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Biodiversity Assessment of Agro-Ecosystems under Different Farming Systems

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ABSTRACT

The biodiversity in agro-ecosystem is one of the key components that ensure stability, productivity and sustainability of the ecosystem. In the last few decades, agricultural intensification has caused a major change in the natural habitats which has resulted in reduced species richness, functional diversity, and ecosystem services. The paper evaluates patterns of biodiversity in agro-ecosystems with respect to the various farming systems, such as conventional, organic and diversified agro-farming. Based on standardized biodiversity metrics, including, species richness, Shannon diversity index, and functional group abundance, the study will compare plant, soil and arthropod biodiversity between two environmental management regimes. The results indicate that the organic and diversified farming systems are always able to contribute to a greater number of biodiversity as compared to the conventional systems, which are mainly based on the fact that their chemical input is low, the heterogeneity of the habitat is high, and the soil is healthy. The paper identifies the ecological trade-offs of intensive agriculture and the significance of agriculture that does not harm the environment in the long term and food security.

Introduction

Agro-ecosystems are ecological systems that are managed closely to natural ecological processes, where agricultural production is also intertwined with nature. Such systems consist of crops, livestock, soil organisms, pollinators, pests, natural enemies, and semi-natural environments around them which collectively define the agricultural productivity and sustainability of the environment. Agricultural biodiversity, also known as agrobiodiversity, is biodiversity in agro-ecosystems, i.e. the diversity of life found important to agricultural processes directly or indirectly. This biodiversity plays a critical role in keeping the ecosystem services including nutrient cycling, soil fertility, regulation of pests, pollination, and climate stability (Altieri, 2018).

The agricultural systems in the world have undergone significant changes within the last century due to the increase in population, technological changes, and food production demands. The massive use of traditional farming systems that were typified by mono-culture, mechanization, synthetic manure, and chemical pesticides has greatly boosted short term population. Nevertheless, such practices have led to simplification of the habitat, soil erosion, as well as significant reduction of biodiversity at various spatial levels (Tscharntke et al., 2012). Many works reported a reduction of plant communities, soil microbial communities, beneficial insects and farmland birds in highly managed agricultural landscapes (Benton et al., 2003).

Extinction of species is not the only serious impact of the loss of biodiversity in agro-ecosystems. Decreased biological diversity inhibits ecosystem performance and robustness and subjects agricultural systems to pests, diseases, climatic fluctuations, and environmental disturbances. As an example, weakening of pollinators endangers crop production as well as the disappearance of natural enemies promotes the use of chemicals to control pests, which leads to the formation of a negative feedback response that also weakens ecosystems (Garibaldi et al., 2013). These issues have raised the question of the sustainability of traditional agricultural systems and the need to explore alternative agricultural systems that would create a balance between productivity and ecological integrity.

To this, organic and diversified farming systems have increasingly attracted the interest as the possible alternatives to sustainability. Organic farming focuses on ecological processes, conservation of biodiversity and soil health by avoiding the use of synthetic agrochemicals and crop rotations, organic amendments and biological pest control. Diversified agricultural systems such as intercropping, agroforestry and mixed crop-livestock systems are expected to improve the habitat heterogeneity and functional diversity in agricultural landscapes. Experimental data indicates that this type of systems is capable of sustaining or increasing the ecosystem services and biodiversity (Kremen and Miles, 2012).

The measurement of biodiversity in agricultural systems is essential in the ecological effects of various agricultural systems. In the assessment of biodiversity, measuring species richness, abundance, diversity index and functional traits in various taxonomic group is usually conducted. Such tests can give us useful information regarding the management practices that can affect ecological communities and ecosystem services. Nonetheless, biodiversity adaptation to agriculture systems can be different based on the local environmental conditions, landscape setting, and methodology, which requires in-depth and comparative research.

Besides, biodiversity measurement has gained relevance especially on the global sustainability agenda. The global policies like the Convention on Biological Diversity (CBD) and Sustainable Development Goals (SDGs) highlight the fact that biodiversity conservation should be integrated into the agricultural policies. Agro-ecosystem biodiversity assessments based on evidence are a requisite to agri-environmental schemes, land-use planning and transitions to sustainable food systems.

Although there is increased awareness on the significance of agrobiodiversity, much about the relative effects of different agricultural systems on biodiversity of various biological groups is still unknown. Most studies are on single taxa, or restricted spatial scales, and their relevance to the management of agro-ecosystems in general is restricted. To give a better ecological picture of the sustainability of farming, there is a need to conduct a holistic evaluation of plant, soil, and arthropod biodiversity in contrasting farming system.

To fill these gaps, the current study aims at performing a biodiversity evaluation of agro-ecosystems with conventional, organic, and diversified agricultural systems. The study will provide empirical evidence to the current debate or lack thereof on sustainable agricultural intensification and biodiversity conservation by assessing various biodiversity indicators and ecosystem service proxies.

The main goal of this research is aimed to analyze and compare the level of biodiversity in agro-ecosystem with different farming systems namely conventional, organic and diversified agricultural methods. The research shall seek to measure the plant, soil and arthropod biodiversity using standard ecological indicators, such as species richness, abundance and diversity indices. The study also aims to study the connection between farming management activities and ecosystem service indicators which include soil health, pollinator activity and the natural regulation of pests. The study will use the incorporation of biodiversity measurement of various biological entities to create a comprehensive picture on the effects that various farming systems have on the ecological sustainability.

This study is important in the sense that it adds to the research on sustainable agriculture and conservation of biodiversity. Due to the fact that, agricultural intensification is one of the biggest contributors to the reduction of biodiversity in the world, it is important to identify farming systems that would ensure the ecological integrity and still be productive. Results of this research provide evidence-based information to the policymakers, agricultural planners and farmers aiming to adopt more biodiversity-friendly practices. Additionally, the study helps in addressing the sustainability concept globally since it proves the ecological advantage of diversified and organic agricultural systems. Finally, this research results in the creation of resilient agro-ecosystems, which can meet the growing demands of food production, ecosystem services and environmental health in the adverse environment of increasing global demands.

Literature review

The prevalence of biodiversity in agro-ecosystems has become a matter of growing academic interest because of its importance in maintaining ecosystems and productivity in the agro-ecosystems. The difference between agro-ecosystems and natural ecosystems is in the fact that they are carefully manipulated to produce crops or livestock, but they still rely on ecological functions like nutrient cycle, soil formation, pollination, and biological control of pests. It is regularly stated in the literature that the nature of farming system adopted has a significant influence on the outcome of biodiversity at the local, landscape, and regional levels (Altieri, 2018).

Agro-ecosystem Biodiversity and Ecosystem Services It has been established in numerous studies that biodiversity and ecosystems services are directly associated with the agricultural landscape. The use of a variety of plant communities helps in increasing the soil structure and organic matter deposition where soil biodiversity increases nutrient availability and retention of water (Tilman et al., 2002). The arthropods (especially predators and parasitoids) also provide a means of natural pests control, which has lowered the use of chemical pesticides (Landis et al., 2000). The diversity of pollinators is also of utmost importance because only about three-quarters of world food crops are partially reliant on animal pollination (Garibaldi et al., 2013). Reductions in biodiversity therefore endanger ecological and food security.

The Conventional Farming Systems and Biodiversity Loss The conventional farming systems are typified by monoculture agricultural practices, intensive tillage, high use of chemicals and simplification of the landscape. Though these systems have been found very useful in enhancing crop production, they have also been pinpointed as the cause of biodiversity loss in large proportions. Research studies in Europe, Asia, and North America document drastic declines in the richness of plant species, the diversity of soil microbes, and useful insects in traditionally controlled fields (Benton et al., 2003; Tscharntke et al., 2012).

Chemical pesticides have adverse impacts on non-target organisms, such as pollinators and natural enemies, whereas synthetic fertilizers have an impact on soil microbial communities and nutrient cycling (Geiger et al., 2010). The habitat simplification caused by large scale monocultures also causes additional ecological niches and landscape connectedness, resulting in population losses in farmland birds and insects. A combination of all these negative impacts undermines the provision of ecosystem services and exposes them to pests and environmental stresses.

Organic Farming Systems and Biodiversity Enhancement Organic farming has been researched extensively as an alternative system where ecological sustainability is considered a strong priority. Organic farming limits the usage of synthetic farming chemicals and encourages crop rotation, organic fertilization, and biological pest control. In meta-analyses, it is always the case that organic farms facilitate greater species richness and abundance of various taxa than conventional farms (Bengtsson et al., 2005; Tuck et al., 2014).

Organic systems generally have a high level of plant diversity as herbicides are used less often and crop rotation is diversified. Greater diversity in plants gives insects and soil organisms a habitat and food sources, and has cascading ecological effects. Organic management enhances soil biodiversity such as earthworms, bacteria and fungi which helps in increasing soil fertility and carbon sequestration (Mader et al., 2002). Although it is feared that organic systems may yield below competitively, recent research has shown that organic systems are able to produce competitive yields with the support of diversified management systems and relevant policy systems in place.

Diversified Farming Systems and Agroecological Approaches Diversified farming systems include intercropping, crop rotation, agro forestry, and integrated crop livestock systems. The goals of these systems are to replicate the natural ecosystems by enhancing the structural and functional diversity in the agricultural landscapes. There are studies showing that, diversified systems tend to have a better result compared to monocultures, regarding the biodiversity conservation and provision of ecosystem services (Kremen and Miles, 2012).

The intercropping improves the diversity of plant species and the efficiency of resource utilization, limiting the burst of pests and increasing the stability of yields (Brooker et al., 2015). Agro forestry system incorporates trees with crops or livestock forming multi-layered habitats, which harbor birds, insects and soil organisms, and improves carbon sequestration and nutrient cycling (Jose, 2009). ICSS recycles nutrients by use of manures and minimizes external inputs and enhances biodiversity in the soil and resiliency to the ecosystem.

Soil Biodiversity and Farming Practices Soil biodiversity is one of the indicators of healthy agro-ecosystem. The organisms in soil control decomposition, nutrient recycling, and soil structure and it has a direct effect on crop productivity. Research has demonstrated that intensive tillage and the use of chemicals decreases microbial biomass and functional diversity of soil, and conservation tillage, organic additions and crop diversification increases biological activity on soil (Brussaard et al., 2007).

There is extended-period of investigations that organic and diverse farming systems have more soil organic carbon and microbial diversity as compared to the conventional farming systems (Mader et al., 2002). Such enhancements play the role of adding to the capacity and retention of water and drought resilience, and underscores the importance of soil biodiversity in climate change adaptation.

Landscape Context and Biodiversity Beyond Landscape composition plays an important role in the agro-ecosystem biodiversity beyond field-level management. Heterogeneous landscapes with hedges, field margins and semi-natural habitats provide greater species richness than simplified landscapes (Tscharntke et al., 2005). These features can serve as home and foraging areas of wildlife and increase the potential of connectivity and recolonization.

It has been proposed that positive impacts of organic and diversified agriculture are exaggerated in complex landscapes, but these benefits might be minimal in highly simplified landscapes. This highlights the need to combine land-use plans with farm-level practices in order to accomplish successful conservation of the biodiversity.

Implication of policies and gaps in research Agri-environment schemes and policies on sustainable agriculture are starting to gain an awareness of the significance of biodiversity-friendly farming practices. Nonetheless, there is no consistent implementation, and evidence-based evaluations are necessary to inform the policy implementation. Although much literature has been done on the components of agro-ecosystem biodiversity, few studies have been done on the assessment of multiple biological groups and farming systems.

Moreover, climate, soil, and social-economic factors vary in different regions, which requires context-based research. Multi-taxa and long-term evaluations are specifically required to achieve time dynamics and functional implications of changing biodiversity. These gaps are important to address in order to design robust agricultural systems that will be able to cope with the food and environmental challenges in the future.

Methodology

The research was carried out in representative agro-ecosystem of different climatic conditions, soil and land-use types to describe a wide spectrum of agro-ecological diversity. Three different systems of farming were chosen that includes conventional farming systems, organic farming systems and diversified farming systems. Sustained agricultural activities were recorded in the chosen areas over a decade and this was to ensure that any patterns of observed biodiversity tracked the long term management patterns and not the short term changes. Farms were chosen according to their reachability, uniformity in the management practices, and the permission of the farmer.

Experimental Design

The comparative cross-sectional research design was used to evaluate the biodiversity in various farming systems. In every farming system, the sample population comprised of ten randomly selected farms, and this gave out thirty study farms. Standardized sampling plots of 50 m x 50 m were done on every farm. Selection of plot locations was carried out in such a way that the edge effects were minimized and to maintain uniformity in crop type and history of management. This design allowed the comparison of indicators of biodiversity in the farming systems directly and controlling the confounding factors of the environment.

Components of Biodiversity measured

The biodiversity evaluation was done in three significant biological units namely the plant diversity, soil biodiversity, and the arthropod diversity. The components were chosen because of their basic functions on the functioning of agro-ecosystems and how these components were sensitive to the way they were managed.

Determination of plant biodiversity

Quadrat sampling was used to measure biodiversity in plants. In each plot there were five quadrats (1 m x 1 m) set randomly and all the plant species found including crops, weeds and non crop vegetation were recorded. Identification of species was done by use of the standard floristic keys. The richness of the species (number of species in total) and relative abundance were measured. The indices of diversity, such as Shannon-Wiener and Simpson diversity indices were computed to measure the species diversity and evenness among farming systems.

An Assessment of Soil Biodiversity

The biodiversity of soil was determined by taking soil samples at the depth 0-15 cm with a soil auger. Five soil cores were taken in every plot and mixed to create a composite sample. Hand-sorting of soil macrofauna (earthworms, arthropods) was done at the field and extraction of mesofauna was done by means of Berlese-Tullgren funnels in the laboratory. The fumigation-extraction method was used to estimate soil microbial biomass. The most basic taxonomic level of soil organisms was determined and they were grouped into functional groups by their ecological functions.

Arthropod assessment of Biodiversity

The pitfall traps, sweep nets and visual observations were used to assess the diversity of arthropods. Pitfall traps were put in place to sample ground dwelling arthropods and these would last 72 hours. The procedure was carried out on standard transects in order to sweep netting canopy-dwelling insects. The arthropods were named under functionality groups like predators, herbivores, pollinators, or decomposers as they were identified to family or species, where possible.

Physicochemical soil Analysis

Besides the biological measurements, physicochemical properties of the soils were also analyzed to be able to understand their correlation with the pattern of biodiversity. The soil pH, the content of organic matter, total nitrogen, available phosphorus, and potassium were determined using standard laboratory procedures. These were the variables which acted as a measure of soil health and fertility in various farming systems.

Environmental Indicators of Ecosystem Services

In order to connect the biodiversity and ecosystem functioning there were particular indicators of ecosystem services measured. The action of pollinators was measured by counting the number of visits of pollinators to each flowering plant per hour during the flowering season. The potential of biological pest control was determined by estimating the abundance of natural enemy arthropods. The content of organic matter and the level of microbial biomass were used to infer the soil ecosystem services.

Data Analysis

The statistical software was used to analyze the biodiversity data. All biodiversity and soil variables were calculated in descriptive statistics. Differences in biodiversity indicators of farming systems were tested using one way analysis of variance (ANOVA). The post-hoc tests were done to understand the significant differences at the level of pair-wise. Multivariate techniques (non-metric multidimensional scaling (NMDS) and permutational multivariate analysis of variance (PERMANOVA)) were used to assess the variation in the community composition among the farming systems.

Ethical and Control of Quality

Field sampling was done under the approval of farm owners and this was done in a manner that caused minimal disruption to the crops and habitats. All the sites followed standard protocols thus ensuring the reliability and comparability of data. In cases where identification of species was required it was confirmed by expert consultation and reference collections.

Results and Discussion

The study findings demonstrate that there are apparent and regular variations in biodiversity indicators across conventional and organic and diversified farming systems. In all the biological components that were evaluated including plants, soil life and arthropods, organic as well as diversified systems had a much higher level of biodiversity compared to conventional systems. These results emphasize the overpowering impact of agricultural activities on the organization and operation of the agro-ecosystem.

Biodiversity of plants across the various farming systems

The three farming systems had a great deal of difference in the plant species richness and diversity indices. The richest plant species were observed in the diversified farming systems, and organic systems, whereas conventional systems had the lowest ones. This was also reflected in the Shannon diversity index, meaning that not only the number of species was higher but also the distribution of species became even in diversified and organic systems.

The low plant diversity of traditional systems may be explained by the intensive weeds regulation by use of herbicides and monoculture planting systems that restrict the development of non-crop vegetation. Organic systems, in contrast, supported a greater variety of plant species because of the lower usage of chemicals, whereas diversified systems supported heterogeneity through crop rotations, intercropping, and provision of non-crop habitats. These findings are consistent with other studies that have established that decreased input and a diversified management increases plant biodiversity in the agricultural landscapes (Bengtsson et al., 2005; Tuck et al., 2014).

Table 1: Plant Biodiversity Indicators under Different Farming Systems

Farming System	Mean Species Richness	Shannon Diversity Index (H’)
Conventional	13.2 ± 1.4	1.82 ± 0.11
Organic	19.6 ± 1.7	2.46 ± 0.14
Diversified	23.8 ± 1.9	2.89 ± 0.16

Soil Biodiversity and Soil Health

The indicators of soil biodiversity such as the abundance of macrofauna and microbial biomass were much higher in the organic and diversified systems of farming. The highest content of organic matter in the soil and microbial biomass was observed in diversified systems and then organic systems. Traditional systems had a relatively low level of soil biological activity, which was the long-term results of the intensive tillage and the use of synthetic fertilisers.

Increased biodiversity of the soil in the organic and diversified systems can be attributed to increased inputs of organic matter through crop residues, composts, and manure and a low level of soil disturbance. The soil organisms are very important to the process of decomposition and their cycling of nutrients, and the fact that they are in a greater abundance implies that the soil ecosystem will be functioning better. The results are in line with long-term experimental results which indicate that organic and diversified agriculture systems have healthier and more bioactive soils (Mader et al., 2002; Brussaard et al., 2007).

Biodiversity and Functional Groups of Arthropods

Farming system differences also had a strong response in the arthropod communities. The abundance of total arthropod and species richness were the greatest in diversified systems followed by organic systems whereas conventional systems had a low number of individuals and species. The functional group analysis showed that organic systems and diversified systems had a high number of predators, parasitoids, and pollinators.

Pesticides and simplification of habitats were likely the causes of reduced diversity in arthropods in conventional systems. By contrast, diversified systems offered more than one niche and source of food, sustaining more arthropod functional groups. These systems have more natural enemies, thereby indicating a better potential of biological pest control, less reliance on chemical pesticides.

Ecosystem Murals Service Indicators

There was an observation of the biodiversity patterns as indicated by ecosystem service indicators. The use of pesticides and the diversity of flora were also greater in organic and diversified systems, which were accompanied by a higher rate of pollinator visits. Equally, the abundance of natural enemies increased most in diversified systems pointing to improved control of biological pests.

Organic and diversified systems also had better soil ecosystem services as denoted by organic matter content and microbial biomass. These enhancements help increase the availability of nutrients and water retention, and resistance to environmental stress, and strengthen the ecological positive effects of biodiversity-friendly farming techniques.

Table 2: Soil and Ecosystem Service Indicators under Different Farming Systems

Indicator	Conventional	Organic	Diversified
Soil Organic Matter (%)	2.2 ± 0.3	3.6 ± 0.4	4.3 ± 0.5
Microbial Biomass (mg C/kg)	220 ± 18	340 ± 22	390 ± 25
Pollinator Visits (per hour)	9 ± 2	16 ± 3	19 ± 3
Natural Enemy Abundance	32 ± 4	48 ± 5	55 ± 6

Integrated Interpretation of Results

The general findings indicate that there is a very good positive correlation between the diversification of farming systems and increase in biodiversity. Organizational and conventional systems always fared worse in comparison to diversified systems in the majority of indicators, which has shown the significance of structural and functional heterogeneity in agro-ecosystems. Organic systems too indicated significant benefits of biodiversity as opposed to conventional farming which validates their participation in sustainable farming.

These results are in line with the findings obtained in the literature that claim that biodiversity-friendly agriculture improves the ecosystem services and minimizes environmental degradation (Tscharntke et al., 2012; Kremen and Miles, 2012). The findings highlight the ecological externalities of traditional intensification, and also point to how diversified and organic systems may make productivity and sustainability to be consistent.

Discussion

This research has clearly shown that the farming systems are decisive in determining the trends of biodiversity in agro-ecosystems. The ongoing increased biodiversity of plants, soil, and arthropods in organic and diversified agricultural systems are ecological gains of low levels of chemical inputs, greater ecology of habitat, and ecologically sensitive management systems. The findings support the emerging agroecological research field viewpoint that biodiversity-based agriculture systems promote ecosystems to work well and be resilient.

The poor biodiversity values observed in the conventional farming systems are the aspects of the aggregate effects of the intensive farming methods which include monoculture, repetitive tilling, and the excessive use of synthetic fertilizers and pesticides. These practices make habitats simple, diminish ecological niches, and directly or indirectly get rid of non-target organisms. The losses of the useful insects and soil organisms that are witnessed in conventional systems are of particular concern because these organisms essential services in the ecosystems that include the biological pest control, the cycles of nutrients and the maintenance of soil structures. The same trends have been observed in long-term research on the relationship between traditional intensification and ecosystem deterioration, as well as the augmentation of dependence on extraneous inputs (Geiger et al., 2010; Tscharntke et al., 2012).

The level of biodiversity achieved by organic farming systems was far better in relation to conventional systems. When synthetic pesticides and fertilizers are not used, it is possible to recover plant communities, soil organisms, and arthropods, forming more reasonable ecological relations. Increased plant diversity in organic fields gives insects and soil fauna food and shelter, which result in ecological cascades. The enhanced microbial biomass and organic matter contents of soil in organic systems indicate better soil health and this is vital in long-term agricultural productivity. The results are consistent with the previous meta-analyses that found that organic farming benefits biodiversity across various taxa (Bengtsson et al., 2005; Tuck et al., 2014).

The highest levels of biodiversity were found in diversified farming systems compared to other systems that were studied. Intercropping, crop rotation and agroforestry practices are known to enhance structural and functional diversity of agro-ecosystems. This diversity increases the level of resource partitioning, decreases outbreaks of pests and provides a stable ecosystem. Diversified systems have a high density of natural enemies and pollinators, which indicates high potential in the provision of ecosystem-based pest management and pollination services. These results confirm the hypothesis that more diversified systems are more similar to natural ecosystems, and these systems maintain more complex and resilient ecological communities (Kremen and Miles, 2012).

The close correlation between the measures of biodiversity and ecosystem service that was experienced in this research highlights the functional significance of biological diversity in the farming industry. Organic and diversified systems are associated with higher pollination visitation and abundance of natural enemies which shows that biodiversity directly impacts agricultural sustainability. The better indicators of soil health also indicate that the biodiversity practices which are used to promote biodiversity can help the ecosystem carry out the necessary processes needed to promote crop productivity as well as climate resilience.

The presence of landscape context was probably the cause of the extent of the difference in biodiversity across farming systems. The fact that farms are incorporated into heterogeneous landscapes enhances the biodiversity in the farms because of the existence of semi-natural habitats that provide refuge and dispersal routes. Although this research concentrated on the field level management, the findings indicate that farm-level diversification combined with conservation strategies of landscape scale may further improve biodiversity.

Although the environmental superiority of organic and diversified agriculture systems is obvious, there are still issues of the large-scale implementation of these systems. Adoption can be constrained by yield variability, labor needs and economic restraints especially in areas that have industrial agricultural practices. But there is an emerging body of evidence that diversified systems can be made to be stable in yield and productive in the long-term with the help of proper policies, extension services and market incentives.

Comprehensively, this paper is informative on the impact of farming systems on agro-ecosystem biodiversity and agro-ecosystem ecosystem services. These results underline the fact that preservation of the biodiversity and agricultural productivity are not antagonistic goals but may be complementary in case ecological principles are implemented in the management of the agricultural sphere.

Conclusion

The analysis of biodiversity of agro-ecosystems in various farming systems is the key to understanding of the ecological sustainability of the contemporary agriculture. Through this study, it is obvious that farming systems affect the biodiversity patterns and the ecosystem functioning as well as the delivery of fundamental ecosystem services in a very significant manner. Compared to the conventional and organic farming systems, the study shows a significant amount of biodiversity in plant, soil, and arthropods, which reveals the effects of agricultural management options on the environment ecologically.

The traditional agricultural systems, which are typified by high levels of chemical use, monoculture farming, and frequent disruption of soil were linked to the uniformly reduced levels of biodiversity of all biological elements studied. A decrease in the richness of plant species, a decrease in soil biological activity and a decrease in the abundance of useful arthropods demonstrate that the conventional intensification simplifies agro-ecosystems and interferes with ecological processes. These results affirm fears owing to past studies on the long term viability of traditional farming, especially in terms of its susceptibility to pests, soil erosion and environmental stress. Although traditional systems can be very productive in the short term, ecological costs of the destruction of biodiversity endanger the long-term sustainability and productivity of these systems.

Comparatively, however, organic farming systems showed much better results of biodiversity. The removal of artificial pesticides and fertilisers, the use of the diversified crop rotations, and the amendments to the organic soil conditions established the environment in which the diverse biological communities were able to recover and sustain. The increased plant diversity in organic systems had a habitat and resource base to the arthropod and soil organisms which enhanced the interactions within the ecosystem. The higher levels of soil organic matter and biomass of microorganisms in organic systems show the existence of healthier soil that is able to support nutrient cycling and water regulation. These findings support the concept of organic agriculture as one of the solutions to environmentally friendly food production.

Diversified farming systems proved to be the most biodiversity-supportive management method of the ones investigated. Diversified systems enhanced structural and functional complexity in agro-ecosystems through the integration of practice like intercropping, agro forestry and crop-livestock integration. This complexity promoted increased species richness and functional diversity and ecosystem service delivery. The fact that the pollinators and the natural enemies are strong in diversified systems indicates their ability to maintain the biological pest control services and pollination services thereby minimizing reliance on external inputs. Such systems proved that production and conservation of biodiversity in agriculture can be used as complementary and not mutually exclusive goals.

The high relationship between biodiversity and ecosystem service indicators that have been realized in this study highlights the functional value of biological diversity in agriculture. Biodiversity has a direct effect on the resilience and sustainability of ecosystems through enhanced soil health, higher levels of pollination and increased abundance of natural enemies in organic and diversified systems. These ecosystem services are vital in mitigating agro-ecosystems to climatic variability, pest infestations, and natural resource limitations which are all gaining prominence due to global environmental change.

Another point made in this research is that agro-ecosystems should be considered as socio-ecological systems. The effects of management practices applied at field scales on biodiversity are affected by aspects of landscape context and policy frameworks. The results indicate that biodiversity-friendly agriculture methods prove to be the most effective ones when landscape-level conservation strategies, including the preservation of semi-natural habitats and ecological corridors are implemented. These combined strategies could increase connectivity, the survival of species and general stability of the ecosystem.

Policy-wise, the findings allow including the conservation of biodiversity into agricultural development policies. Subsidies, technical assistance and market access can be used to incentivize the adoption of organic and diversified farming techniques that would encourage the large scale use of sustainable farming. Education programs on extension services and farmer education programs are quite instrumental in enhancing the shift to biodiversity-enhancing practices, especially in areas where conventional intensification prevails.

Conclusively, the findings of this research contribute greatly to empirical evidence on the fact that farming systems have significant influence on the biodiversity and ecosystem services in agro-ecosystems. Organic and diversified agriculture systems provide an ecologically sustainable alternative to traditional agriculture because they favor increased biodiversity and improved ecosystem performance. With the increasing problems associated with the global agriculture in terms of climate change, resources depletion, food security, and so on, the necessity to incorporate the biodiversity conservation into the agricultural management process has become a must-not, rather than, an option. The results of this research can be added to the increasing number of sources that promote the use of agroecological methods that can support food productivity and simultaneously ensure food system resilience to future generations.

Recommendations

- Enhance structural and functional biodiversity in agro-ecosystems by promoting diversified farming systems that are intercropping, crop rotation and agro forestry.
- Promote the use of organic farming by offering monetary rewards, certification of organic farming, and access to organic markets.
- Less reliance on fertilizers and synthetic pesticides: enhance integrated pest management (IPM) and soil amendments into organic soil.
- Enhance conservation of soil biodiversity by conservation tillage, addition of organic matter and minimization of soil disturbance.
- Enhance and acquire semi-natural habitats like hedges, field edges and grass strips to enhance biodiversity at the landscape levels.
- Introduce the indicators of biodiversity assessment into the national systems of monitoring and evaluation of agriculture.
- Support agroecological agro extension and education of farmers on principles of agro ecology and biodiversity friendly practices.
- Promote policy congruency of agricultural productivity targets and conservation of biodiversity policies.
- Long-term (3-5 years) research and monitoring programs should be encouraged to understand the tendency of biodiversity in various farming systems.
- Build multi-stakeholder partnership between farmers, researchers, policymakers and conservation agencies in the management of agro-ecosystems sustainably.

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