management of agricultural pests but there are lots of limitations to their application. This might be linked to the safety issue of a serious hazard from the various active ingredients. Therefore, there is a need to make sustainable, green, eco-friendly biopesticides.

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ROLE OF INDIAN WOMEN IN AGRICULTURE: A REVIEW

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Abstract:

Agriculture in India remains an important sector because it contributes about 15% of the Indian economy. Women are the backbone of rural Parts of the Indian panorama in agriculture. Women play a significant role in Indian agriculture by contributing to regular and allied activities of agricultural production. They are the torchbearers of social, economic and environmental transformations for new India. In rural communities in India, are mainly dependant on agriculture and allied activities. Agriculture is the primary source of livelihood and about 80 percent of rural population is engaged in agriculture. However, the nature and level of their involvement differ with the variations in agricultural production. Their involvement in various aspects of farming, including cultivation, livestock management, post-harvest activities, and even entrepreneurship make remarkable changes in Indian agriculture. Women are major stakeholders in growth of agricultural sector for the New India. The rural women will recognize that ensuring access to resources like education, health services and ownership rights and access to skill development programmes will improve agriculture productivity and help in building an empowered nation. This paper highlights the engagement of the women workforce is an important era of agricultural development. It also focuses on the nature and extent of women participation in Indian agriculture.

Keywords: Rural women, Agriculture, Work participation, Labour force.

Introduction:

In recent developmental world women plays a major role in the development of agriculture. The changes in agriculture through mechanization, hybrid varieties of crops, and innovative growth nutrients are boosting agricultural production. The uncontrolled population and increase in the requirement of food resources are fulfilled by modern agriculture. The growing recognition of agriculture has become an important role of women in the social and economic transformation of rural parts of India. The famous economist Amartya Sen rightly said that women's agency should become a determinant factor to take care of the overall development of society.

In the Indian agriculture sector, more than 50% of overall manpower is engaged in agriculture and allied activities. From this, women constituted 38% of the agricultural labour force and employed two-thirds of the female workforce in India. Women are working extensively in agricultural and allied activities including domestic activities as well. As per sectoral distributions of women in rural India, it indicates that 70% of women are engaged in agriculture and allied activities, In industries 15% and in service sectors 14% respectively. While, in urban parts of India only 8% of women are involved in the agricultural sector, 63% of women are engaged in the service sector, and 32% are involved in the industrial sector. They are engaged in various farm operations ranging from preparation of cultivable land to till harvesting of the agricultural yield. The Government has framed the agricultural policies by integrating women as an active agent of agricultural development and also initiated various schemes and incentives for women to increase the status of women in society.

Review of literature:

Kumar *et al.* (2019) concluded that female involvement in agriculture is falling day by day and year by year, due to primitive working conditions and low wages. So, women tend to leave the agriculture sector and move to the non-agrarian sector, where they get a better wage according to educational qualifications and experience with high social status and working environment. Chakma and Ruba (2021) discussed that women invariably face societal challenges, but they still play a major role in diverse agricultural activities. They actively participate in post-harvesting activities of field crop production. Sasa *et al.,* (2022) noted that systemic gender based biases or inequalities are one of the major issues limiting women in engaging and accessing agriculture related resources. One of the issues discussed in this review is that credit constraints for women put a severe limit on the full participation of women in agricultural related activities, thereby leading to less contribution to the economic development and self-sufficiency of the rural community. Women have been contributing enormously to agricultural growth and development through their involvement in crop production, horticulture, animal husbandry, fisheries, natural resource management. The need of the hour is on how to bridge the gender gap and empower women with new knowledge and technology is a great challenge, particularly in the context of socio-economic and climate related changes (Patil and Babus, 2018).

Women in agriculture- concern, involvement, and empowerment:

Women's significance to agriculture cannot be underestimated, they are involved in numerous agricultural and allied activities. Women work as farmers, caretakers, and in domestic activities. Most of the contribution of women is not recognized and they are treated as household labour. Women's empowerment is limited by many factors like family limitations, religious barriers, early marriage, and lack of education. Women play a major role in the following sections of agriculture and allied activities.

Cultivation of the crops:

In rural parts of India women are the primary cultivators of certain crops like vegetables, fruits, and pulses. They work in agriculture from the process of cultivation of crops till their harvesting Women are actively involved in various farming activities. The activities include sowing seeds, transplanting seedlings into the farm, removing weeds, watering crops, and harvesting crops.

Management of livestock:

In India, about 60% of rural women are engaged in earning and expenditure choices of the household. Livestock rearing is a woman's job and supports farm-level activities as well as family income by spending 3 to 5 hours a day. Women are the main caretakers of locally adopted livestock in India. Livestock is a major source of income along with agriculture for rural life in India. They are actively involved in all types of livestock activities like fodder collection, cleaning and care of animals, Milking, and other domestic animal-related activities. Women are often responsible for the care and management of livestock such as cattle, goats, and poultry. They ensure the well-being of the animals, including feeding, milking, and healthcare.

Post-harvest activities:

In India, Agriculture is the largest industry and it requires the highest manpower in various farm operations. The majority of agricultural jobs are less skilled jobs, such as sowing, transplanting, weeding and harvesting, etc. The women are needed to do the typical work as a labourer or cultivator in sowing and weeding activities. Many women also participate in agricultural work as unpaid or less-paid subsistence labuor. Women play a crucial role in post-harvest activities such as threshing, winnowing, sorting, and processing of agricultural produce. They are often involved in many tasks like drying grains, cleaning vegetables, and preparing food items for storage or sale.

Entrepreneurship:

Many women in rural areas engage in entrepreneurial activities related to agriculture. They set up small-scale businesses such as dairy farming, poultry farming, beekeeping, and food processing units. These ventures not only contribute to household income but also create employment opportunities in rural communities.

Seed preservation and conservation:

The transplanting, drying of seed grains, cleaning of grains, and processing were major farm activities that were completely done by farm women. They are often the custodians of traditional knowledge related to seed preservation and conservation. The rural women will preserve the vegetable seeds and other local varieties of crops that will help to preserve the traditional varieties of crops. They play a crucial role in saving indigenous seeds and preserving biodiversity in agriculture.

Water collection and management:

The majority of the area of India has having dry region. Hence, in the summer season, these areas are facing a severe shortage of water for drinking and agricultural purposes. In the regions where water scarcity is high, women are actively involved in water management activities at domestic and farm operations including irrigation, water conservation, and rainwater harvesting. They often use traditional knowledge to optimize water usage in agriculture.

Knowledge transfer:

Women are key agents in the transfer of agricultural knowledge and practices within families and communities. They gain knowledge about agriculture and related activities from their daily connection with farm operations. India has a vast history of traditional Ayurveda and rural women are knowledgeable about the traditional medicines that will be beneficial to cure serious diseases. They pass down traditional farming techniques, indigenous knowledge about crop varieties, and sustainable agricultural practices to future generations.

Overall, women in India play multifaceted roles in different sections of agriculture and allied activities by contributing significantly to food security, rural livelihoods, and sustainable development. Despite facing various socio-economic challenges, their resilience and contributions remain indispensable to the agricultural sector. Efforts to empower women in agriculture through education, training, access to resources, and supportive policies are essential for realizing their full potential and promoting inclusive agricultural development in India.

Complications in women's growth in the agriculture sector in the Indian context:

In India, women play a very vital and major role in the agriculture sector. Few Indian women have agricultural productive resources like the availability of land, animals, and mechanical equipment to increase production. The involvement of women in the decision-making process, either inside or outside the home is very negligible. In agriculture, women perform all un-mechanized tasks and perform multiple tasks, which adds more burden to them. Many women workers in agriculture are illiterate and hence they are exploited by landlords as a labour force and they will get very low wages as compared to other sectors. They are also not aware of their legal rights.

Conclusion:

Rural women are engaged in agriculture activities depending on the socio-economic status of their family and regional factors. Indian Women are having lack innovative knowledge of agriculture, hence majority of rural farmers adopt traditional methods of farming. More facilities should be provided to poor rural women for land, agricultural, and livestock extension services. To prevent exploitation by landlords by rural women in agriculture government must formulate policies to enhance their skills and their work should be counted in economic indicators. The mainstreaming of rural women via ensured access to resources, technology, education, and health facilities will improve agriculture productivity.

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AI-ENHANCED GENOMIC INTELLIGENCE: REVOLUTIONIZING AGRICULTURAL ECOSYSTEM MANAGEMENT

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Abstract:

The integration of genetics and AI has emerged as a pivotal force in modern ecosystem management, with a special focus on the role of genetics. This combination has revolutionized our understanding of biodiversity and its conservation in agricultural contexts. By leveraging AI-driven genetic analysis, we gain valuable insights into the genetic diversity of crop species, facilitating targeted conservation efforts and fostering resilience in the face of agricultural challenges. Genetics plays a crucial role in crop identification, conservation prioritization, disease detection, and adaptive management strategies. Additionally, AI enables real-time monitoring of genetic health in agricultural settings, offering a proactive approach to pest management and climate change adaptation. This paper emphasizes the significance of genetics and AI in guiding evidence-based decisions for agricultural ecosystem restoration and preservation, ushering in a new era of effective and sustainable agricultural management practices.

Keywords: AI, Genomics, Agriculture, Ecosystem Management, Biodiversity Conservation, Genetic Diversity, Crop Improvement, Sustainable Agriculture, Precision Farming, Crop Monitoring, Yield Prediction, Data Analytics

Introduction:

Ecosystem management stands as a cornerstone endeavor, crucial for preserving and restoring the delicate equilibrium of natural habitats, ensuring their sustainability, and safeguarding the welfare of all living organisms. As the complexity and demands of ecosystem management continue to escalate, technological advancements have become indispensable tools in this arena. (Gu, Yanzhang, 2021). One such groundbreaking advancement is the fusion of genetics and Artificial Intelligence (AI), which has fundamentally transformed our approach to understanding and addressing ecosystem management challenges. Genetics, delving into the study of genes and heredity, offers invaluable insights into the biodiversity and genetic diversity encapsulated within ecosystems (Chu, 2020). With the advent of AI, we have acquired unparalleled computational prowess, facilitating the rapid and precise analysis of vast genetic datasets (Mahboob *et al.,* 2023). This integration has paved the way for leveraging genetic information to augment ecosystem management practices and conservation endeavors. In this discourse, we delve into the pivotal role of genetics in ecosystem management, with a specific focus on how AI-driven genetic analysis empowers us to make informed decisions conducive to sustainable environmental practices (Bibri *et al.,* 2024).

Our exploration encompasses a spectrum of applications spanning species identification, conservation prioritization, disease detection, and adaptive management strategies. Additionally, we underscore the significance of real-time genetic health monitoring through AI, enabling proactive responses to challenges posed by invasive species and climate change. By accentuating the symbiosis between genetics and AI, we endeavor to illustrate how these cutting-edge technologies propel evidence-based decisions for ecosystem restoration, preservation, and sustainable management (Bibri *et al.,* 2024). The integration of genetics and AI heralds a transformative era, holding the promise of safeguarding our natural world for present and future generations.

The pivotal role of genetics in ecosystem management lies in its capacity to furnish crucial insights into the genetic diversity and structure inherent within ecosystems. Understanding the genetic architecture of populations is indispensable for formulating effective conservation and management strategies, as it affords comprehension of their evolutionary trajectory, adaptive potential, and resilience to environmental vicissitudes (Rubio *et al.,* 2020).

Genetic research facilitates the identification of unique genetic markers, pivotal for species identification and demarcation of distinct populations. This knowledge proves instrumental in guiding conservation initiatives, aiding in the identification of endangered or vulnerable populations necessitating immediate attention and protection. Genetics assumes a pivotal role in prioritizing conservation endeavours by identifying genetically diverse populations serving as repositories of adaptive traits. Preserving such diversity fortifies the resilience of ecosystems, enabling them to withstand multifarious stressors and threats such as climate change, habitat degradation, and diseases (Kardos and Luikart, 2021). Genetics also lends itself to disease detection and management within ecosystems. By deciphering the genetic underpinnings of disease resistance or susceptibility in species, scientists can formulate targeted disease surveillance and management protocols, curbing the impact of disease outbreaks on ecosystems. Genetic data also inform adaptive management strategies, facilitating the adoption of dynamic conservation measures predicated on real-time genetic insights (Segelbacher *et al.,* 2022). This adaptive approach ensures the efficacy and relevance of conservation efforts amidst evolving environmental challenges. The amalgamation of genetics with advanced AI and computational tools has further accentuated its role in ecosystem management. AI-driven genetic analysis expedites the processing and interpretation of extensive genetic datasets, empowering scientists to make judicious decisions and prognostications predicated on comprehensive genetic information.

Biodiversity assessment and technological contributions

Biodiversity assessment is a systematic evaluation of the diversity of living organisms within a specific ecosystem or geographical region. It involves comprehensive data collection, analysis, and interpretation to understand species richness, abundance, genetic diversity, and ecological interactions. The primary objective of biodiversity assessment is to grasp the composition and distribution of various species, including plants, animals, microorganisms, and fungi, along with their genetic variations within their habitats. These assessments offer crucial insights into ecosystem health, resilience, and functioning, guiding conservation and management efforts effectively. Various techniques are employed for biodiversity assessment, ranging from traditional field surveys to cutting-edge genetic analysis and remote sensing technologies. These methods enable scientists and conservationists to identify and document species, assess population sizes and dynamics, and comprehend their roles in maintaining ecosystem stability and services (Mattia *et al.*, 2023).

Table: 1 Contributions to biodiversity assessment and their descriptions

Contribution	Description
Genetic Identification	AI-driven genetic analysis enables the identification and differentiation of species based on genetic markers.
Population Structure	Genetic data aids in understanding population genetics, gene flow, and spatial distribution.
Phylogenetic Analysis	Genetic information assists in constructing phylogenetic trees, revealing evolutionary history.
Functional Diversity	Genetics and AI provide insights into species' roles in ecosystem functioning.
Endangered Species Monitoring	Genetic markers track the genetic health of endangered species and vulnerable populations.
Detection of Cryptic Species	Genetic analysis uncovers hidden biodiversity with cryptic genetic differences.
DNA Barcoding	AI automates the analysis of short genetic markers for rapid species identification.
Community Composition	Genetic data assesses species diversity and interactions within ecological communities.

These contributions demonstrate how the integration of genetics with AI enhances biodiversity assessment by providing valuable insights into species diversity, population structure, evolutionary history, and functional roles within ecosystems

Application of AI in crop improvement and breeding programs

Crop improvement and breeding programs play a pivotal role in developing new cultivars with enhanced traits such as yield, quality, and resistance to biotic and abiotic stresses. Traditionally, these programs rely on labor-intensive and time-consuming methods for trait evaluation, pedigree analysis, and selection of parental lines. (Aswini *et al.*, 2023). However, with the advent of AI technologies, breeders now have access to powerful computational tools that can revolutionize the breeding process. AI offers opportunities to expedite breeding cycles, improve prediction accuracy, and unlock the full potential of genetic diversity for crop improvement.

Genomic selection, a prominent application of AI in breeding, involves predicting the performance of individuals based on their genomic profiles. By analyzing large-scale genomic data from breeding populations, AI algorithms can identify genetic markers associated with target traits and predict the breeding value of individuals with high accuracy. This enables breeders to make informed decisions about which individuals to select as parents for the next generation, thereby accelerating the breeding process and increasing genetic gain.

Another key application of AI in crop improvement is trait mapping, which involves identifying genomic regions associated with specific traits of interest, such as disease resistance or drought tolerance. AI algorithms can analyze genotype-phenotype associations from genome-wide association studies (GWAS) or linkage mapping experiments to pinpoint candidate genes or genetic markers linked to target traits. This information provides valuable insights into the genetic basis of trait variation and facilitates the development of molecular markers for marker-assisted selection (MAS) in breeding programs.

Table: 2 AI Applications in crop improvement and breeding programs

Key Factor	**Description**	**Impact on Crop Improvement**	**AI Model**
Genomic Prediction	Predicts plant performance based on genomic profiles	Facilitates precise parent selection for breeding programs	Machine Learning algorithms
Trait Mapping	Identifies genomic regions associated with specific traits	Guides targeted trait improvement efforts	Genome-wide association studies (GWAS), Deep Learning models
Experimental Design	Optimizes breeding trial designs	Improves efficiency by simulating and evaluating strategies	Reinforcement Learning, ptimization algorithms
Phenotyping Automation	Automates phenotypic data collection	Enables rapid and accurate assessment of traits	Computer Vision, Sensor Fusion technologies
Decision Support	Provides insights and recommendations for breeding decisions	Guides breeders in making informed choices	Expert Systems, Decision Trees

AI enables breeders to optimize experimental designs, predict breeding outcomes, and design efficient crossing schemes through simulation modeling and optimization algorithms. By simulating virtual breeding populations and evaluating different breeding strategies, breeders can identify optimal breeding schemes that maximize genetic gain while minimizing costs and resources. This computational approach enhances the efficiency and efficacy of breeding programs, leading to the development of improved crop varieties tailored to meet the diverse needs of farmers and consumers. The table below outlines key factors and their descriptions in the application of Artificial Intelligence (AI) in crop improvement and breeding programs. These factors play a crucial role in leveraging AI technologies to enhance various aspects of agricultural practices, from genomic prediction to decision support for breeders **(**Khan *et al.*, 2023).

The integration of AI in crop improvement and breeding programs holds immense promise for revolutionizing agricultural productivity, sustainability, and resilience. By harnessing the power of AI-driven technologies, breeders can accelerate the development of improved crop varieties that address the evolving needs of global food security and contribute to the advancement of sustainable agriculture **(**Khan *et al.*, 2023).

Challenges and opportunities in implementing AI for sustainable agriculture

The adoption of AI technologies in agriculture offers unprecedented opportunities to enhance productivity, optimize resource use, and mitigate environmental impacts. AI-driven solutions can enable data-driven decision-making, precision agriculture, and automation of farm operations, leading to more sustainable farming practices. However, the implementation of AI in agriculture also faces several challenges, including access to data, technology adoption barriers, and ethical considerations. This topic delves into these challenges and highlights the opportunities for overcoming them to realize the full potential of AI in promoting sustainable agriculture (Rehman. and Farooq, 2023).

Key challenges:

Data accessibility and quality: Limited access to high-quality data and heterogeneous data sources pose challenges for developing robust AI models for agriculture.

Technology Adoption Barriers: Farmers may face barriers in adopting AI technologies due to factors such as cost, lack of technical expertise, and resistance to change.

Ethical and social implications: AI applications in agriculture raise concerns regarding data privacy, algorithmic bias, and the socio-economic impact on rural communities.

Infrastructure and connectivity: Inadequate infrastructure and limited internet connectivity in rural areas hinder the deployment of AI-powered agricultural solutions.

Regulatory and Policy Frameworks: The absence of clear regulatory frameworks and policies governing AI in agriculture can impede innovation and investment in the sector.

Key opportunities:

Data collaboration and sharing: Collaborative efforts among stakeholders to share data and develop data-sharing platforms can address data accessibility challenges.

Capacity building and training: Training programs and capacity-building initiatives can empower farmers and agricultural professionals to leverage AI technologies effectively.

Ethical guidelines and standards: Establishing ethical guidelines and standards for AI in agriculture can ensure responsible and transparent use of AI technologies.

Infrastructure development: Investments in infrastructure development, such as rural connectivity and digital infrastructure, can improve access to AI solutions in rural areas.

Policy Support and Incentives: Governments can provide policy support, incentives, and subsidies to encourage the adoption of AI technologies in agriculture and foster innovation.

Addressing the challenges and capitalizing on the opportunities associated with implementing AI for sustainable agriculture is essential for realizing the full potential of AI in transforming the agricultural sector. Collaborative efforts involving stakeholders from the government, industry, academia, and civil society are crucial for overcoming barriers and harnessing the benefits of AI to promote sustainable agriculture practices and food security (Rehman. and Farooq, 2023).

Crop monitoring:

Crop monitoring is a vital component of modern agricultural practices aimed at assessing the health, growth, and performance of crops throughout their growth cycle. It involves the systematic observation, measurement, and analysis of various crop parameters to optimize management practices, maximize yields, and ensure sustainable agricultural production. Crop monitoring provides farmers and agronomists with valuable insights into crop conditions, enabling timely interventions to address issues such as pest infestations, diseases, nutrient deficiencies, and adverse environmental conditions (Halstead *et al.*, 2021)

1. Crop monitoring techniques: Crop monitoring techniques encompass a wide range of methods and technologies used to collect data on crop health, growth, and environmental conditions. These techniques can be broadly categorized into traditional methods and modern, technology-driven approaches.

2. Traditional methods:

Visual observation: Farmers and agronomists conduct regular field visits to visually inspect crops for signs of health, growth, and stress. Visual observation involves assessing factors such as leaf color, size, and shape, as well as the presence of pests, diseases, and weeds.

Manual sampling: Soil and plant samples are collected from different locations within the field and analyzed in laboratories to assess soil fertility, nutrient levels, and crop health indicators.

Weather monitoring: Weather stations are installed in fields to monitor temperature, humidity, rainfall, and other meteorological parameters that influence crop growth and development.

Field surveys: Surveys are conducted to gather information on crop condition, yield estimates, pest and disease prevalence, and other relevant factors.

Modern Technology-driven Approaches:

Remote sensing: Satellite imagery, aerial drones, and unmanned aerial vehicles (UAVs) equipped with sensors capture high-resolution images of fields to monitor crop health, detect anomalies, and assess vegetation indices such as NDVI (Normalized Difference Vegetation Index).

IoT sensors: Internet-of-Things (IoT) devices installed in fields collect real-time data on soil moisture, temperature, pH levels, and nutrient concentrations, providing continuous monitoring and alerts to farmers.

Machine learning and AI: Advanced algorithms analyze data collected from remote sensing, IoT sensors, and other sources to identify patterns, predict crop performance, and provide actionable insights for optimized crop management.

Data analytics: Big data analytics platforms process large volumes of data from multiple sources to generate actionable insights, enabling data-driven decision-making and precision agriculture practices.

These modern techniques offer several advantages over traditional methods, including real-time monitoring, greater accuracy, scalability, and cost-effectiveness. By leveraging technology, farmers can make informed decisions and implement timely interventions to maximize crop yields, minimize losses, and ensure sustainable agricultural practices. This following table presents a comparative analysis of traditional methods and AI-driven monitoring systems in the context of crop monitoring.

Table 3: Comparison of traditional methods and AI-driven monitoring systems in crop monitoring

Aspect	Traditional Methods	AI-driven Monitoring Systems
Data Collection	Relies on manual observation and visual inspection of crops, soil, and weather conditions.	Utilizes advanced technology such as satellites, drones, sensors, and weather stations to collect data automatically.
Precision	Subjective judgments based on human observation may lack precision and accuracy.	Uses artificial intelligence algorithms to analyze data with high precision and accuracy.
Efficiency	May require significant time and effort for data collection and analysis.	Processes large volumes of data quickly, providing real-time insights and recommendations.
Detection of Crop Conditions	Relies on visual cues and occasional sampling, which may miss subtle changes in crop conditions.	Can detect subtle changes in crop conditions using advanced image analysis and machine learning algorithms.
Timeliness of Information	Information may be delayed or outdated due to manual data collection and analysis.	Provides real-time monitoring and timely alerts, enabling proactive decision-making.
Resource Optimization	Limited ability to optimize resource inputs such as water, fertilizer, and pesticides.	Enables precise resource management based on real-time data, reducing waste and improving efficiency.
Decision Support	Relies on farmer's experience and intuition for decision-making.	Provides data-driven recommendations and insights to support informed decision-making.

5. Utilization of IoT agricultural ecosystem system

Utilization of IoT (Internet of Things) and sensors for real-time crop monitoring represents a cutting-edge approach to agricultural management, leveraging advanced technology to enhance crop productivity and sustainability. This innovative strategy involves the integration of IoT devices and various sensors into agricultural systems to collect, analyze, and utilize real-time data for monitoring crop conditions and environmental factors.

The utilization of IoT and sensors for real-time crop monitoring revolutionizes agricultural management by enabling farmers to make data-driven decisions, optimize resource usage, and maximize crop productivity while minimizing environmental impact. This innovative approach represents a significant step forward in sustainable agriculture, empowering farmers to manage their operations more efficiently and effectively in an ever-changing environment.. (Tomicic, 2022).

This table illustrates the integration of Internet of Things (IoT) devices and few sensors for real-time monitoring in agricultural settings. It highlights various sensor types, their functions, and the data.

Table: 4 IoT Sensors for real-time monitoring in agricultural settings

Sensor Type	Function	Data Collected
Soil Moisture Sensors	Measures soil moisture levels	Soil moisture content
Weather Stations	Monitors weather conditions	Temperature, humidity, rainfall, wind speed, solar radiation
Crop Health Sensors	Assess crop health	Crop growth stage, leaf color, temperature, humidity, nutrient levels, pest presence
GPS Sensors	Tracks crop and equipment	Location of crops, field boundaries, navigation routes
Drone-mounted Sensors	Captures aerial imagery	Aerial imagery, multispectral images, thermal images
Wireless Camera Systems	Provides visual monitoring	Visual data of crop condition, growth pattern

This table demonstrates the diverse range of sensors and IoT devices utilized in modern agriculture for real-time monitoring, enabling farmers to make informed decisions based on up-to-date information about their crops and environmental conditions.

Yield prediction:

Yield prediction refers to the process of estimating the expected output or yield of a crop before it is harvested. It involves analyzing various factors that influence crop growth and production to forecast the potential amount of harvestable crop. In simple terms, yield prediction helps farmers anticipate how much crop they can expect to harvest from their fields. This information is crucial for making important decisions related to crop management, resource allocation, marketing strategies, and financial planning.

Yield prediction models typically take into account factors such as historical yield data, weather conditions, soil quality, crop health indicators, and management practices. By analyzing these factors, these models can provide insights into the expected yield for a specific crop in a given area. (Thomas van Klompenburg a, *et al.*, 2020), The following table view the Yield prediction serves several purposes:

Table 5: Purposes of yield prediction in agriculture

Purpose	Description
Planning and Decision Making	Helps farmers and stakeholders plan activities, make informed decisions regarding crop selection, planting schedules, and resource allocation. Optimization of planting strategies to meet market demand and maximize profitability.
Risk Management	Enables farmers to anticipate risks associated with crop production by identifying factors affecting yield outcomes, such as weather variability and pest infestations. Implementation of risk management strategies to mitigate losses.
Resource Optimization	Facilitates efficient use of resources like water, fertilizers, and pesticides by adjusting input levels according to expected production. Minimization of waste and environmental impact while maximizing productivity.
Market Planning	Allows farmers to plan marketing strategies and negotiate contracts with buyers effectively. Alignment of production with market demand to optimize selling prices and secure profitable sales opportunities.
Financial Planning	Crucial for financial planning and budgeting for agricultural operations. Estimation of future crop yields to forecast revenues and expenses, secure financing, and manage cash flow effectively for financial sustainability.
Policy Formulation	Utilized by government agencies and policymakers to formulate agricultural policies, allocate resources, and address food security issues. Development of targeted interventions and support programs based on accurate forecasts.

This table summarizes the various purposes served by yield prediction in agriculture, highlighting its importance in planning, risk management, resource optimization, market planning, financial planning, and policy formulation.

Role of AI and machine learning algorithms in yield forecasting:

Yield forecasting plays a crucial role in modern agriculture, providing valuable insights into expected crop production and enabling farmers to make informed decisions regarding resource allocation, market planning, and risk management. In recent years, the integration of Artificial Intelligence (AI) and Machine Learning (ML) algorithms has revolutionized the process of yield forecasting, offering unprecedented accuracy and efficiency.

AI and ML algorithms have the capability to analyze large and complex datasets, including historical yield data, weather patterns, soil conditions, crop health indicators, and management practices. By processing these vast amounts of data, AI systems can identify intricate patterns and correlations that may not be apparent through traditional methods. This allows for more accurate and reliable yield predictions, even in the face of dynamic environmental factors and changing agricultural practices. AI-driven yield forecasting models continuously learn and adapt from new data inputs, improving their predictive capabilities over time (Dikshit and Pradhan, 2021). This adaptive nature enables farmers to adjust their strategies in response to evolving conditions, maximizing productivity and profitability.

Table 6: Applications of AI and machine learning in yield prediction

Aspect	Description
Data Analysis	Analyzes large datasets of weather, soil, and crop health data to identify patterns and trends.
Predictive Modeling	Builds models that learn from historical yield data and environmental factors to forecast future yields.
Precision Agriculture	Applies AI-driven techniques to optimize crop management practices and maximize yields.

This table outlines the various roles played by AI and machine learning algorithms in yield forecasting. It highlights how these technologies are used for data analysis, predictive modeling, and precision agriculture practices to enhance yield prediction accuracy.

Integration of data sources for yield prediction:

Yield prediction in agriculture relies on the integration of diverse data sources to provide accurate and reliable forecasts. These data sources encompass a wide range of information related to weather patterns, soil conditions, historical yield data, crop health indicators, and management practices, Thomas van Klompenburg a, *et al.*, 2020). The integration of these data sources is essential for developing robust predictive models that account for various factors influencing crop productivity. Below, we outline the key data sources integrated for yield prediction:

Table 7: Data Sources for yield prediction

Data Source	Description
Weather Data	Includes temperature, rainfall, humidity, and other meteorological parameters.
Soil Quality	Measures soil nutrients, pH levels, moisture content, and other soil properties.
Historical Yield Data	Records past crop yields for the same or similar crops grown in the area.
Crop Health Indicators	Observes factors such as plant growth stage, leaf color, pest and disease presence.

This table presents the various data sources used for yield prediction, including weather data, soil quality information, historical yield data, and crop health indicators. It highlights the importance of integrating multiple data sources to improve the accuracy of yield forecasts.

Accuracy and reliability of AI-driven yield prediction vs. traditional methods

AI-driven yield prediction methods leverage advanced algorithms and machine learning techniques to analyze vast datasets and make predictions about crop yields. These methods often exhibit higher accuracy and reliability compared to traditional approaches for several reasons.

This table compares the accuracy and reliability of AI-driven yield prediction models with traditional methods. It emphasizes the superior performance of AI-driven models in terms of accuracy and efficiency. Comparison of the accuracy and reliability of AI-driven yield prediction versus traditional methods presented in table

Table 8: Comparison of yield prediction accuracy

Prediction Method	Accuracy Rating
AI-Driven Models	High accuracy due to advanced algorithms and analysis of large datasets.
Traditional Methods	Moderate accuracy based on historical data and manual analysis, subject to human error.

Table 9: Comparison of the accuracy and reliability

Aspect	AI-Driven Methods	Traditional Methods
Data Handling	Capable of handling large, heterogeneous datasets with numerous variables.	Limited in handling complex datasets and may struggle with diverse data types.
Adaptability	Can adapt to changing conditions and learn from new data to improve predictions.	Less flexible and may require manual adjustments to account for evolving factors.
Prediction Accuracy	Studies indicate higher accuracy compared to traditional methods, particularly when trained on extensive datasets and optimized	Generally lower accuracy, especially when dealing with complex agricultural systems and diverse environmental factors.
Reliability	More reliable in generating consistent predictions across different scenarios due to capturing subtle relationships between variables.	May be less reliable due to potential biases or inaccuracies introduced by human judgment or limited data availability.

This table provides a clear comparison of the strengths and weaknesses of AI-driven yield prediction methods versus traditional approaches, highlighting the advantages of AI in terms of data handling, adaptability, accuracy, and reliability.

Potential benefits for farmers

Table 10: Potential benefits for farmers

Benefit	Description
Improved Planning	Enables better crop management decisions, resource allocation, and risk mitigation strategies.
Enhanced Productivity	Maximizes crop yields by optimizing input use and minimizing losses.
Better Financial Management	Helps farmers make informed financial decisions and improve profitability.

The benefits of AI-driven yield prediction for farmers are manifold, encompassing improved decision-making, risk mitigation, resource optimization, cost reduction, sustainability, and profitability. By leveraging advanced predictive analytics and machine learning algorithms, farmers can make informed choices to enhance productivity while minimizing risks and resource wastage.

This table outlines the potential benefits that farmers can derive from AI-driven yield prediction. It highlights the positive impact on planning, productivity, and financial management in agricultural operations.

Table 11: Benefits of AI-Driven yield prediction for farmers

Benefits	Description
Improved Decision-Making	AI-driven yield prediction provides farmers with accurate and timely information about expected crop yields, enabling informed decisions for optimal practices.
Risk Mitigation	Predicting crop yields helps farmers assess and mitigate risks associated with weather, pests, and market fluctuations, allowing proactive measures for protection.
Resource Optimization	AI-driven prediction allows farmers to optimize resource use like water and fertilizers, matching field needs efficiently and reducing waste.
Cost Reduction	By minimizing input waste and optimizing resource allocation, AI-driven prediction helps in reducing production costs, enhancing overall profitability.
Enhanced Sustainability	Efficient resource management facilitated by AI-driven prediction promotes sustainable farming practices, lowering environmental impact.
Increased Profitability	Overall benefits of AI-driven prediction lead to improved farm profitability through higher yields, reduced costs, and better risk management

This table presents a concise overview of the key benefits that AI-driven yield prediction offers to farmers, aiding in decision-making, risk mitigation, resource optimization, cost reduction, sustainability, and profitability.

Conclusion and Future Directions:

The integration of genetics and Artificial Intelligence (AI) stands as a beacon of hope in the realm of ecosystem management and agriculture. Throughout this paper, we have explored the transformative potential of this synergy, from revolutionizing biodiversity assessment to enhancing crop improvement and monitoring practices. As we conclude, it is evident that genetics and AI offer unparalleled opportunities for advancing evidence-based decision-making, sustainability, and resilience in agricultural ecosystems.

Future directions:

AI-driven precision agriculture expansion: Explore further integration of AI technologies into precision agriculture practices, including the development of advanced AI algorithms for real-time monitoring, decision-making, and automated management of agricultural systems.

Genomic data sharing initiatives: Promote collaboration and data sharing among research institutions, agricultural stakeholders, and policymakers to build comprehensive genomic databases. This will facilitate more extensive genetic analysis, fostering innovation in crop improvement, disease resistance, and conservation efforts.

Ethical AI frameworks: Establish ethical guidelines and regulatory frameworks to ensure responsible and equitable use of AI in agriculture. Address concerns related to data privacy, algorithmic bias, and socioeconomic implications, fostering trust and acceptance of AI-driven technologies.

Enhanced data connectivity: Invest in infrastructure development to improve internet connectivity and data accessibility in rural areas. This will enable widespread adoption of AI-driven agricultural solutions, particularly in regions with limited digital access.

Interdisciplinary research collaboration: Encourage interdisciplinary collaboration between geneticists, agronomists, data scientists, and policymakers to address complex agricultural challenges. By combining expertise from multiple fields, innovative solutions can be developed to enhance food security, sustainability, and resilience in agricultural ecosystems.

AI Education and training: Develop educational programs and training initiatives to equip farmers, agricultural professionals, and researchers with the skills and knowledge needed to effectively utilize AI technologies. This will facilitate the adoption of AI-driven practices and empower stakeholders to leverage the full potential of genomic intelligence in agriculture.

Climate-smart agriculture integration: Integrate AI-driven genomic intelligence into climate-smart agriculture strategies to mitigate the impacts of climate change on agricultural productivity and resilience. Leverage genetic diversity and AI-powered prediction models to develop climate-resilient crop varieties and adaptive management practices.

Policy support and investment: Advocate for policy support and investment in AI research and development for agriculture at the national and international levels. Create incentives and funding opportunities to stimulate innovation, accelerate technology adoption, and promote sustainable agricultural practices guided by genomic intelligence.

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MICROBIOLOGY IN NURSING PRACTICE AND SUSTAINABLE AGRICULTURE

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Introduction:

Microorganisms are small living organisms that can't see without external apparatus, such as a microscope. They have a diverse and extensive range across the globe. Generally, they are abundant in air, water, and soil. A lot of microorganisms require oxygen to survive, but some microorganisms don't require oxygen to survive, and they can grow in anaerobic conditions. Generally, microorganisms are categorised into several groups such as algae, fungi, bacteria, viruses, protozoans, and prions (see figure 01). The term "germs" refers to the microbes that cause disease (Wu and Lewis, 2013). These microorganisms cause diseases in human beings, animals, plants, birds, and crops. A diverse range of microorganisms live inside and outside human beings, like the body skin, placenta, mammary glands, lungs, livers, uterus, intestine, stomach, respiratory tract, and oral cavity. Several microorganisms reveal beneficial activity for the human host. Generally, these microorganisms that exist on the host and do not cause infection are considered normal microbiota (Bagg and Neilands, 1987).

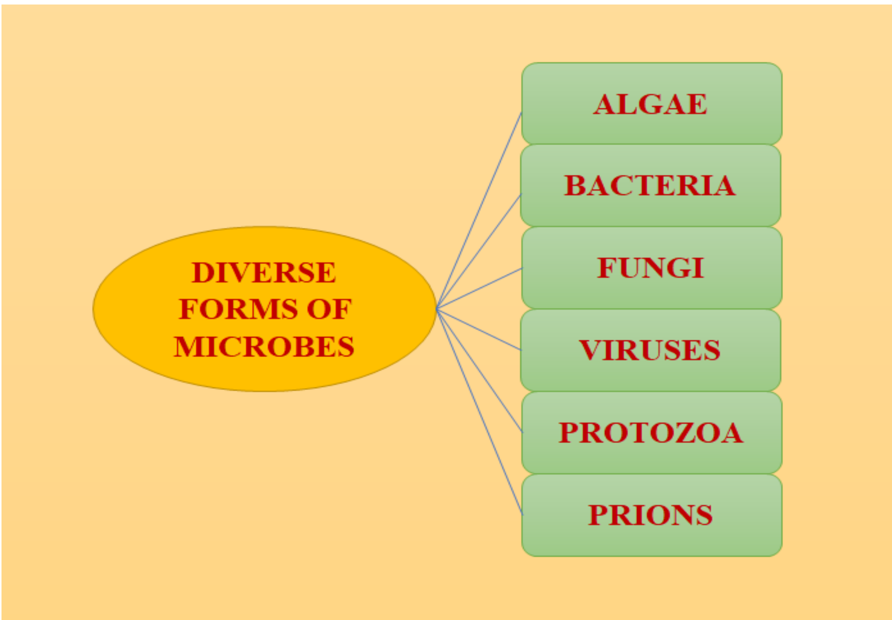

Figure 1: Microbial diversity found in nature

Microorganisms produce several of the most significant products in the pharmaceutical, dairy, baking, food, agriculture, vaccines, vitamins, and fermentation industries. Numerous microorganisms are used as bio-fertilisers in an eco-friendly agro-ecosystem, including

Rhizobium, Arbuscular mycorrhizal fungi, Azotobacter, Cyanobacteria, Aspergillus, and plant growth-promoting rhizobacteria. Several food and dairy products, such as yoghurt, cheese, bread, chocolate and single cell protein (SCP), are also produced by microbial activities. Microorganisms are used in the production of antibiotics, probiotics, and vaccines (Kalsoom *et al*, 2020). Bioremediation is a process in which microorganisms degrade physical and chemical hazardous waste materials. Microorganisms perform an essential role in the remediation of water, soil, and sediment pollutants (Abatenh, 2017). Microorganisms reveal both beneficial and harmful activities (see figure 02).

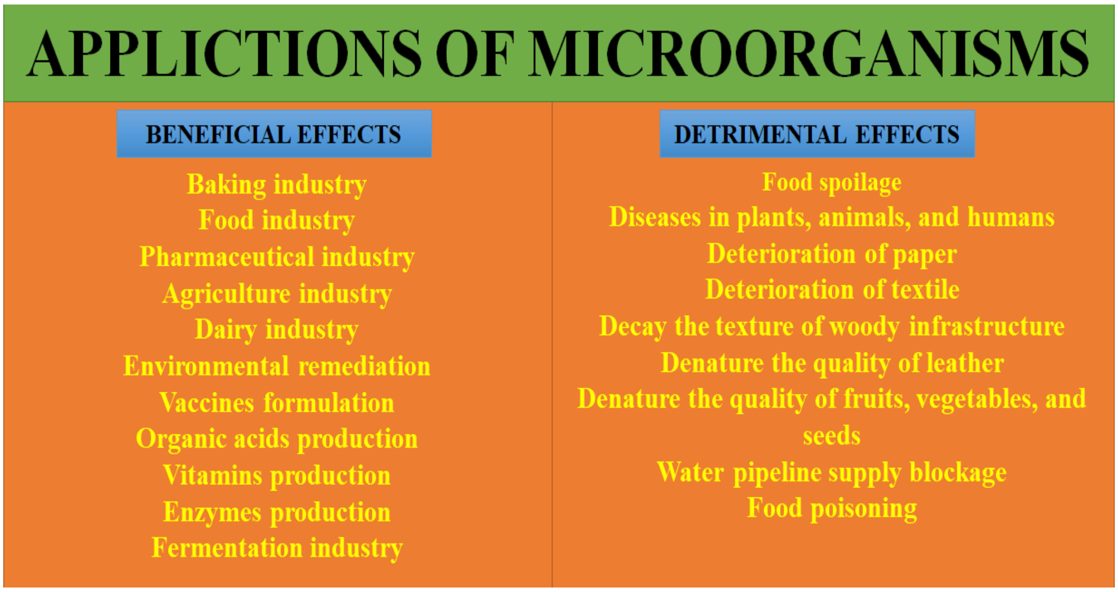

Figure 2: Beneficial and detrimental effects of microorganisms

Microbiology in nursing practice:

Microbiology facilitates nursing personnel getting more attention from patients who have weak immune systems because those with feeble immunity can be stuck in pathogenic microbial traps. A microbiological study provides awareness about morphology, growth, biochemical, and genetic characteristics. It offers novel infections and advanced molecular techniques for the detection of casual agents. The contribution of microbes in the formation of medicines, vaccines, and antibiotics can't be forgotten (Dhir, 2019). Every day, nursing personnel interact with the pathogenic microbial community in the clinical health system. They accomplish hospital infection control to ensure the health protection of patients from infectious microbial diversity. Dealing with the microbial population in hospital services is an equally threatening task. It is an unexpected assignment to maintain microbial-free conditions on hospital premises, but allow several protective measures because the microbial population can't be seen without external apparatus. The microbial community always resides on the human body, but these are categorised into two groups: pathogenic microbes (which cause diseases in humans) and non-pathogenic microbes (the normal micro-flora of the human body that don't cause any diseases and provide protection against pathogenic microbes). Therefore, the study of the microbial world facilitates nursing personnel in establishing preventive measures because it is directly associated with human beings. A hospital-acquired infection, or nosocomial infection, develops during hospital care when it encounters patients or hospital personnel. Nosocomial infection is a dangerous problem in developing countries for hospital management (Damanik *et al*., 2012). Medical microbiology is a vast aspect that deals with the study of countless diseases causing pathogenic microbes. It can be generally categorised into several types:

Bacteriology: It deals with the study of bacterial size, shape, arrangement, metabolism, and mode of infection. Some human pathogenic bacteria are *Salmonella typhi, Pseudomonas aeruginosa, Mycobacterium tuberculosis, Staphylococcus aureus, Streptococcus pneumoniae,* and *E. coli*.

Virology: It deals with the study of size, shape, composition, transmission, and epidemiology. Some human pathogenic viruses are polio virus, hepatitis-B virus, hepatitis-C virus, HIV, and variola virus.

Mycology: It deals with the study of fungal morphology, physiology, metabolism, and pathogenesis. Some human pathogenic fungi are Aspergillus, Candida, and Taloromyces.

Parasitology: It deals with the study of parasites that cause various diseases in humans, such as protozoa, helminths, and arthropod parasites. Some human pathogenic parasites are plasmodium, Entamoeba, Ascaris, and blood-flukes.

Sterilisation and disinfection processes:

The sterilisation and disinfection processes facilitate a vital role in infection control. The sterilisation process totally eliminates the microbial spore, while the disinfection process can't completely remove the microbial spore. Various disinfectants are applied, including sodium hypochlorite, povidone-iodine, hydrogen peroxide, peracetic acid, ethanol, chlorhexidine, and glutaraldehyde (Yoo, 2018). Sterilisation methods are categorised into three broad groups:

Physical sterilisation methods: Moist heat sterilisation (autoclaving), dry heat sterilisation (hot air oven, red heat, flaming, and incineration), sunlight, and radiation (infrared, ultra violet, X-rays, and gamma rays).

Autoclave: It is equipment that eliminates microorganisms, including bacteria, fungi, viruses, and spores, due to steam pressure. It is very useful in the medical healthcare system to sterilise surgical, laboratory, and pharmaceutical equipment (Chaukate *et al*., 2022).

Hot air oven: It works on the dry heat principle to sterilise laboratory, clinical, and surgical instruments, including glass petri plates, slides, beakers, flasks, scissors, blades, scalpels, and other metallic instruments. It is generally useful for heat-bearing materials that don't melt at high temperatures. It completely removes bacteria, fungi, viruses, and spores. The time period correlates to temperature in this process: 170°C for 30 minutes, 160°C for 60 minutes, and 150°C for 150 minutes (Patil *et al*., 2023).

Chemical sterilisation methods: Liquids (alcohol, aldehyde, phenolics, halogens, and dyes) and gases (formaldehyde, ethylene oxide, and β-propiolactone).

Mechanical sterilisation methods: Filtration and sedimentation processes.

Antibiotic susceptibility test:

An investigation of bacterial species growth inhibition by very low concentrations of atibiotic or antimicrobial substances with definite conditions is called an antibiotic susceptibility test. Several methods are used to determine the antibiotic susceptibility of any antimicrobial substance against bacterial growth, including the disc diffusion method, the agar-well diffusion method (Bagul and Sivakumar, 2016), and the poisoned food technique. A minimum inhibitory concentration is the lowest concentration of an antimicrobial substance that inhibits bacterial growth. The intention of the antibiotic susceptibility test is to disclose that the antimicrobial substance is effective against the test bacterial pathogen under standard conditions.

Environmental monitoring:

Environmental monitoring is a very useful aspect of ensuring the hygienic condition of a hospital or health care organisation. Pathogenic microorganisms persist everywhere in nature, while hospital environments contain a high risk of pathogens. Therefore, it is important to investigate the hygeinic conditions using several parameters, such as the swab, contact plate, and molecular techniques. Hospital hygienic conditions terrify nursing personnel. Several pathogenic microorganisms reside on the surfaces of hospitals, like *Clostridioides difficile, Klebsiela pneumoniae, Staphylococcus aureus,* and *Acinetobacter baumannii* (Galvin *et al*., 2012). The role of microbiology in nursing practice should be followed by nursing personnel (see figure 03).

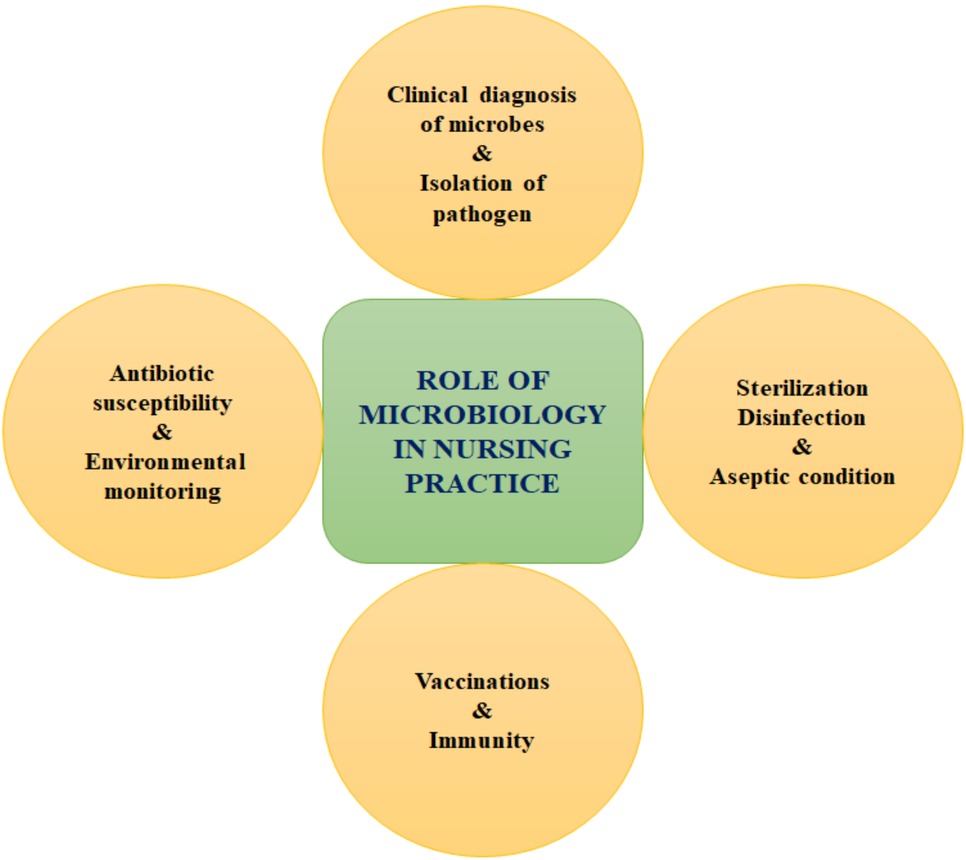

Figure 3: Role of microbiological applications in nursing practice

Identification of micoorganisms:

Microorganisms are cosmopolitan and found everywhere in nature, including in air, soil, and water. Identification of microorganisms is the most important aspect in the fields of clinical, pharmaceutical, environmental, and food microbiology. Various laboratory methods are used in the identification and detection of microorganisms. The identification of microorganisms depends on the characteristics of their physiological, biochemical, and morphological appearance. But nowadays, molecular techniques for identifying microbial cells have been established that detect microorganisms very easily. The identification methodologies are categorised into two groups:

Phenotypic methods: It depends on the basis of diverse characteristics of the microbial cell, including size, shape, colour, arrangement, behaviour, and physiological functions. The identification of microorganisms categorises them into three major groups: (I) morphological characteristics (identified by several techniques, including Gram staining, acid fast staining, spore staining, and capsule staining) (II) physiological characteristics (identified by pH, temperature, oxygen requirement, and osmotic pressure tolerance) (III) biochemical characteristics (identified by biochemical tests including catalase, citrate, coagulase, and urease) (Dawodu and Akanbi, 2021).

Molecular methods: Various molecular techniques are used for the identification of microorganisms, such as polymerase chain reaction, DNA sequencing, and mass spectrometery (see figure 4).

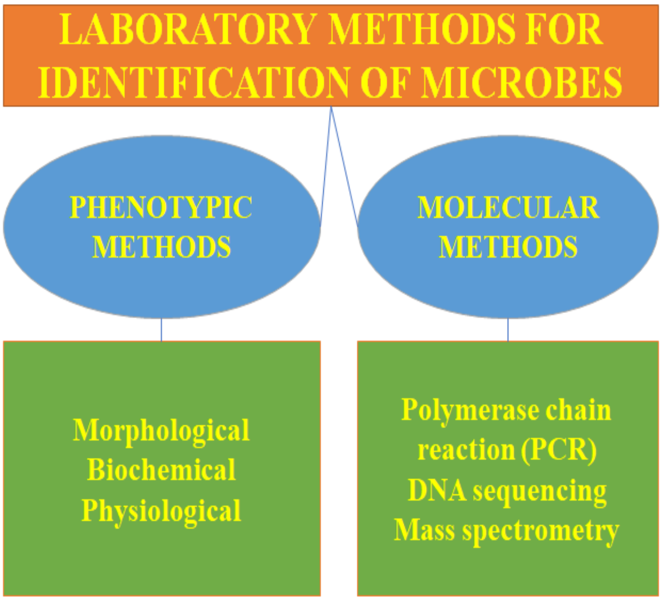

Figure 4: Various methods for identification of microorganisms

Staining techniques:

The staining techniques are very useful to identify bacteria as well as fungi. Several staining reagents or mounting reagents are used in staining techniques to examine the specimen under a microscopic lens, resulting in accurate information regarding microorganisms. It is a result of bonding between dyes and cell components. It provides the morphological structure of species, such as the bacterial cell wall structure, capsule, and spore. Several types of staining are applied in microbiology, including simple, negative, Gram staining, and acid fast staining (Prakash, 2014).

Procedure for simple staining:

1. Prepare a bacterial smear on a clean glass slide.
2. Air-dry or heat-fix the bacterial smear.
3. Stain with crystal violet, or safranin, or methylene blue for 1 minute.
4. Excess amount of stain, wash with water.
5. Examine the bacterial slide under the oil immersion lens.

Procedure for Gram staining:

1. Prepare a bacterial smear on a clean glass slide.
2. Heat-fix a bacterial smear.
3. Stain with crystal violet for 1 minute.
4. Excess amount of stain, wash with water.
5. Flood with Gram iodine for 1 minute.
6. Wash the excess amount of Gram iodine with water.
7. Decolorize with 95% alcohol.
8. Counterstain with safranin for 30 seconds.
9. Wash the excess amount of safranin with water.
10. Examine the bacterial slide under the oil immersion lens.

Procedure for acid fast:

1. Prepare a bacterial smear on a clean glass slide.
2. Flood with carbol fuchsin.
3. Heat-steam the smear for 3–5 minutes.
4. Wash the stain with water.
5. Flood with acid alcohol for 10 to 20 seconds.
6. Counterstain with methylene blue for 1 minute.
7. Wash the excess amount of methylene blue with water.
8. Examine the bacterial slide under the oil immersion lens.

Application of microbiology in agriculture:

Chemical fertilisers and pesticides reveal a very harmful impact on the environment, including humans, animals, fish, and birds. Chemical fertilisers and pesticides have perpetrated environmental pollution that causes climate change, global warming, soil texture, soil acidification, and mineral depletion. It is very necessary to develop alternative sources of chemical fertilisers and pesticides that may be eco-friendly and helpful in controlling global pollution. Microorganisms play a significant role in agriculture; a wider range of bacterial species are associated with agricultural crops, such as bacillus, clostridium, and micrococcus. Several microorganisms facilitate soil texture and quality, which enhance plant growth and productivity. They convert complex organic materials into simple inorganic materials. Agricultural crops use these inorganic elements to improve crop quality.

Plant-microbe symbiotic interaction is very essential to encouraging nutrient cycles. It reveals significant plant growth, health, and productivity. The roles of the microbial population are efficiently remarkable (see figure 05). Absolutely, cyanobacteria (blue-green algae) perform crucial roles in nitrogen, oxygen, and carbon cycles (DeRuyter and Fromme, 2008). It has been proven that rhizosphere microbes play a vital role in plant development and soil texture's establishment. Plant growth-promoting rhizobacteria (PGPR) are highly beneficial symbiotic microbes in crop yields that colonise the root. This microbial population promotes plant growth, development, and production, as well as protecting plants from diseases. It secretes various kinds of essential enzymes and crucial substances that facilitate enhancing soil efficiency. Mycorrhizal association is a symbiotic interaction between higher plant roots and fungi in which the plant provides carbohydrates to the fungal component, and in exchange, the fungal component delivers nutrients as well as phosphorus to the plant. Mycorrhizae support enhanced plant growth, health, and productivity due to the sufficient availability of phosphorus required for the host plant. Mycorrhizae improve crop yields, control phytopathogens, reduce the risk of diseases, and enhance plant resistance to drought. Various bacterial species, such as *Rhizobium leguminosorum*, *R. meliloti*, and *R. trifoli*, take part in symbiotic nitrogen fixation. PGPR play an important role as symbiotic nitrogen fixers with plants in the agro-ecosystem. Azospirillum is a genus of symbiotic plant growth-promoting rhizobacteria that boosts the growth, development, and production of several crops such as *Triticum aestivum*, *Oryza sativa*, and *Zea mays* (Steenhoudt and Vanderleyden, 2000).

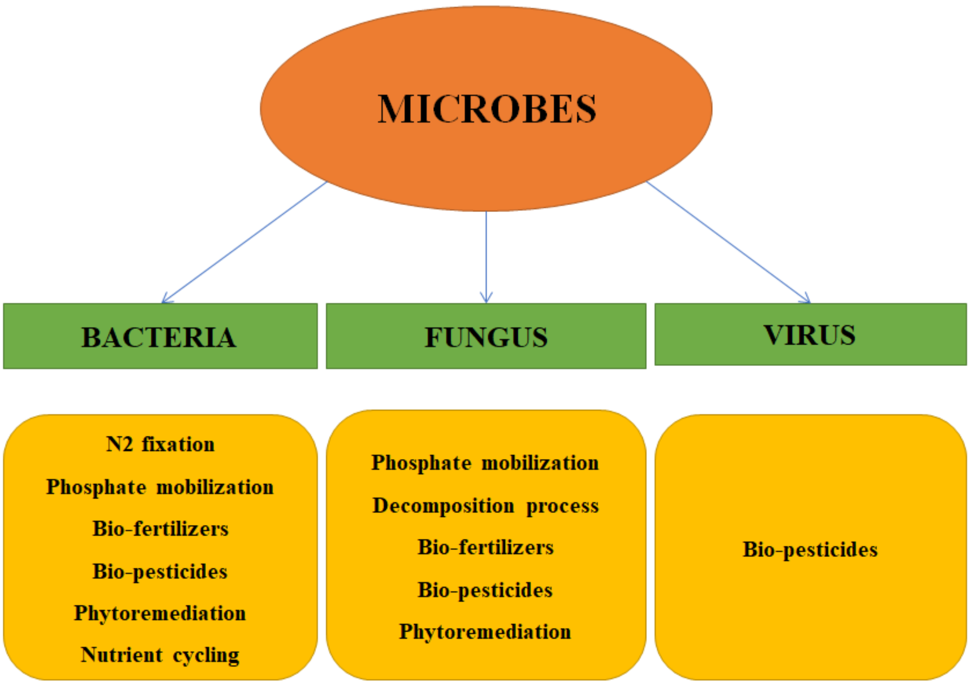

Figure 5: Role of microorganisms in an eco-friendly agro-ecosystem

Plant root exudates:

The association of plants and microorganisms plays an essential part in the formation and improvement of soil texture, fertility, and development, which facilitate plant growth, health, and productivity. The rhizosphere is a minor region of soil adjacent to the plant root that is highly supplemented with nutritional components. The tip of the plant root facilitates the plant root's growth, especially cell division, and also secretes root exudates. Microbial density depends on the existence of organic materials in the rhizosphere, which are found more than bulk soil. The rhizosphere region contains root exudates and other root tissues that provide carbon to the microbial community and, in return, accumulate nitrogen and phosphorus for plants. Plant roots release various types of organic materials, which depend on environmental conditions such as temperature, relative humidity, and plant age. The plant root exudates are extensively significant in plant growth, development, and production (see figure, 06). The plant root exudates contain primary and secondary metabolites, including organic acids (acetic, succinic, propionic, sinapic, citric, butyric, and caffeic acid), carbohydrates (glucose, maltose, fructose, sucrose, and xylose), enzymes (phosphatase, dehydrogenase, peroxidase, and dehalogenase), vitamins, amino acids, etc. They play a marvellous role in the metabolic activities of microorganisms and also essentially, stimulate the biogeochemical cycles (Zishan and Manzoor, 2022).

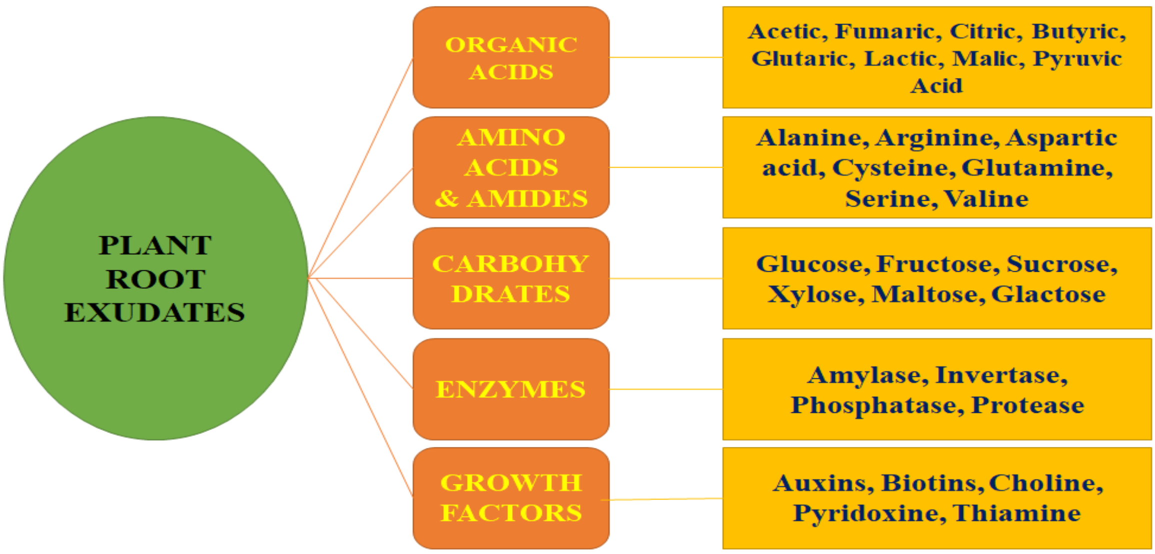

Figure 6: Different types of plant root exudates secretion by plant root

Generally, microorganisms reside in the association of entirely plants such as roots, leaves, flowers, stems, and fruits, in which both benefit from each other (see figure 07). Various microorganisms are nurtured on the aerial plant portion, including algae, fungi, bacteria, and protozoa (Verma *et al*., 2016). Fungi such as Alternaria, Penicillium, Mucor, Aspergillus, and Cladosporium colonise plant leaves. Algae also contain a significant amount of phyllosphere microorganisms like green algae (*Chloroidium saccharophilum*, *Prasiococcus calcaris*, and *Rosenvingiella radicans*) (Lin, 2012). However, a large number of microorganisms can be isolated and cultured from various healthy plant portions. Most investigations of phyllosphere microorganisms have been interconnected on the leaf portion, which is considered the most significant aerial plant portion. Few investigations of microorganisms have been accomplished on buds and flowers (Andrews and Harris, 2000).

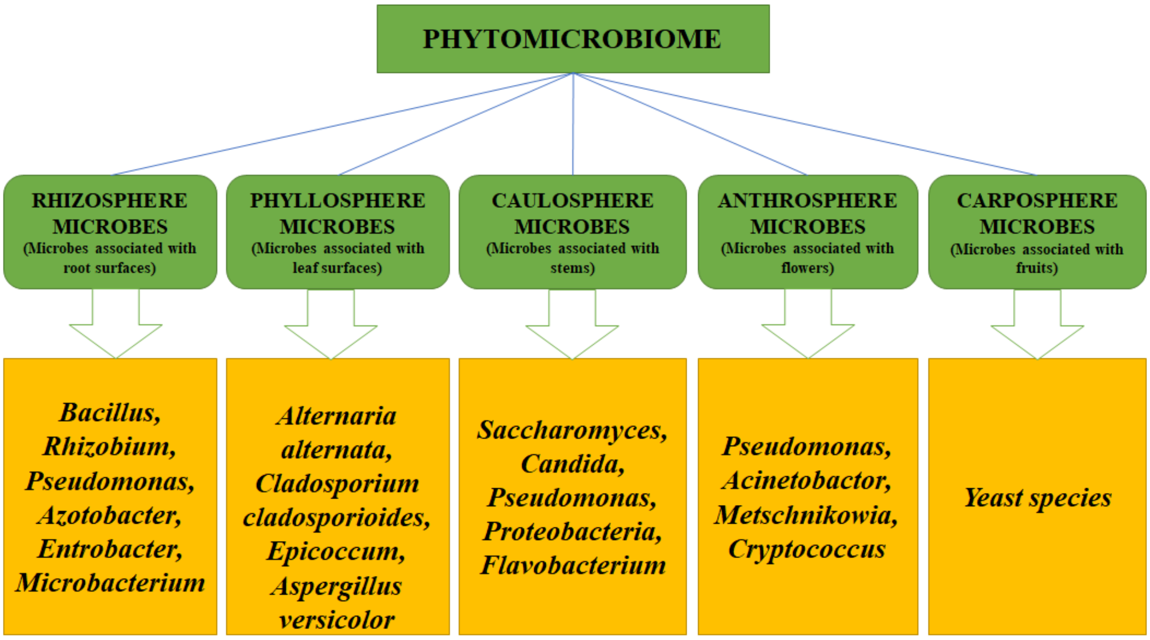

Figure 7: Different types of association of plant parts with microorganisms

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RETROSPECTS OF AUGMENTATIVE BIOLOGICAL CONTROL IN INDIA AND ABROAD

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Introduction:

Biological control is the use of a population of one organism to reduce the population of another organism. Biological control has been in use for at least 2000 years, but modern use started at the end of the nineteenth century. Four different types of biological control are known: natural, conservation, classical and augmentative biological control. Natural biological control is an ecosystem service whereby pest organisms are reduced by naturally occurring beneficial organisms. This occurs in all the world's ecosystems without any human intervention and in economic terms, is the greatest contribution of biological control to agriculture (Waage and Greathead, 1988). Conservation biological control consists of human actions that protect and stimulate the performance of naturally occurring natural enemies. This form of biological control is currently receiving a lot of attention for pest control. Conservation biological control of pests is focused on the role of the natural microbiome in suppressing pests in soil and crop residues, and of the natural microbiome in and on plants in providing resilience to pest infection (Mendes *et al*., 2011). In classical biological control, natural enemies are collected in an exploration area (usually the area of origin of the pest) and then released in areas where the pest is invasive, often resulting in permanent pest population reduction and enormous economic benefits. As this was the first type of biological control deliberately and widely practiced, it is called ''classical'' biological control (DeBach, 1964). In augmentative biological control (ABC), natural enemies (parasitoids, predators or micro-organisms) are mass-reared for release in large numbers either to obtain immediate control of pests in crops with a short production cycle (inundative biological control) or for control of pests during several generations in crops with a long production cycle (seasonal inoculative biological control) (van Lenteren, 2012).

History

ABC is thought to have been used for the first time in China around 300 AD (van Lenteren and Godfray, 2005). Modern ABC started in the 1880s with the use of the insect pathogen *Metarhizium anisopliae* by Metchnikoff in Russia for control of beetles in various crops (MacBain Cameron, 1973). The first species used in augmentative biological control were a hymenopteran (*Metaphycus lounsburyi* (Bartletti)) and a coleopteran (*Chilocorus circumdatus*), both in 1902. Natural biological control occurs on 89.5 billion ha of the world's ecosystems (land with vegetation), of which 44.4 billion ha is used for some form of agricultural activity (including forestry and grassland). Natural and inoculative biological control contribute to managing indigenous and alien pest problems in natural and managed ecosystems, and in controlling vectors of human and veterinary diseases. The most widely used natural enemies in inoculative weed and insect control (e.g., *Aphelinus mali*, *Aphytis lingnanensis*, *Cotesia flavipes*, *Cryptolaemus montrouzieri*, *Rodolia cardinalis*, *Teleonemia scrupulosa*) have been introduced in more than 20 countries/regions worldwide and resulted in permanent control of the pest (Cock *et al*. 2010). Inoculative biological control is used on 350 million ha (10 % of land under cultivation).

The ‘‘ecosystem service’’ provided by natural and inoculative biological control has an estimated value of at least 400 billion US$ per year, which is enormous, even when compared with the annual amount of 30 billion US$ spent on chemical pest control. The impact of biological control is creating and sustaining public goods, such as food security, food quality, reduced pesticide use, human health (especially for farmers and farm workers), invasive alien species control, protection of biodiversity and maintenance of ecosystem services. Inoculative biological control is estimated to be used on 10 per cent of land under cultivation and over the last 120 years, 165 pest species have been brought under long-term control. Worldwide 170 species of invertebrate natural enemies are produced and sold globally for periodical release in augmentative biological control of more than 100 pest species on about 0.4 per cent of land under cultivation (Cock *et al*. 2010). Augmentative biological control is operated by state-funded or commercial biofactories. It is applied in the open field crops that are attacked by only a few pest species and in greenhouse crops, where the whole spectrum of pests can be managed by a suite of natural enemies (van Lenteren, 2000b). Its popularity can be explained by a number of important benefits when compared with chemical control: there are no phytotoxic effects on young plants, premature abortion of fruit and flowers does not occur, release of natural enemies takes less time and is more pleasant than applying pesticides, several key pests can be controlled only with natural enemies, there is no waiting period after release of natural enemies and this allows continuous harvesting without danger to the health of personnel.

Viability of commercial biological control market

Producers of natural enemies are understandably reluctant to provide data about market developments, profit margins and sales volumes. In 2015, the global pesticide market had a value of US$ 58.46 billion. The global market of biological control agents (invertebrates and microorganisms) was approximately US$ 1.7 billion in 2015, which is less than 2 per cent of the pesticide market. Growth of the market for synthetic pesticides is expected to be between 5 and 6 per cent over the next five years, but interestingly, growth of the biological control market has been faster: it showed an annual increase of sales of 10 per cent before 2005 and more than 15 per cent per year since 2005. The largest European biological control companies are still getting the main part of their income from sales of invertebrate biological control agents, but the contribution of microbial biological control agents is steadily increasing.

Commercial ABC is used in protected crops (e.g., vegetables, ornamentals) and high-value outdoor crops (e.g., strawberries, vineyards), contributing to about 80 per cent of the market value of invertebrate biological control agents. Biological control programs for each of these crops may involve up to 15–20 different species of natural enemies. The remaining 20 per cent of the market value for natural enemies comes from application of relatively simple, cheap but effective biological control programs often using only one biological control agent (e.g., *Trichogramma* spp. against lepidopterans in cereals and sugarcane, and *Cotesia* spp. against lepidopterans in sugarcane) (van Lenteren, 2000). Almost 40 per cent of the income of the European companies originates from invertebrate biological control agents sold for control of thrips, another 30 per cent for control of whitefly, 12 per cent for control of spider mites, 8 per cent for control of aphids, and the remaining 10 per cent for control of various other pests. Since 2005, predatory mites have contributed enormously to the growth of the market for invertebrate biological control agents as a result of: the rediscovery of their use for control of whiteflies, finding more efficient species for thrips control, the development of techniques to enhance dispersal and establishment of predatory mites in crops and the development of new highly economic production technologies (Bolckmans *et al*., 2005).

Natural enemies used in augmentative biological control worldwide

Cock *et al*.'s (2010) database lists more than 170 species of invertebrate natural enemies that are used in augmentative biological control in Europe. In 2010, no less than 230 species of invertebrate natural enemies originating from ten taxonomic groups were used in pest management worldwide. Collection of new data in 2016 showed the use of almost 350 natural enemy species. Invertebrates are commercially produced for biological control of weeds (40 species), for soil improvement (six species), as feed and food (40 species), and as pollinators (ten species). After predators and parasitoids, microbial biological control agents are the next most commonly used organisms in ABC. 209 microbial strains from 94 different species commercially available for control of pests. Information we could obtain on registered strains was not always consistent. In some cases agents seem registered without strain information or under different strain identifications for different regions, so that some organisms may be listed more than once. Microbial biological control agents are produced by approximately 200 manufacturers, but this are an underestimate as no data are available for China or India.

There is a great diversity of manufacturers and often they are specialised in one or two types of microorganisms and production methods. The majority of manufacturers are small to medium-sized companies. Recently, large multinational agro-chemical companies are getting involved in the production and marketing of so-called biopesticides, again through the acquisition of small to medium-sized companies. New companies are still founded on a regular basis, and acquisitions and mergers occur frequently. There is a similar trend to consolidation as that which occurred in the seed and chemical pesticides business in the past decades. The majority of species belongs to the Arthropoda (219 out of 230 species = 95.2%) and only 11 species (one belonging to the Mollusca and ten belonging to the Nematoda) are non-arthropods.

Within the arthropods, four taxonomic groups provided most natural enemies: first of all, the Hymenoptera (52.2%, 120 species), next the Acari (13.1%, 30 species), followed by the Coleoptera (12.2%, 28 species) and Heteroptera (8.3%, 19 species). The large number of hymenopteran species used in augmentative control can be explained as follows: compared to predators, hymenopteran parasitoids are more specific and, therefore, have a much more restricted host range, which is considered important in preventing undesirable side effects. Acarid predators are popular because they can easily be mass reared; they can be released by mechanical means, may control several pest species, do not spread actively over large distances and are relatively small. The last two characteristics help to prevent negative effects on non-target species. An example of a recent acarid species becoming very popular in use is *Amblyseius swirskii* (Calvo *et al*. 2011).

During the initial seven decades of augmentative biological control (1900–1969) 11 species (0.11 year-1) became available, mainly hymenopterans (seven species). From 1970 onwards the number of new species becoming commercially available increased from 1.2 year-1 (1970–1979), to 5.5 year-1 (1980–1989), culminating in 10.9 year-1 during the 1990s, and decreased to 4.2 year-1 during the first decade of the 21st century. The strong increase in newly available natural enemies during the period 1970–1999 is caused by several factors. First of all, many pests developed resistance to insecticides after the initiation of large-scale pesticide applications in the 1950s. This called for renewed use of already known biological control agents. And, if one natural enemy was used against an insecticide resistant pest, other pests in the same crop also needed to be managed with non-chemical control methods, including biological control. This stimulated a search for new natural enemies and the development of Integrated Pest Management (IPM) (van Lenteren and Woets, 1988).

For crops produced in greenhouses, biological control made it possible to use honey bees and bumble bees for pollination. Due to the great success of this type of pollination (reduced labour costs and, above all, increased production), growers were even more motivated to use biological control not only for pests, but also for diseases (Albajes *et al*. 1999). At the same time, environmental and health concerns about pesticides encouraged design and implementation of IPM and biological control worldwide. The relationship of number of species becoming available over time for the four taxonomic groups that provided most species of natural enemies is similar to that of all species combined. They all show a peak during the period 1990–1999, with one obvious difference: heteropterans have only been used in augmentative control from 1990 onwards.

The commercial insectaries were first established in the USA where Everett J. Dietrick was the pioneer of the commercial insectary industry. In 1950, he started his first insectary in his garage in Riverside, California. Later in 1951, the Rincon-Vitova insectary was established by Stubby Green and Doug Green to produce *C. montrouzieri*. These two insectaries (Rincon-Vitova and Dietrick's garage insectaries) were the first commercial insectaries in the world. Today, Koppert is the world's largest insectary, which was started by a Dutch grower, J.

Koppert. DeBach (1964) reported that large-scale production of commercial BCAs began after the Second World War. In 1997, there were only 64 commercial insectaries worldwide, 26 in Western Europe, eight in Central Europe, ten in North America, five in Australia and New Zealand, five in Latin America, five in Asia and five in Russia. Five years later there were about 85 commercial insectaries worldwide, 25 in Europe, 20 in North America, six in Australia and New Zealand, five in South Africa, about 15 in Asia (Japan, South Korea and India) and about 15 in Latin America (van Lenteren, 2003b).

In 2009, there were 130 commercial insectary companies worldwide, of which 30 were larger (more than 10 people employed) and 100 smaller (2–10 people employed) companies. Van Lenteren (2012) reported that throughout the world, 530 commercial companies produced biological control agents in 2011, among them 30 larger companies (more than 10 people employed) and it was estimated about 500 smaller (2–10 people employed) companies. Thus, over the last 14 years (1997–2011) commercial insectary companies expanded rapidly around the world. Viability of commercial biological control market Producers of natural enemies are understandably reluctant to provide data about market developments, profit margins and sales volumes. In 2015, the global pesticide market had a value of US$ 58.46 billion. The global market of biological control agents (invertebrates and microorganisms) was approximately US$ 1.7 billion in 2015, which is less than 2% of the pesticide market. Growth of the market for synthetic pesticides is expected to be between 5 and 6% over the next five years, but interestingly, growth of the biological control market has been faster: it showed an annual increase of sales of 10% before 2005 and more than 15% per year since 2005.

Impact of release rates on the effectiveness of augmentative biological control agents

Impact of release rate when parasitoids were used for biological control

Of the 19 pests targeted with a parasitoid, in 12 cases (63%), increasing the release rate of the parasitoid did not significantly affect the density or mortality of the pest or the rate of parasitism. All of the parasitoids used were Hymenoptera. Thus, release rates of hymenopteran parasitoids did not significantly impact the effectiveness of biological control in 63% of studies reviewed Impact of release rate when predators were used for biological control of the 23 pests targeted with a predator, in 15 cases (65%), increasing the release rate of the predator did not significantly affect the target pest density. Fifteen of the biological control agents (43%) were parasitoids. All of the parasitoids were from the order Hymenoptera. Nineteen pests (45%) were targeted with parasitoids. Of the pests targeted with parasitoids, the most common order was Hemiptera (8 pests; 42%), followed by Diptera (6 pests; 32%), and Lepidoptera (5 pests; 26%). Twenty of the biological control agents (57%) were predators. The order most commonly used as a predatory biological control agent was Acari (11 agents, 55%), followed by Hemiptera (6 agents, 30%), Coleoptera (2 agents, 10%) and Neuroptera (1 agent, 5%). Twenty-three pests (55%) were targeted with predators. The most common order targeted with predators was Acari (11 pests; 48%), followed by Hemiptera (7 pests, 30%), Coleoptera (2 pests, 9%), Thysanoptera (2 pests, 9%), and Lepidoptera (1 pest, 4%).

Success stories in world

1. Laboratory and field studies supporting augmentation biological control of oriental fruit moth, *Grapholita molesta* (Lepidoptera: Tortricidae), using *Trichogramma dendrolimi* (Hymenoptera: Trichogrammatidae)

Field trials were conducted in a 53.6 ha organic pear orchard in Daxing district, Beijing, China (116°270 E 39°590 N) during *G. molesta* occurrence season (from late April to early October) in 2018 and 2019. The main cultivar planted in the orchard was *Pyrus pyrifolia* cv. Cuiyu. Trees were 5 years old with an average height of 2.5 m, spaced 0.7 m apart in rows 3.0 m apart, and had Augmentative biocontrol with natural enemies in India

suffered significant damage by *G. molesta* in recent years (Zhang *et al*. 2021). Normally, the pesticides spirotetramat, emamectin benzoate, abamectin, pyridaben and thiamethoxam were applied at petal-fall, post-bloom, fruit set, young fruit, and fruit enlargement stages, respectively. Laboratory assays indicated that *Trichogramma dendrolimi* parasitized G. *molesta* at the highest rate. Parasitoids took longer to oviposit in older host eggs, and fewer eggs were parasitized when they were more than 3 days old. Field tests produced ca 60% cumulative parasitism of sentinel *G. molesta* eggs with one release of *Trichogramma dendrolimi*, with most parasitism occurring within 24 h. Female wasps dispersed up to 12 m from release point.

2. Development and area wide application of biological control using parasitoid *Aphidius gifuensis* against *Myzus persicae* in China

Ecologically safe and environment-friendly pest control strategies and technologies are important to ensure the quality of Chinese agricultural products and sustainable agricultural development. Aphids are among the world's major agricultural and forest pests, and *Myzus persicae* Sulzer (Hemiptera: Aphididae) is one of the main agricultural pests in China, transmitting various viral diseases and causing reductions in crop yield and quality that regularly triggered applications of synthetic insecticides (Yu *et al*. 2021). *Aphidius gifuensis* Ashmead (Hymenoptera: Braconidae) is an important endoparasitoid of many aphids. Starting in 2000, the Yunnan Tobacco Company has developed methods for large-scale rearing of this parasitoid on this aphid, and technological systems for augmentative releases of *A. gifuensis*. The augmentative use of this parasitoid has achieved area-wide suppression of *M. persicae* in tobacco and other crops in China. This approach is being applied on large areas, covering more than 3 million ha between 2010 and 2015. This programme is currently the largest biological control programme in China. Over 500 mass-rearing facilities were constructed in 16 provinces with a total surface area of 420000 m2 and a breeding capacity of 24000 million parasitoids per breeding period. This technology has effectively controlled the aphid on tobacco, while other beneficial insects have increased in the absence of insecticide applications, further protecting biodiversity in the fields and providing long-term ecological benefits. The use of this technology has also been expanded to other crops, solving problems of insecticide resistance in the targeted aphids, reducing pesticide residues and environmental pollution, and yielding benefits for society, the economy, and the environment.

Augmentative biological control in India

The National Agricultural Policy has laid special emphasis on Integrated Pest Management (IPM) and use of biocontrol agents in order to minimize the indiscriminate and injudicious use of chemical pesticides, which is also the cardinal principle of the Government of India on plant protection. The IPM implementation at national level has proved effective not only in reducing pesticide usage, but also in reducing pest induced losses in the country, amply evidencing a bright future for the successful use of biological control agents in pest control programmes. India is rich in natural enemy biodiversity and facilitated as many as 27 natural enemies of Indian origin being established in other countries for crop pest suppression. Thus, there is ample opportunity in India for effective management of pests, diseases and weeds through effective utilization of its vast natural enemy fauna. Biological control of crop pests and weeds made its humble beginning with the launching of the All India Coordinated Research Project (AICRP) in 1977 at Bangalore with full financial support by the Department of Science and Technology, Government of India.

Recognition of the importance of biological control came during the VIII plan with the creation of Biological Control Centre (BCC) which was functioning under the administrative control of NCIPM, Faridabad. A greater thrust for planned biological control programme started in 1987 when ICAR took over the erstwhile *Commonwealth Institute of Biological Control* (CIBC), its insect collections, physical facilities including the prime land on Bellary Road on NH-7, Bangalore. The BCC which was functioning as the PC Cell of AICRP on Biological Control of Crop Pests and Weeds was upgraded to the *Project Directorate of Biological control* (PDBC) with headquarters at Bangalore. The Directorate started functioning from 19th October 1993 with six laboratories and 16 AICRP centers. In the XI plan, the PDBC was renamed and reoriented into *National Bureau of Agriculturally Important Insects* (NBAII) on 25th June, 2009 and the mandate was redefined and, in the 12th, five-year plan, it was rechristened to the present name (ICAR - National Bureau of Agricultural Insect Resources) with effect from 24th September, 2014.

The AICRP-BC has 16 regular SAU centers (PC unit, 11 regular SAU centers with salary and contingencies and 4 with only contingencies).

1. AICRP PC Cell, NBAIR, Bangalore
2. Acharya N. G. Ranga Agricultural University, Anakapalle
3. Professor Jayashankar Telangana State Agricultural University, Hyderabad
4. Anand Agricultural University, Anand
5 Assam Agricultural University, Jorhat
6. Govind Ballabh Plant University of Agriculture and Technology, Pantnagar
7. Kerala Agricultural University, Thrissur
8. Mahatma Phule Krishi Vidyapeeth, College of Agriculture, Pune
9. Sher-e-Kashmir University of Agricultural Sciences and Technology, Srinagar
10. Punjab Agricultural University, Ludhiana

11. Tamil Nadu Agricultural University, Coimbatore
12. Yashwant Singh Parmar University of Horticulture and Forestry, Solan
13. Central Agricultural University, Pasighat*
14. Maharana Pratap University of Agriculture and Technology, Udaipur*
15. Orissa University of Agriculture and Technology, Bhubaneswar*
16. University of Agricultural Sciences, Raichur*.

    * With only contingency support.

Collaboration with other institutes, linkages with clients, end users, etc.

1. NCIPM, New Delhi
2. CARI, Port Blair
3. Chaudhary Charan Singh Haryana Agricultural University, Hissar
4. College of Agriculture, Kolhapur
5. NRC for Soybean, Indore
6. National Research Centre for Weed Science, Jabalpur
7. Navasari Agricultural University
8. S. D. Agricultural University
9. UAS, Dharwad
10. UAS, Bangalore
11. Vasantdada Sugar Institute, Pune

The project also has linkages with several private industries like

1. M/s DOW AgroScience, Mumbai
2. M/s Sri Biotech Laboratories India Ltd., Hyderabad
3. M/s Multiplex Biotech Pvt. Ltd., Bangalore
4. M/s Venkateshwara Chemicals, Secunderabad
5. M/s Agri Bio-Tech Research Centre, Kerala
6. Kerala Cente for Pest Management, Moncombu, Kerala

Success stories in India

1. Punjab

Mass rearing of natural enemies: Punjab Agricultural University, Ludhiana

Validation and dissemination of biocontrol technologies for the management of sugarcane borers at farmers' fields using bioagents, *T. chilonis* and *T. japonicum* in sugarcane conducted over an area of 1840, 2820, 2446, 3906 and 4230 hectares at farmers' fields during 2012-13, 2013-14, 2014-15, 2015-16 and 2016-17, respectively in collaboration with sugar mills of Punjab. Validation and dissemination of bio-suppression of maize stem borer, *C. partellus* using egg parasitoid, *T. chilonis* at farmers' fields in maize crop conducted at farmer's fields over an area of 20, 10, 81, 130 and 142 hectares during 2012-13, 2013-14, 2014-15, 2015-16 and 2016-17, respectively. Validation and dissemination of biocontrol based pest management technologies using bioagents, *T. chilonis* and *T. japonicum* for the management of leaffolder, *Cnaphalocrocis medinalis* and yellow stem borer *Scirpophaga incertulas* conducted over an area of 20, 20, 60 and 66 hectares during 2013-14, 2014-15, 2015 and 2016- 17, respectively at farmers' fields in organic rice.

2. Andhra Pradesh

Mass rearing of natural enemies: Acharya N. G. Ranga Agricultural University, Anakapalle

ICAR- Tribal sub–Plan Programme implemented by AICRP on Biological Control Scheme, Arakuvalley Tribal Farmers with small land holdings of half an acre to one acre were benefited. Front line demonstrations, training programmes, method demonstrations, field days were conducted on Organic farming techniques in 83 acres area of paddy, 50 acres of rajmah and 50 acres of ginger at six villages i.e., Kothavalasa and Gunjariguda, Dumbriguda mandal, Araku valley and Naduguda, Ramguda of Araku valley and Asarada, Idulabailu of Chinthapalli areas Visakhapatnam district, Andhra pradesh during 2015-16 and 2016-17. Enhancement of yield levels by 93% with improved quality benefitting 45 paddy farmers covering 43 acres.

3. Assam

Mass rearing of natural enemies: Agricultural University, Jorhat

Enabling large scale adoption of proven bio control technologies (2012-13, 2013-14, 2014-15,2015-16 & 2016-17) Area covered: 50 hectares (2012-13), 30 hectares (2013 -14), 30 hectares (2014 -15), 20 hectares (2015 -16) and 30 hectares (2016 -17) Large scale adoption of proven bio control based IPM package in rice was carried out in the farmer's field at village Pirakota of Jorhat district. The BIPM package consisted of application of *Beauveria bassiana* @ 1013 spores/ha against sucking pests, erection of bird perches @ 10 no /ha, six releases of *T. japonicum* @ 1,00,000 laks /ha at weekly interval starting from 25-35 DAT against *Scirpophaga* spp. and *Cnaphalocrocis* spp, spray of Botanicals (Pestoneem @ 3ml/lit) against sucking pests and *Pseudomonus* @ 10g/lit against foliar diseases, respectively. Large scale demonstration of *Trichogramma chilonis* against the plassey borer, *Chilo tumidicostalis* was carried out in the farmer's field located at Khanikor gaon in Golaghat district covering an area of 50 hectares with Farmer's practice (Chemical control). In farmers' practice four rounds of profenofos 50 EC @ 0.05% was sprayed at 15 days interval. A total of eleven releases of *T. chilonis* @ 50,000/ha/release at 10 days. The per cent incidence of *C. tumidicostalis* in chemical control plot was 14.71 compared to 12.08 per cent in parasitoid released plot. The cane yield attributed in parasitoid released and chemical plot was 73.2 t/ha and 71.39 t /ha, respectively. A net return of Rs.3720 was only achieved in cane yield of IPM plot compared to chemical control plot.

4. Maharashtra

Mass rearing of natural enemies: Mahatma Phule Krishi Vidyapeeth, Pune

Mass production and demonstration of *N. rileyi* MPKV isolate over 62 ha in soybean and potato fields against *S. litura*.

5. Uttarakhand

Mass rearing of natural enemies: Govind Ballabh Pant University of Agricultural Science & Technology, Pantnagar

Rice: Demonstrations using biocontrol technologies (PBAT-3) conducted over an area of 202.0 ha at the end of 196 farmers gave an average yield of 50.75q/ha as compared to 42.25 q/ha obtained with farmers' practices (conventional practices).

Pea: Demonstrations using biocontrol technologies (PBAT-3) conducted over an area of 43.0 ha at the end of 76 farmers gave an average yield of 91.25 q/ha as compared to 54.0 q/ha with farmers practices (conventional practices). Conventional farmers faced a comparative loss both monetarily in terms of cost of inputs and the seed quality, which deteriorated due to the impact of diseases. During 2017 large scale field demonstrations were conducted in basmati rice (189 ha), at the end of certified organic growers at districts Nainital and Udham Singh Nagar (Uttarakhand) for the validation. As per farmer's feedback and observations recorded, the consortium was found effective in reducing bacterial leaf blight, sheath blight and blast in rice by 50-70 per cent as compared to farmer's practices. Farmers obtained an average additional yield of 4.4 q/ha in rice as compared to the farmer's practices.

6. Karnataka

Mass rearing of natural enemies: UAS, Raichur

For the management of pigeon pea pod borer, *Helicoverpa armigera* (Fab.) NBAII Bt strain (NBAII BTG 4) was evaluated for two years (2012-13 and 2013-14) which gave consistent results and the same was proposed for university package of practices (2015- 16). Large scale demonstrations were made over an area of 20 ha. Application of NBAII Bt strain (NBAII BTG 4) @ 2% effectively suppressed pigeon pea pod borer, *Helicoverpa armigera*. Biocontrol agents like *Trichogramma* (500 cards), *Metarhizium anisopliae* (350 Kg) and *Beauveria bassiana* (300 Kg) were produced and demonstrated in sugarcane and rice ecosystem. In collaboration with KSDA, Ballari successfully demonstrated and managed the root grub in sugarcane (210 acre) in Hampsagar by using *M. anisopliae* (2016-17). Similarly, following biocontrol agents like *Trichogramma* (1000 cards), *Metarhizium anisopliae* (300 Kg) and *Beauveria bassiana* (3750 Kg) were produced.

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