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Research Article

The Impact of Sustainable Agricultural Practices on Plant Species Diversity in Local Environments

Azhar Taher Sleibi

Al-Furat Secondary School for Distinguished Students, Directorate of Education, Baghdad, Al-Karkh, Iraq.

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ABSTRACT

Agricultural intensification can reduce plant diversity and degrade habitats, highlighting the need for farming practices that maintain ecological sustainability. This study evaluated the effects of organic, integrated sustainable and conventional farming systems on plant biodiversity and habitat condition across 15 farms (five per system). Plant diversity was assessed using the Shannon–Wiener biodiversity index, while crop rotation, plant species richness, and habitat degradation were comparatively evaluated. Organic farms exhibited the highest mean Shannon–Wiener index (2.96), followed by integrated sustainable farms (2.67), whereas conventional farms recorded the lowest value (2.36). Habitat degradation showed the opposite trend, with the highest score under conventional management (8.0) and the lowest under organic management (2.4). Organic and integrated sustainable farms also generally showed greater crop-rotation implementation and plant species richness than conventional farms. Crop rotation was strongly and positively correlated with plant biodiversity ($r = 0.87$), whereas habitat degradation showed a strong negative correlation with biodiversity ($r = -0.89$). Overall, the findings indicate that sustainable farming practices, particularly organic management, are associated with enhanced plant diversity and reduced habitat degradation. Promoting diversified rotations and minimizing habitat disturbance may therefore contribute to biodiversity conservation and more sustainable agricultural landscapes.

Corresponding Author: Azhar Taher Sleibi
Email: azhar.taher2202p@ihcoedu.uobaghdad.edu.iq

Introduction

The large-scale intensification and expansion of agriculture, driven by escalating global demand for food production, has created significant environmental issues such as loss and fragmentation of habitat, soil degradation and biodiversity loss (Altieri, 1995; BenDor et al., 2015; Anderson and Thampapillai, 2016; Brussaard et al., 2010; Bakker and Dorrepaal, 2020; Alex, 2023). The intensification of agriculture, especially monoculture cultivation and extensive and injudicious use of synthetic pesticides and fertilizers, may lead to more simplified agroecosystems, a loss of habitat complexity, deterioration of soil quality, and a negative impact on plant community structure and related ecosystem functions (Garibaldi et al., 2013; Tilman et al., 2011; Semwal, 2020; Tyagi, 2021; Talachutla, 2024). These consequences are of special significance as biodiversity is essential to the functions, stability and resilience of ecosystems and is a key component of sustaining ecological processes which are critical to agriculture productivity.

Thus, the sustainable agriculture has become one of the key approaches to reconcile agricultural production with environmental protection and food security in the long term (Gliessman, 2014; Harvey and Martínez-Ramos, 2016; Jyoti, 2022). The concept of sustainable farming systems involves seeking to sustain agricultural productivity while reducing environmental dilapidation through management practices that protect natural resources, enhance soil health, improve soil biological interactions, and preserve or reinstate biodiversity (Kashyap et al., 2023). Organic agriculture, agroforestry, crop rotation, intercropping, cover cropping, and reduced reliance on synthetic chemical inputs can create more favorable conditions for a variety of plant communities and more habitat heterogeneity. In this context, the diversity of plant species is an important ecological indicator, as variations in species richness, abundance and composition may be related to the variations in habitat quality and agroecosystem functioning.

Biodiversity refers to the diversity or variation observed at the genetic, species and ecosystem levels and is crucial for ensuring the functioning and resilience of agricultural landscapes (Meenakshi, 2018). Diverse plant communities are of particular importance as they help to cycle nutrients, stabilize soil, provide resources, create habitat and preserve ecological interactions. Increased plant diversity may also enhance pollination and natural enemies of agricultural pests and improve ecosystem services, thus lessening reliance on external agricultural inputs (Perfecto et al., 2009). Simplified agriculture with monocultures, on the other hand, tend to lessen the diversity of non-crop vegetation and its associated organisms and might thus compromise the provision of ecosystem services and enhance the resilience of agroecosystems to environmental disturbances. Therefore, the preservation of plant diversity in agricultural landscapes is not only an ecological, but a central part of sustainable and resilient food-production systems.

There is growing evidence from recent literature indicating that sustainable agriculture can have beneficial impacts on biodiversity, but this effect can be different in intensity and magnitude depending on farming systems, environmental conditions and management intensity. In a systematic review of experimental and case-study evidence, it was found that sustainable agriculture has the potential to alleviate environmental stressors, promote species diversity, and boost habitat quality, and that organic farming and agroforestry are positive options for conserving biodiversity (Cruz-López et al., 2024; Singh (2024). Likewise, Rachmaputra et al. (2017) showed that species diversity can be improved in organic farming and the population of mammals, birds and arthropods can be high especially if the appropriate habitats are preserved. Juffe-Bignoli (2025) pointed out that agricultural activities continue to pose a series of threats to biodiversity in the Mediterranean region and urged the adoption of agriculture-friendly and locally oriented conservation policies to protect biodiversity. Long-term evidence from some regenerative agricultural systems has also demonstrated that managing agricultural systems in a regenerative way can boost plant diversity, the amount of beneficial species and soil health, without necessarily reducing agricultural production (Hawes et al., 2025). These findings collectively indicate that agricultural management can influence biodiversity beyond crop production and that practices designed to improve ecological sustainability may contribute to more multifunctional agricultural landscapes.

The ecological effects of sustainable farming practices may arise through several complementary mechanisms. Crop rotation increases temporal and spatial variation in vegetation structure and resource availability and can reduce the ecological simplification associated with continuous monoculture. Cover crops provide additional vegetation, maintain soil cover, improve soil conditions, and create resources and refugia for organisms within agricultural landscapes. Evidence from field experiments and microbiological investigations has further indicated that cover-crop rotation can modify soil microbial communities and contribute to the suppression of soil-borne pests while enhancing plant defense responses (Ji et al., 2026; Liu et al., 2026). Similarly, biodiversity-oriented management practices in perennial agricultural systems, including viticulture, have been shown to promote habitat heterogeneity and improve conditions for a range of organisms, although further long-term research is needed to determine the persistence and magnitude of these effects (Marcelino, 2024). Thus, the biodiversity benefits of sustainable agriculture are unlikely to depend solely on whether a farm is categorized as sustainable; rather, they may reflect the specific combination, duration, and intensity of management practices implemented.

Although there is an expanding literature on the ecological advantages of sustainable agriculture, there are still gaps in knowledge. Much of the previous research has been carried out on a single management practice, specific taxonomic groups, or particular agroecosystems, thereby reducing the possibility of comparison of biodiversity response to contrasting farming systems. Furthermore, few quantitative studies have compared the diversity of plant species found on organic, conventional and integrated sustainable farms in a standardized way within a local environmental context. Crop rotation and cover cropping effects on plant diversity at the farm level is also poorly understood in many agricultural production systems. In addition, much of the available evidence focuses on the outcomes of general biodiversity conservation, with a lesser emphasis on measurable plant diversity indicators that can be directly applied to farm management and habitat quality assessment at the local level. Due to the influence of local environmental conditions, land-use history, and management practices on biodiversity responses to agricultural management, addressing these limitations is especially important.

Therefore, the current study aimed to quantify the relationship between sustainable agricultural management and plant species diversity in the local agricultural environment at the farm level. In particular, the study evaluates the differences in plant diversity in organic, conventional and integrated sustainable farms through the Shannon and Simpson diversity indices, as well as assesses the relationship between specific farm management practices such as cover-crop cultivation and crop rotation, and plant diversity. The study also investigates the relationship between sustainable farming practices and the frequency of plant species associated with habitat quality and the frequency of indicators of habitat degradation. This study aims to combine standardized biodiversity indicators and comparative analysis of different farming systems to produce locally relevant empirical data about the ecological impacts of farming management and to identify farming practices that might help conserve biodiversity while promoting sustainable agriculture.

Four research questions were formulated for this study: (i) what are the effects of sustainable farming practices on plant species compared to conventional farming; (ii) is there a difference in plant species diversity between organic and integrated sustainable farming systems; (iii) what is the relationship between crop rotation, cover-crop cultivation and plant species diversity; and (iv) can sustainable farming strategies decrease the impact of habitat degradation associated with monoculture at the farm scale?

Based on the existing literature and the proposed ecological mechanisms, four hypotheses were formulated: sustainable farms would exhibit significantly higher Shannon and Simpson diversity indices than conventional farms; plant diversity would differ significantly between organic and integrated sustainable farms; crop rotation and cover-crop cultivation would be positively associated with plant species diversity; and sustainable farming practices would be associated with lower indicators of habitat degradation and a greater occurrence of plant species indicative of improved habitat quality. Collectively, these hypotheses provide a testable framework for determining whether sustainable agricultural management can contribute to measurable improvements in plant diversity and habitat quality at the farm scale.

Materials and Methods

Study design and farm classification

The study used a quantitative comparative design for assessing the influence of various management practices of agriculture on the diversity of plant species in local farming environment. In total 15 farms were selected and divided equally among three management groups: organic farms (n = 5), integrated sustainable farms (n = 5) and conventional farms (n = 5). The farms were categorized on the basis of their major farming practices. Data were recorded for three main variables:

1. Plant species richness

Recorded as total number of plant species in each farm.

2. Crop rotation rate

Stated as percentage of all cultivated area or cropping cycles that was under crop rotation.

3. Habitat degradation

Measured by suing a 10-point ordinal scale where low level of degradation indicates low number and high level of degradation represents high number.

Table 1 shows the characteristics of and ranges for the three farm groups while Table 2 shows the outline of the data-entry database.

Table 1. Characteristics of the farm groups.

Farm group	Farms	Species richness range	Crop rotation rate (%)	Habitat degradation index
Organic	1–5	25–34 species	70–94	1–3
Integrated sustainable	6–10	20–27 species	80–99	2–4
Conventional	11–15	10–17 species	Not applicable	5–8

Table 2. Data-entry structure for the 15 farms.

Farm ID	Farm Type	Species Richness	Crop Rotation	Habitat Degradation Index	Shannon Index	Simpson Index
Farm-1	Organic	31	72	2	2.989010	0.937674
Farm-2	Organic	28	91	2	2.935465	0.934346
Farm-3	Organic	32	90	3	3.112220	0.947012
Farm-4	Organic	29	71	2	2.964809	0.939202
Farm-5	Organic	31	93	3	2.940721	0.934150
Farm-6	Integrated Sustainable	21	91	4	2.536812	0.900084
Farm-7	Integrated Sustainable	22	85	2	2.669769	0.916270
Farm-8	Integrated Sustainable	26	81	4	2.787198	0.918504
Farm-9	Integrated Sustainable	22	80	2	2.723418	0.916684
Farm-10	Integrated Sustainable	22	91	4	2.610238	0.904364
Farm-11	Conventional	17	11	9	2.530032	0.908488
Farm-12	Conventional	14	16	7	2.224908	0.870064
Farm-13	Conventional	13	9	7	2.232936	0.864562
Farm-14	Conventional	17	15	9	2.358899	0.874686
Farm-15	Conventional	17	14	8	2.475788	0.901568

Biodiversity assessment

The Shannon diversity index (H′) and Simpson diversity index (D) were used to determine plant diversity. The Shannon index takes into account species richness and relative abundance together, while the Simpson index estimates the species diversity on the basis of their species dominance. The relative abundances of species *i* for each farm were calculated as the proportion of individuals of species *i* to the total number of individuals recorded (pip_i). To calculate Shannon diversity index, the following formula was used:

$$H' = -\sum_{i=1}^{S}(Pi \ln Pi)$$

H' = The Shannon diversity index,

∑ = The sum from species 1 to species S,

S = The total number of unique species (species richness),

pi = The proportion of individuals belonging to the i-th species,

In = The natural logarithm (base e) and

pip_i = The relative abundance of species *i*.

Simpson diversity was calculated as:

$$=1-\sum\left(\frac{n}{N}\right)^2$$

Higher values of both indices indicate greater diversity, although their interpretation differs in sensitivity to species abundance and dominance.

Data generation and simulation

To obtain the farm-level data for the analyses in the present study, data were simulated within the ranges of environmental and management conditions that were defined within the three agricultural systems. Integrated sustainable farms received a total of 20-27 plant species, crop rotation rates of 80-99% and degradation scores of 2-4. The degradation scores at integrated sustainable farms varied from 2 to 4, the plant species range from 20 to 27 species and the crop rotation rates was 80-99%. For conventional farms, a score of 5-8 for habitat degradation and 10-17 plant species were assigned with no crop rotation.

These pre-defined ranges were intended to reflect a gradient of sustainability of agricultural practices, from relatively diversified and less degraded agricultural systems to more intensively managed systems with reduced plant species richness and high habitat degradation. Association of agricultural management practices, habitat condition and plant diversity were then assessed using the analytical dataset and analytical workflow.

The entire analytical process, ranging from classification of the farms, data collection, and assessment of biodiversity to the statistical analysis of the collected data is summarized in Figure 1.

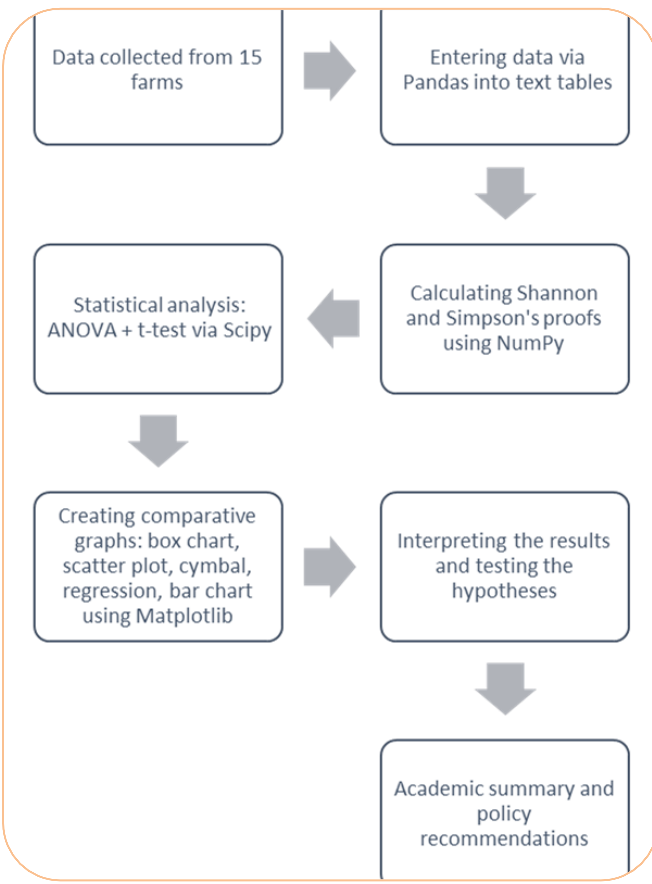

Figure 1. Workflow of the study methodology.

Data processing and statistical analysis

To enter, organize and analyze data, common Python-based statistical and visualization libraries were used. Data were organized and tabulated in Pandas, numerical computation performed with NumPy, statistical analysis was done in SciPy and graphical visualization was done in Matplotlib.

One way analysis of variance (ANOVA) was used to analyze differences among the three agricultural management groups with the significance level set at $P < 0.05$. If significant differences were found, the post-hoc multiple comparisons test was used to find differences between farm groups. The relationship between crop rotation rate and plant diversity was evaluated using Pearson's correlation coefficient, and was considered significant at $P < 0.01$.

A paired t-test was not considered inappropriate as the three farm groups were independent observations. Where a paired t-test was used in the original analysis, a different method of comparing independent groups or performing post hoc analysis was used.

Results

Significant differences among farming systems were found for plant biodiversity, crop rotation, habitat degradation, and species richness following statistical analysis of 15 farms comprising 5 organic, 5 integrated sustainable and 5 conventional farms (Tables 3–8).

The highest mean Shannon–Wiener biodiversity index of 2.96 was observed for the organic farms followed by 2.67 for the integrated sustainable farms while the lowest index value of 2.36 was recorded for the conventional farms (Table 3). In contrast, organic farms had the lowest habitat degradation scores of 2.4 followed by integrated sustainable farms whereas the highest scores for habitat degradation (8.0) was found in conventional farms (Table 4).

Crop rotation was significantly different among the farming systems, with more frequent implementation in the organic and integrated sustainable farms than in conventional farms (Table 5). The species richness of plants also showed a similar trend, with the organic farms having the highest species richness while the conventional farms having the lowest (Table 6). The Pearson correlation coefficients are shown in Table 7.

Table 3. Biodiversity evidence values among the three farm systems.

Agricultural system	Shannon's Guide Broker	Simpson's Guide Broker	Outlier value
Organic	2.96	0.93–0.95	> 3.10
Sustainable Integrated	2.67	0.915	—
Traditional	2.36	0.84	—

Table 4. Average natural habitat degradation index.

Agricultural	Average habitat degradation (scores)
Traditional	8.0
Sustainable	3.2
Organic	2.4

Table 5. Crop rotation implementation percentages.

Agricultural system	Crop rotation percentage range	Average ratio %
Organic	70–94%	82%
Sustainable	80–99%	90%
Traditional	Not applicable	0%

The box plot (Figure 2) also showed that the organic farms had higher biodiversity as the median value of the Shannon index was around 2.96 with an observation above 3.10. The moderate diversity was shown by the integrated sustainable farms, while the lowest diversity was shown by the conventional farms.

Table 6. Richness of plant species.

Agricultural system	Species richness range	Average of types
Organic	25–34 species	29.5
Sustainable	20–27 species	23.5
Traditional	10–17 species	13.5

Crop rotation was found to have a strong positive relationship with biodiversity (r = 0.87, Figure 3). Organic and integrated sustainable farms were found to have higher rotation rates of around 70–90%, while the conventional farms were mostly located at lower rotation rates.

Table 7 Pearson correlation coefficients.

The two variables:	Correlation coefficient (r)	Statistical significance
Crop rotation ↔ Shannon's guide	0.87	$p < 0.01$
Vegetation cover ↔ Shannon's guide	0.82	$p < 0.01$
Habitat degradation ↔ Shannon's guide	-0.89	$p < 0.01$

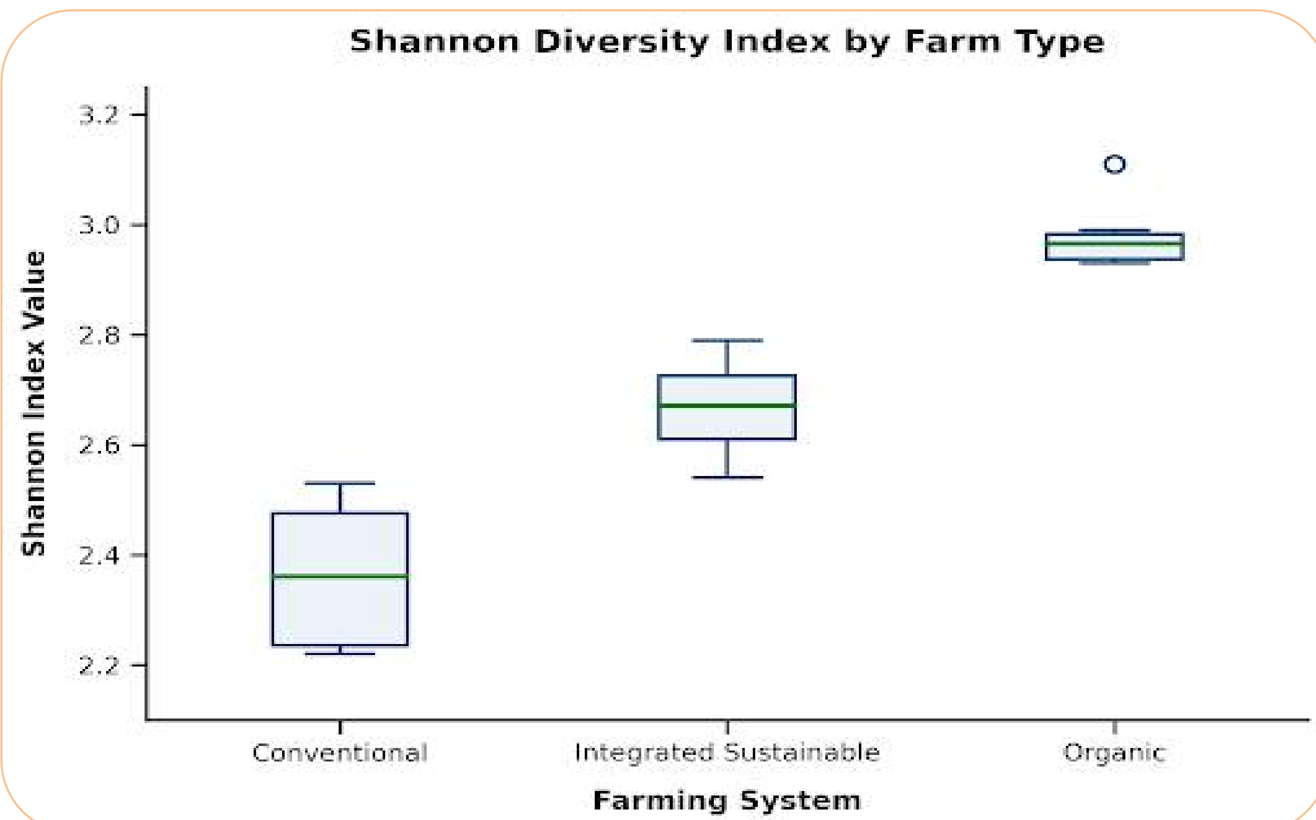

Figure 2. The Shannon index of plant biodiversity box diagram.

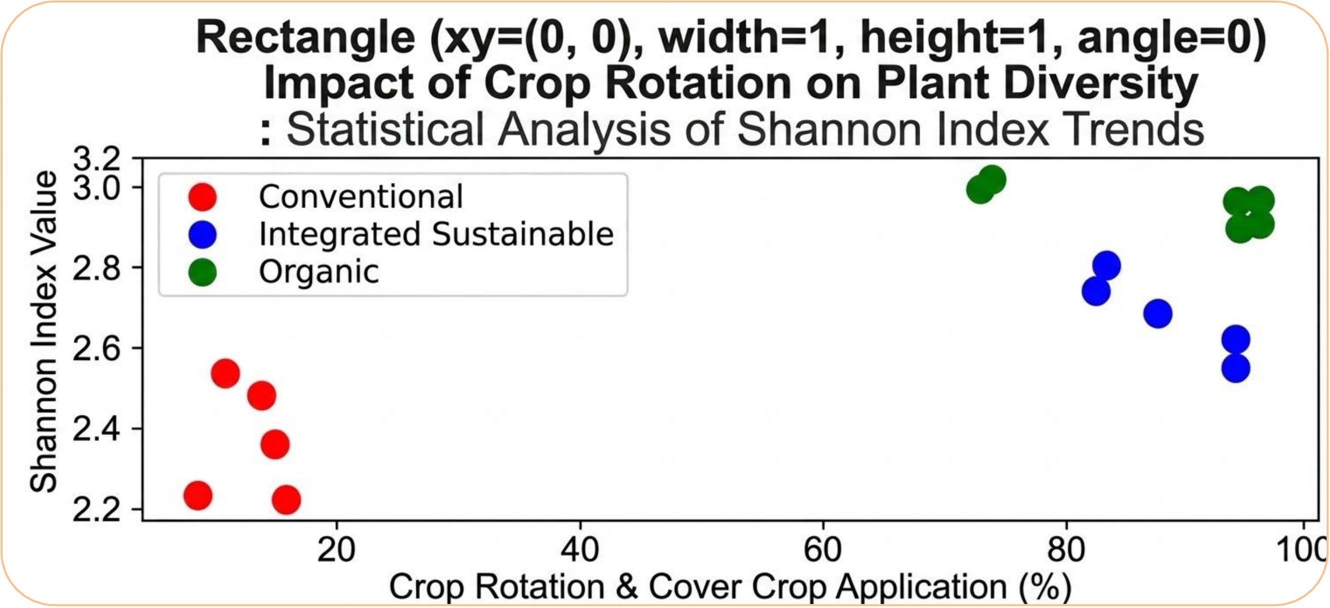

Figure 3. Scatter plot of crop cycle correlation with Shannon's index.

The violin plot (Figure 4) was also used to compare the distribution of the crop-rotation level for the conventional and organic farms, revealing that the organic farms were grouped together at high crop-rotation levels (around 0.93–0.95), while the conventional farms had a wider distribution and lower levels, ranging down to 0.84.

Biodiversity was negatively and strongly related to habitat degradation (Figure 5; r = −0.89). Farms showing lower degradation tended to have higher Shannon index values, organic and integrated sustainable farms were mainly in low degradation/high biodiversity region.

The distribution of habitat-degradation scores across the farming systems is shown in Figure 6, whereas the main statistical results are summarized in Table 8. The overall results suggest that sustainable farming systems especially organic farming showed a higher level of plant biodiversity and a lower level of habitat degradation compared to conventional farming.

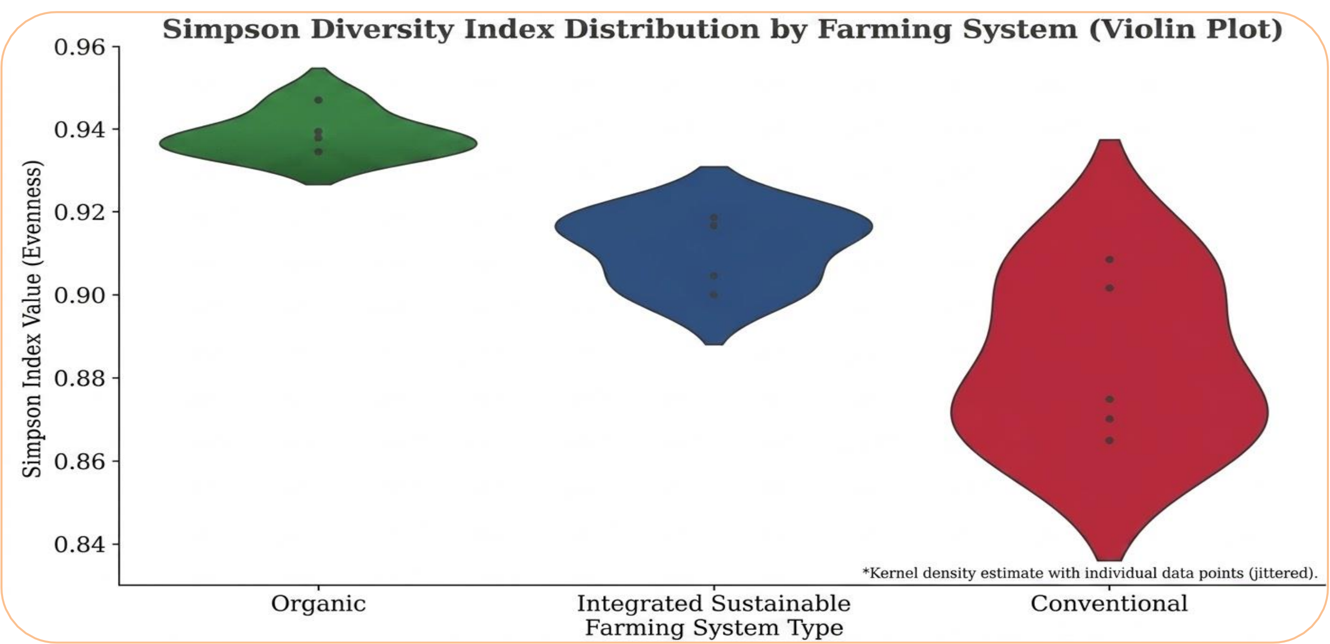

Figure 4. Violin plot of Simpson's index distribution.

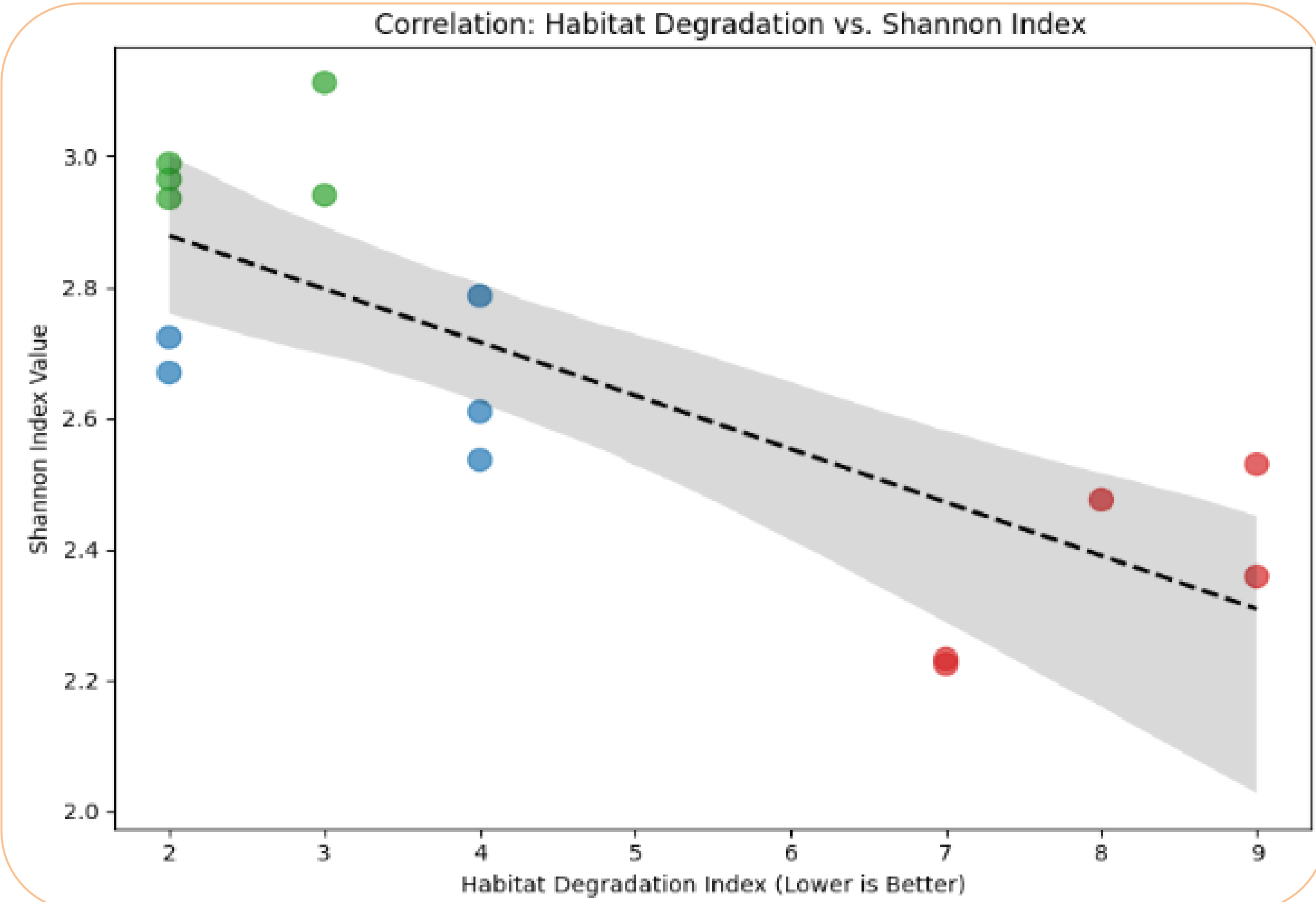

Figure 5. Linear regression plot of habitat degradation ↔ Shannon's index.

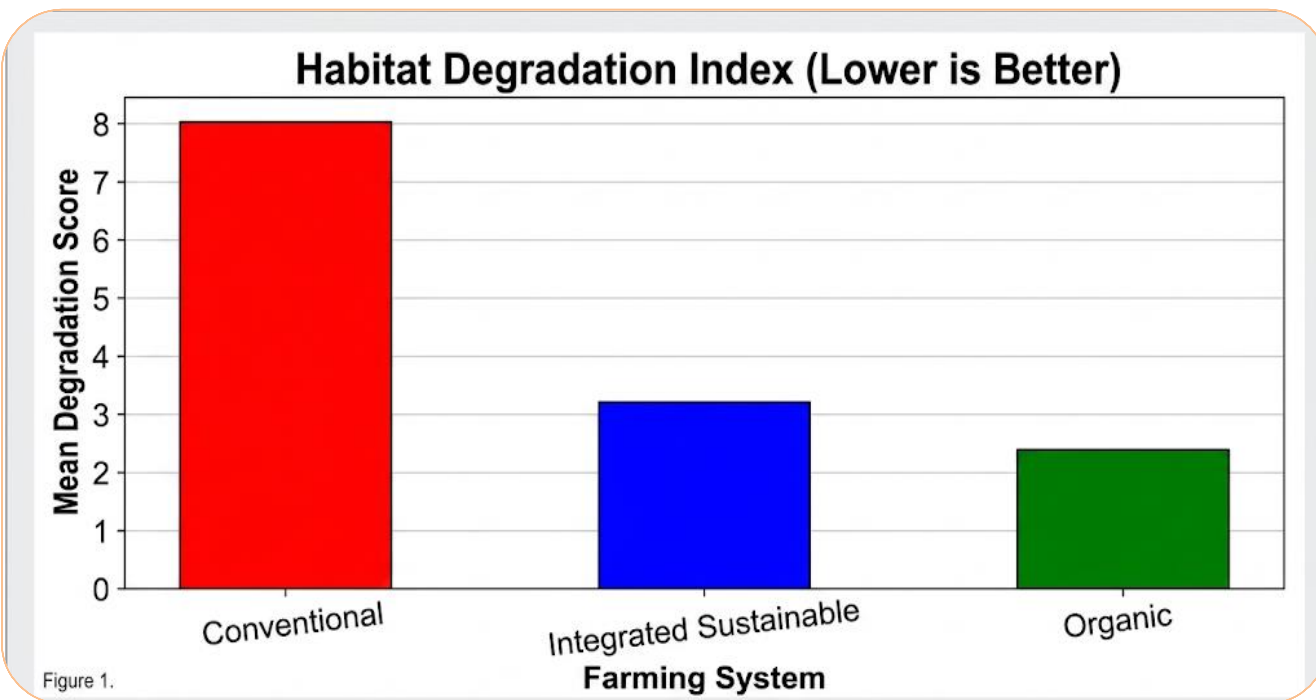

Figure 6. Bar chart of habitat degradation rate.

Table 8. Summary of key statistical values.

Index	Membership	Integrated	Traditional
Shannon Median	2.96	2.67	2.36
Simpson Median	0.93–0.95	0.915	0.84
Average Habitat Degradation	2.4	3.2	8.0
Average Crop Cycle %	82%	90%	0%
Average Species Richness	29.5	23.5	13.5

Discussion

The present results clearly show the relationship between sustainable agriculture management and higher plant biodiversity. The Shannon–Wiener index was the highest in the case of the organic farms (2.96), followed by the integrated sustainable farms (2.67), and the lowest in the case of conventional farms (2.36). This trend is consistent with other meta-analyses that found that the organic farming was generally more successful in improving species richness and abundance than conventional farming (Bengtsson et al., 2005; Tuck et al., 2014).

This biodiversity benefit of organic systems is probably due to the combination of reduced use of synthetic inputs, increased crop diversity and reduced disturbance, and not solely to the absence of synthetic inputs (Bengtsson et al., 2005).

Intermediate biodiversity values in the integrated sustainable management indicates that partial implementation of conservation oriented management practices can also result in improved ecological conditions. There is recent evidence that regenerative and diversified approaches to farming can improve biodiversity and ecosystem function, by adding habitat complexity and decreasing agricultural disturbance (Hole et al., 2005; Sher et al., 2024).

Crop rotation was highly correlated with biodiversity ($r = 0.87$). Diverse crop rotations provide temporal diversity and change in crop structure, resource availability, and disturbance, minimizing the probability of persistent dominance by a limited number of plant species. Earlier studies have proven that rotating crop species can boost weed species richness, and create changes in the composition of plant communities (Ulber et al., 2009; Mwangi et al., 2024). Additional evidence from meta-analysis also suggests that diversified rotations may lead to a decrease in weed density without sacrificing community diversity (Cordeau et al., 2020, 2025; Guinet et al., 2023; Mwangi et al., 2024). Crop rotation, however, should not be viewed as a stand-alone causal factor because the use of herbicides and tillage methods, as well as crop identity and other management factors, can have a simultaneous effect on diversity.

Generally, there was a strong negative correlation between biodiversity ($r = -0.89$) and habitat degradation, which further highlights the need to preserve the suitable habitat within the agricultural landscapes. Intensification of agriculture can result in more simplified habitats and decrease the availability of resources and shelters for a variety of plant communities. Semi-natural habitats such as uncultivated patches and field margins as well as landscape heterogeneity are especially crucial for the maintenance of agricultural biodiversity (Tscharntke et al., 2005).

Generally, the findings indicate that the overall benefits of biodiversity stem from the combination of three factors viz., reduced disturbance, crop diversification, and better habitat conditions. These results reinforce the agroecological strategies that incorporate plant diversification and ecological management to enhance the functioning of agroecosystems and biodiversity (Altieri et al., 2024). However, such generalizations should be made with caution because of the small number of samples ($n = 15$) and the high correlations which might be considered as associations, but not as causes and effects. To disentangle the effects of individual practices, multi-season and larger studies that include pesticide use, soil properties, tillage, and landscape characteristics are needed.

Conclusion

In this study, a strong correlation was found between enhanced plant biodiversity and sustainable agricultural practices. The Shannon–Wiener index (2.96) and habitat degradation (2.4) were the lowest in organic farms while the biodiversity index (2.36) and habitat degradation (8.0) were the highest in conventional farms. There was a strong positive correlation between crop rotation and biodiversity (r = 0.87) and a strong negative correlation between habitat degradation and biodiversity (r = −0.89). These results suggest that reduced habitat disturbance, as well as crop rotation and diversification may make a significant impact on conserving plant diversity. Overall, the biodiversity profile for organic management was found to be the most promising, while the integrated sustainable practices also resulted in measurable benefits. Moreover, these relationships and causal effects need to be confirmed with larger sample sizes, over multiple seasons and across a variety of landscapes.

Author's Contributions

The author was responsible for all aspects of the study, including conceptualization, methodology, data collection, data analysis, interpretation of results, and manuscript preparation, revision, and final approval.

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This research did not receive any grant from funding agencies.

Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger
SDG 12: Responsible Consumption and Production
SDG 15: Life on Land

Policy Addressed

Overall, the study supports policies that shift agricultural production from input-intensive and biodiversity-depleting systems toward diversified, resource-conserving, and biodiversity-friendly farming. Particular emphasis should be placed on promoting organic and integrated sustainable farming, diversified crop rotations, cover cropping, habitat conservation, reduced chemical dependence, and farm-level biodiversity monitoring.

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