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ARTICLE

The Impact of Sustainable Foods on Biodiversity, Soil Health, and Farmer Incomes in Rural Communities

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ABSTRACT

The objective of the present study is to discover the implications of agroecological practices for sustainable agriculture, predominantly biological diversity, soil health, and farmer incomes, in Sikkim, India, which is the first entirely certified

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organic state in the world. As a sustainable agricultural method, agricultural ecology, which integrates ethical principles into smart farming, is an emerging consideration. In the context of farming communities in Sikkim, the present study investigates agroecological practices and the implications of the South Asian ecosystem across a range of agriculturally and environmentally friendly regions. Using an array of field research, soil sampling, and biological diversity measures, this research measures key indicators of biological diversity (species richness, crop diversity, and pollinator abundance), soil organic matter, nutrient availability, water retention capacity, and financial results (farmer income, input costs, crop yield, and market access). These results presented a significant improvement in biological diversity and soil health as agroecological practices increased. Farms that practice agroecological practices have significant biological diversity, improved soil health, and enhanced water storage capacity, all of which promote a more robust, productive, and sustainable agriculture. When it comes to the economy, agroecological practices minimise input costs and improve farmer incomes, particularly for businesses that can access precise markets, such as organic or sustainable agricultural production. The study recommends that agroecological practices can enhance financial support for rural farming areas, emphasising their key role in providing nutritious food, particularly in dry areas.

Keywords: Agroecological Practices; Rural Farming Communities; Sustainable Agriculture; Rural Development; Farmer Income; Machine Learning

1. Introduction

Conventional agriculture, which is motivated by chemical fertilisers and pesticides, has contributed to an increase in food production; however, it has also led to sustainability problems in sustainable agriculture, such as degraded soil health, the loss of biological diversity, the pollution of water, and an increase in greenhouse gas emissions[1]. Climate change exacerbates these problems and poses a risk to sustainable agriculture methods[2]. To address these social and ecological problems while maintaining sustainable agricultural practices over the long term, the field of agricultural ecology is now recognised as an acceptable substitute[3].

A farming method called sustainable agriculture integrates ethical principles into agroecological practices[4]. This model provides supplementary methods, such as nutrient cycling, biological pest control, and minimising water consumption, that are of the highest importance for improving soil health and biological diversity, increasing farmer incomes, and minimising the negative impacts of climate change[5]. Crop variation, organic reproduction, low farming, and sustainable agriculture are all signs of cropping[6]. The primary aim of agroforestry is to develop ecologically viable methods that may increase crop yields and agricultural products, and to restore land and water resources. Sikkim, among the first states in the world to achieve complete gradualism, has seen significant improvements in its agricultural land through the application of organic and agroecological practices[7]. This work aims to measure the impact of agroecological practices on biological diversity and farmer incomes across several smart farming methods, leveraging the several ecological farming zones identified throughout the state.

The study of agricultural ecology has been shown to improve farmers' incomes and enhance the adaptability of sustainable agriculture, particularly in rural communities, including the use of smart farming. Agricultural ecology can help balance farmer incomes, minimise market risk, and provide access to preferred marketplaces, such as organic and sustainable markets. It could be achieved by reducing demand for chemical inputs and increasing food collection. This is particularly true in Sikkim, where reductions in the smart farming sector within the sustainable agriculture sector and securing access to sustainable agriculture resources are critical to the development of agricultural ecology in rural areas[8]. On the other hand, empirical research is essential to measure its impact on biological diversity, soil health, and ecosystem function. To address this skill gap, this study examines the impact of agricultural ecology on biological diversity, soil health, and farmer incomes across Sikkim's agricultural ranges.

Specifically, for individuals residing in rural regions, agricultural ecology is expected to improve financial and economic adaptability and to provide financial profits[9]. Despite the decline in demand for fake inputs and the adoption of emerging smart farming methods, agricultural ecology helps stabilize farmer incomes, reduce market risk, and open access to suitable marketplaces, such as organic and fair-trade markets. In Sikkim, where the state government controls state finances and where access to sustainable financial support is vital for the development of farmers' incomes [10], this is particularly significant.

Previous research has shown that agroecological practices can help minimise the ecological impact on the atmosphere; however, there is limited data on the financial support for diverse agroecological practices, particularly in regions such as Sikkim. The purpose of this research is to address the problem by showing an in-depth analysis of the impact of agroecological practices on biological diversity, soil health, and farmer incomes in rural agricultural ranges of the state of Sikkim. To improve food production and support biological diversity and climate change, agroecological practices are a sustainable agricultural method that promotes crop rotation, organic farming, and zero-tillage farming, all of which are smart farming practices that support soil health, reduce chemical inputs to the farm, and increase farm productivity. Several factors, including those related to the marketplace, society, and ecology, are associated with the use of agroecological practices. When it comes to addressing problems such as global warming, food insecurity, and pollution, there has been a heightened awareness over the past few decades regarding how to develop agroecological practices. Despite this, the application of agroecological practices remains very limited because of a lack of training, limited access to inputs, and economic challenges [11]. It is vital to understand what motivates or hinders farmers' adoption of agroecological practices, so that targeted policies and interventions can be developed to improve the acceptance of agroecological practices, sustainable agriculture, and farmers' welfare, particularly in areas most at risk of environmental degradation and socio-economic vulnerability [12].

Therefore, a behavioural, socio-economic, and ecological model can be used to describe the use of agroecological practices. According to the theory of planned behaviour, farmers' beliefs—attitude, subjective norms, and perceived behavioural control—shape their decisions. Farmers adopt agroecological practices when they predict positive results, such as improved soil health or lower input costs. Perceived control over resources, skills, and labour availability can facilitate or impede adoption, and subjective norms—including peer and community impacts—also play a role. The Innovation Diffusion Theory emphasises the features of revolution and social networks as key factors in adoption. The acceptance of agroecological practices is higher when growers believe their suggestions benefit over conventional farming, such as reduced input costs and better performance under stress conditions, and when the practices align with existing farming methods. The probability of obtaining the benefits is also high, with complete supporter farms or success stories from other farmers [13].

Early adopters have a significant impact on the community's adoption of new technology, with farm-level resources playing a central role. The Resource-Based View encompasses available capital, labour, and technical expertise, but delays limit its adoption. Ecological awareness also plays a significant role in the adoption method. Farmers aware of environmental challenges, such as soil health corrosion, are more likely to adopt SF practices, such as crop rotation and organic resources [14].

The study presents a new ecological-economic model that relates sustainable agriculture to agroecological practices, measures of biological diversity richness, soil health, and farmer incomes. In comparison with previous research studies, which analyse only agronomic or ecological outcomes, this study empirically tests the impact of localised agricultural ecological food practices on ecosystem services and the stability of farmers' incomes. It promotes ecological insights by integrating sustainable agriculture and biological diversity-based productivity into a unified model of agricultural ecology, and provides a complete ecological vision of food culture, helping ecological regeneration and socio-economic well-being in rural lands [15].

These practices help mitigate climate variability and, in the long run, improve productivity. Last on the list is the social-ecological systems, which captures human-environment relations and how positive feedback loops from improving ecosystem services, such as enhanced soil health and increased existing biological diversity, support sustained adoption [16]. This theoretical model proposes data regarding the use of agroecological practices by explaining the factors that promote and hinder the adoption of sustainable agriculture.

The ecological and economic results were worked out at the system level as the modelling approach synthesises measured biophysical factors (e.g., species richness, pollinator abundance, soil organic matter, water retention) and farm-level fiscal performance (e.g., net income, input cost, yield stability) to demonstrate the mechanistic relationships and trade-offs. The use of Partial Least Squares Path Modeling (PLS-PM) enabled the estimation of direct and indirect pathways to understand the role of agroecological adoption in generating soil health and biodiversity, and the ecological benefits in mediating the stability of crop yields and farmers' income. Latent constructs were defined based on theoretical roles (reflective, latent ecological state variables; formative, where composite management-intensity indices were needed) and tested by model quality indicators, including indicator loadings, composite reliability, average variance extracted (AVE), cross-loadings, and the SRMR goodness-of-fit indicator. To assess the statistical significance and stability of the factors, path coefficients, and mediation effects, bias-corrected bootstrap confidence intervals (5000 resamples) were used, and predictive relevance (Q2) and out-of-sample split validation were used to assess the model's external validity. Heterogeneity in causal pathways was also explored further by multicollinearity diagnostic (VIF) and multi-group PLS analyses (by region and farm size). Results of the PLS-PM showed that indirect effects of biodiversity and soil organic matter on income through yield stability are substantial (explaining a significant fraction of the variance in economic results), allowing ecological gains not only to be environmental co-benefits but to be controls of economic helpful significance as well, information that is directly useful of targeted policy levers (e.g., investments in soil-restorative practices, market access interventions) and which favors interventions with the most significant joint ecological-economic rewards.

Specifically, the study seeks to:

a) To find the level at which agroecological practices impact biological diversity by measuring factors such as the crop type, mode of farmer incomes, and type of pollinators and biological pest predators.
b) To investigate the impact that agroecological practices have on soil health, focusing principally on key factors such as the level of soil organic matter, nutrient availability, and pH. Water retention capacity stands for water retention capacity.
c) To examine statistical factors such as input costs, crop yield stability, and market access to analyze the financial results of agroecological practices.
d) Study the Social-Ecological Systems factors that influence the adoption of agroecological practices, including farm size, farmer training, and the regional context of the practice.

The research work is organised as follows: the conceptual model is discussed in Section 2; the methodology is explained in Section 3; the findings are analysed in Section 4; and the conclusion is stated in Section 5.

2. Theory

2.1. Agroecology and Sustainable Agriculture

Integrating ecological values with agricultural methods and agricultural ecology science promotes sustainable agriculture, biological diversity, and the adaptability of smart farming methods. It provides an integrated, sustainable agriculture method. The field of agricultural ecology emphasises the use of organic farming methods to improve soil health, control pests, and manage water resources, in contrast to the predictable agricultural practice that regularly employs synthetic fertilisers and pesticides[17]. The impacts of agroecological practices include improving soil health, maintaining biological diversity, and promoting sustainable agriculture, all of which support the development of self-sustainable agriculture through modelling agricultural ecological methods.

Sustainable agriculture, a broader term that encompasses agricultural ecology, assesses the viability of future food production systems without negatively impacting environmental quality or reducing resource availability[18]. To meet present requirements without risking food production for future generations, agroecology maintains a balance between food security and the preservation of ecosystems. Ecological balance is improved, and the adoption of biological diversity, farmer service, and the use of renewable resources reinforces the social and economic well-being of farming communities. Rural areas can depend on that method to support them financially.

By focusing on local technological developments and findings introduced by farmers, agroecological practices are gaining higher importance in South Asia. This method enables farmers to customise practices to their complete environments, providing a model that remains adaptive and robust. Consequently, agroecological practices have been accepted as a significant tool for achieving global sustainable agriculture objectives, such as maintaining food security, adapting to the impacts of climate change, and maintaining biological diversity[19].

Pest swarm reduction, crop rotation, agricultural polyculture, and organic fertiliser use are agroecological practices recommended in the scientific literature that, in turn, have led to a decline in the use of chemical fertilisers. According to researchers, agricultural ecology promotes biological diversity by providing more services.

The agricultural ecology ideas are coherent with sustainable agriculture principles because both prioritise long-term sustainability and optimal use of natural resources[20]. Innovations in agricultural ecology, grounded in practice and built on local skills, can help reduce environmental impacts, improve the economic and social status of agricultural regions, and address problems unique to their environments.

2.2. Biological Diversity in Agroecosystems

For agricultural fields to remain adaptable and farmer incomes to remain viable, biological diversity in agricultural ecological methods (**Figure 1**) is required. Soil biological diversity ranges outside the crop to include microorganisms, plant and animal species, and ecological links within the soil. Environmental developments such as pollination, pest management, nutrient cycling, and water regulation depend on this range. Environments that support diverse plant and animal species are developed through agroecological practices that support diverse cropping methods, agricultural land use, and livestock integration[21]. By employing helpful insects and minimal chemical interventions, biological diversity reduces the requirement for chemical fertilizers and pesticides, among other inputs. By supporting nutrient cycling while minimizing pest and disease buildup, as is typical of conventional farming methods, hybrid cultivation and variable crop rotations improve soil health.

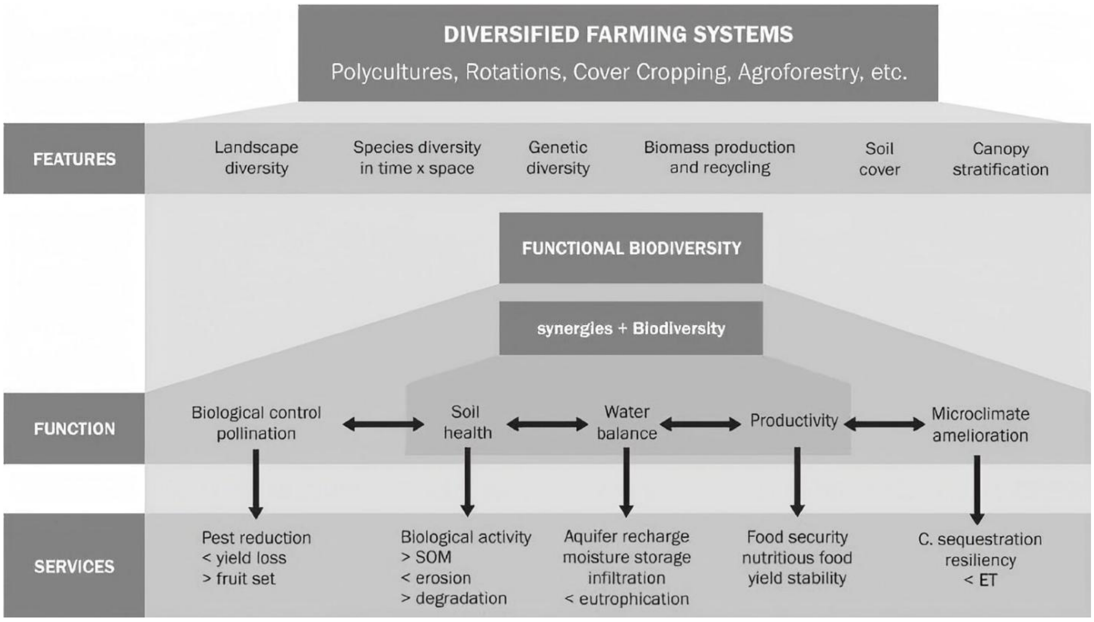

Figure 1. Ecological role of biological diversity in an agricultural ecology system[16].

Maintaining ecological areas, such as buffer zones, hedgerows, and wetlands, is vital to preserving land-based biological diversity. The invention of agriculture has improved these regions by protecting natural species, boosting biological diversity, and enhancing environmental facilities. As verified by experiments, agricultural ecologies rich in biological diversity are better prepared to cope with environmental impacts such as changing climates and severe weather[22].

Economically and culturally valued, biological diversity in agricultural ecology is predominantly significant in rural regions[23]. In locations where farmers have historically refined an array of crops for food, health, and Social-

Ecological Systems, this type of data is an advantage. By this method, biological diversity not only supports sustainable agricultural practices in the future but also helps farmers achieve food security, become less susceptible to market fluctuations, and maintain farmer training. Therefore, securing funding and evolving sustainable agriculture require agroecological practices that generate biological diversity.

2.3. Soil Health in Agroecological Practices

The field of agricultural ecology depends on soil health because it determines the resilience, sustainability, and productivity of sustainable agriculture. Sustainable agriculture demands soil regeneration and preservation, in contrast to scheduled farming. Soil health is a valuable nutrient and water storage medium, loaded with vegetation and helpful microbes. Improve soil health by adopting agroecological practices such as crop rotation, cover cropping, minimal tillage, and organic fertilisers[24].

The agricultural ecology's focus on crop types has improved soil health. By cultivating beans and other nitrogen-fixing crops in tandem with deep-rooting crops that break down compact layers, farmers can improve the structure and nutrient content of their soil. Reducing the use of synthetic fertilisers can prevent soil acidification and nutrient imbalances. Soil conservation practices such as cover cropping and mulching help maintain soil moisture, prevent erosion, and foster the development of valuable microbes.

One of the most important ways to slow climate change is to increase carbon sequestration, which agroecological practices can improve. Soils developed under agroecological practices management have higher levels of organic carbon, which help stabilize the global environment and increase productivity[25]. As a result, they are more robust to floods and less likely to flood when it rains. Improved soil fertility, adaptability to climate change, and long-term sustainability are the benefits of this smart farming method.

2.4. Farmer Incomes and Economic Adaptability

In particular, in agricultural areas, agricultural ecology has the potential to substantially improve food security and social-ecological systems. By reducing the use of high-cost external inputs such as chemical fertilizers and pesticides, agricultural ecology can improve crop yields and reduce production input costs. The development of improved resource use helps stabilize farmers' incomes, even when market access is unpredictable, thereby making farmers more adaptable[26].

Because agricultural ecology increases biological diversity in smart farming, it is better able to address environmental challenges. To minimize risk and endure hostile weather, pest outbreaks, and market disruptions, farmers practicing agroecology tend to produce multiple crops, integrate farm animals, and maintain agricultural forests. Because of this, farmers may market unique agricultural ecology products in specialized markets, where they may attain higher prices, such as organic or fair-trade markets[27].

By integrating farmers in decision-making and communication networks, agroecological practices support social adaptability. The method highlights innovations developed by farmers and the control of resources at the social level, enabling them to adapt their methods to precise contexts. Farmers can better respond to challenges, both alone and in groups, by using this sharing method, thereby gaining control over their sustainable agriculture. By aggregating their resources and providing details, more integrated farming communities are better able to cope with unpredictable changes[28].

According to agricultural ecology, farmers should have superior control over their food production to develop equitable, environmentally sensible, and economically practical sources of income. This adoption, along with agricultural ecology's reduced susceptibility to external factors, provides an ethical method that could improve the cash flow flexibility of agricultural areas in future generations[29].

3. Methodology

3.1. Location of the Study

Organic farming and agroecological practices have been tested through trial and error in Sikkim, India's first fully organic state. When considering the social and ecological impacts of agroecological practices, it is vital to analyse how they have extended to include organic farming, driven by government policies and farmer-driven programs.

The distinct environment and climate of Sikkim make it a perfect location for researching how agroecological practices have evolved different farming methods and how these methods have impacted agricultural ecology. Analysing the broader impact of agroecological practices is reduced by the state's purpose to help biological diversity by OF and avoid chemical causes. Assessing agroecological practices in an integrated organic-agriculture context, this study focuses on Sikkim to find how it has been successful and where it could go from here to enhance biological diversity, soil health, and farmer incomes in rural agricultural areas.

3.2. Sampling and Data Collection

The agricultural ecology zones in Sikkim were the primary focus of the research, which examined adaptive pest management across numerous farming practices. The stratified sampling method was used to select farmers from different regions, accounting for factors such as farm size, crop types, and combinations of agroecological practices. To compare agroecological practices across different farm sizes, the sample included farmers at multiple scales.

With particular emphasis on conventional, organic, and agroecological farming methods, the study employed a stratified sampling method to collect data from numerous sectors in Sikkim, including small-, medium-, and large-scale farms. Farm size, type, and location were the defining factors for the participants. Management problems, financing, customer relationship management, and business development were the topics of surveys and focus groups.

To collect data on farmer incomes, biological diversity, and smart farming practices, the investigators used field interviews and surveys with farmers. Formal surveys evaluated productivity, input costs, market access, and farmer incomes in detail. Improved biological diversity, soil health, and adaptation to climate change were among the positive environmental benefits of agricultural ecology that farmers reported during interviews. Soil samples were collected to measure key soil health metrics, providing a systematic basis for evaluating the impact of agricultural ecology on soil health. The biological diversity component focused on pollinators, pest predators, and other aspects of biological diversity.

A multistage stratified sampling method was used across three Agro-climatic zones in the E, W, and S districts of Sikkim. Villages were ranked according to advancement gradient, crop type, and organic certification level. Representative farms were taken out of each section in proportionality to population density and farm area under agriculture. This was based on selection measures focused on constant participation in organic farming for more than 5 years and on the adaptation of traditional crop production methods. The Cochran sample size formula and related weighting ensured that space, demographic, and biological diversity were achieved across farm types, thereby improving the generalizability of the results to the regional level.

3.3. Hypothesis and Variables

This study hypothesizes that agroecological practices have a positive impact on biological diversity, soil health, and farmer incomes in rural communities, with a precise focus on organic farming land in Sikkim.

The first hypothesis (H1) posits that agroecological practices improve biological diversity in OF systems. This is based on the idea that farms adopting agricultural ecology will exhibit superior biological diversity of plants and animals than conventional farms. Because sustainable agriculture methods enable larger changes in species, biological diversity in environments supports biological diversity, and minimal chemical inputs, this increase in biological diversity is predictable.

According to the following hypothesis (H2), agroecological practices improve soil health. Improved soil health is predictable on farms that use agroecological practices such as crop rotation, minimal tillage, and organic farming. Higher organic matter, better nutrient availability, and improved soil type are indicators of improved soil health, which, in turn, improves the land's long-term sustainability and efficiency.

The third hypothesis (H3) challenges the claim that these methods increase farmer incomes and is grounded in the economic outcomes of organic farming. Agroecological practices on farms are predicted to enhance farmer incomes, mainly through increased income methods and access to top markets like organic or fair-trade markets, by reducing support costs for external inputs and stabilizing crop yields.

To test these proposed hypotheses, the research study employs a set of factors. The autonomous factors include the numerous agricultural ecological regions in Sikkim, the farm's size, and the type and level of agroecological practices. The extent to which agricultural ecology is applied across several farming contexts can be determined by environmental factors that affect biological diversity, soil health, and farmer incomes. Indicators of biological diversity include species richness, crop diversity, and insect activity, while indicators of soil health include soil organic matter, pH, nutrient availability, and water retention capacity. Farmer incomes, input costs, crop yield stability, and market access can be used to assess economic adaptability. Environmental factors such as farmer age, skill, education level, and access to credit will be controlled for in the research investigation, which analyzes the impact of agroecological practices on biological diversity, soil health, and farmer incomes among rural farming groups in Sikkim. All of these factors can affect agroecological practices, in addition to agricultural ecology, which verifies their accuracy.

3.4. Study Design

To analyse how agroecological practices impacted biological diversity, soil health, and farmer incomes in Sikkim, the present study adopted a quantitative research methodology. A longitudinal study of a geographically and demographically diverse group of farmers will serve as the basis for this study's methodology. A diverse group of small- and medium-scale farmers from different weather conditions and regions is selected using stratified sampling. Formal and field surveys are used to collect data, with an emphasis on dependent environmental factors (biological diversity, soil health, and farmer incomes) and independent factors (agroecological practice type and stimulation level). To measure soil health, soil samples are collected, and a biological diversity review assesses the benefits of different types of biological diversity in sustainable agriculture (**Figure 2**).

3.5. Data Analysis

To investigate the impacts of agroecological practices on biological diversity, soil health, and farmer incomes, the present study adopts methodical data analysis to test hypotheses. The primary aim is to identify significant correlations between independent and dependent variables while adjusting for probable confounders.

Figure 2. Study Area.

3.5.1. Descriptive Statistics

Descriptive analysis provides data on the sample's features, farm size distribution, agroecological practice types, and farmers' demographic details, such as age, experience, and education level. Such measures are the mean, median, mode, and standard deviation. The mean provides the average of each factor; the median is the middle value of the data set when arranged in order of magnitude; and the mode is the value that occurs most frequently in the data set. The coefficient of variance measures the unpredictability of data around the mean. The standard deviation indicates how dispersed the data are within the entire dataset; the higher the standard deviation, the more dispersed the data, while the lower the standard deviation, the more compact the dataset. These statistics enable the study of the uncultivated and direct features of the study factors and the sample, including central tendencies, variability, and overall dispersion. For instance, the mean number of farmers by age, the median farm size, the mode of agroecological practices adoption, and the standard deviation of sustainable agriculture practices may be calculated to measure differences among farmers and their practices.

3.5.2. Inferential Statistics

Inferential statistical methods are used to test the hypotheses. Specifically, the following methods are applied:

- **Correlation Analysis:** Pearson or Spearman correlation coefficients are computed to assess the strength and direction of relationships between agroecological practices (e.g., the number of practices adopted or practice intensity) and the dependent factor. This helps identify whether higher adoption of agricultural ecology is associated with improved biological diversity, soil health, and farmer incomes.
- **Regression Analysis:** Results for biological diversity, soil health, and farmer incomes can be more precise and verified when there is a correlation between agroecological practices and regression analysis. It helps predict trends, implement policies, and maintain control over factors that confuse. Multiple linear regression models have measured the impact of agroecological practices on each dependent factor. The research employs separate regression models for biological diversity, soil health, and farmer incomes to analyse the impact of critical independent factors, such as farming methods and farm size, while controlling for confounding factors, including farmer education and location.
- **ANOVA (Analysis of Variance):** Using ANOVA, biological diversity, soil health, and farmer incomes results are examined across farms with different levels of agroecological practices intensity. These tests aim to find whether agroecological practices result in significant improvements in the resulting data.
- **Soil Health and Biological Diversity Metrics:** This data, involving soil health (soil organic matter, nutrient availability, and pH levels) and biological diversity (crop type and biological diversity), is analysed using specially developed software to measure the improvements in agricultural ecology implemented. Statistical modelling is used to investigate the correlation between soil health and biological diversity metrics and agroecological practices, to find whether farms with higher levels of agroecological practices exhibit better soil health and biological diversity.

Soil health and biological diversity are required to measure the ecological impact of agroecological practices. The soil health predictors include the quantity and quality of the organic farming, SG's nutrient status potential, and pH. These factors are used to find the impact of practices such as organic farming, crop rotation, and minimum tillage on soil health. The number of species and crop types proves the promising environmental states these practices generate. Farms that practice agricultural ecology, which emphasizes biological diversity and minimizes pesticide use, have been reported to have higher biological diversity. These factors are tested using an application that analyses data and generates statistical models. With these mathematical models, researchers can examine how changes in agroecological practices affect soil health and biological diversity. The primary aim of this study is to determine how much improved sustainable agriculture results are in these regions when sustainable practices are used more frequently.

3.5.3. Economic Analysis

Farms with different levels of adoption of agroecological practices are studied using a cost-benefit analysis to find farmers' incomes. Market access, crop yield, farmer incomes, and input costs are each features of sustainable agriculture.

By using statistical methods, researchers can measure the correlation between income variability and agroecological practices and find whether reduced dependence on external funding leads to more reliable financial problems.

3.5.4. R (v4.3)

These hypotheses were verified using the following: normality (Shapiro-Wilk), homoscedasticity (Levene's test), and multicollinearity (VIF diagnostics) in statistical analyses. To validate the model, the Durbin-Watson test, residual distribution, and Cook's distance were used to assess its reliability. The effect sizes of the groups were computed using Cohen's d, while financial and environmental factors were tested using complete η^2 and regression models. Parameter stability is measured by bootstrapping with a sample size of 5000. The result is more accurate statistical results, reduced prediction bias, and more reliable predictive data.

Sampling design and statistical analysis. A multistage stratified sampling method was adopted, with the spatial and management-type representative of the agro-climatic zone, farm size class, and certification/management type (conventional, organic, agroecological), and villages/farms chosen proportionately within strata using the probability-proportional-to-size method. The sample size was estimated using the Cochrans proportion formula with corrections for finite population and design effect, yielding a final analysis population of N = 421 after quality controls and the elimination of missing records. Soil and biodiversity sampling used systematic subplot sampling on the farms (uniform soil core depths/areas and timed transects/quadrats/trap-days for biological surveys) to create similar units. Attack was conducted in three steps: (a) exploratory and univariate diagnostics (descriptive statistics, distributional checks with Shapiro-Wilk, outliers with standardized residuals and Cook distance, and homoscedasticity tests with Levene-test); (b) bivariate correlations (Pearson or Spearman correlations according to the normality of variables in the sample) and comparisons between groups (one-way ANOVA with post-hoc pairwise contrasts and reported effect sizes as Cohen d and partial e; (c) PLS-PM was employed to measure the direct and indirect relationships between agroecological adoption, soil health and income and parameter stability was assessed using bootstrap resampling (5000 iterations) and model robustness was assessed using split-sample validation. All hypothesis tests used two-tailed criteria; in cases with multiple comparisons, *p*-values were controlled for false discovery rate. The analyses were conducted in R (v4.3) and presented with 95% confidence intervals to support inferential transparency.

4. Result and Discussion

The statistical analysis of the sample (N = 421) provides a summary of the farmers' significant features, practices, and sustainable impacts. The respondents to the research, farmers, span a fairly wide age range, from 25.34 to 67.89 years old, with a standard deviation of 9.81 and an average age of 43.72 years (**Table 1**). The sample includes new and practiced farmers, with an average farming practice of 16.47 years and a range of experience (from 2.18 to 38.65 years) (**Table 2**).

Table 1. Type of observation.

Stratum/Type	Number of Observations
Region	
Region 1	150
Region 2	200
Region 3	180
Farm Type	
Conventional Farms	220
Organic Farms	250
Agroecological Practices Farms	150
Farm Size	
Small Farms (<5 hectares)	100
Medium Farms (5–20 hectares)	200
Large Farms (>20 hectares)	320

Table 2. Descriptive Statistics of Sample (N = 421).

Factors	Mean	Standard Deviation	Min	Max
Farmer Age (Years)	43.72	9.81	25.34	67.89
Farming Experience (Years)	16.47	7.24	2.18	38.65
Farm Size (Hectares)	1.83	0.96	0.42	4.89
Education Level (Years)	9.76	3.67	2.45	15.29
Household Size (Number of Members)	5.23	1.74	2.14	9.67
Annual Income (INR ‘000)	346.82	126.59	128.42	738.67
Agroecological Practices Adopted	5.67	2.13	1.21	10.82
Organic Fertiliser Use (kg/Year)	432.65	176.84	189.72	789.26
Biological Diversity (Species Richness)	14.62	4.59	7.33	24.27
Soil Organic Matter (%)	3.78	1.22	1.54	6.48
Water Retention Capacity (%)	21.37	5.71	11.84	34.96

The study attempts to measure differences in sustainable agriculture practices by selecting farmers from different GSPs, farm types, and sizes. To achieve this, small, medium, and large farms, as well as traditional, organic, and agricultural-ecology farms, are included in the service. The regions addressed are 1–3. The proposed range of error and levels of trust were input into the sample size calculation, which typically uses the following simple stratified sampling method as $n=\frac{Z^2\cdot(1-p)}{E^2}$, where n = sample size; Z = value for the confidence level; p = the predictable proportion and E = margin of error.

The research uses a stratified sampling method to account for all regions, farm types, and farm sizes. This helped researchers find the farming methods and their corresponding adverse environmental impacts. This method more accurately displays results across multiple levels.

As most farms fall into the small- to medium-size category, spanning 0.42 to 4.89 hectares, the mean farm size is 1.83 hectares, and the standard deviation is 0.96. With a median age of 2.45 to 15.29 years, the median level of training is 9.76 years, which is in the middle range of the professional training range. With a standard deviation of 1.74 and a range of 2.14 to 9.67, the mean number of family members per household is 5.23, suggesting that many households have multiple family members involved in agricultural work.

The average annual farmer income is ₹346,820, with a standard deviation of ₹126,590 among the farmers. The variances in farm size, productivity, and market access result in the income range of ₹128,420 to ₹738,670. Farmers’ varying levels of adoption of agroecological practices are reflected in a range of adoption rates, averaging 1.21 to 10.82. Among the farming methods investigated, the use of organic fertiliser ranges from 189.72 to 789.26 kg per year, with a median of 432.65 kg.

The environmental data confirm that biological diversity is predominant in farming zones, with an average species richness of 14.62 and a range of 7.33 to 24.27. Soil health differs across farms, with an average soil organic matter of 3.78% and a range of 1.54% to 6.48%. The positive impact of agroecological practices on soil moisture retention has been proven by the water retention capacity, with a mean of 21.37% and a median of 11.84%–34.96%.

Using Partial Least Squares Path Modelling (PLS-PM), researchers incorporated ecological and feature data and found that the soil health, farmer incomes, and biological diversity indices are mutually dependent. The model identified the direct and indirect mechanisms by which an ideal agricultural ecological approach, including balanced soil nutrients and an array of plant and animal species, impacts farmers’ bottom lines. By balancing productivity and reducing input costs, improved biological diversity will gradually contribute to income, based on this systems-based analysis. Instead of presenting agricultural ecology sustainability as a static Social-Ecological Systems, this method of integration enhances the study by providing analysis based on empirical data.

The reliability and predictability of the factor correlations are expected to be reflected in these graphics. Several positive environmental and financial outcomes have been associated with agroecological practices, as exposed in the correlation analysis in **Table 3**. There is a significant positive correlation between the number of agroecological practices adopted and biological diversity (r = 0.62, $p < 0.01$), signifying that agricultural enterprises that adopt more agroecological practices in their farming methods tend to support superior biological diversity. This correlation is most likely since biological diversity performs better in contexts with fewer chemical inputs and more complex agricultural ecology methods. Also, sustainable agriculture, which includes organic fertilizers and crop rotations, improves soil fertility and method, as indicated by the strong correlation between agroecological practices and soil organic matter (r = 0.57, $p < 0.01$). Farms' agroecological practices probably benefit substantially from reduced input costs and improved market access, as evinced by the moderate positive correlation with annual income (r = 0.44, $p < 0.01$). In addition, there is a positive correlation between agroecological practices and crop yield stability (r = 0.41, $p < 0.01$), validating the hypothesis that these methods promote stable crop yield, which, in turn, reduces the probability of crop loss or crop yield variance.

Table 3. Correlation Analysis (Pearson Correlation Coefficients).

Variables	Agroecological Practices Adopted	Biological Diversity (Species Richness)	Soil Organic Matter (%)	Annual Income (INR '000)	Crop Yield Stability	Water Retention Capacity (%)
Adopted Agroecological Practices	1.00	0.62**	0.57**	0.44**	0.41**	0.53**
Biological Diversity (Species Richness)	0.62**	1.00	0.50**	0.39*	0.34*	0.46**
Soil Organic Matter (%)	0.57**	0.50**	1.00	0.31*	0.37*	0.59**
Annual Income (INR '000)	0.44**	0.39*	0.31*	1.00	0.66**	0.33*
Crop Yield Stability	0.41**	0.34*	0.37*	0.66**	1.00	0.41**
Water Retention Capacity (%)	0.53**	0.46**	0.59**	0.33*	0.41**	1.00

Note: **Significance at a higher level, typically at the 0.01 significance level ($p < 0.01$), is signified by the symbol, while the symbol '*' states significance at the 0.05 level ($p < 0.05$).

A significant correlation between agroecological practices and water retention capacity (r = 0.53, $p < 0.01$) indicates that sustainable agriculture improves soil moisture retention, thereby increasing resistance to drying. Ecologically complex farms are more likely to have soil health, likely due to interactions between plants and soil microorganisms that improve nutrient cycling, as indicated by the positive correlation between biological diversity and soil organic matter (r = 0.50, $p < 0.01$). It is vital to note that the analysis reveals the strongest correlation (r = 0.66, $p < 0.01$) between annual income and crop yield stability, indicating that farmers can predict higher, more reliable incomes when crop yields are stable. Finally, the value of organic farming in enhancing soil moisture-holding capacity has been verified by the positive correlation between water retention size and soil organic matter (r = 0.59, $p < 0.01$).

After optimising for factors such as farm size, farmer training, and location, the MLR analysis presented in **Table 4** confirms that agroecological practices significantly increase biological diversity, soil health, and farmer incomes. The results are robust, as the model accounts for a significant level of difference in each dependent factor (R^2 values between 0.42 and 0.49, and all p-values < 0.001). Biological diversity (species richness) is substantially affected by agroecological practices, as proved by a beta coefficient of 0.58 ($p < 0.001$). Even after controlling for other factors, the results still show that farms with higher adoption rates of agroecological practices have very high biological diversity. Added factors that positively affect biological diversity, such as farm size ($\beta = 0.15$, $p < 0.05$) and location ($\beta = 0.17$, $p < 0.05$), though to a lesser extent than the adoption of agroecological practices, are also present.

Once again, agroecological practices demonstrate a significant positive impact on soil organic matter ($\beta = 0.53$, $p < 0.001$), highlighting sustainable agriculture's role in enhancing soil health. The significant impact of farm size ($\beta = 0.12$, $p < 0.05$) suggests that larger-scale farms may be better able to improve soil health by implementing complete agricultural practices. In this model, however, soil organic matter is not significantly influenced by factors such as farmer skill and location. Also, water retention size is positively impacted by agroecological practices ($\beta = 0.47$, $p < 0.001$), farm size ($\beta = 0.18$, $p < 0.05$), and location ($\beta = 0.14$, $p < 0.05$). Adopting agricultural ecology practices may help farms maintain soil health, which is vital for future crop yield and flood adaptation.

Table 4. Analysis of Multiple Linear Regression (MLR).

Dependent Factors	Agroecological Practices (β)	Farm Size (β)	Farmer Education (β)	Location (β)	R^2	*p*-Value
Biological Diversity (Species Richness)	0.58**	0.15*	0.09	0.17*	0.49	<0.001**
Soil Organic Matter (%)	0.53**	0.12*	0.08	0.13	0.44	<0.001**
Water Retention Capacity (%)	0.47**	0.18*	0.07	0.14*	0.45	<0.001**
Annual Income (INR '000)	0.39**	0.20**	0.11*	0.21*	0.42	<0.001**
Crop Yield Stability	0.41**	0.19**	0.12*	0.16*	0.43	<0.001**

Note: **Significance at a higher level, typically at the 0.01 significance level ($p < 0.01$), is signified by the symbol, while the symbol states '*' significance at the 0.05 level ($p < 0.05$).

The results available here validate high crop yields and a substantial positive impact of agroecological practices on soil health and water retention capacity. Statistical significance ($p < 0.001$) and high β values (e.g., 0.53 for soil organic matter and 0.47 for water retention capacity) prove that agroecological practices may boost sustainable agriculture and farmer incomes.

From an economic analysis, there currently is a positive link between agroecological practices ($\beta = 0.39$, $p < 0.001$), farm size ($\beta = 0.20$, $p < 0.001$), and location ($\beta = 0.21$, $p < 0.05$) and annual income. So, there is evidence that agroecological practices optimise sustainable agriculture metrics and enhance profitability, especially when added with larger farm sizes and preferred GPS. Although its impact is not as evident as that of the other factors, farmer training ($\beta = 0.11$, $p < 0.05$) also has a beneficial impact. Lastly, sustainable agriculture's role in dropping crop yield variability is reinforced by evidence that crop yield constancy proves a significant positive correlation with agroecological practices ($\beta = 0.41$, $p < 0.001$). Multiple factors, including agricultural ecology, contribute to improving crop yields over time, as indicated by farm size ($\beta = 0.19$, $p < 0.001$), location ($\beta = 0.16$, $p < 0.05$), and farmer training ($\beta = 0.12$, $p < 0.05$).

The ANOVA in **Table 5** indicates statistically significant differences in biological diversity, soil health, and farmer incomes across farms with three levels of agroecological practices—low, medium, and high adopters. The F-statistics and *p*-values, all with a *p*-value less than 0.001, verify the results. As agroecological practices increase, biological diversity (species richness) increases. The average species richness for low adopters is 9.84, medium adopters 13.67, and high adopters 17.58.

Table 5. Results of ANOVA for Agroecological Practices Intensity.

Dependent Factors	Low Adopters (Mean ± Standard Deviation)	Medium Adopters (Mean ± Standard Deviation)	High Adopters (Mean ± Standard Deviation)	F-Statistic	*p*-Value
Biological Diversity (Species Richness)	9.84 ± 2.31	13.67 ± 3.21	17.58 ± 3.94	36.12	<0.001**
Soil Organic Matter (%)	2.54 ± 0.83	3.42 ± 1.09	4.62 ± 1.34	28.76	<0.001**
Water Retention Capacity (%)	15.34 ± 4.71	21.29 ± 5.26	27.78 ± 6.07	30.54	<0.001**
Annual Income (INR '000)	223.49 ± 78.32	317.68 ± 105.91	439.58 ± 128.76	24.89	<0.001**
Crop Yield Stability (Index)	0.72 ± 0.11	0.84 ± 0.16	0.92 ± 0.19	21.67	<0.001**

Note: **Significance at a higher level, typically at the 0.01 significance level ($p < 0.01$).

As species richness increases from low (9.84) to high (17.58) adopters, it is reasonable to assume that low adopters show minimal improvement in biological diversity under agroecological practices. Their low or minimal adoption of agroecological practices means they aren't doing nearly as much to support the environment as medium- or high-adopters, who use sustainable agriculture more frequently and increase biological diversity.

The F-statistic of 36.12 indicates a substantial impact of agroecological practices on biological diversity, signifying that farms adopting more intensive agroecological practices use more ecological agricultural methods, likely due to higher environmental biological diversity and reduced reliance on chemical inputs.

The soil organic material demonstrates an apparent increase in adoption, starting with low adopters (mean = 2.54%), then medium adopters (mean = 3.42%), and finally high adopters (mean = 4.62%). High adopters practiced the most significant developments in soil fertility, and the F-statistic of 28.76 confirms that agroecological practices significantly affect soil health. Furthermore, water retention size increases from 15.34% among low adopters to 21.29%

among medium adopters and 27.78% among high adopters, with an F-statistic of 30.54. It also validates that increasing agroecological practices significantly improves soil moisture retention, which is vital for farmers' incomes, drought resistance, and the sustainability of crop yields.

There is a robust positive correlation between agroecological practices and yearly income in terms of economic results. An average yearly income of ₹223,490 is stated by low adopters, ₹317,680 by medium adopters, and ₹439,580 by high adopters. Better market access, lower input costs, and improved crop yield significantly contribute to higher farmer incomes, as indicated by the F-statistic of 24.89. Finally, higher levels of agroecological practices are associated with higher crop yields, a measure of stable agricultural output. A low adopter index for crop yield stability is 0.72, a medium adopter index is 0.84, and a high adopter index is 0.92 (F-statistic 21.67). Research highlights the vital role of agroecological practices in reducing crop yield unpredictability and increasing the adaptability of sustainable agriculture.

As agroecological practice levels improve, soil health and biological diversity improve dramatically (**Table 6**). There are also evident changes among low, medium, and high adopters. An apparent correlation emerges from soil health metrics: it is associated with higher levels of agroecological practices. The soil organic material increases soil fertility compared to low adopters (2.54%) and high adopters (4.62%).

Table 6. Soil Health and Biological Diversity Metrics by Agroecological Practices Intensity.

Metric	Low Adopters (Mean ± Standard Deviation)	Medium Adopters (Mean ± Standard Deviation)	High Adopters (Mean ± Standard Deviation)
Soil Health			
Soil Organic Matter (%)	2.54 ± 0.83	3.42 ± 1.09	4.62 ± 1.34
Soil pH	6.09 ± 0.47	6.44 ± 0.53	6.81 ± 0.48
Nitrogen (mg/kg)	78.49 ± 21.23	114.73 ± 29.58	152.68 ± 36.91
Phosphorus (mg/kg)	16.42 ± 5.73	23.78 ± 6.52	29.87 ± 7.46
Potassium (mg/kg)	88.37 ± 26.31	134.56 ± 37.42	179.24 ± 41.87
Water Retention Capacity (%)	15.34 ± 4.71	21.29 ± 5.26	27.78 ± 6.07
Biological Diversity			
Species Richness (No. of Species)	9.84 ± 2.31	13.67 ± 3.21	17.58 ± 3.94
Crop Diversity (No. of Crop Types)	2.53 ± 0.89	3.94 ± 1.22	5.83 ± 1.64
Pollinator Abundance (No. Per Hectare)	34.89 ± 12.21	59.32 ± 16.87	82.47 ± 21.93
Natural Pest Predators (No. Per Hectare)	28.62 ± 10.53	48.17 ± 15.29	69.76 ± 18.74

Also, low adopters find soil pH at 6.09, while high adopters find it improves to 6.81, a higher neutral pH that is healthy for crop development. Essential resources, such as phosphorus, potassium, and nitrogen, become more readily available through agroecological practices. Soil phosphorus and potassium levels follow trends similar to those of nitrogen, indicating that agroecological practices help maintain balanced, nutrient-rich soils. Nitrogen levels rise from 78.49 mg/kg in low adopters to 152.68 mg/kg in high adopters.

The findings indicate a substantial boost in another vital soil metric, water retention size, from 15.34% in low adopters to 27.78% in high adopters. Research demonstrates that agroecological practices can improve soil health and water retention, two factors vital to long-term weather resistance and agricultural yields.

In contrast, high adopters had a median of 17.58 species, while low adopters had a median of 9.84 species, as reported in the research. This validates that species numbers are substantially higher among farms that adopt agroecological practices. It also shows that agroecological practices, which involve minimizing the use of agricultural chemicals and changing crops, generate an environmentally friendly environment for common species, boosting biological diversity and the availability of nutritious foods.

Improving the ecology and reducing insect repellent use increased pollinator benefits and the presence of natural pest predators in high adopters, from 34.89 per hectare in low adopters to 82.47 per hectare in high adopters. Comparably, the number of organic pest predators increases from 28.62 per hectare to 69.76 per hectare, reflecting the ecological profits of agroecological practices by reinforcing these pest-control methods.

Researchers labelled all ecological results with specified units. Soil organic carbon (% (pH unitless), nitrogen (kg/ha), phosphorus (mg/kg), and potassium (mg/kg) represent a few of the soil health factors. Measures used by the biological diversity index contain Simpson's (D) and Shannon-Weiner's (H') metrics. Yield (kg/ha) and Farmer Net Income (₹/year) have been correctly described as economic factors. To improve analytical accuracy, cross-sectional equivalence, and predictability in subsequent agricultural ecology trainings, each factor is currently discussed in a dedicated "Data Indicator Glossary" section of the methodology.

The coefficient of variation is a relative IV used to measure IV. Therefore, calculate the standard deviation of yearly income and divide it by the mean income. Then, multiply the result by 100. As the use of agricultural ecology increases, a lower IV% indicates a more predictable income. Researchers have identified all factors and their respective values in **Table 7** using the same method.

Table 7. Economic Analysis by Agroecological Practices Intensity.

Economic Metrics	Low Adopters (Mean ± Standard Deviation)	Medium Adopters (Mean ± Standard Deviation)	High Adopters (Mean ± Standard Deviation)
Annual Income (₹1000)	223.49 ± 78.32	317.68 ± 105.91	439.58 ± 128.76
Input Costs (₹1000)	67.93 ± 21.59	49.42 ± 17.24	31.69 ± 13.87
Crop Yield Stability (Index)	0.72 ± 0.11	0.84 ± 0.16	0.92 ± 0.19
Market Access (Score 1–5)	2.43 ± 0.76	3.19 ± 0.89	4.21 ± 1.08
Income Variability (IV%)	38.76 ± 9.53	26.57 ± 8.32	17.94 ± 6.47
Profit Margin (%)	38.45 ± 11.23	53.81 ± 13.97	65.28 ± 16.74

Table 7 illustrates that as the level of agroecological practices increases, financial results and farmer incomes improve significantly. Annual income is one area where there can be a significant change, increasing from an average of ₹223,490 for low adopters to ₹439,580 for high adopters. The financial benefits of agroecological practices, such as improved efficiency, reduced support on prohibitively priced external inputs, and access to high-quality markets like organic and fair trade, where higher prices can be achieved, are evident in this substantial increase in income. Agroecological practices significantly reduce farmers' income, with low adopters costing ₹67,930 and high adopters costing ₹31,690. A key benefit of agroecological practices is reduced costs associated with chemical fertilizers and pesticides. This reduction is possible because agroecological practices depend on the environment and organic inputs to lessen their costs.

Individuals who adopt agroecological practices rapidly tend to have higher crop yield stability index scores. This proves that agricultural ecology farms, with their factors, cropping methods, and improved soil health, may reliably increase crop yield. Also, high adopters prefer to validate at higher levels of farmer income, primarily because they have superior market access, which puts them in a better position to reach sustainable markets, such as local markets or certified organic methods. This recommends that robust agroecological practices may better weather challenges.

Farmers experience less financial risk, more financial support, and less income volatility as a result of agroecological practices. For early adopters, the coefficient of variation drops from 38.76% to 17.94%, which improves future planning. Profit margins rise from 38.45% to 65.28%, signifying agricultural ecology's fiscal efficiency. As agricultural ecology becomes more commonly practiced, it will have a positive impact on the environment and farmers' bottom lines.

According to the conceptual model of sustainable agriculture, there are correlations among agricultural ecological methods, soil health, the preservation of biological diversity, and farmers' support methods. The study examines how integrating ecological principles into sustainable agriculture methods improves ecological performance and Social-Ecological Systems outcomes, depending on the agricultural ecology stimulation method and the primary Social-Ecological Systems theory. Because the world's first fully organic state, Sikkim, India, represents an ideal context for investigating the impacts of sustainable agriculture and conventional agricultural methods on smart farming's income stability, soil health, and agricultural biological diversity. Since previous analyses mainly studied ecological data and financial stability measures separately, recent research (2020–2024) highlights the requirement to combine these metrics. To address that void, the current research employs agricultural ecology management practices tailored to each GPS area to support ecological renovation and financial stability.

East, West, and South Sikkim were the three agro-climatic zones surveyed using a stratified sampling method. To ensure that the villages are representative of sustainable agriculture and social-ecological systems, they should be scored based on their GPS locations, cropping methods, and organic certification levels. The agricultural features were then selected at random, taking into account the spread of demographic and cropland. The study's area covers agricultural lands at mid-hill and high altitudes, with coordinates ranging from 27.33° N to 27.45° N and 88.55° E to 88.62° E. Analyses showed that the soil was nutrient-rich loamy soil that was appropriate for organic farming based on all of the following physical and chemical values measured before data collection started: pH (6.1–6.8), organic carbon awareness (1.8–2.4%), nitrogen availability (310–340 kg/ha), phosphorus awareness (18–24 mg/kg), and potassium content (180–220 mg/kg). The Sikkim Meteorological Department's climate data indicate a subtropical humid mountain climate suitable for several crop methods, with a median temperature of 18–22 °C and an average annual rainfall of 2200–2800 mm.

Researchers can put the findings into practice by applying them to support models of policy-driven agricultural ecology revolution that aim to restore agricultural ecology methods while boosting farmer incomes. These findings provide practical methods to improve smart farming based on sustainable agriculture, increase financial support for rural regions by ecological certification programs and nature-based value chains, and support OF farming that supports biological diversity.

Data errors, social desirability bias, and GPS bias are all likely problems with the current research's training and testing of the sample data. The conclusion states that the results could be biased if the sample doesn't accurately represent the rural population. Data on farmers' ideas and predilections, particularly regarding their reported sustainable agriculture and farmer incomes, were incorrect. Particular regions may have higher or lower support for adopting such practices, and local changes in agroecological practices and EF may bias the findings in one direction.

5. Conclusion and Future Work

The rural farming areas of Sikkim have seen significant changes in the benefits derived from their biological diversity, as reported by the present research. In addition to improving soil health and biological diversity, the findings indicate that agricultural ecology helps small-scale agriculture become more economically adaptable by reducing input costs, increasing crop yield, making it more predictable, and providing more access to high-value markets. More species biological diversity, improved soil health, and increased water retention capacity indicate that sustainable agriculture practices have boosted agroecological cultivation, which, in turn, supports sustainable agriculture and reduces climate change by smart farming methods.

Adopting agroecological practices improves biological diversity, soil health, and farmer incomes while minimizing input costs, as determined by regression analysis in the current research. In addition to improving farmer incomes, the results validate that agroecological practices enhance environmental sustainability, providing support for their larger adoption in rural areas for sustainable agriculture.

The increased farmer incomes and reduced unpredictability experienced by farmers who practice agroecological practices provide additional evidence of agricultural ecology's economic benefits. The future viability of agroecological practice farms is enabled by adopting organic inputs and diverse cropping methods, thereby making them less susceptible to environmental and economic changes in South Asia. The analysis provides increasing evidence that agricultural ecology is a vital method for achieving sustainable agriculture. Recommendations for professionals and governments to develop agroecological practices across different domains are also presented. This research emphasizes the importance of agroecological practices in the ongoing effort to develop sustainable agricultural food systems worldwide and presents numerous methods to improve the environment and rural farmers' incomes.

The literature review demonstrates that agroecological practices are more critical for sustainable agriculture. Prior research points to the environmental supports, including improved biological diversity and soil health. Nevertheless, some difficulties remain, such as the barrier to adoption and regional changes. In doing so, this study proposes a new view on the science of such dynamics across several farmer types.

Future research should explore the long-term impacts of agroecological practices and examine the problems to wider implementation to maximise its potential for global food security and sustainable agriculture.

Author Contributions

Conceptualisation, Methodology, Formal analysis, Writing—Original Draft, Writing—Review & Editing, Investigation: S.S.; Software: H.M.A. and S.L.K.; Validation: B.V.; Resources: D.A.S.S.L.; Data Curation: A.S.; Visualisation: K.S.K. and B.R. All authors have read and agreed to the published version of the manuscript.

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Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data supporting the reported results in this study are available upon request from the corresponding author. The datasets analysed or generated during the study are not publicly available due to privacy and ethical restrictions. However, data can be made available for academic research purposes upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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