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ENVIRONMENTAL REMEDIATION THROUGH BIOREMEDIATION

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ABSTRACT

Contaminated land, air, and water pose significant environmental challenges. Bioremediation utilizes microorganisms to remove pollutants, converting hazardous chemicals into non-hazardous products. Its effectiveness depends on factors such as the pollutant's chemical nature, contamination site, type of microorganisms, and environmental conditions. Microbial degradation occurs through specific metabolic pathways, relying on the capabilities of native bacteria, fungi, or plants. The success of bioremediation hinges on these microorganisms' inherent abilities and characteristics.

KEYWORDS: Bioremediation, Environment, Microorganisms, Pollutants, Metabolic Pathways

INTRODUCTION

Bioremediation is an innovative and effective approach to addressing environmental contamination. The underlying principle of bioremediation is the utilization of microorganisms that can naturally degrade a wide range of toxic substances. These microorganisms, which include bacteria, archaea, and fungi, are ubiquitous in soil, water, and air, and possess the innate ability to metabolize and detoxify pollutants, transforming them into non-hazardous products.

PRINCIPLE OF BIOREMEDIATION

Microorganisms capable of utilizing various carbon sources and degrading numerous toxic contaminants are naturally present in soils. By providing optimal conditions, these microbes can be stimulated to enhance their natural degradation processes. The primary aim of bioremediation is to encourage microbial activity by supplying optimal levels of nutrients and other essential chemicals to degrade or detoxify hazardous environmental substances. In this process, microbes act as scavengers.

ROLE OF MICROORGANISMS

Microorganisms are ubiquitous in soil, oceans, and air. The primary bio-remediators include bacteria, archaea, and fungi. Pseudomonas species are predominant in bioremediation processes, with other significant examples including Mycobacterium, Alcaligenes, and Nocardia. In some cases, the synergistic action of multiple microorganisms may enhance the degradation of a single compound. These microbes consume and metabolize organic substances for nutrients and energy, thereby converting hazardous organic substances into inert products. Complete microbial digestion results in harmless byproducts, primarily water.

RECALCITRANT XENOBIOTICS

Xenobiotics refer to foreign or synthetic chemicals such as pesticides, herbicides, or other organic compounds present in the environment. Bioremediation offers an effective and economical method for disposing of these toxic chemicals. However, some compounds resist biodegradation and persist in the environment due to their chemical and biological inertness, stability, lack of suitable microbial enzyme systems, inability to enter microbial cells due to large molecular size or absence of transport systems, or their toxicity which may produce highly toxic byproducts that inhibit microbial activity.

FACTORS AFFECTING BIOREMEDIATION

The process of bioremediation is influenced by various factors, including:

- The chemical nature of the xenobiotic
- The microorganisms used
- Nutrient and oxygen supply
- Temperature and pH

Aliphatic compounds generally degrade more easily than aromatic ones due to the complexity of ring structures and branching chains, which decrease biodegradation efficiency. Microbial activity can be enhanced through increased nutrient supply or the addition of stimulating agents, a process known as bio-stimulation. Introducing competent exogenous microbes, with or without nutritional enrichment, can further enhance microbial activity, known as bioaugmentation.

BIOREMEDIATION TECHNOLOGIES: IN SITU AND EX SITU

Bioremediation can be classified into in-situ and ex-situ approaches. In-situ bioremediation involves enhancing the growth and proliferation of existing microbial populations at the contamination site by adding nutrients such as nitrogen and phosphorus. This method is cost-effective but time-consuming and subject to seasonal variations affecting microbial activity. Ex-situ bioremediation entails collecting toxic waste materials from polluted sites and treating them with microorganisms in designated locations. This method offers better control and efficiency with shorter treatment times but is more costly compared to in situ bioremediation.

DISADVANTAGES OF BIOREMEDIATION

Bioremediation is limited to biodegradable compounds. Not all compounds undergo rapid and complete degradation, and there are concerns that biodegradation products may be more persistent or toxic than the parent compound.

CONCLUSION

Bioremediation is an environmental clean-up method that relies on the inherent characteristics of indigenous microbes to degrade hazardous chemicals. It has the potential to mitigate the impact of byproducts from human activities such as industrialization and agriculture. The process is considered eco-friendly and cost-effective.

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GREEN MANURING: A SCIENTIFIC APPROACH FOR SOIL FERTILITY IMPROVEMENT

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ABSTRACT

Green manuring, the practice of incorporating undecomposed plant material into the soil, is increasingly recognized for enhancing soil fertility and promoting agricultural sustainability. Leguminous green manure crops, in particular, play a vital role by biologically fixing atmospheric nitrogen. This process reduces the need for external inputs and enriches the soil with organic matter. Green manuring is environmentally friendly and complements integrated nutrient delivery systems, contributing to improved soil structure, aeration, and biodiversity while controlling weeds and pests.

KEYWORDS: Biological nitrogen fixation, Green manuring, Organic matter, Soil fertility

INTRODUCTION

It has been widely reported that leguminous green manure crops play an important role in soil health management and have recently received increased attention for improving soil fertility and agricultural sustainability. Green manuring involves incorporating undecomposed fresh or dry plant material into soils, either in situ or transported from a distance. Additionally, leguminous green manure crops biologically fix atmospheric nitrogen. Biological nitrogen fixation (BNF) is a microbiological process that converts atmospheric nitrogen into a form usable by plants, offering an economically attractive and ecologically sound option for reducing external inputs and enhancing internal resources. This process involves ploughing decomposing green plant tissues into the soil to boost fertility, providing an environmentally friendly way to supply nutrients and improve soil structure. Along with inorganic fertilizers and bio-fertilizers, green manuring is a key component of an integrated nutrient delivery system. Leguminous or non-leguminous trees and shrubs can be cultivated on wastelands or bunds to provide vegetative material for green manuring. The goal of green manuring is to supply the soil with nitrogen, the most critical and often deficient nutrient, by adding organic matter.

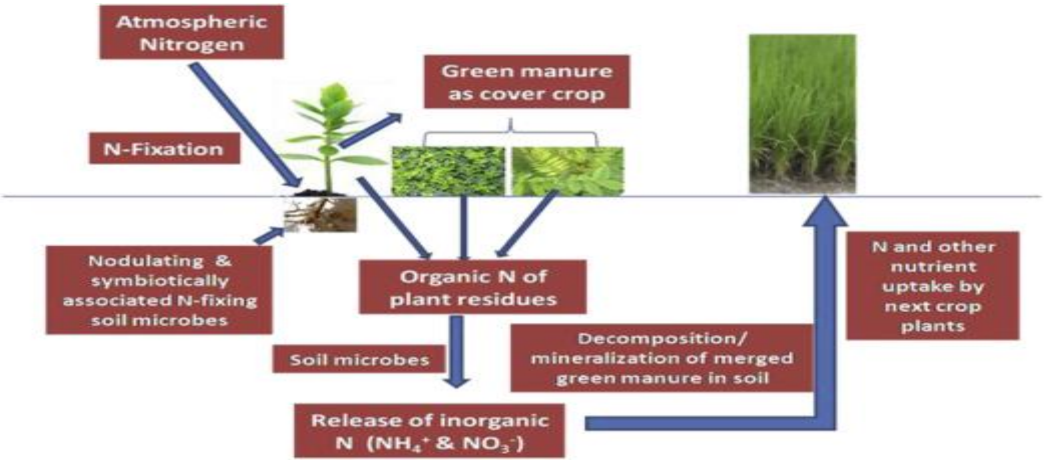

Fig 1. Different activities when applying green manuring

WHY GREEN MANURING?

- *Improves Soil Fertility:* Enhances nutrient content and organic matter in the soil.
- *Adds Nutrients:* Supplies essential nutrients to the soil.
- *Improves Aeration:* Enhances soil aeration, benefiting plant root systems.
- *Enhances Soil Structure:* Promotes better soil structure and stability.
- *Weed Control:* Helps in managing and reducing weed growth.
- *Pest and Disease Control:* Aids in controlling insect/mite pests, nematodes, and diseases.
- *Increases Biodiversity:* Stimulates growth of beneficial soil microbes and other organisms.
- *Reduces Leaching Losses:* Minimizes nutrient loss through leaching.
- *Prevents Erosion:* Helps reduce soil erosion.

CHALLENGES OF GREEN MANURING

- *Lack of Research:* Limited research on green manure crops.
- *Termite Issues:* Termites pose a problem in alluvial soils.
- *Seed Quality:* Poor availability of good quality green manure seeds.

IDEAL GREEN MANURE CROP QUALITIES

- *Rapid Growth:* Capable of establishing and growing quickly.
- *High Biomass Production:* Produces significant green material within a short period.
- *Climate Tolerance:* Tolerant to adverse conditions such as drought, waterlogging, extreme temperatures, and pests.

- *Effective Nitrogen Fixation:* Should possess adequate Rhizobium nodulation potential for nitrogen fixation.
- *Deep Root System:* Develops deep, fibrous roots to improve soil structure and nutrient uptake.
- *Easy Incorporation:* Should be easy to incorporate and decompose quickly.

TYPES OF GREEN MANURING

In Situ Green Manuring:

- ✓ Involves growing specific crops directly in the field either independently or alongside the main crop.
- ✓ Aims to improve soil fertility and structure by incorporating these crops into the soil. Examples: Sanhemp, Dhaicha, Urd, Mung, Cowpea, Berseem, Senji.

Green Leaf Manuring:

- ✓ Involves collecting leaves and tender twigs from shrubs and trees grown on bunds, wastelands, and nearby forests.
- ✓ Incorporates these materials into cultivable fields. Examples: *Ipomea*, *Jatropha gossypifolia*, various fodder crops, green manuring crops.

Table 1. Suitable Green Manures for Field Crops

Field crops	Suitable green manures
Rice	Sunhemp, Sesbania, Wild Indigo
Wheat	Sunhemp
Finger millets	Sunhemp
Sorghum	Sunhemp, Subabul, Cowpea
Sugarcane	Sunhemp
Banana	Lupin, Sunhemp, Cowpea, Guar, Horse gram.

CULTIVATION OF IMPORTANT GREEN MANURE CROPS

Dhaincha: Dhaincha have two species Sesbania *aculeata* and *Sesbania rostrata*.

a) *Sesbania aculeata*: Root nodulating legume with leaf composition 3.50% N, 0.60% P_2O_5, 1.20% K_2O. Incorporates at 8-10 weeks after sowing. Grows under diverse soil and climate conditions. Recommended seed rate: 50 kg/ha. Green matter yield: 10-20 t/ha. Nitrogen fixed: 75-80 kg/ha.

b) *Sesbania rostrata*: Nodulates on stem and root. Thrives in waterlogged conditions but sensitive to alkaline soils. Seed rate: 30-40 kg/ha. Requires scarification with sulfuric acid for germination.

Green matter yield: 15-20 t/ha. Nitrogen fixed: 150-180 kg/ha. Suitable for paddy and rainfed crops.

Sunhemp (*Crotalaria juncea*): Vigorous green manure crop, incorporates at 10 weeks after sowing. Seed rate: 45-50 kg/ha. Green matter yield: 15-20 t/ha. Nitrogen fixed: 75-80 kg/ha. Suitable for various crops including sugarcane, cotton, orchards, agroforestry systems, garden crops, paddy, and irrigated wheat. Leaf composition: 2.30% N, 0.50% P_2O_5, 1.80% K_2O.

Green Gram (*Vigna radiata*): Produces high biomass (2.9 to 4.4 t/ha). Short vegetation duration (60-75 days). Seed rate: 30 kg/ha. Nitrogen fixed: 38-50 kg/ha. High nutrient content with pH 5.2, OC 27%, OM 79%, N 3.6%, P 2440 ppm, C: N 6.75, K 29.6%, Mg 11%.

GREEN LEAF MANURES

Gliricidia (*Gliricidia maculata*): Shrub pruned to 2-3 meters for green leaf purposes. Pruned 2-3 times annually. Leaves contain 2.76% N, 0.28% P_2O_5, 4.60% K_2O.

MERITS OF GREEN MANURING

- ✓ Contributes 50-175 kg N/ha.
- ✓ Adds substantial organic matter.
- ✓ Enhances water and nutrient retention.
- ✓ Increases microbial population.
- ✓ Improves soil physical condition and nutrient availability.
- ✓ Environmentally friendly with no adverse soil impact.

CONCLUSION

Green manuring is a scientifically validated method for improving soil fertility and promoting agricultural sustainability. By incorporating undecomposed plant material into the soil, green manuring enhances soil structure, aeration, and organic matter content, while also controlling weeds, pests, and diseases. Leguminous green manure crops, in particular, offer the added benefit of biological nitrogen fixation, reducing the need for external nitrogen inputs. Despite challenges such as the availability of quality seeds and research, green manuring remains an environmentally friendly and economically viable practice that supports long-term soil health and productivity.

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APPLICATION OF DRONE TECHNOLOGY IN HORTICULTURAL CROPS

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ABSTRACT

Drone technology is revolutionizing horticulture through precision farming, agricultural surveillance, and yield estimation. Equipped with multispectral and hyperspectral sensors, drones enhance crop health monitoring, while GPS and GIS technologies support the precise application of pesticides and fertilizers. They also improve disaster response speed and minimize environmental impacts. Despite these advancements, challenges such as high initial costs, legal constraints, and a lack of technological expertise persist. Future research and regulatory adjustments will be crucial for the broader adoption of drones in Indian horticulture.

KEYWORDS: Drone technology, GPS, GIS, UAVs.

INTRODUCTION

The possibilities for using drone technology in horticultural crops have recently attracted a lot of attention because of its ability to drastically change agricultural practices. Drones, technically otherwise known as UAVs, can conduct enhanced crop monitoring, precise irrigation, and efficient pesticide applications singularly or as a part of Unmanned Aircraft Systems (UAS), conferring numerous advantages. By deploying multispectral and thermal imaging sensors, data on plant health, soil moisture, and pest infestations can be meticulously collected (Dutta and Goswami, 2020). These capabilities enable timely and informed decisions to be made by farmers, thereby optimizing crop yield and reducing resource wastage. The integration of drones into horticulture is further supported by advancements in the domains of autonomous flights and Machine Learning (ML) algorithms, which facilitate the precise targeting of interventions. Moreover, environmental sustainability is promoted through the reduced application of chemicals and water resources, thus mitigating the ecological footprint of agricultural activities.

PRIMARY AVENUES OF IMPLEMENTATION

In the contemporary landscape of Indian horticulture, the incorporation of drone technology has surfaced as a transformative innovation, particularly within the sector. The multifaceted applications of drones have substantially enhanced productivity, efficiency, and sustainability. Drones in Indian horticulture have exhibited significant potential across various critical domains, including crop monitoring, Precision Agriculture (PA), pesticide and fertilizer application, disaster management, yield estimation, research, and development.

CROP HEALTH MONITORING AND ASSESSMENT

Crop health monitoring and assessment have been revolutionized by the deployment of drones equipped with multispectral and hyperspectral sensors. These sensors capture processable data to generate detailed images depicting various plant health parameters, enabling the early detection of diseases, nutrient deficiencies, and water stress. Such proactive measures facilitate timely interventions, mitigating potential crop losses and optimizing input usage. In India, where extensive landscapes prevail, drones provide a practical solution for comprehensive crop surveillance, reducing dependence on labour-intensive manual monitoring practices. The integration of advanced imaging techniques with artificial intelligence (AI) algorithms has further enhanced the efficacy of crop health monitoring. This technological advancement ensures that precise and timely actions can be taken to address emerging issues, thereby safeguarding crop yields and quality (Al Dawasari et al., 2023; Dutta and Goswami, 2020).

PRECISION AGRICULTURE (PA)

Another area where drones have been shown to have a significant impact is precision agriculture. Drones can provide accurate field maps using Geographic Information System (GIS) and Global Positioning System (GPS) technologies, allowing for site-specific agricultural management (Quamar et al., 2023). This includes the variable rate application of inputs such as water, fertilizers, and pesticides. The precision afforded by drones ensures that these inputs are applied only where needed, thereby conserving resources and minimizing environmental impact (Zhang and Kovacs, 2012).

PLANT HEIGHT MEASUREMENT

Recent advancements have identified multispectral drone imaging as a useful tool for assessing tree crop canopy structure. Finding the best values for the flight planning variables is an important part of this programme since it affects the quality of the imagery and the maps that are produced that biophysically characterize crops and trees. To get the best drone imagery, variables including flying height, image overlap, flying direction, speed, and solar elevation need to be carefully considered. Results showed that data quality was improved when flying low picture pitch angles, high solar elevation, and along the hedgerow (Tu et al., 2020).

SPRAYING PROTECTIVE AND NUTRIENT AGROCHEMICALS

Traditional methods of agrochemical applications often result in uneven distribution and excessive use of chemicals, posing risks to both crops and the environment (Bisht and Chauhan, 2020). Drones, however, facilitate uniform and controlled application, reducing the number of chemicals required and minimizing human exposure to hazardous substances. This method not only enhances the efficacy of pest and disease control measures but also supports the production of healthier, chemical-residue-free horticultural products. Advanced drone technologies enable the precise targeting of specific areas within a field that requires treatment. This targeted approach minimizes the impact on non-target organisms and reduces the overall chemical load on the environment (Nawaz et al., 2019).

FORECASTING AND ESTIMATION OF YIELD

Yield estimation and forecasting are essential in horticulture. Drones are increasingly being employed for these purposes, capturing high-resolution images and utilizing advanced algorithms to estimate crop yield with high accuracy (Narasimha Reddy and Brahma Reddy, 2023). Farmers and policymakers can make informed decisions regarding the marketing, storage, and distribution of horticultural produce based on the procured information. The predictive capabilities of drones contribute to enhancing the economic stability of farmers and ensuring food security. The integration of machine learning techniques with drone imagery has further improved the accuracy of yield estimation models. Machine Learning algorithms can analyse vast amounts of data for pattern recognition and correlations that are indicative of crop yield potential. This advanced analytical capability enables more precise yield predictions, which are critical for effective agricultural planning and management (Dutta and Goswami, 2020).

RESEARCH AND DEVELOPMENT

Drones can have noteworthy roles in the Research and Development Sector of Horticultural Sciences and its allied disciplines. They facilitate the collection of extensive and precise data required for scientific research. This includes monitoring plant growth, studying the effects of different agricultural practices, and conducting experiments on crop varieties. Integrating drones in research activities accelerates the pace of innovation and the development of new techniques and technologies in horticulture. Moreover, implementing Drone Technology in research enhances the accuracy and reliability of experimental results, as it minimizes the odds of human error and ensures consistent data collection protocols (van der Mewre et al., 2020).

CHALLENGES

This newly evolved technology has some major challenges like data analysis, regulations, and cost scalability.

- Data Interpretation and Analysis: Managing and processing the massive amounts of data that agricultural drones collect can be difficult and time-consuming. To extract practical insights from drone data, farmers must develop intuitive software and analytical tools. (Emimi et al., 2023).
- Rules and Safety: While using agricultural drones, operators need to follow aviation rules and safety precautions. Among the most important issues to handle are ensuring adherence to airspace laws, protecting privacy, and reducing the risks involved in flying close to populated areas. (Emimi et al., 2023)
- Cost and scalability: For small-scale farmers, the expense of purchasing and maintaining agricultural drones may be a deterrent. For drone technology to be more widely used and accessible, it must become more affordable and scalable, especially in terms of training, equipment, and support services. (Emimi et al., 2023)

PROSPECTS

During the Green Revolution of the 1960s, India achieved self-sufficiency in food grain production by utilizing modern cultivation techniques, including high-quality seeds, efficient irrigation, chemical fertilizers, and pesticides. Drones collect data related to crop yields, soil quality, nutrient levels, and weather patterns. This data can then be used to accurately map existing issues and develop data-driven solutions. Drone analysis includes soil pH, salinity, texture, slope, water availability, and hazard assessment based on mapping results (Khadse, 2021). UAVs are used by farmers and producers to assess crop development, track biodiversity, and observe ecological landscape aspects. Furthermore, they can also be utilized efficiently for water spraying and other pesticides due to the harsh topography of farmland, especially when farmers must cultivate crops there. Robotics has improved crop output and productivity in the agriculture industry in addition to drones. Robotic weed eaters and sprayers are reducing the use of pesticides (Sylvester, 2018).

CONCLUSION

Despite countless benefits, the widespread adoption of drone technology in Indian horticulture faces several challenges. High initial investment costs, lack of technical expertise, and regulatory constraints are significant barriers. However, initiatives by the government and private sector to promote drone usage, coupled with advancements in technology, are expected to overcome these hurdles. The prospects of drone technology in Indian horticulture are promising, with potential applications extending to precision irrigation, soil health monitoring, and beyond. Policy reforms aimed at creating a favourable regulatory environment for drone operations in agriculture are critical for facilitating their widespread adoption. Additionally, capacity-building initiatives focused on training farmers and agricultural professionals in the use of UAVs and UAS will be essential for ensuring its effective deployment. With the advent of novel technologies over time, the cost of drones is expected to decrease, making them more accessible to small and marginal farmers. Farming techniques and resources will be enhanced by farmers implementing these cutting-edge technologies. Such cutting-edge technological progress can open the door to sustainable agriculture.

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PLANT GROWTH PROMOTING RHIZOBACTERIA: A RAY FOR SUSTAINABLE CROP PRODUCTION UNDER DROUGHT PRONE DRYLAND CONDITIONS

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ABSTRACT

Globally, drylands, covering 42.3% of croplands, are crucial for food security. Approximately 72% of these drylands are in developing nations such as India and Africa, which face severe weather challenges, including prolonged droughts and frequent famines. Climate change exacerbates drought stress, leading to increased crop failures and a 9-10% reduction in global crop production, threatening food security. To address this, eco-friendly practices like PGPR (Plant Growth-Promoting Rhizobacteria), VAM (Vesicular-Arbuscular Mycorrhiza), and other bio-stimulants are essential. PGPR, in particular, offers a cost-effective and sustainable method for enhancing plant growth and crop productivity in dryland agriculture.

KEYWORDS: Drought stress alleviation, Eco-friendly, PGPR, Sustainable agriculture

INTRODUCTION

The escalating global population, water scarcity, poor moisture retention capacity, low soil fertility, low SOC, and climate change threaten dryland farming through increased vulnerability to droughts and other extreme weather events. Among a group of abiotic stresses (moisture stress, salinity, heat stress, heavy metal stress, etc.) drought/moisture deficit stress is the single most stressful environmental factor threatening successful crop production under dry land tracts of the world. It has been projected that drought stress may cause serious plant growth problems on more than 50% of the earth's arable lands by 2050. Further, the increased drought frequency resulted in 9–10 % reduced crop production which threatens global food security.

Drought has multi-dimensional effects that alter various physiological and morphological characteristics in plants (Figure 1). The shortfall of soil moisture produced by drought, decreases soil water potential, causing cell dehydration, reduced cell division, expansion, production of reactive oxygen species (ROS), and reducing plant water use efficiency (WUE) and crop yields. Thus, it is necessary to find solutions that enhance plant tolerance to drought stress and allow crop productivity that satisfies the increasing food demands.

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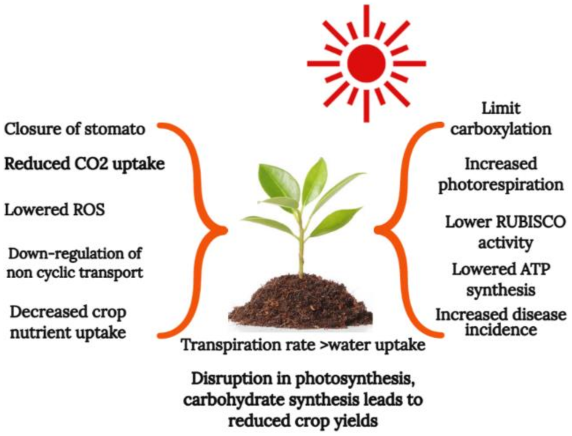

Fig.1 Effect of drought on plant

The technical, economic, and ecological limitations of conventional breeding strategies have sparked interest in the exploration of alternative low-cost, natural, and ecologically friendly initiatives, viz., plant growth-promoting rhizobacteria (PGPR). PGPR are free-living soil bacteria that colonize root systems and support plant growth by modifying the defence response of plants under moisture stress.

PLANT-ASSOCIATED BENEFICIAL BACTERIAL BIOMES

The microbes are ubiquitous and survive from a favourable system to extremely unfavourable/harsh conditions. A gram of rhizospheric soil contains nearly $9x10^7$ bacteria, $4x10^6$ actinomycetes, $2x10^5$ fungi, $3x10^4$ algae, $5x10^3$ protozoa, and $3x10^1$ nematodes (Glick 2014). Bacteria are the most common rhizospheric microbiomes and control various physiological and biochemical functions in plants. The beneficial bacterial communities associated with plant ecosystems have been classified into three types (a) phyllosphere, (b) endophytic, and (c) rhizospheric.

Table 1. Classification of beneficial bacterial communities

Phyllospheric Bacteria			**Endophytic Bacteria**
Stem (caulosphere)	Leaves (phylloplane)	Fruits (carposphere)	Interact with internal tissues of root, stem flower, fruits or seeds
Genera	*Achromobacter, Acinetobacter, Agrobacterium, Arthrobacter, Bacillus, Delftia, Methylobacterium, Pantoea, Pseudomonas, and Xanthomonas*		*Azoarcus, Achromobacter, Burkholderia, Nocardioides, Herbaspirillum, Pantoea, Klebsiella, Gluconoacetobacter, Enterobacter,*

The bioaugmentation of plants with PGPR is considered one of the critical methods to overcome the adverse effects of drought. Generally, plants release root exudates into the rhizosphere to attract soil microbiome. A large number of rhizospheric microbes from various genera, including *Methylobacterium*, *Pseudomonas*, *Serratia*, *Rhizobium*, *Paenibacillus*, *Erwinia*, *Enterobacter*, *Flavobacterium*, *Bacillus*, *Azospirillum*, *Burkholderia*, *Arthrobacter*, *Alcaligenes*, and *Acinetobacter*, have been identified for plant growth promotion (Tsadik et al., 2020; Yadav, 2021). These plant-beneficial microbiomes will support plant growth either directly or indirectly by promoting a favourable environment in the rhizosphere (Figure 2). Thus, plant-microbial interaction is thought to be imperative for improving soil fertility, plant growth, and production for agricultural sustainability.

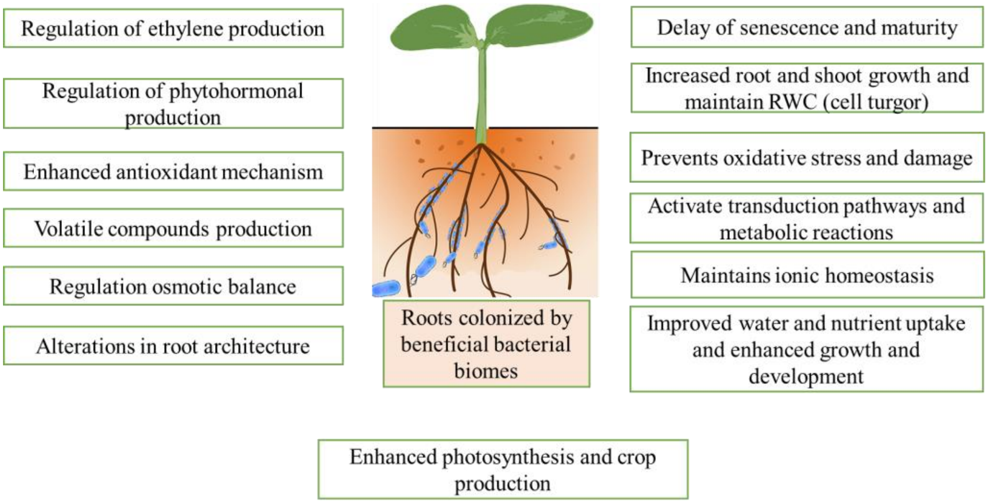

Fig.2. Mechanisms of drought stress tolerance as mediated by beneficial rhizobacterial biomes

MECHANISMS OF DROUGHT STRESS ALLEVIATION BY RHIZOBACTERIA

Adaptation by rhizospheric bacteria towards moisture-stress environments helps in improving health and drought stress tolerance in crop plants. Plant-associated bacterial microbes can function as drought stress tolerance by altering plant morpho-physiological processes, plant hormonal balance, and plant biological processes as shown in figure 2.

Several scientific investigations have well documented that drought can be counterbalanced by inoculating the plant with plant growth-promoting rhizobacteria (Table 2).

Table 2. Scientific research evidence

PGPR	**Host plant**	**Effect**	**Reference**
Bacillus velezensis	Maize	Enhanced drought tolerance through ACC deaminase and EPS-producing activity	Nadeem et al. (2021)
B. amyloliquefaciens	Pearl millet	Reduced the ethylene production through ACC deaminase activity and thereby increased the plant survival rate and growth under moisture stress	Murali et al. (2021)
Ochrobactrum sp. (EB-165) and *Microbacterium sp. (EB-65)*	Sorghum	Increased plant relative water content by regulating stomal closure.	Govindasamy et al. (2020)
Pseudomonas fluorescens (S3X)	Maize	Increased root and shoot growth by increased production of IAA which enhanced drought tolerance.	Notununu et al. (2022)
Bacillus pumilis (DH-11) and *Bacillus firms* (40)	Potato	Increased accumulation of enzymatic antioxidants *viz.*, ascorbate peroxidase helps to reduce ROS damage under moisture stress.	Ullah et al. (2019)
Streptomyces sp. (IT25 and C-2012)	Tomato	An increase in total sugar (sucrose and fructose) enhanced osmotic adjustment to overcome moisture stress.	Abbasi et al. (2020)
Alcaligenes faecalis (AF3)	Maize	10% increased root length under moisture stress conditions.	Pereira et al. (2020)
Streptomyces strain IT 25 or C-2012	Tomato	Increased the fruit weight by 25-35 % by regulating shoot growth.	Abbasi et al. (2020)

CONCLUSION

Taken together the co-inoculation of plants with beneficial rhizobacteria is a potential way forward to alleviate drought stress naturally. As rhizobacteria adopt multiple approaches such as regulation of ethylene production, phytohormonal balance, osmotic adjustment, enhanced morpho-physiological factors etc help to ameliorate drought stress effectively and will also solve the food security problem. Moreover, rhizobacteria can provide a better and more cost-effective alternative for drought tolerance in crop plants.

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REVOLUTIONIZING AGRICULTURE: ARTIFICIAL INTELLIGENCE FOR CROP IMPROVEMENT

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ABSTRACT

Food scarcity is a growing global concern due to rapid population increase, impacting food availability and supply. To address food shortages and challenges like pests, diseases, water scarcity, and climate change, various technologies have been developed to boost crop production. Plant genomics aids in identifying and sequencing genes for resistance to adverse conditions. Among these techniques, artificial intelligence (AI) and machine learning have emerged as promising approaches to enhance crop production and reduce yield loss, showing significant potential for data-driven decision-making in agriculture.

KEYWORDS: Crop Models, Machine Learning, Plant Breeding, Plant Genomics

INTRODUCTION

Today, the world faces threats to food security, primarily due to the rapid increase in population, which is expected to reach nine billion by 2050 (Tilman et al., 2011). Meeting the demands of a growing global population for agricultural goods is a critical issue that has been, and will continue to be, addressed. Meeting the food demand of a growing population through traditional farming alone is challenging. This problem can be addressed through two main approaches: crop management and crop improvement using -omic data, including genomic, phenomic, and environmental data. Innovative methods include capturing data and extracting information from plants using High Throughput Phenotyping (HTP); systematically designing, applying, and collecting data to monitor weather, soil conditions, and management practices; gathering information from crops and fields through GIS, GPS, and remote sensing; and using companion -omics technologies to quantify gene transcripts, metabolites, proteins, and other molecules.

ARTIFICIAL INTELLIGENCE (AI)

AI is a field of study that uses technology, including computer systems, robotics, and digital equipment, to simulate human intelligence and cognitive processes (Patel et al., 2021). AI has experienced several periods of increased interest and effort, known as AI summers, and periods of reduced interest, known as AI winters (Ilkou and Koutraki, 2020). AI encompasses diverse sub-fields, which can be broadly categorized into symbolic and sub-symbolic AI (Ilkou and Koutraki, 2020; Nilsson, 1998). Symbolic AI includes robotic process automation and inductive logic programming, while sub-symbolic AI focuses on machine learning, computer vision, and natural language processing.

AI APPLICATIONS IN CROP IMPROVEMENT

Analysing Genomic Data

Whole-genome sequencing of smaller genomes and the development of new technologies that accelerate cloning and sequencing processes have advanced plant genomics research, complete DNA sequencing for certain species, and biotechnology and plant breeding. Genomic selection (GS) can be enhanced through breeding methods like marker-assisted selection (MAS), which relies on identifying individual loci that affect a phenotype. GS uses genome-wide DNA markers to predict the phenotypes of studied populations, creating models that help predict the phenotypes of untested populations. Conventional GS approaches include best linear unbiased prediction (BLUP) methods like genomic BLUP (GBLUP) and ridge regression BLUP (rrBLUP), as well as Bayesian models such as BayesA, BayesB, BayesC, BayesR, and Bayesian LASSO. These GS approaches significantly help identify genetic variance, predict breeding values, increase accuracy in selecting complex traits, and support sustainable agriculture.

Prediction of Crop Yield

AI models can accurately forecast crop yields by analyzing historical data, weather patterns, and real-time conditions. According to AgTech, they are 20% more accurate than traditional techniques (GlobalAgTechInitiative, 2023). Plant growth, development, and yield can be predicted using crop models based on environmental conditions and crop management. AI systems can analyze the previous 30 years of meteorological data to predict weather patterns, helping farmers plan activities such as planting, irrigation, pest and disease management, and harvesting. AI-powered sensors and imaging technologies, such as remote sensing and GIS satellite imagery, assess soil properties like moisture, nutrients, pH, and temperature, which are useful for land management, agricultural planning, and environmental assessment. Convolutional neural networks (CNNs) are used to analyze satellite images and predict crop yields. Crop modelling platforms such as DSSAT, ORYZA, EPIC, SWAP, CROPSYST, STICS, IMPACT, APSIM, TOA, and GTAP help predict crop yield using soil, climate, plant data, and management practices. Crop modelling has become a major tool for addressing challenges related to climate change, global food security, and bioenergy (Jagermeyr et al., 2021; Lobell et al., 2013).

Plant Breeding

AI automates phenotyping processes, including the measurement and analysis of plant characteristics. Machine learning algorithms assess traits like color, plant height, leaf size, disease resistance, and yield potential. By leveraging machine learning, AI can optimize breeding programs to predict the most effective mating schemes and select elite parental lines, leading to improved offspring quality and reduced breeding time. Machine learning algorithms identify genetic markers associated with desirable traits and detect patterns and correlations between genetic and phenotypic data. Breeding predictions and recommendations are dynamically updated and improved through the continuous learning of machine learning algorithms. AI enhances the efficiency and accuracy of DNA sequencing processes by aiding in error correction, base calling, and assembly of DNA sequences, making the entire sequencing process more reliable and faster. AI models can make plant breeding more adaptable to uncertainties such as climate change by adjusting to changing environmental conditions and plant responses. Overall, AI streamlines processes, reducing the time and expenses associated with conventional breeding techniques.

Monitoring of Diseases and Pest Outbreaks

AI tools play a vital role in pest identification, classification, monitoring, and control. AI algorithms are used for controlling, tracking, and managing agricultural inputs at optimal times, reducing the undesirable consumption of pesticides. Various applications, such as Plantix, Leaf-Byte, Bioleaf, Cotton Ace, and Apizoom, have been developed for diagnosing and identifying insect pests. AI integrated with entomology enables effective and timely management and forecasting of pests and diseases. Pest and disease detection can be accomplished using image recognition with machine learning algorithms. Smart traps have been developed for automatic remote monitoring of pests.

AI Techniques Used for Detection of Diseases in Agriculture:

AI tools help to detect pests and diseases through Image processing and Convolutional neural networks (CNNs).

i) Image processing:

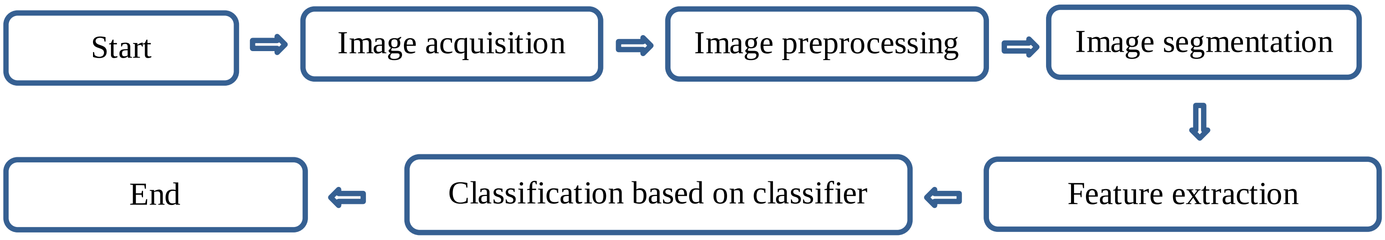

Fig 1: Basic flowchart of Disease Detection and Classification

ii) Convolutional Neural Networks:

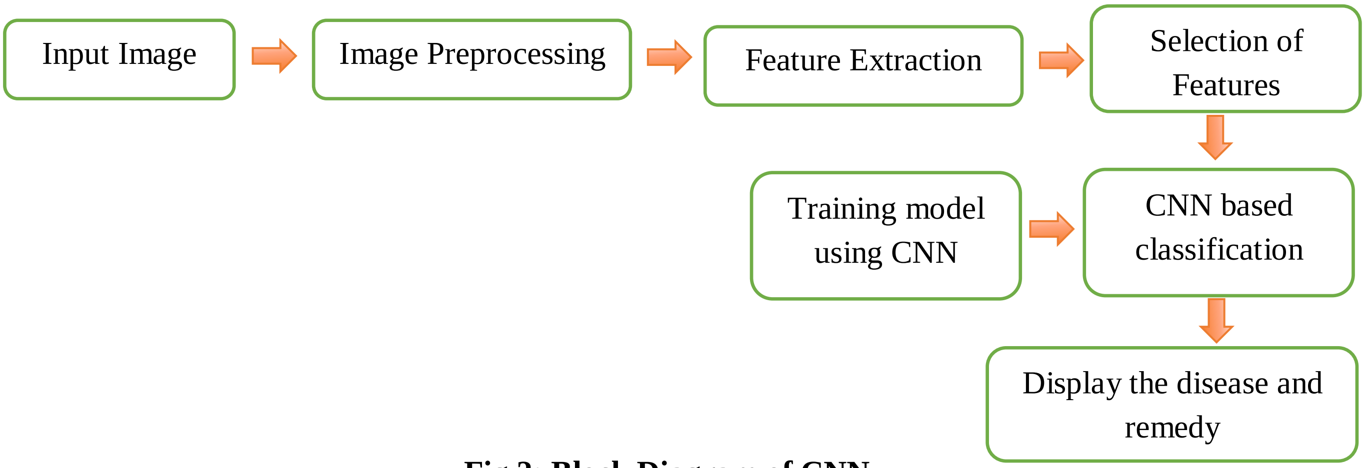

Fig 2: Block Diagram of CNN

Precision Agriculture

AI applications optimize planting, fertilization, pesticide application, and irrigation schedules based on real-time data and predictive models. Drones and sensors integrated with AI can monitor crop health, identify stresses early, and recommend targeted interventions. Variable Rate Technology (VRT) using AI allows farmers to adjust input application rates like fertilizers, pesticides, and seeds throughout the field based on soil variability, thereby optimizing yields, reducing costs, and minimizing environmental impact. Remote sensing technologies, like satellites and drones, provide data on crop health, soil moisture, disease pests, and nutrient status, helping farmers make informed decisions for effective crop management. AI enables the sharing of best practices and insights across farms and refines recommendations based on feedback and new data.

FARM MANAGEMENT DECISION

AI-powered tools help farmers make informed decisions about crop health, soil conditions, extreme weather events, and market trends. AI optimizes resource allocation, such as water, pesticide, and fertilizer application, to reduce costs and waste and improve farm efficiency. AI can simulate farm equipment failures, help schedule maintenance and optimize usage to reduce downtime and assist farmers with financial planning, budgeting, and risk management. AI facilitates the automation of farm operations, such as autonomous tractors and drones, to improve efficiency and reduce labour costs. AI-powered decision support systems provide farmers with data-driven information and quick interventions.

CONCLUSION

The predicted population growth in the coming years presents a significant obstacle, as it will be challenging to feed everyone adequately. Additionally, water constraints, climate change, technological advancements, and other environmental issues will lower food output. Fortunately, crop enhancement technologies play a crucial role in increasing agricultural productivity. Effective use of digital technology, including sensors, artificial intelligence, remote sensing, automation of farm machinery, and machine learning, is crucial for better crop monitoring and water management. However, farmers face challenges when adopting AI, including the cost of implementing AI systems and the need for technical expertise.

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SMART FERTILIZERS FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

The global population's increasing food demand necessitates enhanced sustainable crop production. Fertilizer application is crucial for improving crop yield and soil fertility, but conventional methods can lead to nutrient loss through leaching, volatilization, and eutrophication, reducing nutrient use efficiency. Next-generation smart fertilizers, designed with innovative formulations, aim to maximize agricultural production while minimizing environmental impact. These advanced fertilizers include controlled-release fertilizers, nano-fertilizers, bioformulations, and IoT-based nutrient management practices. Their adoption is essential to meet global food needs and reduce environmental harm.

KEYWORDS: Bioformulations, Controlled release fertilizer, Nano fertilizer, Nutrient use efficiency

INTRODUCTION

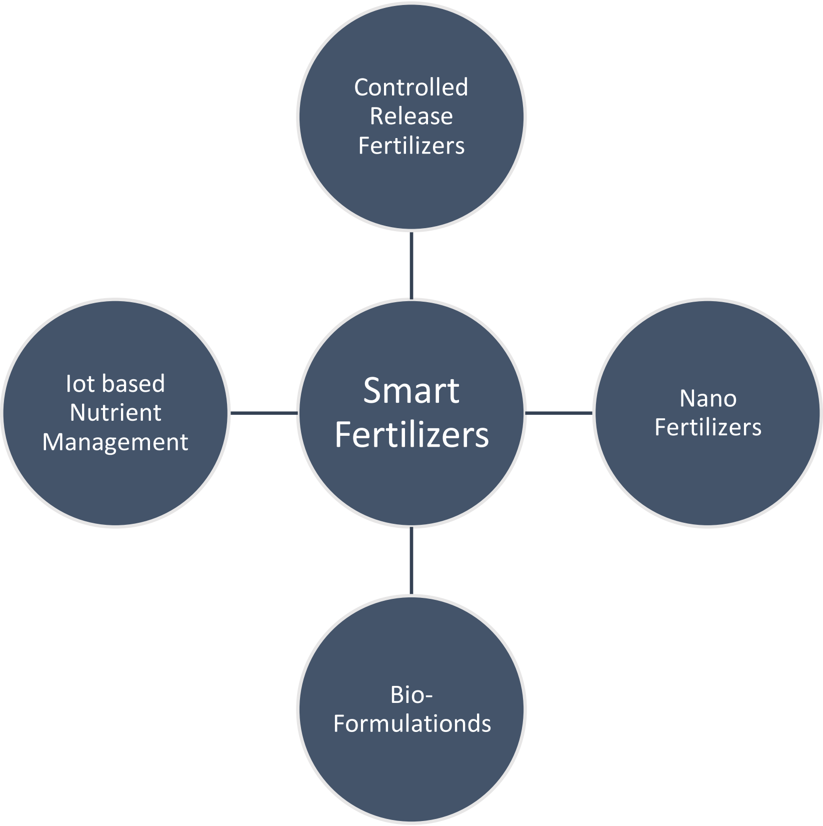
Agriculture confronts the challenge of ensuring food security for the escalating global population without endangering environmental security as demand for the world's food systems amplifies in the upcoming decades. The primary channel for food supply, agriculture, necessitates immediate support for enhancing crop productivity. Potential strategies include employing high-yield varieties and optimizing irrigation and fertilization methods. Fertilizer application is a critical agricultural management practice for increasing crop yield and improving soil fertility by augmenting the supply of fertilizers and soil amendments (Aryal et al., 2021). Although fertilizers are designed to improve nutrient use efficiency, several pathways of losses can significantly reduce their effectiveness. These losses include leaching, denitrification, microbial immobilization, fixation, and runoff. As a result, a substantial amount of nitrogen (40-70%), phosphorus (80-90%), potassium (50-70%), and micronutrients (more than 95%) are lost in the environment, leading to pollution (Kanjana, 2017). These losses have detrimental consequences on the environment globally, such as the contamination of groundwater from leached nutrients and reduced efficiency of applied fertilizers. New generation smart fertilizers, with innovative formulations, are designed to maximize agricultural production while minimizing environmental harm. These advanced fertilizers represent a modern approach to agricultural methods that emphasize precision, sustainability, and environmental responsibility (Kanjana., 2017). To meet the expanding global demand for food while minimizing the environmental impact of farming, these advancements are imperative.

Smart fertilizers involve the precise dosage and timing of fertilizer application using advanced technologies, to optimize crop yield and minimize agrochemical usage. By accurately monitoring the environment, these tools can help create and promote the use of sustainable fertilizers. Conventional fertilizer practices can lead to poor nutrient management and loss of nutrients through leaching, but smart fertilizers offer a more advantageous alternative (Vejan et al., 2021). These next-generation fertilizers aim to address the limitations of conventional fertilizers and support environmentally responsible and productive agriculture. Among the various types of smart fertilizers, controlled-release, nano-fertilizers, bioformulation fertilizers and IoT-based fertilizer applications are notable innovations that can enhance nutrient use efficiency and sustainably improve crop yield. According to Raimodi et al. (2021), smart fertilizers are defined as "any single or composed nanomaterial, multicomponent, and/or bioformulation containing one or more nutrients that can adapt the timing of nutrient release to the plant nutrient demand via physical, chemical, and/or biological processes, thereby improving crop growth and development and reducing environmental impact when compared to conventional fertilizers".

TYPES OF SMART FERTILIZERS

Controlled release fertilizer

Controlled-release fertilizers (CRFs), which are sometimes referred to as coated or encapsulated fertilizers, can be described as "a granular fertilizer coated with polymer/resin/coating materials that delay the nutrient release from the fertilizer core and extend its availability significantly longer than traditionally available nutrient fertilizer" (Trenkel et al., 2010). CRFs, as described by Shaviv (2005), are fertilizers in which the factors governing the rate, pattern, and duration of release are known and controllable during their preparation. In contrast, slow-release fertilizers release nutrients at a slower rate than conventional fertilizers, but the rate, pattern, and duration of release are not well controlled. Common examples of slow-release fertilizers include microbially decomposed N products, such as urea-formaldehyde, and coated or encapsulated products, classified as controlled-release fertilizers (Trenkel, 1997). The European Standardization Committee (CEN) Task Force has established criteria for controlled-release fertilizers, specifying that the rate of nutrient release must be slower than that of conventional fertilizers. Specifically, no more than 15% of the nutrients should be released within 24 hours, no more than 75% within 28 days, and at least 75% within the stated release time.



Nano fertilizers

Nano-fertilizers are available in both powder and liquid forms and involve the engineering, design, and application of nanoparticles. These fertilizers are defined as products in the nanometer range that provide nutrients to crops. Nanoparticle-based fertilizers are a type of fertilizer that delivers nutrients precisely for optimal plant growth. These fertilizers can be administered either in real-time to the rhizosphere or through foliar sprays. They are designed with small size, high surface area, and reactivity to enhance the solubility, diffusion, and availability of nutrients to plants. By doing so, they increase crop productivity by utilizing unavailable plant nutrients in the rhizosphere. Nano-fertilizers improve nutrient release kinetics and plant uptake efficiency, resulting in benefits such as higher crop yields, reduced nutrient loss to the environment, and improved nutritional content and shelf life. The use of nano-fertilizers can help reduce the risk of eutrophication and subsequent degradation of natural resources.

Bioformulations and Biostimulants

Bioformulations are fertilizers that include active or dormant microorganisms, including bacteria and fungi, which can affect growth and nutrition (Tayade et al., 2022). These microbial preparations comprise beneficial microorganisms that possess the ability to fix, solubilize, or mobilize plant nutrients, thereby enhancing plant growth and crop yield. Plant bio-stimulants are substances or materials, other than nutrients and pesticides, that can influence physiological processes in plants when applied to plants, seeds, or growing substrates in specific formulations. Bio-stimulants can have direct hormonal effects on plants, which can lead to benefits such as increased root growth, improved root efficiency and enhanced nutrient uptake. These effects can be particularly useful when transitioning from chemical to organic fertilization regimes. The primary categories of bio-stimulants encompass humic substances, protein hydrolysate and amino acid stimulants, seaweed extract, and PGPR. Bio-stimulants refer to natural or synthetic compounds that may be administered to seeds, plants, and soil, to enhance vital and structural processes in plants, ultimately leading to increased tolerance to adverse environmental conditions, higher seed and grain yield, and improved quality. Bio-stimulants are effective in reducing the necessity for fertilizers. They are capable of enhancing nutrient efficiency, abiotic stress tolerance, and crop quality traits, even in small concentrations, regardless of the nutrient content of the substances. On the other hand, biofertilizers and bio-stimulants have an indirect impact on nutrient availability, as they do not directly provide nutrients. Instead, they consist of live microbial formulations or compounds that facilitate the acquisition and absorption of essential nutrients.

Internet of Things (IoT) based nutrient management

The utilization of the Internet of Things (IoT) in agriculture presents significant potential for real-time monitoring of soil temperature, nutrient requirements and moisture levels. By doing so, farmers can gain valuable insights into the availability of soil nutrients, enabling site-specific nutrient management practices that conserve resources and minimize environmental pollution. IoT systems can also be utilized for automated fertilizer delivery through drones and smart irrigation systems, which can increase nutrient and water use efficiency. Furthermore, IoT technologies allow farmers to remotely monitor and manage their farms, enabling timely interventions and improving overall farm management. Overall, the integration of IoT into farming practices can contribute to sustainable nutrient management and enhance sustainable agricultural productivity.

CONCLUSION

In the realm of Indian agriculture, considerable technological advancements are currently being made. Although the use of smart fertilizers has been developed, their application in agriculture remains limited. When contrasted with conventional fertilizers, smart fertilizers exhibit several notable advantages. The integration of smart fertilization techniques allows for the decrease of application losses, the reduction of the amount of fertilizer required, and the alignment of nutrient availability with crop demand. Smart fertilizers are essential for enhancing nutrient use efficiency, protecting the environment, achieving long-term cost savings, promoting sustainable productivity, reducing greenhouse gas emissions, improving soil health, and enhancing climate resilience. In summary, smart fertilizers represent a significant breakthrough in agricultural technology, offering a multitude of benefits. The adoption of smart fertilizers is a crucial step in the direction of more efficient and sustainable agricultural practices

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SOIL MICROBIOME: ROLE IN AGRICULTURE AND AGRONOMIC MANAGEMENT

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ABSTRACT

The soil microbiome, comprising bacteria, fungi, and archaea, is pivotal in agriculture. These microorganisms enhance nutrient availability through biological nitrogen fixation, phosphorus solubilization, potassium mobilization, and siderophore production, thus boosting soil fertility and crop yields. They also improve soil structure, suppress pathogens, and support plant growth through symbiosis. However, they can cause nutrient losses and harbor harmful pathogens, affecting plant health. Understanding these interactions informs sustainable farming practices, potentially reducing reliance on synthetic fertilizers and chemicals, thereby promoting eco-friendly agriculture and improved crop productivity.

KEYWORDS: Decomposition, Nutrient Cycling, Soil Microbiome, Sustainable Agriculture

INTRODUCTION

The soil microbiome, a complex community of microorganisms including bacteria, fungi and archaea, plays a crucial role in agriculture. On the positive side, these microorganisms drive nutrient cycles like biological nitrogen fixation, solubilization of insoluble phosphorus, mobilization of potassium, and siderophores production for enhancing iron availability and mineralization of other nutrients. They also improve soil structure, suppress pathogens through induced systemic resistance and facilitate plant growth through symbiotic relationships, leading to improved crop yield and soil fertility. However, the soil microbiome can also cause nutrient losses through nitrification/ denitrification and harbor harmful pathogens, that negatively affect plant health and productivity (Pasmionka et al., 2021). Understanding the soil microbiome’s intricate interactions and functions, both beneficial and detrimental, opens new avenues for sustainable farming practices and effective agronomic management. Hence, soil microbiome pave the way for eco-friendly farming approaches by substituting the use of synthetic and harmful chemicals and fertilizers.

ROLE IN DECOMPOSITION

Decomposition is a biological process driven by various microorganisms that convert complex biomass compounds into simpler molecules through oxidative or enzymatic hydrolysis. This process involves different thermophilic stages: mesophilic, thermophilic, cooling, and maturation phases, which together complete the composting process. The result is a stable, dark, and nutrient-rich substrate similar to humus, with its specific composition varying based on the original waste material.

The dominant bacterial phyla and their specific role at respective stages in the composting process (Ana et al., 2023) are as follows:

Bacterial phyla	Role	Dominant stages	Temperature range
Firmicutes	Lignocellulose degradation	Mesophilic stage	20-60°C
Proteobacteria	Mineralization of nitrogenous organic substrate under anaerobic conditions	Mesophilic	20-50°C
Actinobacteria	Degradation of recalcitrant materials and suppression of pathogens	Thermophilic stage	50-60°C
Bacteroidetes	Lignocellulosic biomass decomposition under anaerobic conditions	Cooling phase	-
Chloroflexi	Biogeochemical cycle of chlorine	Maturation phase	-

In comparison to bacteria, fungi are the dominant and efficient organic compound decomposers, attributed to their hyphae - producing nature. Basidiomycota and Ascomycota are worth mentioning examples.

ROLE IN NUTRIENT ACQUISITION

The positive impact of fungi on nutrient uptake is due to three main factors:

- Enhanced absorption of accessible nutrients from the soil through the expansion of root surface area.
- Improved nutrient availability by solubilizing insoluble nutrients, such as phosphorus.
- Increased nutrient mobility due to faster intracellular transport.

The nitrogen - fixing ability of several microorganisms had already been exploited. With or without the formation of association with plant system, either having nodule formation or not, the nitrogen - fixing bacteria contributes to a significant amount of nitrogen fixation inside the soil. The increased soil nitrogen status will further enhance crop growth, supporting improved yield. Plant growth-promoting rhizobacterial strains, mainly *Bacillus pumilus* S1r1 and *Klebsiella pneumoniae* Fr1 significantly increased the biomass yield of maize (67.98 and 67.20 g plant-1, respectively). Greater increment noted in *Bacillus pumilus* S1r1 was attributed to better biological nitrogen fixation (up to 304 mg N2 fixed plant^{-1}) and other plant growth-promoting abilities like, indole acetic acid (IAA) production and phosphate solubilization (Kuan et al., 2016).

The potassium mobilization and release from the fixed sites of soil is mediated by soil microorganisms, which will increase the different fractions of potassium, thereby contributing to crop growth and development. Basak and Biswas (2019) reported that inoculation of *Bacillus mucilaginosus* significantly improved the potassium (K) solubilization and K release from the waste mica, which increased the biomass yield and K uptake of sudan grass by more than 1.3 and 1.5 times, respectively in comparison to without inoculation.

The formation of the siderophore metal complex by bacteria increases the uptake of several essential micronutrients, especially iron which will be present in ferric form, an unavailable form for plants. These siderophores from bacteria will take the ferric form of iron, even under deficit conditions and will cross the cell’s outer layer through specialized channels, which later release these ions into the cytoplasm. The low molecular weight siderophores produced by Bacillus subtilis LSBS2 were found to increase the iron content in leaf, shoot and seed of sesame (484, 563 and 562.6 µg g-1, respectively). Along with the ability of IAA production and phosphorous solubilization, Bacillus subtilis inoculation recorded higher dry weight (2 g plant-1) and pod number (12 plant-1) than control and pure siderophore inoculation (Nithyapriya et al., 2021).

ROLE IN SOIL AGGREGATION

Soil microorganisms produce a wide array of organic compounds, that can bind soil particles, form aggregates and improve their stability. Glomalin, a glycoprotein produced in the hyphae of *Gigaspora gigante* had higher insolubility and hydrophobicity, imparting greater stability to soil aggregates. The iron content of glomalin (0.8 - 8.8 %) was considered as the main reason for soil aggregation, as the low inherent iron content of Texas soil resulted in decreased aggregate stability (Wright and Upadhyaya, 2018).

ROLE IN STRESS ALLEVIATION

Stress is anything that hinders plant growth. Microorganism have their role in both, causing stress and curbing as well. Apart from biotic factors, heavy metal, water deficiency, salinity and extreme temperatures have negative impacts on crop growth, which constitute an abiotic group of stress factors. However, microorganisms can reduce the impact of these factors on crop performance. Wu et al. (2016) reported that the arbuscular mycorrhizal fungi, *Rhizophagus irregularis* produced significant amounts of extracellular polymeric substances on the fungal surface, which adsorbed and reduced Cr(VI) to Cr(III)-phosphate analogs. Additionally, the intraradical fungal structures and cell walls in mycorrhizal roots reduced Cr(VI) to Cr(III) and complexed Cr(III) by carboxylic ligands. Thus, reduced the Cr translocation to plant cytoplasm and imparted resistance against heavy metal stress.

The fungi and bacteria also have a role in defending the plant system by altering their gene expressions, to impart resistance against the infestation from harmful microbes. Xing et al. (2020) identified the resistance-inducing determinants from Bacillus simplex strain against soybean cyst nematode, *Heterodera glycines*. The six identified compounds, cyclic (Pro-Tyr), cyclic (Val-Pro), tryptophan, cyclic (Leu-Pro), uracil and phenylalanine reduced the development of nematodes in soybean roots. However, the first three compounds also had a role in reducing the nematode number.

ROLE IN NUTRIENT LOSSES

Under the nitrification process, ammonia gets oxidised into nitrite and then to nitrate, mediated by *Nitrosomonas europea* and *Nitrobacter winogradskyi*, respectively under aerobic conditions, leading to potential leaching loss of nitrogen from soil. However, the nitrate might get reduced into nitrous oxide and molecular nitrogen through denitrification by anaerobic bacteria like *Pseudomonas* sp. and Micrococcus sp. etc. (Pasmionka et al., 2021).

CONCLUSION

Soil microbiome has a significant role in agriculture and agronomic management. The role starts from solubilizing the unavailable form of nutrients to make them bioavailable and even controls the induction of systemic resistance against biotic stress. They also trigger the production on antioxidative enzymes to scavenge free radicals or reactive oxygen species produced in plants under different stress situations. Hence, there is a need to preserve, support and enhance the growth of soil microbiome, which has huge potential to replace substantial amounts of inorganic fertilisers and synthetic protection chemicals. Thus, acts as a major step towards sustainable production.

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SOIL ORGANIC MATTER MANAGEMENT STRATEGIES FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

Soil Organic Matter (SOM) management is crucial for sustainable agriculture, as it enhances soil fertility, structure, and microbial activity. SOM, composed of plant and animal residues at various decomposition stages, provides essential nutrients and improves soil health. Key management strategies include conservation tillage, cover crops, crop rotation, crop residue management, nutrient management, and organic amendments. These practices enhance soil organic carbon content, promote microbial diversity, and sustain agricultural productivity. Effective SOM management ensures nutrient cycling and soil fertility, which are essential for long-term agricultural sustainability.

KEYWORDS: Conservation tillage, Nutrient, Organic matter, Sustainable Agriculture

INTRODUCTION

Soil Organic Matter (SOM) consists of a complex system of substances, ranging from organic residues undergoing decomposition, metabolic products of microbes, products of secondary synthesis, and humic substances. SOM serves as a soil conditioner, nutrient source, substrate for microbial activity, environmental preserver, and major determinant for sustaining agricultural productivity. Nutrient exchanges between organic matter, water, and soil are essential for soil fertility and need to be maintained for sustainable production (FAO, 2005). Maintaining soil organic matter levels and optimizing nutrient cycling are fundamental for the sustained productivity of agricultural systems (Mullongy and Merckx, 1991). As leaf litter and woody material fall to the forest floor, they become organic material. SOM is what remains once this material has decayed to the point where it can no longer be recognized. When organic matter has broken down into a stable humic substance that resists further decomposition, it is called humus. Sustainable management methods that promote soil health will be the key challenge in the future; soil quality indicators are just tools for achieving that.

SOIL ORGANIC MATTER

SOM is the organic component of soil, consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by soil microorganisms. SOM exerts numerous positive effects on soil physical, chemical, and biological properties, providing regulatory ecosystem services. SOM increases soil fertility by providing cation exchange sites and acting as a reserve of plant nutrients, especially nitrogen (N), phosphorus (P), and sulfur (S), along with some micronutrients, which are slowly released upon soil organic matter mineralization.

CONSTITUENTS OF SOIL ORGANIC MATTER

SOM consists of a variety of components in varying proportions and intermediate stages, including an active organic fraction (microorganisms, 10-40%) and resistant or stable organic matter (40-60%), also referred to as humus (FAO, 2005).

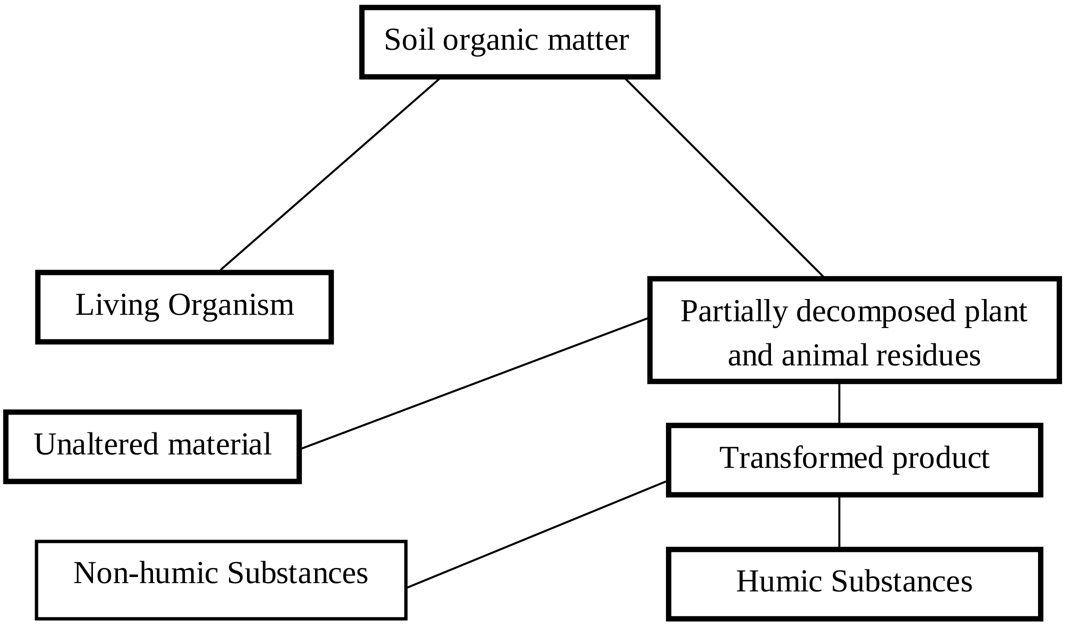

Fig. 1: Components of soil organic matter (FAO, 2005)

BENEFITS OF SOIL ORGANIC MATTER

Soil organic matter benefits soil fertility and plant nutrition in the following ways:

- ✓ Humic substances impart a dark brown colour to the soil, facilitating warming and better plant growth and yield.
- ✓ Physical conditions of the soil, like structure, porosity, and water-holding capacity, are maintained through the application of organic matter.
- ✓ SOM acts as a reservoir for plant nutrients and prevents leaching of vital elements.
- ✓ SOM increases nutrient absorption due to its high cation exchange capacity.
- ✓ SOM can form stable complexes with metals, influencing their availability to plants and microorganisms.
- ✓ SOM acts as a source of N, P, S, and micronutrients, made available through mineralization.
- ✓ SOM contributes to the formation and stabilization of macroaggregates, enhancing soil structure.
- ✓ Increased SOM enhances microbial diversity and biomass.

MANAGEMENT STRATEGIES OF SOIL ORGANIC MATTER FOR SUSTAINABLE AGRICULTURE

Proper management of SOM is pivotal to sustainable agriculture, attainable through scientific agricultural management practices like conservation tillage, crop rotation, crop residues, organic amendments, and land use planning.

Conservation Tillage

Conservation tillage reduces the intensity and frequency of plowing, leaving crop residues on the soil surface. This practice enhances soil organic carbon content and accumulates more SOM under zero tillage, sustaining soil health.

Cover Crops

Using cover crops, such as legumes and small grains, improves soil organic carbon content. Rotating legumes and grasses with food crops enhances soil organic carbon.

Crop Rotation

Cropping systems produce more biomass carbon than monocropping. Including green manure crops in rotation improves SOM status and microbial carbon. Rotating legume crops increases productivity and maintains ideal C:N ratios and SOM levels.

Crop Residues

Managing crop residues is important for improving soil organic carbon content levels. Crops and cropping systems maintain soil organic carbon stocks over time through the quantity and quality of residues returned to the soil.

Nutrient Management

Maintaining soil organic carbon content is possible through the integrated use of farmyard manure, green manure, compost, and other organic and inorganic fertilizers.

Organic Amendments

Organic amendments like compost, manure, and crop residues improve soil organic carbon status. These amendments control soil properties and fractions essential for the long-term viability of agricultural production systems (Singh et al., 2019).

CONCLUSION

Effective management of Soil Organic Matter (SOM) is fundamental for sustainable agriculture, ensuring long-term soil health and productivity. By incorporating practices such as conservation tillage, cover crops, crop rotation, crop residue management, nutrient management, and organic amendments, farmers can enhance soil organic carbon content and improve overall soil fertility. These strategies support nutrient cycling and microbial diversity and contribute to environmental preservation. Sustainable SOM management is essential for maintaining soil quality, enhancing agricultural productivity, and securing food systems for future generations.

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THE SOCIO-ECONOMIC STATUS OF INLAND FISHERMEN OF HOOGHLY DISTRICT IN WEST BENGAL

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ABSTRACT

This study explores the socio-economic status of inland fishermen in the Hooghly district of West Bengal. With fish as a critical source of animal protein, this research highlights the demographics, education levels, family compositions, pond holdings, and income sources of the fishing community. Data from 48 sample fishermen across eight villages were analysed. Results indicate that the majority are middle-aged, primary-educated, and depend heavily on fishing for income. The study provides a comprehensive understanding of the fishermen's socio-economic conditions, crucial for informed policy-making and development initiatives.

KEYWORDS: Marine fisheries, Nominal GDP, Pisciculture, Socio-economic background

INTRODUCTION

Fish contributes over 16% of animal protein to human diets, making it a vital dietary source (FAO, 1997). Fish is regarded as a nutrient-dense food with several health advantages. Omega-3 fatty acids, vitamins, minerals, protein, and other essential nutrients are all abundant in fish.

Fish farming, often known as 'pisciculture', is a type of aquaculture in which fish are commercially raised in an artificial habitat such as ponds, cages, or any other setup. Because India is bordered by oceans and rivers, the fishing sector is a significant element of its economy, and the country obtains foreign rupees from trading fish and fish products. Inland and marine fisheries are the two primary categories of fishing. The primary focus of this study is inland fisheries. Inland fisheries include the management and growing of fish and other aquatic creatures in freshwater environments such as lakes, rivers, ponds, and reservoirs (Lynch et al., 2023). With about 8% of worldwide fish production, India is currently the third-largest fish-producing nation in the world, behind China and Indonesia. There are over 2.8 crores fisherman in India overall. 44% are female, and 56% are male; according to the figure, the female population engaged in fish farming is 1.232 crores, while the male community is 1.568 crores

(NABARD Annual Report 2022). The majority of fish farmers (82%) are involved in inland fish farming, with the remaining 18% engaged in sea fisheries.

West Bengal is the sixth largest economy by nominal GDP and the second largest fish-producing state (Handbook Fisheries Statistics, 2022, Department of Fisheries, Government of India). The Department of Fisheries, Government of West Bengal, states that the state has abundant inland water resources, which make up roughly 23.09% of all inland water resources in India. West Bengal has 23 districts with a total population of 912.76 lakhs, and the total fishing population is almost 32, 36,261 (3.54%), resulting in an average of 140707 fishermen per district. Nadia, Hooghly, Murshidabad, Bardhhaman, Purba Medinipur, North 24 Parganas, South 24 Parganas, and Birbhum are the principal fish-producing districts in West Bengal. Of all the districts in West Bengal, Hooghly district comes in fifth place for fish production.

Fishermen are a community that primarily produces, cultivates fish in rivers, ponds, lakes, or other inland sources, and catches fish at sea; this sector provides them with the majority of their income. The current research focuses on the many socioeconomic factors and characteristics of this fishing community in the Hooghly district. The main objective of the current study is (i) To get knowledge about the socio-economic condition of the inland fish farmers in the Hooghly district.

METHODOLOGY

Primary data for this study were acquired from a sample of fish farmers in the Hooghly district. Hooghly is one of West Bengal's principal fish-producing districts. Of the eighteen blocks in the Hooghly district, four were selected at random. For the study, two fish-producing villages from each block total of eight villages were chosen at random. Six fishermen were randomly selected from each village, for a total of 48 sample fishermen in this study. To gather information, a thorough survey was carried out in the chosen villages. By using the personal interview method and filling out the early-planned schedule, primary data were obtained from the sample farmers. To get insight into the socioeconomic background of the fisherman, information was gathered about their age, family structure, degree of education, pond size, and average annual income.

RESULTS AND DISCUSSION

The sample fish farmers are classified into different categories based on their age, literacy level, pond holding etc. In this paper, these socio-economic aspects of the farmers are described and analyzed.

Age-wise distribution of the farmers

The fish farmers in the study region are classified into five age groups: 30-39 years, 40-49 years, 50-59 years, 60-69 years, and 70 years or beyond. It has been shown that the majority of farmers (37.50%) are between the ages of 40-49 years, based on the data gathered from them. The 30-39 age group, which accounts for 29.17% of farmers and has an average age of 34.78 years, comes next. Of all farmers, 16.67% are in the 50–59 age group, with an average age of 55.25. 10.42% of farmers are between the ages of 60-69 years, with an average age of 62.60 years. With an average age of 73.33 years, the over-70 group is the smallest, accounting for only 6.24% of the sample (Table 1).

Table 1. Age-wise distribution of the fish farmers in the study area

Age group (years)	No of farmers	Average age (years)
30-39	14 (29.17%)	34.78
40-49	18 (37.50%)	43.77
50-59	8 (16.67%)	55.25
60-69	5 (10.42%)	62.60
>70	3 (6.24%)	73.33
The overall average age of all 48 sample farmers		46.87

Family composition of the sample farm families

The family composition and average size are shown in the following table, where Five categories have been used to classify the sample farmers: marginal, small, semi-medium, medium, and large. The table shows the average family size as well as the number of male and female members for each group. It may be inferred from the results that small farmers have the largest family (5.10), while marginal farmers have the lowest (2.60). For each category, there are more male members in the family than female members. With 2.58 male members and 2.23 female members, the sample farm households have an average family size of 4.81 (Fig 1).

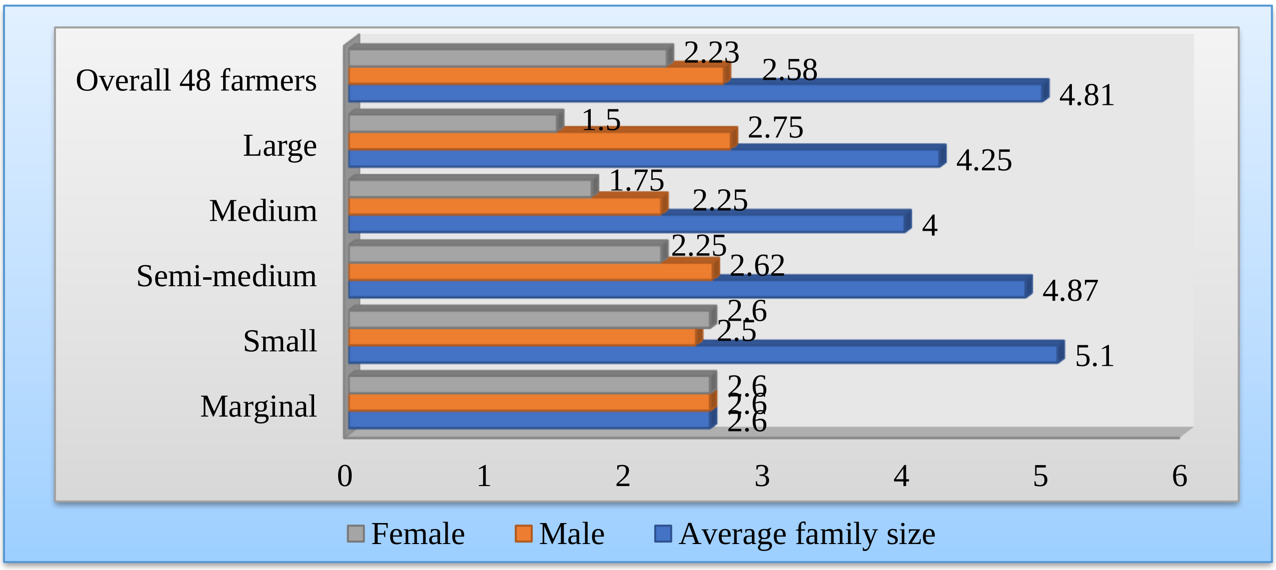

Fig 1. Family composition of the farmers and their proportions

Education levels of the sample fish farmers:

14.58% of all the sample farmers are illiterate. Primary education is the most common level, completed by 18 farmers (37.5% of the sample). 9 farmers, or 18.75% of the sample, reported having completed secondary education. Out of the sample, 14 farmers, or 29.17% of the total, have finished higher secondary education (Table 2). This distribution shows that the farmers come from a wide range of educational backgrounds, with a large majority having finished at least primary school.

Table 2. Education levels of the sample fish farmers in the study area

Education level	Number of farmers	% to the total sample farmers
Illiterate	7	14.58
Primary	18	37.50
Secondary	9	18.75
Higher secondary and more	14	29.17
Total	48	100

Pond holding of the farmers

Fish farmers in the district are divided into five categories based on their pond size: marginal (<1 ha), small (1-2 ha), semi-medium (2-4 ha), medium (4-10 ha), and large (>10 ha) Semi-medium farmers make up the majority (33.33%) of the sample farmers, with an average pond holding of 3.64 ha, according to the data gathered from them. With an average pond holding of 0.61 ha, marginal farmers make up about 25% of the farming population. With average pond holdings of 1.62 ha, 7.10 ha, and 11.84 ha, respectively, the percentages of small, medium, and large farmers are 16.67%, 8.33%, and 16.67%. The average pond holding of all sample fish growers is 4.20 hectares (Fig 2.).

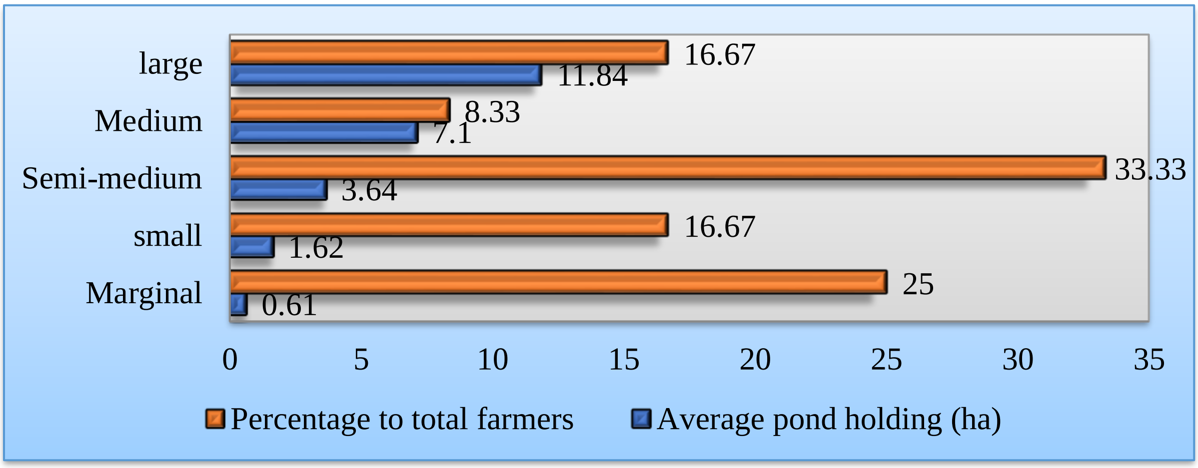

Fig 2. Pond holdings of the sample farmers and their proportions

Sources of annual income and their shares

The total yearly family income of farming households is comprised of both farm revenue and non-farm income. Crop, livestock, and fishery revenue are all included in the category of farm income; in the study region, non-farm income is mainly divided into two categories: income from businesses and income from any service. With an average yearly income of Rs 1,259,676.69, fishing is the primary source of revenue among all income sources, making up 76.31% of total annual income. While services provide Rs 251,000.00, or 15.20% of the total yearly household income, business operations earn Rs 140,111.11, or 8.49% of the overall income annually. The primary source of income for the family is fishing, followed by jobs and business, with an average annual income of Rs 1,650,787.80 (Table 3).

Table 3. Different sources of annual income of the sample fish farmers

Sl. No.	Sources of income	Average income per annum (Rs)	Percentage to total annual income
I (Farm income)	Fisheries	1259676.69	76.31
	Cropping	-	-
	Livestock	-	-
II (Non-farm income)	Business	140111.11	8.49
	Service	251000.00	15.20
III	Total	1650787.80	100

CONCLUSION

The socio-economic analysis of inland fishermen in Hooghly district reveals a community primarily engaged in fish farming with significant reliance on this sector for income. Most fishermen are middle-aged with primary education and come from moderately sized families. The average pond holding is modest, reflecting limited resources. Fishing remains the dominant source of income, supplemented by small-scale business and service activities. These insights underscore the need for targeted support and interventions to enhance the livelihood and sustainability of this vital sector in West Bengal.

Suggested readings

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TURNING WASTE INTO WEALTH: SUSTAINABLE SOLUTIONS FOR CROP RESIDUE MANAGEMENT IN INDIA

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ABSTRACT

Crop residues, traditionally considered agricultural waste, are now seen as valuable resources with multiple uses. Recycling these residues converts surplus farm waste into useful products, fulfilling crop nutrient requirements. To sustain productive cropping systems, it is crucial to protect soils from erosion, conserve soil organic matter, provide optimal conditions for soil biota, and mitigate the adverse environmental effects of high fertilizer applications. Proper management of crop residues can achieve these goals, enhancing soil health and productivity while reducing environmental impact.

KEYWORDS: Biogas generation, Biochar production, Composting, Crop residue management

INTRODUCTION

Agriculture has a huge impact on the overall Indian economy. In India, with diverse ecological and agricultural regions, a wide variety of plant species are cultivated on large tracts of land. The vast majority of crop residues are left in the field after harvest. After harvesting the economic parts of the crop, the rest of the crop parts, including the stems, leaves, seed pods, and roots, are known as crop residue. More than 686 million tonnes of crop residue are produced every year, of which 368 Mt comes from cereal crops (Hiloidhari et al., 2014). Among cereal crops, rice and wheat are the dominant crops, contributing about 154 and 131 Mt, respectively, to the total crop residue production. Rice residue holds the major share in total crop residue burnt, leading to increased emissions of methane, nitrous oxide, and carbon dioxide equivalents, thereby elevating the global warming potential every year. For instance, the production of 1 kg of rice returns 2.6 times more carbon dioxide equivalent emissions to the environment than other cereals (Source: FAOSTAT 2022). Agriculture is the second-largest sector, having a 19.9% share after the energy sector, which holds a 68.1% share in total carbon dioxide equivalent emissions (Source: FAOSTAT 2022). Therefore, the proper utilization of these crop residues is of prime importance to improve agricultural waste management, reduce pollution, and attain sustainability.

MANAGEMENT OF CROP RESIDUE

1. Crop Residue Burning:

Traditionally, farmers have relied on the conventional practice of burning residues in the field. This approach is adopted due to the challenges it poses to tillage and subsequent operations for the next crop. However, this practice can lead to the loss of valuable nutrients and soil organic matter.

Reasons for Residue Burning In-situ:

- ✓ Scarcity of labour for manual harvesting.
- ✓ Use of combine harvesters.
- ✓ Timeliness in operation and clearing of the field.
- ✓ Control of pests and short-term availability of nutrients.

Rice straw burning has adverse effects on soil and the environment. This method results in substantial nutrient losses and unnecessary waste of valuable resources, eliminating potential sources of carbon, bio-active compounds, feed, and energy that could benefit rural households and small industries. The heat generated during crop residue burning contributes to elevated soil temperatures, significantly reducing the beneficial microbial population and microbial diversity.

2. Baling and Removing the Straw:

An alternative approach to reduce crop residue burning involves the removal of residues from the field for various applications. In the context of baling and collection, a baler creates compact bales from paddy stubble. This process involves two machines: a raker for arranging straw into linear heaps and a baler for compressing the straw into bales. The raker consolidates straw into linear heaps, while the baler compacts the straw into rectangular or cylindrical bales.

Removal Practices include utilizing residue as:

Livestock Feed

Utilizing residues from crops like rice or wheat as fodder presents a viable option. However, the higher silica content of rice residues poses a challenge for microorganisms to effectively break down the material (Fazlyzan et al., 2022). In northern states such as Punjab, Haryana, and Uttar Pradesh, farmers commonly use threshing machines to separate grains, resulting in straw pieces with lengths ranging from 1 to 3 cm. These straw remnants are recognized as valuable feed for livestock, and farmers have realized that wheat straw is more suitable for cattle feeding compared to paddy straw.

Crop residue burning

Bale- making

Livestock feeding on crop residue

Compost

Paddy straw mushroom

Biogas plant

Surface mulching of crop residue

Compost Making

Composting is an ex-situ technique involving the decomposition of organic material in a separate location before returning it to the soil. The Indian Agricultural Research Institute has introduced an innovative bio-decomposer technique known as Pusa Decomposer. The Pusa Decomposer, primarily a fungi-based liquid solution, softens the hard stubbles, enabling seamless integration with the soil as valuable compost. This eco-friendly approach addresses the problem of stubble burning and serves as an alternative to chemical fertilizers.

Biochar Production

Biochar is a finely textured, carbon-rich, and porous substance known for its high stability, with over 65% carbon content. This material is derived through a thermo-chemical conversion process called pyrolysis, conducted at low temperatures in an oxygen-free environment. Biochar is widely recognized as a cost-effective and environmentally friendly solution, with its chemical composition influenced by the type of feedstock used and the conditions of the pyrolysis process. This versatile material serves as a soil improver, offering dual benefits of carbon sequestration and enhanced soil health (Das and Ghosh, 2020).

Crop Residue Usage in Bio-Thermal Power Plants

As an alternative to mitigate the environmental impact of stubble burning, the government has proposed a solution involving thermal power plants. The initiative encourages these power plants to procure crop residues directly from farmers and utilize them for electricity generation. Rice residues, a common by-product of agriculture, can be effectively utilized as a biomass resource for generating electricity. Jalkheri, District Fatehgarh Sahib in Punjab is the first plant in India based on the usage of biomass.

Biogas Production

Rice straw emerges as a viable organic material for generating bioenergy and biofuels, specifically in the form of biogas, which typically consists of approximately 50-75% methane and 25-50% carbon dioxide. Harnessing biogas from crop wastes stands out as a promising and environmentally friendly alternative to the prevalent practice of stubble burning.

3. Paddy Straw for Mushroom Cultivation

Paddy straw is a primary raw material for mushroom cultivation, specifically for cultivating straw mushrooms. The term "paddy straw mushroom" encompasses various edible mushroom species cultivated on substrates derived from rice straw or other cereal straw-based materials. The cultivation can also extend to substrates made from organic materials like cotton, sugarcane, corn husks, or a combination of these with rice or other cereal straw, allowing farmers flexibility based on availability and local agricultural practices.

4. Surface Retention and Mulching

Residue retention involves preserving crop remains left in the field to enhance soil properties using fresh plant material or existing crop residues. The key benefits of retaining crop remains on the soil surface include reducing weed growth, leading to cost savings on weedicide application. This approach diminishes the reliance on chemical fertilizers, as it positively influences the physical, chemical, and biological attributes of the soil. It also serves as a protective measure against soil erosion by augmenting organic carbon and total nitrogen within the upper 15 cm of the soil (Maitra et al., 2018).

5. Residue Incorporation

Integrating stubbles back into the field is a more viable choice, despite the associated increase in stubble management costs. Plants inherently contain essential nutrients, which are retained within the straw. The in-situ incorporation of straw into the soil leads to notable improvements in various physical soil properties, including infiltration rate, water holding capacity, bulk density, cation exchange capacity, and overall soil structure.

CONCLUSION

India produces a significant amount of plant residues annually; innovative and sustainable solutions are imperative to tackle the challenges posed by these residues. Shifting towards sustainable crop residue management practices is indispensable for enhancing soil health, reducing environmental pollution, and ensuring long-term agricultural productivity. By embracing these alternatives, India can move towards a more sustainable and economically viable agricultural system, benefiting both farmers and the environment.

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