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FOSTERING MICROBIAL DIVERSITY THROUGH CROP DIVERSIFICATION: A PATHWAY TO RESILIENT AGRICULTURE

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ABSTRACT

The agro-ecosystem, comprising crops and their environmental interactions, is significantly influenced by soil microbial diversity, which impacts soil and crop health. Monoculture practices, prevalent in India's rice and wheat-based systems, degrade soil health and diminish microbial diversity by promoting selective microbial proliferation. Crop diversification is proposed as a sustainable alternative, enhancing soil health, microbial diversity, and resilience. By incorporating various crops, crop diversification improves nutrient cycling, soil structure, and organic matter content while reducing the need for chemical inputs. This holistic approach promotes biodiversity, pest control, and economic stability, contributing to more sustainable and resilient agricultural systems.

KEYWORDS: Crop diversification, Microbial diversity, Monoculture, Soil health

INTRODUCTION

The ecosystem comprises of various living entities and their interaction with the environment. The agro-ecosystem mainly focuses on crops and their associated environmental domains *viz.* soil, atmosphere and water. Crops and soil form an inseparable part of each other's environment where there is an interdependence of their health observed at micro and macro levels. The ecosystem functioning is affected by various factors which include climatic and edaphic factors. One of the major determinants of soil health and crop growth is the microbial diversity of soil. It plays a major role in soil and crop health as it is correlated with every single soil health character and plant developmental process. From the process of soil formation by aiding in weathering to the functioning of bio-geochemical cycles and stabilization of soil-plant ecosystem microbes play a dominant role in the entirety of edaphic functions and cycles. The microbial count, diversity and proliferation are greatly affected by the type of crop grown on the soil. Growing the same type of crop on soil promotes a particular set of microbes which eventually overgrow other species owing to the competitive advantage. India has primarily two main cropping systems *viz.,* rice-based and wheat based cropping system. Being commercial and dominant it occupies a larger part of agricultural land thus leading to the same inputs and cultivation practices over the year. Hence, it has a long-term adverse effect on the soil organic carbon and microbial faction. The contemporary period has witnessed a degradation in soil health at multiple levels due to various reasons. The bio-diversity is for sustainability which over decades has been scaled down with the advent of modern farming practices (Maitra and Ray, 2019). This has called for a more sustainable solution posing economic benefits; crop diversification being an effective holistic approach.

MICROBES IN SOIL

Soil harbours a complex and dynamic ecosystem consisting of multiple co-existing microbes which interact among themselves and with plants. The species diversity and population dynamics of microbes depend on the number of factors *viz.* moisture, aeration, pH, temperature, crop type, etc. Their density varies with their location as rhizosphere soil has higher microbial density which decreases in bulk soil. The rhizosphere has as much as twenty times more active microbes than the bulk soil due to higher plant-derived C compounds around the roots hence it is called a microbial hotspot (Kuzyakov and Blagodatskaya, 2015). They are involved in various activities that sustain the ecosystem and various dynamics of the plant-soil continuum, which mainly includes decomposition, fixation, mineralization, soil aggregate formation, plant growth promotion, bioremediation and soil health indicators. Plant microbiomes enhance and promote nutrient turnover in nutrient-poor or degraded soil and also enhance soil hydraulic properties, such as infiltration, seepage and water retention and reduce the hydrophobic nature of soil thus facilitating large-scale restoration of soil and ecosystem (Coban *et al.*, 2022). Based on population bacteria are dominant followed by actinomycetes and fungi. While fungi are dominant in terms of biomass among microbes. Soil microbes have inter and intra-specific relationships with other microbes as well as plants *viz.,* symbiotic (e.g. *Rhizobium* in roots of legumes), parasitic (e.g. soil-borne pathogens infecting roots or plants), competition for resources, amensalism, commensalism, proto-cooperation, etc. The nature and properties of the microbial interactions will discern the value of plant association which further considerably enhances plant-microbe associations and services (Duchene *et al.*, 2017).

MONOCULTURE: EROSION OF SOIL MICROBES

Monoculture refers to the practice of growing single-crop species over years on the same piece of land. Apart from having limitations in terms of unsustainable production, lack of utilization of resources, and economic risks due to loss of crop; it also has a direct effect on the soil by depletion of nutrients, an imbalance of nutrient cycling, increased activity of crop specific pest or pathogen, the input of certain chemicals in more amounts, soil compaction, etc. It creates a certain condition for a prolonged period which favors a certain set of organisms in terms of environmental conditions and substrate and eliminates other organisms not acquainting with the conditions created under the crop. A negative feedback loop is created in soils under monoculture which goes on further diminishing the microbial diversity and activity. This can be stated as the deforestation of soil microbial fauna and flora as it brings down the microbial diversity to a considerably narrow range.

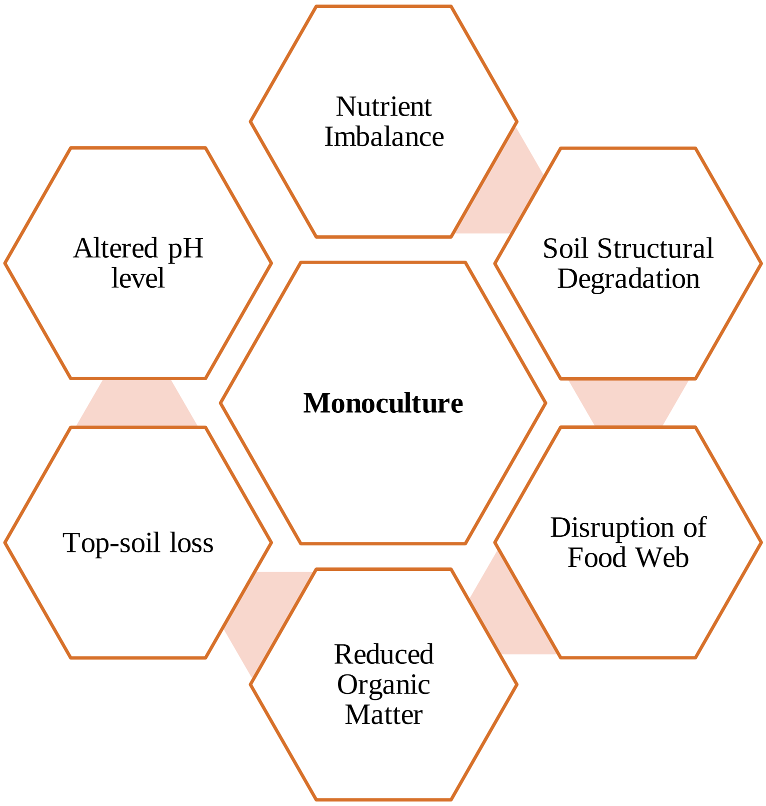

Fig. 01. Negative effects of monoculture that affect microbial diversity and population

❖ STEPS THAT CAN BE TAKEN TO MAINTAIN MICROBIAL DIVERSITY

1. PROMOTE CROP DIVERSIFICATION AND SUSTAINABLE LAND USE PRACTICES:

   Crop Diversification and Sustainable Agriculture: Adoption of practices like crop rotation, cover cropping, and reduced tillage to maintain soil health and microbial diversity.

   Agro-forestry: Integrate trees and shrubs into agricultural systems to increase carbon sequestration maintain habitat complexity and support microbial communities.

2. PROTECT AND RESTORE FORESTS:

   Protected Areas: To conserve remaining natural forests and their microbial ecosystems, protected areas should be established and enforced.

Reforestation and Afforestation: The planting of native tree species should be promoted for the restoration of degraded lands and enhancing microbial habitats. Reforestation steps should consider the original biodiversity of the area.

3. SUPPORT CONSERVATION POLICIES:

Legislation: Frame and support laws and regulations for the protection of forests and the promotion of sustainable land use.

Incentives: Policies providing economic incentives for conservation and sustainable land management practices should be encouraged.

4. PROMOTE BIODIVERSITY MONITORING AND RESEARCH:

Microbial Surveys: Regular surveys should be conducted to monitor microbial diversity and health in various ecosystems.

Research: Invest in research to understand the role of microbes in ecosystems and use this knowledge to formulate conservation strategies.

5. ENCOURAGE COMMUNITY INVOLVEMENT AND EDUCATION:

Local Engagement: Local communities should be involved in conservation efforts, as they play a crucial role in protecting microbial diversity.

Education: Raise awareness about the importance of and the impacts of monoculture and deforestation on microbial diversity and promote sustainable practices at the community level.

6. IMPROVE LAND MANAGEMENT TECHNIQUES:

Soil Conservation: Implement soil conservation practices to prevent erosion and maintain microbial habitats.

Water Management: Manage water resources carefully to avoid runoff and pollution that can impact soil and microbial health.

7. IMPLEMENT TECHNOLOGICAL SOLUTIONS:

Remote Sensing: Monitor cropping system, forest cover and its impact on ecosystems using satellite imagery and remote sensing technology.

GIS Tools: Use Geographic Information Systems (GIS) to decide, implement and monitor the conservation efforts.

CROP DIVERSIFICATION

According to IPES-Food (2016), Crop Diversification is defined as the maintenance of "Multiple sources of production, and varying what is produced across farming landscapes (intercropping) and overtime (crop rotation)."

In India, the area under crop rotation is estimated to be around 30 million ha which mainly includes cereal-based rotation systems while around 1 million ha area is under intercropping (excluding intercropping in horticultural crops), and they estimate that between 12 and 15 million farmers are practising crop rotation of which between 0.70 and 0.90 million are practising intercropping. (*https://www.ceew.in/publications/sustainable-agriculture-india/crop-rotation-intercropping*)

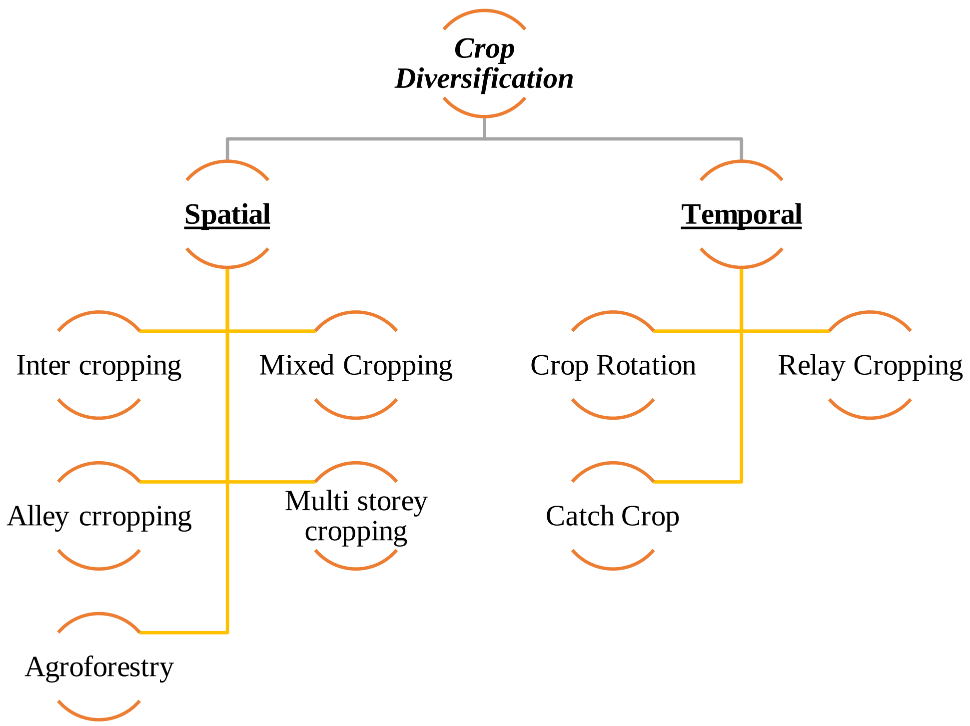

Fig. 02: Types of Crop Diversification

Spatial and Temporal Diversification are two different types of cropping patterns followed on a farm to diversify crops and enhance cropping intensity. Spatial crop diversification includes intercropping, alley cropping, multi-storeyed cropping, mixed cropping and agro-forestry where more than one plant species is incorporated on the land at the same time while temporal crop diversification is achieved through crop rotation, relay cropping and catch cropping. Multi-cropping is practised to produce more crops from a unit of land by efficient resource utilization along with providing insurance against total crop failure due to weather aberrations, particularly under rainfed conditions. Moreover, it maximizes profit without large investments and without impeding soil fertility. It also breaks the cycle of pathogens and pests.

CROP DIVERSIFICATION HAS THE FOLLOWING BENEFITS CONSIDERING AN OVERALL ASPECT OF FARM SYSTEM

1. ENHANCED SOIL HEALTH

   Growing a variety of crops helps in maintaining soil structure, fertility and overall health. Different plants have varying nutrient requirements and rooting patterns, which can reduce soil erosion and degradation in terms of nutrient depletion and physical structure along with preserving the topsoil. Moreover, it also enhances the organic matter and soil macro and micronutrients on a long-term basis.

2. RESOURCE UTILIZATION

   There is more efficient utilization of resources *viz.*, space, light, water and nutrients due to varying canopy structure, rooting pattern and nutrient requirements. This leads to more effective use of water at different depths and use of nutrients at different times. It was noted in a study that the compatibility between root systems of intercropped maize and faba bean resulted in the spreading of roots of intercropped maize underneath the roots of faba bean resulting in an increased soil space available for exploitation of water and nutrients (Xue *et al.*, 2016).

3. PEST AND DISEASE MANAGEMENT

   The cycles of insects, pathogens and weeds are disrupted by crop diversification along with increasing beneficial microbes and insect populations. A varied crop system reduces the intensity and incidences of pest and disease outbreaks, as pathogens and pests specific to one crop may not find suitable hosts in a diversified field.

4. IMPROVED RESILIENCE TO CLIMATE CHANGE

   Crop diversification increases resilience to extreme weather events and climate variability. Due to the varying tolerance of different crops to drought, heat, and floods, a mix of crops can reduce the risk of total crop failure. It also increases the resilience of the farming system against climate change in terms of sustainability, productivity and economics.

5. ECONOMIC STABILITY

   Diversifying crops can provide a safety net against market fluctuations. If one crop fails or its market price drops, other crops might still yield profits, reducing economic risk for farmers.

6. INCREASED BIODIVERSITY

   An increase in the genetic, species and ecosystem biodiversity is observed by crop diversification. It promotes biodiversity on farms, which can benefit other wildlife, including pollinators and beneficial insects. This increased biodiversity can contribute to a more balanced and sustainable ecosystem.

7. NUTRITIONAL BENEFITS

   Growing a variety of crops can promote a more diverse and balanced diet with a range of nutrients. This is particularly important in areas where dietary diversity is low. It addresses food and nutritional security.

8. SUSTAINABLE FARMING PRACTICES

   The need for synthetic fertilizers and pesticides is reduced as diversification involves rotating crops and using different farming practices. This approach supports more sustainable and environmentally friendly agricultural practices.

9. RISK MITIGATION

   Diversified cropping systems are less susceptible to risks such as market changes, price volatility, and climate impacts. This approach can provide a buffer against uncertainties and improve long-term agricultural sustainability. It also reduces the chances of loss by failure of the single crop to weather or market vagaries and provides an alternate option in periods of risk.

10. CULTURAL AND LOCAL KNOWLEDGE

    Crop diversification often involves incorporating traditional and indigenous crop varieties, which can preserve cultural heritage and local knowledge about farming practices. It also boosts the economic potential of rural communities by the development of agro-based industries.

CROP DIVERSIFICATION: RESTORATION OF SOIL MICROBES

Crop Diversification increases the genetic and species diversity of soil by flourishing a range of macro and micro flora and fauna through various interactive, stimulative and inhibitive phenomena. These number of different intermediary effects are discussed below which conclusively enhance microbial population and activities in soil.

1. VARIETY OF ROOT EXUDATES: Root Exudates are organic compounds that include sugars, amino acids and other nutrients which differ according to species, plant habit and root characteristics. The different types of exudates act as food sources for different types of soil microbes. Thus cultivating a variety of crops on a single piece of land increases the range of exudates soil which in turn thrives, diversifies and amplifies the microbial community of soil.
2. DIVERSE PLANT-MICROBE INTERACTIONS: The interaction of plants with microbes like bacteria and fungi varies according to crop type or species which promotes or hinders specific microbial growth. For instance, crops of the Leguminosae family harbour *Rhizobium* spp. in their roots while roots of higher plants have a strong Mycorrhizal network. When two cut flower species were grown together in a mixed cropping system, significantly higher (20–70%) mycorrhizal colonization was observed in

mixed-cropped plants than in the corresponding monocropped plants (Riaz and Javaid, 2017). Thus, incorporating different types of crops also creates niches for the wider range of microbes in the soil. Moreover, the production of certain organic compounds and pumping of certain ions form the basis of the functioning of many microbes eg. Methanogenic bacteria thriving in methane-rich conditions.

3. IMPROVED SOIL STRUCTURE: Different crops have varying root lengths, structures and characteristics which affect their movement in soil, moisture extraction pattern and in turn soil structure and porosity at various depths of soil profile. This consecutively affects soil water infiltration, permeability, seepage and aeration. This creates a habitable environment for soil microbes. Including a tap root plant and fibrous root plant results in the formation of various pores due to root proliferation differences and also the distribution of water in soil which in turn provides aeration and moisture in large volumes of soil thus creating a hospitable habitat for various microbes.
4. ENHANCED NUTRIENT CYCLING: Complex Nutrient Cycling processes are attributed to diverse crops. For example, atmospheric nitrogen fixation is carried out by legumes while crops harbouring Mycorrhiza can mobilize phosphorus. Thus, the enhanced nutrient cycling results in various forms of organic or inorganic forms of nutrients which directly play a role in supporting a broader spectrum of microbial life where each one is benefitted by one or the other nutrient conditions. Moreover, the inclusion of legumes as intercrops increases the total, dissolved and available form of nitrogen and phosphorus which is directly beneficial for microbes and crops. An increase in the abundance of soil bacteria and actinomycetes was observed on intercropping cucumber with garlic compared with monocultures due to increased alkaline phosphatase activity in soil (Xiao *et al.*, 2012).
5. INCREASED ORGANIC MATTER: Diversified cropping systems increase organic matter in the soil, specifically those including legumes or cover crops. It is added in the form of dried leaves or crop residues or slaughed off root residues and root exudates. Organic matter is a substrate for energy and nutrients for soil microbes as it has a high amount of carbohydrates, proteins, fats and cellulose which on breakdown release energy which is used by microbes in their physiological processes and further proliferation. Thus, organic matter being sufficient in amount it supports a rich and diverse microbial community. The enhancement in microbial properties is subjective to both the type of main crop and intercrop. Enzymatic activities are enhanced in systems involving woody crops and legumes. Moreover, many tree species grown in the agroforestry systems being leguminous increase N through fixation and produce high-quality leaf and plant litter with a narrow-C: N ratio thus increasing the organic matter of the soil. (Curtright and Tiemann, 2021)

6. REDUCTION OF CHEMICAL INPUTS: Chemical inputs like synthetic fertilizers and pesticides can be detrimental to non-target organisms. Switching to crop diversification can lower the need for chemical inputs considerably which helps in maintaining microbial diversity.
7. SUPPRESSION OF PATHOGENS

   Most of the soil-borne pathogens depend on a single host crop. Their life cycle is disrupted by crop rotation or multiple cropping. This obliteration of pathogens allows beneficial microbes to proliferate and increase soil microbial diversity. When compared with monoculture soybeans, a significant reduction was observed in root galling on soybean when grown in the intercropping system with marigolds (El-Hamawi *et al.*, 2004).

CONCLUSION

Multiple practices promoting soil health and microbial diversity can be adopted based on available resources and ecosystem characteristics. Crop diversification, due to the inclusion of multiple species of plants in spatial and temporal dimensions results in multi-faceted positive changes in soil in terms of physical, chemical and biological factors which results in an enhanced microbial community development which further results in a better plant-soil-microbe interaction at micro and macro levels due to better crop growth, soil health, nutrient cycling and resource use efficiency. Thus, it can be a one-stop solution for enriching soil in terms of microbes thus increasing soil health and resilience.

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