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Effects of intensive agricultural management practices on soil biodiversity and implications for ecosystem functioning: A review

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Abstract
Agricultural intensification often leads to environmental disruptions that can significantly alter soil biodiversity, impacting ecosystem functions; however, the links between these effects are not well understood. Agricultural intensification refers to the intensified use of agricultural resources, generally by shifting from intermittent to continuous cultivation on the same land. The degree of intensification can be calculated as I=L×N×P×E×W, where I is intensification, L is land-use diversity, N is nutrient use, P is pest management, E represents energy input, and W stands for water management, all scaled from 0 to 1. Microbial diversity in soil exists at three levels: genetic, species, and ecological. Assessing how agricultural practices impact these functions often involves using performance-based indices. Research has shown that intensive farming practices can negatively affect microbial diversity. For instance, fertilization alone does not always significantly alter microbial populations, but combining fertilizers with organic manure can lead to higher yields and increased greenhouse gas emissions. In monocropping systems, reduced microbial diversity has been linked to poorer soil structure and organic carbon content. Fungal populations are particularly sensitive to tillage practices, with no-tillage systems fostering greater fungal abundance compared to conventional tillage. Furthermore, studies suggest that soil biodiversity declines with higher pesticide use and intensified land use. Consequently, sustainable agricultural practices that balance productivity with environmental health are necessary to maintain soil biodiversity and ecosystem functions.

Keywords: Intensification, ecosystem, microbial community, soil biodiversity

1. Introduction
Environmental perturbations caused by agricultural intensification may alter soil biodiversity in a manner that affects ecosystem functioning, but links are not well quantified (de Graaff *et al*., 2019) [2]. Agricultural intensification is a set of patterns of land-use change with the common feature of increased use of the same resources for agricultural production, usually because of a switch from intermittent to continuous cultivation of the same area of land. Land is shrinking and population is increasing day by day, so there is huge demand for food. To satisfy the demand, intensification of agriculture has been taking place mostly after green revolution in India in the forms of monoculture, tillage, high disturbance of soil, residue burning, imbalanced fertilizer application, excessive pesticide usage etc. All these affect soil biodiversity i.e. it causes species imbalance, while some groups increase in number, some are eliminated. This is our great concern as we know soil biodiversity is the most vibrant and dynamic part of any ecosystem. It is not only important for crop production but also affects several functions. So as reported by de Graaff *et al*. (2019) [2] it is obvious that change in soil biodiversity will also impact the agro-ecosystem functions.

1.1 Agricultural intensification and its components
Agricultural intensification is a set of patterns of land-use change with the common feature of increased use of the same resources for agricultural production, usually because of a switch from intermittent to continuous cultivation of the same area of land.

As reported by Ruthenberg (1980) [11], the degree of intensification may be estimated as: I = L X N X P X E X W Giller *et al*. (1997) [4] Needs and challenges of agricultural intensification 3 where, all on a 0-1 scale, I is intensification, L is land-use intensity, N is nutrient use (0 for completely internal recycling, 1 for completely external manure/fertilizer inputs), P is pest management (0 for no intervention, 1 for full mechanical/chemical control), E is the energy input per hectare (whether based on labour or fossil fuel and it results from increased tillage, cropping intensity, irrigation), and W is water management (0 for no intervention, 1 for completely controlled irrigation and/or drainage). As a certain value of I can be obtained by various combinations of L, N, P, E and W this definition embraces the potential for management options with similar degrees of intensification which are favourable for soil biodiversity. Due to intensification of agriculture in India, fertilizer and pesticide consumption, sale of tractors, net irrigated area are increasing at a great rate from 1950 onwards.

1.2 Soil Biodiversity

Soil biodiversity is generally defined as the variability of living organisms in soil and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (UNEP (1992)). Soil biodiversity is mainly of three types-genetic, species and ecological diversity. Genetic diversity is the amount and distribution of genetic information within species. Species diversity is the Number and abundance of species within microbial community and ecological diversity is Number and abundance of habitats of biotic communities within which diverse organism live and evolve (Nannipieri *et al*. (2017)) [10]. There are mainly two components of species richness and species evenness. Species richness: Species richness is the number of different species present in an ecological community, landscape or region or number of species per sample. It is simply a count of species, and it does not consider the abundances of the species or their relative abundance distributions. Species evenness: It indicates relative abundances of the various species in a particular area that means it indicate numbers of organisms are being present with in a particular species. Species evenness increases as species are more evenly distributed in a sample and maximum evenness is obtained when all the species are equally abundant.

1.2.1 Method of measurement of microbial diversity

1.2.1.1 Culture-dependent methods

1.2.1.1.1 Dilution plating and culturing methods: Traditionally, the analysis of soil microbial communities has relied on culturing techniques using a variety of culture media designed to maximize the recovery of different microbial species. It has been estimated that less than 0.1% of the microorganisms found in typical agricultural soils are culturable using current culture media formulations.

1.2.1.1.2 Community-level physiological profiles: One of the most widely used culture-dependent methods for analyzing soil microbial communities is community-level physiological profiles. Carbon source utilization patterns of soil microbial communities are called community level physiological profiling. This BIOLOG system contains 96 wells that are fill up based on with 95 different carbon sources (one is control) which is utilized by different groups of microorganisms in different pattern. This utilization pattern of each substrate is detected by the reduction of a tetrazolium dye, which results in a colour change that can be quantified spectrophotometrically at 590 nanometers. The pattern of substrates that are oxidized can be compared among different soil samples from a series of times or locations as an indication of differences in the physiological functions of microbial communities.

1.2.2.2 Culture-independent methods

Because of the inherent limitations of culture-based methods, soil microbial ecologists are turning increasingly to culture-independent methods of community analysis. This technique based on-

a) The extraction of nucleic acid (DNA or RNA) from the soil sample by either direct or indirect method
b) Amplification of that extracted nucleic acid by polymerized chain reaction
c) Identification and quantification of molecules that are specific to certain microorganisms or microbial groups
d) There are several culture independence techniques that is are widely used for measurement of microbial diversity like- Direct count method, Denaturing/ Temperature gradient gel electrophoresis (DGGE/TGGE), Phospholipid fatty acid (PLFA) analysis, Phylogenetic analysis

1.2.2.2.1 Direct count method: This method is based on staining of nucleic acid and proteins of microbial cells with some specific dye followed by counted directly with the help of fluorescence microscope. The dye used for identification of bacteria in agar film are included fluorescein isothiocyanate (FITC), acridine orange (AO), ethidium bromide (EB) and europium chelate with a fluorescent brightener differential stain (DFS) for bacteria whereas stains for active bacterial cells include FDA or redox probes such as 2-(p- iodophenyl)-3-(p-nitrophenyl)-5-phenyl tetrazolium chloride (INT) or 5-cyano-2,3- ditoyl tetrazolium chloride (CTC)**.** Phenol aniline blue (PAB) has been used to stain hyphae in agar films and on membrane filters**.** Direct counting by fluorescence microscopy can give 100–1000 times more than the numbers obtained by plate counting.

1.2.2.2.2 Denaturing/ Temperature gradient gel electrophoresis (DGGE/TGGE): Denaturing gradient gel electrophoresis (DGGE) or temperature gradient gel electrophoresis (TGGE) are the most useful method for characterizing bacterial communities in environments such as hydrothermal vents, hot springs, activated sludge, phyllosphere, biodegraded wall paintings etc. This method is based on the melting behaviour of the double stranded DNA molecule. It remains double-stranded until it reaches the denaturant concentration or temperature that melts the double-stranded molecule. As the DNA melts, it branches, thus reducing the mobility in the gel. In this method, 1st DNA molecules are extracted from the soil by both direct and indirect method. DNA fragments are amplified with help of polymerized chain reaction**.** DNA molecules are electrophoresed in an increasing gradient of chemical denaturant (DGGE) or in an increasing temperature gradient (TGGE) until double stand of DNA molecule is melt**.** Since the melting behaviour is largely dictated by the nucleotide sequence, the separation will resolve individual bands.

1.2.2.2.3 Phospholipid fatty acid (PLFA) analysis: Another approach used to overcome the problem of selective culturing for assessing the structure of soil microbial communities and determining gross changes that occurred due to soil disturbances such as cropping practices, fumigation etc. is phospholipid fatty acid (PLFA) analysis.

This technique is based on the extraction, fractionation, methylation, and chromatography of the phospholipid component of soil lipids. Phospholipid fatty acids are potentially useful signature molecules due to their presence in all living cells particularly in cell membranes and not in other parts of the cell as storage products. This is important because cell membranes are rapidly degraded and the component phospholipid fatty acids are rapidly metabolized following cell death. That is why it can serve as important indicators of active microbial biomass. The presence and abundance of these signature fatty acids in soil reveals the presence and abundance of organisms or groups of organisms in which those signatures can be found.

2. Soil biodiversity under different intensive agricultural practices

2.1 Nutrient management effects on soil biodiversity: In intensive agriculture system, imbalanced and high dose of mineral fertilizer affects soil biodiversity and consequently changes ecosystem functioning. If high dose of fertilizer is added, nutrient is more in available form. So, microorganisms get high amount of available nutrient, so there is reduced enzyme activity in soil which ultimately leads to diminished biological potential of soil. Again, excessive use of fertilizer causes species imbalance and changes community structure (Mc Laughlin *et al*. 1995) [9]. All these ultimately result in changing soil biodiversity. Huang *et al*. (2019) [6] reported that in long term mineral fertilizer (19 years) experiment in paddy soil, bacterial diversity has been significantly changed from control but within treatments no significant change is there. But within functional groups, with higher dose of nitrogenous fertilizer, the population of nitrogen fixing organisms has been decreased. Again, denitrifier population is more than control may be because of higher substrate concentration (NO3-) and dissolved organic carbon. This dissolved organic carbon is increased may be because plant residue and roots secrete higher amount of exudate in fertilized plots. Bhattacharyya *et al*. (2013) [1] has done similar experiment on effect of integrated nutrient management in paddy soil at CRRI, Cuttack. They also found no significant change in heterotrophic, methanogenic, ammonia oxidizer and denitrifier bacterial population within treatments.

2.2 Effect of monocropping vis-à-vis crop rotation effects on soil biodiversity: Another component of intensive agriculture is monoculture. Tiemann *et al*. (2015) [12] has mentioned that in diversified cropping, greater quantity and quality of residues entering soils enhances microbial activity and vice versa for mono cropping which results in mega- aggregate formation and stabilization. Enhanced microbial activity and concomitant increases in microbial by-products accelerates**.** micro-aggregate formation which results in erosion control and water regulation. Increasing stocks of stable soil organic carbon under high diversity cropping also help in better carbon sequestration than mono cropping. Tiemann *et al*. (2015) [12] studied different cropping systems having different crop diversity index ranging from crop diversity index 1 for monocropping and crop diversity index 15 for diversified cropping in mesic typic hapludalfs. They studied phospholipid fatty acid concentrations (nmol FAMEs g−1 soil) of the major microbial groups and found that both in micro and macro aggregate it was lesser in monocropping than diversified cropping for both bacteria and fungi. It means as compared to diversified cropping, bacterial and fungal diversity is less in macro and micro aggregate in monocropping.

2.3 Effects of tillage on soil biodiversity: Another component of intensive agriculture is intensive tillage. Mc Laughlin *et al*. (1995) [9] mentioned that intensive tillage operation causes mechanical injury which reduces the population of earthworm, eggs and larva of different arthropods. Intensive tillage reduces aggregate stability which results in increased erosion i.e. loss of topsoil and nutrient. Again, in intensive tillage, soil disturbance is more. So, crop residues are decomposed faster and consequently more carbon loss is there. So, less amount of element is available for body building of microorganisms, which changes microbial population. All these affect soil biodiversity which ultimately has great impact on ecosystem functions. Frey *et al*. (1999) [3] studied bacterial and fungal abundance in conventional (CT) and no- tillage (NT) agroecosystems. They reported that bacterial biomass carbon was significantly higher in NT compared to CT at only two sites for the 0-5 cm depth of soil while fungal biomass carbon was significantly higher in NT as compared to CT in surface soil for all the sites. They hypothesized that fungi are more influenced by tillage than bacteria in NT condition. In conventional tillage, organic matter decomposition is more and available form of nutrient is also higher, so fungi cannot compete with bacteria. But in NT, soil disturbance is less and residue remains there, so no chance of such type of competition. Again, in NT mechanical injury is not there. So fungal length is significantly higher in surface soil in NT plots as compared to conventional tilled plots. It is found that no till situation is advantageous in comparison to conventional tillage with respect to soil biodiversity and several ecosystem functions. But tillage is convenient for farmers as for easy crop establishment, weed management etc. These ill effects can be reduced considerably with residue management can be done with tillage. In this aspect Hao *et al*. (2019) [5] studied microbial community under different tillage practices and residue management. Hao *et al*. (2019) [5] studied microbial community under different tillage practices and residue management. Biolog ecoplate study was conducted and average well colour development (AWCD) was studied. From that Shannon index was calculated. The AWCD is an indicator of the carbon-source specific microbial activity in the ecoplates. The larger the AWCD is, the stronger the metabolic capacity of the soil microbial carbon sources.

2.4 Effects of land-use intensity on soil biodiversity: Another component of intensive agriculture is increased land use intensity. Land use intensity has a significant impact on the diversity and composition of bacterial and fungal communities which affect several agroecosystem functions. Studied bacterial and fungal diversity in different land use-intensity in anthrosol. The gradient of management intensity was based on abandoned fields, long-term abandoned fields (abandoned for 26-29 years, low), three distinct medium term abandoned fields (16 -23 years, med) and three distinct short term abandoned fields (6 -9 years, high). Land use intensity had a significant impact on the diversity and composition of bacterial and fungal communities. In the study different gradients of land use intensity made it possible to link land use intensity with microbial diversity. Interestingly, no simple decrease in soil microbial diversity (i.e. richness and 1/D) with increasing land use intensity was observed. Instead, the general trend observed for both bacterial and fungal communities, was an increase in diversity (i.e. richness and 1/D) under medium land use intensity, as compared to low- and high-intensities (D = Simpson index). This finding suggests that the hump-back model, describing the response of a community to stress, may also be applied to the microbial

response to perturbations associated with land management intensity. According to this model, a decrease in apparent diversity may occur (i) in highly stressed environment due to dominance of particularly competitive species through competitive exclusion, and (ii) in highly unstressed environment due to the dominance of particularly adapted species through selection. Contrastingly, moderate stress may increase apparent diversity by lowering the likelihood of competitive exclusion and the selection mechanism. In the study, this suggests that increasing land management intensity in agroecosystems may not necessarily have a negative, linear impact on soil microbial diversity, but may instead enable an optimum i.e. optimum was reached for both bacteria and fungi at medium intensity land use.

2.5 Effects of pesticides on soil biodiversity: In intensive agriculture, pesticide is used indiscriminately to control pest. Pesticides form one of two three pillars of green revolution, the other two being new and rapidly replaced seed varieties, and high fertilizer inputs. Pesticides, which comprise insecticides, herbicides, fungicides and others, are designed to kill something somewhere McLaughlin *et al*. (1995) [9] reported that pesticides are mostly non selective in nature and has immense negative impact on non- target species. Again, drift hazard is great concern of dust formulation of pesticides which reduce diversity and abundance of arthropods and others. Toxicity of pesticides kills different soil organisms altogether biodiversity. The modern biotechnological tools are nowadays more frequently being used to study the soil microbiological diversity. In this connection, Zhang *et al*. (2016) [14] reported that bacterial 16S rRNA gene abundances were significantly lower in the plots where higher dose of pesticide was applied (almost 5 times of recommended dose) than the plots where lower dose of pesticide was applied and control plots.

3. Future Studies

More study is needed to quantify agricultural intensification, soil-biodiversity and agro- ecosystem functions. Mechanistic understanding of the links between agricultural intensification, loss of soil biodiversity, and ecosystem functioning requires more targeted approaches. For example, selective removal of (groups of) soil organisms known to be affected by agricultural intensification could be combined with measurements of ecosystem functioning and monitoring of soil biodiversity. This will be helpful in predictions of the agroecosystem functions in response to change in soil biodiversity due to agricultural intensification and other environmental perturbations. It will help the researchers to work on different aspects that leads to refinement of intensive agriculture practice.

4. Conclusion

Due to shrinkage of land and ever-increasing population intensive agriculture is unavoidable. But in absence of proper management practice, in many cases, biodiversity is influenced negatively in intensive agriculture, which subsequently adversely affects different agro- ecosystem functions. So, the need of the hour is to refine intensive agriculture. For e.g. instead of using only high dose of synthetic fertilizers, integrated nutrient management practice can be adapted, instead of rice monoculture we can go for higher cropping diversity where legumes are included in cropping sequence. Again, intercropping and rotation to reduce pesticide use, assessment of the severity of pest species competition prior to pesticide use, proper residue management and incorporation may successfully benefit agriculture Thus with many such different management practices intensive agriculture can be refined in such a way that it becomes sustainable and eco-friendly and at the same time will be able to feed the ever-increasing population.

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