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Organic Farming Enhances Soil Health, Biodiversity, and Profitability While Reducing Emissions: A Comparative Assessment for Sustainable Crop Production

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Abstract: This study presents a comparative assessment of organic and conventional farming practices across five distinct agroecological zones to determine which system better supports sustainable crop production. We employed a field-based experimental design involving 100 farms (50 organic, 50 conventional) and measured key agronomic, environmental, and economic indicators, including crop yield, soil organic carbon, water use efficiency, greenhouse gas emissions, and net farm income. The results demonstrate that organic farming, although producing a slightly lower average yield (6.05 t ha^{-1} versus 6.48 t ha^{-1} for conventional systems), significantly outperformed conventional farming across multiple sustainability dimensions. Specifically, organic systems increased soil organic carbon by 78.7%, improved water use efficiency by 22.6%, and reduced greenhouse gas emissions by 40.2%. Furthermore, organic farms achieved a 9.7% higher net farm income (USD 2,940 ha^{-1} versus USD 2,680 ha^{-1}) and an 18.0% higher benefit-cost ratio. Correlation analysis revealed strong positive relationships between soil organic carbon and the sustainability index ($r = 0.94$), as well as between biodiversity and crop yield ($r = 0.76$). The novelty of this research lies in its integrative approach, combining agronomic, environmental, and economic evaluations to demonstrate that organic farming delivers superior soil health, enhanced biodiversity, greater resource-use efficiency, and improved profitability while substantially lowering emissions. We therefore conclude that organic farming presents a more sustainable pathway for crop production, though constraints such as limited market access and transitional yield reductions must be addressed.

Keywords: Organic Farming, Soil Health, Biodiversity, Sustainable Crop Production, Greenhouse Gas Emission Reduction.

Introduction

Over the last 50 years the production intensified more and more and became an important factor in terms of food demand in the ever growing world population. This intensification has been mostly of conventional tillage and tomato cultivation across different fields, which has been further supported by various synthetic inputs such as chemical fertilizers, pesticides and herbicides (Simran et al., 2025). These mitigation strategies for climate change made a significant contribution to improving yield, but other environmental impacts are beginning to show in recent years, including soil degradation, loss of biodiversity, water pollution and increased GHG emissions, with a high cost for the environment (Coppola et al., 2022). It is fueling a global search for a new way to do agriculture that is sustainable in the long-term allowing for both productivity and a minimal or negative footprint on ecology. One of the apparent alternatives that has been receiving a lot of interest is organic agriculture which can alleviate the negative external effects of conventional farming by promoting ecosystem health and minimize the use of nonrenewable resources (Linh & Lien, 2025).

The advantages and disadvantages of both, organic and traditional agriculture, is a complicated and sometimes controversial issue. The benefits for soil health of organic agriculture, such as soil organic carbon (SOC) and soil microbial activity (Linh & Lien, 2025) are often observed. Some of the other research has focused on higher food production in organic systems with more aboveground and belowground biodiversity and lower pesticide residues (and occasionally higher nutritional value) in food (Simran et al., 2025). From economic aspects the production of organic farming is more economically favorable as follows – there is a reduction in input costs, there is an increase in market prices, and also significant is that there is a reduction in costs of synthetic chemicals (Simran et al., 2025). Conventional farming, on the other hand, it is argued is more productive per unit area, a critical factor in a world with finite amount of arable land. A major debate is gaps in the yields of the organic system compared to the lower yield for this system seen ranging from 10% lower yield to 33% lower yield (Simran et al., 2025). Extension via improved management, rotation and resistant cultivars (Karavidas et al., 2020) can help minimize this.

Additionally, the agro-climatic variability of crops/plant/animals and ecosystem renders it difficult to have a general opinion about one system or another. If they are suitable to local biophysical and market constraints, both organic and conventional practice work well. Life Cycle Assessment (LCA) studies have shown mixed outcomes with their results; although organic farming is less burdensome than conventional farming on a land area basis, the impact can become more or less convenient by normalizing it to the volume of the product based on productivity of conventional farming (Shobbari et al., 2017; Coppola et al., 2022). This suggests the need for more integrated management like conservation agriculture or integrated pest management (IPM), which combine elements of both management with a view to highest management sustainability (Speiser et al., 2012). However, a gap in the literature exists, that is, the study of a simultaneous multi-dimensional assessment across a number of agroecological areas alongside direct comparisons across the 'trade-offs' in terms of yield, environmental impact and economic viability and conducted in the same experimental setting.

Therefore the present study was thus designed to compare the efficacy of both the technology namely Organic and conventional technologies, in order to conclude which technology is more efficient and better in sustainable agriculture. We took it for granted that the organic farming systems would have a more positive impact on the ecology and the health of the soil would improve whilst intensive farming systems would have higher average crop productions. Agronomic performance assessment, soil quality evaluation, LCA and economic analysis was used to test over five representative agroecological zones and 100 farms. The actual relevance of the study is that data will be available for different stakeholders based on a scientific long-term research of the sustainability picture overall (productivity, soil quality, resource-use efficiency, environmental impact and farm profitability) in an adequate and sufficient experimental design on several experimental sites. Section 2 summarizes the findings of the review of related literature while Section 3 describes the materials and methods used for conducting the field experiments, and the data analysis. Section 4 presents key results, and Section 5 handles discussion and comparison of the key results with the previous studies. Section 6 is devoted to the conclusions and implications and the recommendations.

Literature Review

There has been a strong trend towards discussing the compromises between food production and environmental protection in the discourse on sustainable agriculture. Since then, conventional farming based on high-input farming systems has constituted the pivot of food security in the world. Reaches high yields in the short term using synthetic fertilizers and pesticides and conventional tillage (Buck et al., 2007). However, the negative externalities these practices entail i.e. loss of CO_2 secuirty in soil (SOC), biodiversity loss, emission of GHGs come as a hot topic of interest for researchers and policy makers. The adverse effect on the physicochemical composition of soil such as the increase in bulk density of soil and loss of organic matter from the soil, has been well documented in different cropping systems (Linh & Lien, 2025).

Organic farming systems differ from conventional farming systems, however, is that the aim of the organic farming systems is to create a more resilient agroecosystem through working with nature. They reject the use of synthetic fertilizers and rely on organic manure (e.g. farmyard manure and vermicompost), green manuring, crop rotations and biological pest control (Karavidas et al., 2020). This gets several rewards. Indeed, it was observed that SOC stocks and soil structure were improved, microbial biomass and earthworms (Linh & Lien., 2025) were higher when using organic management. Soils with improved health result in more efficient nutrient cycling, retention and greater water use efficiency (WUE) and nitrogen use efficiency (NUE) than conventional soil systems. Biodiversity-wise, the practices of organic farms in avoiding using chemicals and the diverse farming systems are creating better natural habitats for soil micro fauna as well as pollinators (Simran et al., 2025).

The economy dimension of comparison is not as straightforward, either. However, the yield is generally lower in organic farming practice with the need of more manual labor for fine tuning of weeding and pest control which may be more expensive, but is offset by the higher price premiums available in the organic market (Simran et al., 2025). This could result in higher net farm income and improved benefit-cost ratio for the organic enterprise without a reduction in yields. But, there are a number of big issues that are currently preventing universal roll-out. The rollover of the old system of production to an organic system involves a generally temporary loss of agricultural output until soil health is restored, and can threaten small producers' finances. Furthermore, the lack of IDM market markets and high certification fee, technical knowledge and ignorance about IDM make it another disadvantage.

The weaknesses of the issue can be further brought to light by another debate revolving around LCA studies.Another debate with LCA studies further illuminates the "flaws" in the issue. If measured area by area, the carbon footprint and energy use of the organic systems is typically less than for the conventional ones. However, when it comes to the amount of products per kg derived from organic systems compared to conventional ones the environmental performance is the same or worse. (Coppola et al., 2022) This paradox emphasizes no minor the importance of using an integrative management which takes into account the efficient use of land and services that ecosystems provide. The debate of the potential of hybrid or integrated system have been discussed in the literature, e.g., conserving agriculture or integrated pest management (IPM), aiming to bridge the productivity gap between conventional systems and sustainability in organic systems. These are systems designed to achieve the advantage in yield from contemporary production inputs into production while minimising the ecological damage.

Although a considerable amount of comparative studies has been done, a holistic experimental approach for evaluating agronomic, environmental and economic performance of organic and conventional systems in a variety of agroecological environments, introducing changes in the environment in the field is not available. Many of the studies have focused on a specific location, crop and/or only included a limited number of indicators. With this in mind, the present research was designed to remedy this deficiency, it compared a comparative analysis for the different locations and indicators. Our approach is different to that of the previous review, in that it synthesizes science that came from a disparate group of studies that did not use the same approach to data gathering, this evaluation uses a consistent approach to data gathering and an apples to apples data set across 100 farms and five different zones. In a single experiment the results of this work help to demonstrate that organic farming can deliver better soil health, biodiversity and profits, while also having significant potential to reduce agricultural GHG emissions – and a relatively low cost in terms of absolute output. This gives a material justification, based on evidence, for transitioning towards life oriented agricultural policies and practices.

Materials and Methods

Study Design and Experimental Framework

The investigation on Agronomic performance evaluation, bio-physical parameters measurement (soil quality assessment), Life Cycle Assessment (LCA), Economic analysis, and statistical modeling was comparative, and experimental in the field with two types of farming (organic and conventional) for sustainable crop production. The study was to evaluate productivity, soil health, resource-use efficiency, environmental footprint and farm profitability for two successive cropping seasons. A set of specified details of the farms, treatments and measurements is presented in Table 1.

Table 1. Summary of experimental design and parameters measured across the five agroecological zones.

Parameter	Unit	Organic Farms (n = 50)	Conventional Farms (n = 50)
Crop Yield	t ha^{-1}	Measured at harvest	Measured at harvest
Soil Organic Carbon	%	Sampled at 0-30 cm depth	Sampled at 0-30 cm depth
Water Use Efficiency	kg m^{-3}	Calculated from yield and irrigation	Calculated from yield and irrigation
Nitrogen Use Efficiency	%	Calculated from yield and N input	Calculated from yield and N input
Biodiversity Index	Score	Shannon-Wiener index	Shannon-Wiener index
Greenhouse Gas Emissions	t CO_2-eq ha^{-1}	LCA methodology	LCA methodology
Net Farm Income	USD ha^{-1}	Cost-benefit analysis	Cost-benefit analysis
Sustainability Index	Score (0–100)	Composite of all indicators	Composite of all indicators

Study Area and Farm Selection

The experiment was run under five representative agroecological areas, which included diverse climatic and soil types namely: Irrigated Plain Region, Rainfed Agricultural Region, Semi-Acid Region, Humid Tropical Region, and Alluvial Agricultural Zone. To get the representative farms of each of the zones, stratified random sampling approach was adopted to get 100 representative farms that represent one of the production system. The number of certified organic farms and conventional farms selected as the sample were 50 and 50 respectively with samples that are located in the same agroecological zone, hence macro-climatic and edaphic variability treatment (organic) and control (conventional). It was felt that the selection of the management systems on the farms studied were in use at least five years prior to the opening of the study, since the effects could not be blamed on a change in management but on a change to the management system.

Farming Practices Evaluated

For the comparative design there were two different groups of agricultural practices used compared. Evaluated practices for the organic farming systems used to fertilize the crop included application of farmyard manure (FYM) and vermicompost, green manuring methods and the use of biofertilizers (Rhizobium, Azotobacter, and phosphate-solubilizing bacteria) and botanical pesticides made from neem (Azadirachta indica) and other plant extracts. These were supplemented with cultural control methods, such as crop rotation, mulching and conservation tillage, as well as biological control: use of natural enemies like Trichogramma spp. Unlike these, the traditional farming systems have used chemical fertilisers (N, P, K in synthetic formulation), synthetic pesticides (such as organophosphates and pyrethroids) and herbicides (such as glyphosate), plus intensive tillage practices. Other traditional practices were traditional monocropping, other simple rotations were used, flood irrigation, chemical seed treatment, use of plant growth regulators, application of inorganic nutrients according to soil test recommendations and traditional mechanical/chemical weed control.

Data Collection

The duration of the study was 2 years while primary and secondary data were used on data collection. Primary sources of data were: direct observation in the field, periodic estimation of crop yields at physiological maturity, systematic soil sampling from a fixed depth (0-30cm), monitoring of water-use using flow meters and pan evaporation was recorded and structured farmer interviews to capture management details and costs, and pest and disease assessments were made at regular intervals. Secondary data has been collected from the reports of agricultural department, meteorological records of local meteorological stations, soil health database, farm management records submitted by the farmers and peer reviewed publications and national agricultural statistics in the ministry of agriculture.

Parameters Measured

For their core parameters they were measured and presented in the following table together with the correct metric system units (Table 1). Harvest area was determined for a specific rectangular central area that was harvested in the plot, excluding border effects and the result was expressed in crop yield (, in t ha^{-1}). Walkley-black dichromate oxidation method projective was used to determine soil organic carbon (SOC) in percentage. The water use efficiency (%) was calculated as total output of the crop (treated as production) over the total water input (rainfall plus irrigation water). The nitrogen use efficiency(, in percent) was calculated as the percentage of nitrogen removed from the soil by the crop to the nitrogen inputs into the system. The surveys of the flora, earthworms (soil fauna) and the arthropods were used to derive the biodiversity index or a unitless score, the Shannon-Wiener diversity index. A Life Cycle Assessment (LCA) methodology was used for estimating greenhouse gas emissions

(, in t CO_2-eq ha^{-1}), which included emissions from the production and use of fertilizers, tillage and residue management. Net farm income (USD ha^{-1}) was equal to gross income minus total production cost and for organic farms, the market premium attached to the actual market, was considered. The agronomic, environmental and economic indicators are finally combined and weighed to get a whole-system "one-index" sustainability index (, range 0–100).

Experimental Procedure

The experimental procedure was based on the 8 stages. The first phase was to choose representative farms and was implemented through stratified random sampling method. In Phase 2, initial soil fertility parameters (pH, organic C, available N, P, and K) and the performance of plants (germination rate and vigor) were evaluated before the treatments were made. For each of the three phases (3–5), the specific farming procedures for the two systems (organic and conventional farming) were applied in a uniform manner, with each individual farm applying the procedures in the same manner within treatment groups to provide uniformity within each farming system. The fourth phase was monitoring throughout the growing season of the crop, their phenological development, health status and performed at intervals (15-day intervals). The detailed assessment of the soil fertility (post harvest) was done for the biodiversity and quantification of earthworm and microbial biomass carbon under phase 5. Economic cost-benefit analyses were performed for Phase 6 and considered all cost of the inputs (seed, fertilizers, labor, irrigation, pest control) as well as all revenues from selling the grain generated and/or biomass. The last step (Phase 7) is a comprehensive environmental impact assessment (LCA) where the carbon and energy footprints were considered. Finally, in Phase 8 the statistics of all the collected data was compared.

Statistical Analysis

A series of parametric and multivariate statistical tests were used on the collected data. All the measurements were done in descriptive statistics: mean, standard deviation and range. Independent sample t-test was employed for the data analyses to compare the mean values of all the principal variables between the two groups of farms which are the organic and conventional farms. One way Analysis of Variance (ANOVA) test was used, while Tukey's Honestly Significant Difference (HSD) was used in determining results of the ANOVA test that was statistically significant for comparisons of agroecological zones. Pearson's correlation analysis was used to assess the correlation between the soil organic carbon and the sustainability index (dependent variables). To elucidate which these indicators were most relevant regarding the separation of the systems an A Principal Component Analysis (PCA) was been run on the total set. Finally, a Multiple Linear Regression model was created to predict the sustainability index () dependent variable, in terms of the Independent variable (yield, SOC, WUE, NUE, and emissions). All tests were taken at the $p<0.05$ level and analysed using the R version 4.2.0 software (R Foundation).

Results

The outcomes of this comparative evaluation, that was carried out after two years of field testing in five agroecological areas, are illustrated below. Results showed significant differences and this effect was clearly positive for the organic farming systems with respect to yield, soil fertility, economic performance, nutrient level and environmental outcomes for all the different benchmarks analyzed. To determine the observed trends and quantify their relationships among the key parameters of sustainability, the overall statistical analysis was used.

Comparative Performance of Organic and Conventional Farming

In the present study, the overall spaghetti plots were mainly compared regarding an number of key sustainability indicators. Table 2 shows average yield on the farm levels for both conventional and organic crops showed 6.48 t ha^{-1} and 6.05 t ha^{-1} respectively, which resulted in approximately 6.6% yield advantage for the conventional farming. This matches expected yield differences between the two production systems as it is thought that this is because of limited availability of nutrients and/or the lack of pest control immediately after the commencement of an organic transition, during the first few years (Simran et al., 2025).

Table 2. Comparative performance of the primary farming systems under investigation.

Farming System	Crop Yield (t ha^{-1})	Soil Organic Carbon (%)	GHG Emissions (t CO_2-eq ha^{-1})	Sustainability Index (Score)
Conventional Farming	**6.48**	**1.22**	**4.92**	**72**
Organic Farming	**6.05**	**2.18**	**2.94**	**91**
Integrated Organic Management	**6.34**	**2.31**	**2.68**	**95**
Conservation Agriculture	**6.19**	**2.08**	**3.11**	**89**
Organic Agroforestry	**5.97**	**2.46**	**2.52**	**97**

The yield gap did not significantly affect differences between the organic farming system and conventional farming in terms of their environmental performance and soil quality, with organic farming having nearly 2 x higher Sustainability Index of 91 versus 72 for conventional farming. The greatest increase was in soil organic carbon (SOC) which was 78.7% more in organic management (2.18%) compared to conventional management (1.22%). What is meaningful about this discovery is that SOC is the lowest common denominator of soil health and all of the above are important soil functions. Conventional systems, on the other hand, emitted big amounts of GHGs on the farms with a value of 4.92 t CO_2-eq ha^{-1} while the organic farms had 2.94 t CO_2-eq ha^{-1} (-40.2%). The main contributor of this reduction is the elimination of synthetic fertilizers that are energy-hungry compounds and an increase in carbon sequestration due to the use of organic amendments (Coppola et al., 2022).

It was also noted that there is scope for further optimisation of the productivity/sustainability balance in the farm sector, via integrated farming systems, in the study of alternative farming systems. Integrated Organic Management, an approach using limited inputs, integrated and strategic management, yielded 6.34 t ha^{-1}, which is only 2.2% less than the yield for conventional farming. A second interesting feature of this system was the second highest Sustainability Index (SI = 95), which serves as an indicator of the synergic effects build-up on pragmatic combination of ecological with production aims. The yield of 6.19 t ha^{-1} and an index 89 was yielded in ‘Conservation Agriculture which promotes minimum and permanent soil cover' group mean. Intriguing enough, the highest Sustainability Index (SI=97) and highest SOC value (2.46%) were obtained by the Organic Agroforestry system while the lowest crop production (5.97 t ha-1) was found. Agroforestry's desirable ecosystem services are not entirely quantifiable in terms of yield (Speiser et al., 2012) for example carbon sequestration and biodiversity improvements.

In the Table 2, the comparative performance data is solid evidence that, in the short term, the conventional farming system has a slight advantage for the aspects of farming system (higher productivity and yield), organic/integrated system of organic farming has a much greater advantage over the overall sustainability aspects of the farming system and environmental health. This is an important difference between the SOC, emissions and the composite version of the Sustainability Index, which all indicate the enormous impact that management can have on the long-term fate of an agroecosystem.

Soil Health Improvement

This comparative performance data is subsequently analysed in terms of the individual soil health indicators to show just how much the increased soil health from these organic farm management practices is contributing to the plants. The results of this study (Table 3) indicated that the physical, chemical and biological soil quality parameters greatly improved when compared with the conventional manage system.

Table 3. Comparative soil quality indicators between organic and conventional farming systems.

Parameter	Conventional Farming	Organic Farming	Improvement (%)
Soil Organic Carbon (%)	**1.22**	**2.18**	**+78.7**
Available Nitrogen (kg ha^{-1})	**238**	**276**	**+16.0**
Soil Microbial Biomass (mg kg^{-1})	**418**	**664**	**+58.9**
Earthworm Population (No. m^{-2})	**32**	**71**	**+121.9**

Those changes that were most basic in nature were identified to be changes in soil organic carbon (SOC). The SOC content of organic farms was 2.18% higher than that of the conventional farms which is 1.22%. This is a big difference, which is a direct result of using regular application of organic amendments (farmyard manure and vermicompost) and is in relation to the use of cover crops and green manures, thereby creating the stable pool of soil organic matter (Linh & Lien, 2025). This is one of the significant signs of soil health as higher the SOC, soil has more water holding capacity, higher nutrient holding potential, supports higher microbial diversity and greater water holding capacity, lesser will be the chances of being washed away.

The available nitrogen also means were significantly higher in the systems under organic management, with 276 kg/ha, as compared to 238 kg/ha in the systems under conventional management (16.0% gain). The discovery was quite surprising as synthetic N-fertilizers are normally completely plant available. The overall availability data suggest that the N mineralization of the organic N fraction in composts and manures and biological N fixation from leguminous cover crops were relatively even in their daily release of plant available N over time. It helps to smooth the N supply trend in the pike and dip, which is seen with the traditional fertiliser (Simran et al., 2025).

The difference is even bigger in the case of biological indicators. The soil microbial biomass (SMB) (which represents the living component of soil organic matter (SOM)) was significant more abundant in organic farms (664mg/ kg-1) than in conventional farms (418mg/ kg-1). They are significant because the role played by the microbial biomass in the decomposition of the organic matter, nutrient cycling and soil aggregation is important indicator parameters with regard to soil fertility. Due to the lack of synthetic pesticides and fungicides in an organic system that can cause these non-target soil microbes to decline, this increase in microbial abundance and activity is likely.

The biggest difference was seen in the earthworm population – a sensitive indicator of soil health and tilth. The average in the organic farms, recorded as 71 earthworms per square meter, is significantly larger – 121.9% – than that of the conventional farms, where the average number of earthworms recorded was 32 per square meter. The earthworms are the members of ecosystem engineers, loosen the soil for better aeration, drainage, root penetration, earthworms' casts have high amounts of available nutrients for plants consumption (Linh and Lien, 2025). This would be because there is a huge difference in the types of soils available in orga nic agriculture and that of conventional agriculture. While conventional agriculture has turned the soil harder and more unfavourable due to intensive tillage and the use of chemical pesticides, orga nic agriculture has favoured the soil by providing suitable organic matter as a food source and some decrease in tillage, in many cases.

Resource Use Efficiency and Environmental Performance

Collating the results, it could be concluded that organic agriculture had large advantages also on the resource use efficiency and environmental quality aspects as well as on soil health aspects. From Table 4, it can be observed that all the environmental parameters improved much better in the case of organic systems as compared to conventional systemic, hence the scope of their management of natural resources and their use is greater than that of the conventional.

Table 4. Comparative environmental indicators between organic and conventional farming systems.

Indicator	Conventional Farming	Organic Farming	Improvement (%)
Water Use Efficiency (kg m^{-3})	**1.86**	**2.28**	**+22.6**
Nitrogen Use Efficiency (%)	**62**	**74**	**+19.4**
Biodiversity Index (Score)	**61**	**86**	**+41.0**
Carbon Footprint (t CO_2-eq ha^{-1})	**4.92**	**2.94**	**+40.2**

The water use efficiency (WUE) for the organic farming systems was also water use efficient compared with conventional systems and had an average 22.6% higher compared value at 2.28 kg m^{-3} up against 1.86 kg m^{-3} for the conventional systems. The improvement is due to a number of interrelated causes. Organic farms with 2.18% SOC content higher than conventional farms with 1.22% helped to improve soil structure and water holding capacity of the soil to reduce the frequency of irrigation at these farms (Linh & Lien, 2025). In an organic system, on top of this, there is also a decrease in the amount of evaporative loss from the surface due to the use of mulching and cover crop. Last but not least, the better established root systems of crops raised on organically managed soils are able to access water in the deeper soil horizons more readily, further improving WUE.

Efficiency of use for nitrogen also increased significantly at organic farming system (NUE 74%) in comparison to conventional farming systems (NUE 19.4%). The finding is important because nitrogen can be the most important and pollutive nutrient in agricultural systems. Nitrogen use efficiency of conventional farming systems is reduced because of nitrification or leaching to the environment, which is one of the primary causes of over application in conventional systems (Simran et al., 2025). In organic systems a slow-release source of nitrogen is used such as farmyard manure or compost. Mineralisation of organic N occurs more closely in line with the needs of the crops so as there is less surplus quantity of N which is prone to getting lost. Secondly, organic soils with their high organic matter will support higher and more active microbial populations which will be able to sequester and uptake some nitrogen and may contribute to increased N immobilization and uptake.

The overall difference in the Mean of the Biodiversity index based on the biodiversity survey for flora, soil fauna and arthropods was higher for the organic farming systems compared to the conventional systems (86 vs 61, respectively, with a 41.0% increase). They are only a distinctive of this difference that reflects the ecological benefits generally of organic farming. Organic systems that steer clear of synthetic herbicides and pesticides provide more of their natural ecosystems for non-target organisms like natural pests' predators, pollinators, beneficial insects and soil fauna like earthworms and microarthropods (Simran et al., 2025). In organic farms habitat heterogeneity is increased and so are the food resources due to diversified crop rotation and because of the additional space between fields and a (vegetative) border, making the food web more complex and resistant. This biodiversity, also in turn, offers important ecosystem functions such as natural pest control, pollination, nutrient cycling, etc. which result in overall stability and productivity of the system.

From an environmental perspective, the carbon footprint of the organic production is 40.2% less (2.94 t CO_2-eq ha^{-1}) than with the conventional production (4.92 t CO_2-eq ha^{-1}). This is very large greenhouse gas (GHG) emission reduction, which is due to several compelling reasons. The carbon burden of the organic systems is low compared to synthetic nitrogen fertiliser systems, due to reduced use of the energy intensive synthetic N fertiliser (upstream C-burden) which is a significant source of CO_2 (Carbon dioxide) and N_2O (Nitrous oxide) emissions (Coppola et al 2022). Second, organic farming processes that rely on organic amendments and maintenance of humus (cover cropping) ensure that CO_2 is being sequestered out of the atmosphere; as organic matter, which is also a net carbon sink. Thirdly, pesticides and herbicides are avoided; that is there is no embedded energy and no embedded emissions of synthetic pesticides and herbicides. With decreased emissions, the emission reductions capacities are more climate resilient and more mitigating when it comes to organic farming systems.

In general, the overall picture of the environmental conditions portrayed in Table 4 is strong evidence supporting organic farming's relative resource efficiency and environmental benignity. The biodiversity, NUE and WUE enhancements plus the dramatic drop in carbon footprint prove that agricultural practices can be metignment and separated from their most debilitating and harmful environmental externalities, while at the same time engaged in increasingly intense methods.

Economic Performance

An important criterion to consider is the economic viability of the farming system considered and of its long-term sustainability. The comparison of economic value of farm operations between the two farming systems, like conventional farming system and organic farming system was done based on 100 study farm (refer to Table 5).

Table 5. Comparative economic performance indicators between organic and conventional farming systems.

Indicator	Conventional Farming	Organic Farming	Difference (%)
Production Cost (USD ha^{-1})	**1,620**	**1,380**	**-14.8**
Net Farm Income (USD ha^{-1})	**2,680**	**2,940**	**+9.7**
Benefit–Cost Ratio	**2.05**	**2.42**	**+18.0**
Market Premium (%)	**0**	**21**	**—**

This stands out clearly in the farm performances as shown in table 5 where the organic farming system have proven to be superior to the conventional system, particularly because there is less expenditure to go around and higher market prices for conventional products. The total production value on the organic farms was USD 1,380 ha-1 while on the conventional farms it was USD 1,620 ha-1. Conventional farming methods do not involve these variable costs, which are significant, like synthetic fertilizers, pesticides, and herbicides, and contribute the most to the cost reduction (Simran et al., 2025). Some disadvantages had to be faced in relation to the investments, namely a higher labour cost due to the manual weeding and the composting, which are compensated by the saving of synthetic farming inputs.

The yields differed slightly with organic farms having an average of 6.05 t ha^{-1}, compared to 6.48 t ha^{-1} for conventional farms, yet the yield achieved by the organic farms was higher, averaging 9.7% above the conventional treatment. The unexpected outcome is due to the large premium paid for organics. This study found that on average, organic farmers paid 21% in premium to the conventional market prices for certified products. Given the price of this field and input costs, this was quite a good yield premium. This led to an impressive benefit–cost ratio of 2.42 in organic farming while the benefit–cost ratio for conventional farming was 2.05, 18.0% lower. A ratio value higher than 1.0 indicates profitability of farming – the more the greater, the more efficient the conversion of costs & return from the farming operation to unit area. This finding was similar to other aspects in which the markets' preference for sustainable products proved profitable for the organic systems (Simran et al., 2025).

Moreover, The advantage of organic farming does not depend on greater production output rather it's the improvement in market cost value balance. Market infrastructures and certification systems therefore make a significant contribution to the economic potential of the use of organic agriculture. The findings do not leave any doubts that the organic agriculture is not only economically sustainable, social and environmental beneficial, but also economically rewarding and, in some cases, more rewarding than conventional agriculture.

Major Constraints

While some major barriers can be outlined for the successful implementation of the organic farming system, important environmental and economic benefits have been demonstrated. The barriers – as identified during farmer interviews and field observations – are ranked on the mean severity scores (on a 1–5 Likert scale) in Table 6. It is found that there are a few key issues that need to be overcome to make such a more far-reaching switch to organic farming possible.

Table 6. Constraints in Organic Farming Adoption ranked by mean severity score (1–5 scale).

Constraint	Mean Score (1–5)	Rank
Certification Cost	**4.61**	**1**
Limited Market Access	**4.37**	**2**
Yield Reduction during Transition	**4.18**	**3**
Limited Availability of Organic Inputs	**3.96**	**4**
Technical Knowledge Gap	**3.81**	**5**
Pest Management Challenges	**3.66**	**6**

Organic certification costs was the most binding impediment that farmers encountered in adopting organic farming, with an average farmer impact score of 4.61/5. The study shows the cost of a farmer, particularly a small farmer's, crop certification. The direct costs are significant when it comes to obtaining and maintaining a certification as organic, such as the annual inspection fee, documentation costs and costs to certification bodies. There are also significant indirect costs to keep comprehensive records on all inputs and management activities during the 7-year required conversion period, associated with administrative labor. These costs can be very high particularly in the early years of the transition, where the yields tend to be falling and the quality markets for organic produce are not guaranteed

(Simran et al., 2025). The large portion assigned to constraint: Certification cost, shows the importance of policy measures to cover or cut the costs of transitioning farmers to successful certification.

Limited market access was the second most severe constraint with a mean score of 4.37. Even when farmers obtain an organic certification, they can find hard times to sell their products at premium prices paid for organic products because the production and certification process involve more risk. This lack of market infrastructure can force the organic farmers to deal with conventional market types, which thereby overcomes out the price demand of organic farming, which is considered to be economically viable (Simran et al., 2025). In distances where specialty grocery stores are non-existent (or scarce) and where transportation is challenging, the problem is particularly acute in rural areas. This market access problem is exacerbated by generalised lack of consumer awareness and willingness to pay the organic premium in some locations, which might call for adopting some demand-side measures such as consumer awareness initiatives or public procurement programs.

Transition period yield reduction was the third most important constraint with a mean score of 4.18. This is well documented in literature, and happens due to a "lag time" in initial production following the first year in which soil health and biological nutrient cycling processes (BNP) are implemented in management practices. The transition time last for 2-3 years and farmers do not use any synthetic inputs during this transition period and the soil may require additional transition time until it is as productive as conventional soil production, occurring at the rate of 20-40% reduction in output. (Karavidas et al., 2020) At the same time as financial pressure for certification exists, a lower level of production and revenues during this period increases the economic risk for farmers and can be a discouraging factor for many to take a first step toward using certification.

Limited availability of organic inputs was the fourth most important constraint (mean score 3.96). In organic agriculture, chemicals and other standard inputs such as farmyard manure, compost, biofertilizers and botanical pesticides, are only permitted to use natural resources, but this can sometimes be insufficiently available and of bad quality. In intensively farmed systems or where there is limited land for composting and poor quality of livestock manure sources in the peri-urban area, costs and logistics of applying organic matter to improve soils or certified organic seeds/biological pest control systems to increase yield and quality may be too challenging.

The score obtained for technical knowledge gap was 3.81, which was the fifth ranked constrain. The farmers who would like to take steps towards greening often lack the knowledge of agronomic management regarding a more complex organic production system. This includes understanding of nutrient cycling strategies from organic materials, effective crop rotation to control pests and disease and integrated strategies for pest management without the use of synthetic chemicals. Without proper extension support services and training programmes, designed specifically for the use of the organic system, the number of farmers that are able to do so with optimum productivity is hampered and motivation is a problem.

Finally, last pest management problem was ranked as the sixth-limit (mean score 3.66). In heavy infestation, even with the use of biological/botanical pesticides, problems often arise to control the outbreak of pests and diseases on the farm of the organic farmer. Unlike with fast acting chemical solutions to control, in most cases there are no quick and ready solutions using chemical means, and all that will involve a more proactive approach to managing pests – not equally effective across all types of pest and all weather conditions (Karavidas et al., 2020). This recurrent threat of pest attack is also a serious issue and stress factor for organic farmers and resulting in yield variations.

All these limitations give a profile of the issues confronted in the transition to organic farming practices. Table 6 indicates that operation of these systems offers 'rentability' advantages in terms of their environmental and economic performances, while the construction of these systems is generally challenging because of the associated financial, logistical and technical requirements, and the need for targeted facilities policy support to enable them.

Correlation Analysis

A Pearson correlation analysis was conducted between the key sustainability indicators and for all 100 farms, to get further clarity of the interdependencies between the indicators. The resulting correlation matrix (Table 7) illustrates the network of statistically significant, highly positive correlations among the soil organic carbon (SOC), biodiversity, yield and composite sustainability index.

Table 7. Pearson correlation matrix of key sustainability indicators across all farming systems.

Variable	Soil Organic Carbon	Biodiversity Index	Crop Yield	Sustainability Index
Soil Organic Carbon	**1.00**	**0.91**	**0.79**	**0.94**
Biodiversity Index	**0.91**	**1.00**	**0.76**	**0.92**
Crop Yield	**0.79**	**0.76**	**1.00**	**0.83**
Sustainability Index	**0.94**	**0.92**	**0.83**	**1.00**

The results of the analysis revealed that SOC was the most highly correlated variable with the overall sustainability, and was also well correlated with the sustainability index (). This very high coefficient indicates that soil organic carbon is indeed a component of the sustainability index and quite likely a key component. Correlation was positive between SOC levels of the farm and its composite sustainability score with higher SOC corresponded to higher composite sustainability; also, the SOC value was associated with various ecosystem services. Soil quality is a master variable that influences the WCA and soil resource loadings, microbial activity and aggregate stability of soil (Linh & Lien, 2025). The data strongly suggests that in all areas of sustainability, composts and/or cover crops will lead to an increase in diversity and complementarity.

The same positive strong correlation was found between the biodiversity index and the sustainability index (). This is an important association, highlighting the close links between biological diversity and system function. Within a more resilient agricultural system, with diversified rotation where there are no synthetic inputs into the system (such as pesticides) but with the presence of non-crop habitat, nutrient cycles work more efficiently and natural pest control services are more robust, and thus enhancing above-ground and below-ground biodiversity (Simran et al., 2025). The farms with a high level of biodiversity were almost always the most “sustainable” farms.

Two other factors that are assumed to be mutually exclusive were also highly significantly positive () – the SOC and the crop yield. The finding above shows that there is no corresponding decrease in yield associated with an increase in SOC, in contrast this is associated with an increase in yield under a wide range of agroecological conditions. Soils with high organic matter in general have more beneficial properties such as crop root growth, plant available water and nutrients, soil organisms to promote better crop health as outlined by Linh and Lien (2025). Good empirical evidence for investing in soil building practices for simultaneous improvement of both, environmental quality and crop productivity.

Likewise, a moderate positive correlation was found between the yield of crops and biodiversity (). It seems as if ecosystem services produced by the biological diversity like pollination, pest control and nutrient cycling have an impact on a higher and more even yield. The result: the integration of biodiversity conservation is not a zero-sum game as is often thought, but a facilitative and synergistic relationship exists. The correlation between the crop yield and sustainability index was also strongly positive (), which indicates that high yield is quite a plus to contribute sustainability. This perhaps stems from the reality that the most successful ones were also the ones which had brought about positive outcomes in the management of soil health and biodiversity, especially integrated organics and conservation tillage systems.

Discussion

The results of this comparative study have important theoretical and practical relevance to promote the progress in sustainable agriculture. Theoretically, the soils with high organic carbon (SOC) have shown a strong positive correlation to the biodiversity index ($r = 0.94$) and the sustainability index ($r = 0.92$) and it has clashed with the mainstream concept that the adoption of practices for sustainable agriculture and environmental stewardship is between two conflicting values (Simran et al., 2025). Instead, our results are helping to build a new paradigm of soil ecology—a soil health concept that involves soil health and biological diversity working together to increase ecosystem function and crop yields. This almost perfect correlation between SOC and the sustainability index ($r = 0.94$) particularly implies that SOC is not only the result of a soil's state of soil quality, but also a directly acting driver which initiates a chain of positive effects, including increased water holding capacity, nutrient cycling, microbial activity, disease control, etc. (Linh & Lien, 2025). This finding would enrich the current theory on agroecosystems dynamics because if SOC is at the crossroads of positive feedback loops – all of them contributing to enhance the efficiency of resource use, biodiversity and stability of yields.

The economic information from a practical viewpoint has a very strong case in favour of policy and market support of transition to organic agriculture. Despite the 6.6% lower yield, the 21% market premium and 14.8% lower production costs resulted in better net farm income (USD 2,940 ha^{-1}) for the organic farms, thus making the economic viability of organic farming change rapidly with market changes. Policymakers can leverage this information and take specific steps, such as targeting funding for certification (a top constraint with a mean severity score of 4.61) and/or investment in market infrastructure including in rural areas, where market access is limited (mean score 4.37) is a significant constraint. In addition is the need to restructure the extension services to cater for the technical knowledge gap (mean score 3.81) to include training programmes on organic nutrient management, crop rotation and integrated pest management. In the transition period (mean score 4.18), an economic risk on the labour side exists – this risk could be tackled and finished by providing transition-support payments to farmers or by introducing a crop insurance scheme that would cushion the farmers out of the productivity shortfall the transition period (Karavidas et al., 2020). If implemented simultaneously, the different practical steps presented here might play a significant role in resolving the possible problems in adoption described in this study and in accessing the environmental and economic opportunities.

However, there are some methodological limitations for interpreting the findings. Five agroecological areas were selected with 100 farms, 50 of which were both organic and conventional with the former group being representative of the total organic farms in these areas and the later group representative of the total conventional farms in these areas, but may not reflect the variety of the farm's farming systems and environmental setting. Bearing in mind the possibility of publication bias in the overall literature: studies showing positive results for organic systems might be more likely to be published paper than studies demonstrating null or negative results (Coppola et al., 2022). In addition, the length of the field experiments (two years) might not fully reflect the longer-term dynamics of soil organic carbon build-up which may take many years to become established. There are some economic and management variables that are collected from the farmers themselves, which could imply there is recall bias and/or forgotten/inaccurate reporting particularly in the area of costs of production and yields. The assessment of the quality of sustainability indicators, including the biodiversity index, does not have equal validity and therefore needs to be taken as a starting point with caution as the values may vary according to a different scoring system (or through the eyes of different observers).

However, long-term studies of SOC sequestration, a stabilization of SOC's organic fractions and an economic evaluation of the returns should be part of further investigations, with a recommended length of at least 5 or 10 years to better follow the SOC system development beyond the transition stage (Karavidas et al., 2020). Research to specifically study the "best" configurations of organic farming strategies (e.g., timing of cover cropping, limiting tillage, and enhanced composting) to achieve maximum SOC content and productivity (compared to conventional farming systems) is needed to help reduce that productivity gap. In this study, IPM (yield 6.34 t ha-1, sustainability index 95) and OF (sustainability index 97) performed best which implies that future research should include hybrid systems that judiciously combine ecological elements for maximum possible allocations of various trade-offs between food production and ecosystem services (Speiser et al., 2012). Farmer cooperatives and their effects on certification expenses and on market access have not been sufficiently researched; and it is an opportunity to understand more about how digital technologies, such as farmers' precision agriculture tools developed for conventional farming can be adapted to increase farmers' knowledge and improve effectiveness in pest management. Furthermore the geographical restriction of the literature on Latin America (mainly tropical region) should be extended to include tropical and sub-tropical areas and the adaptability of the organic farming to various scales of production, including commercialized "big farm" and smallholder needs, should be investigated. Not least, the social dimension of the adoption of organic systems (socio-psychological aspects) should be investigated, to be able to create more comprehensive policies interventions to satisfy the organizational needs of all the organisms.

Conclusion

The purpose of this comparative assessment was to determine whether over the different agroecological situations, the two farming systems are more suitable for sustainable crop production. This research entailed 100 farms for which the agronomic, environmental and economic indicators were analyzed using an integrative approach to answer the question. While organic agriculture on average features a slightly smaller yield (6.05t ha-1 as compared to a control yield of 6.48t ha-1), our results show that it provides much better performance with respect to the other dimensions of sustainability. The four main findings of this study were: an increase of 78.7%, 22.6%, 40.2%, and 9.7% in carbon sequestration, water use efficiency (WUE), reduction in GHG emission and net farm income was realized under all these conditions respectively as compared to the conventional systems. They contradict one of the misconceptions that has grown and is spreading – that achieving productivity and sustainable land use are direct polar opposites – that there is no evidence that more productive land is necessarily less healthy land or that more healthy soils end up being environmentally less productive. Moreover, soil organic carbon is highly correlated with soil biodiversity ($r = 0.94$) and sustainability index ($r = 0.92$) which underlines a strong empirical support for the positive cross-effects of investments in building soils across the whole spectrum of sustainability.

For more mature organic systems, more in-depth explicit longitudinal studies over an extended period of time (5–10 years, or longer) are required to capture the evolution of SOC levels, production trends, and economic benefits. The combined effort of ongoing research is also to seek an optimum combination of integrated systems (e.g. agroforestry, and conservation tillage) leading to an even greater reduction in the yield gap, but taking advantage of ecosystem services. Second, research on challenges faced by the social and institutional environment identified in this study (e.g., market access, costs of certification, and expertise) would be valuable for consideration in designing policy interventions. This kind of work would aid in putting the promising future of organic agriculture into practice.

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