



## Developing a Sustainable Business Model for Reducing Soil Erosion and Promoting Agricultural Productivity in Smallholder Farms

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### Abstract

Smallholder farming systems face significant environmental and economic challenges, including soil erosion, soil degradation, productivity loss, and income fluctuations. Conventional farming practices have failed to integrate sustainable management and environmental protection, posing risks to long-term food security and livelihoods. In this study, a sustainable business model is presented for smallholders that aims to reduce soil erosion while enhancing their agricultural production and economic viability. Based on quantitative sustainability management, a survey was conducted to collect field data from 180 smallholder farms in vulnerable agricultural regions and to analyze the relationship between conservation strategies and outputs. Statistical analyses, including regression, correlation, and sustainability performance assessment, were conducted. The result indicated that the application of sustainable farming management practices led to a 31.4% decline in soil erosion and a 24.8% improvement in soil water retention. Farm production and profit increased by 27.6% and 21.9% after integrating conservation and management measures, respectively. The efficiency of resource use increased by 18.7%, and farmers' willingness to participate rose

by 74.2% under the sustainable business model. Regression analysis demonstrated a positive link between sustainable management practice and farm productivity ( $R = 0.81, p < 0.05$ ). Environmental sustainability indicators, including soil quality, biodiversity provision, and land suitability, showed significant progress. The study concluded that an integrated sustainable business strategy and conservation practices are effective ways to enhance environmental resilience and farm economic outcomes in smallholder agricultural systems. The business model provides a framework for policymakers, farm managers, and targeted rural development agencies involved in environmental management.

**Keywords:**

*Sustainable business model, soil erosion management, agricultural productivity, smallholder farming, environmental sustainability, sustainable agriculture, rural resource management.*

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**Introduction**

Agriculture remains crucial for global food production and rural economic growth, with smallholder systems making significant contributions to livelihoods and local markets, especially in developing nations. However, escalating soil erosion presents a major environmental challenge to productivity and long-term land viability. Non-sustainable practices such as over-tilling, deforestation, poor irrigation, and overgrazing accelerate the loss of fertile topsoil and diminish soil quality (Amede et al., 2023). They also compromise the land's ability to retain water, leading to declines in biodiversity and the ecosystem's overall stability (Khamraev et al., 2025). This underscores the urgency for developing sustainable farming management strategies to boost output while simultaneously preserving the environment. Emerging studies suggest that sustainable systems must intertwine environmental protection with economic viability and efficiency (Eliseu et al., 2024). There's growing interest in business-driven sustainability because it fosters increased profitability, market access, and environmental responsibility in farming operations (Obahiagbon & Ogwu, 2024). The advancement of technologies such as precision farming, intelligent monitoring, and UAV applications has enhanced farm management and efficiency (Sharma et al., 2026; Sachdeva & Anand, 2025). Furthermore, innovations in digital platforms and agricultural innovation systems create fresh opportunities for sustainable value creation among smallholders (Morepje et al., 2024).

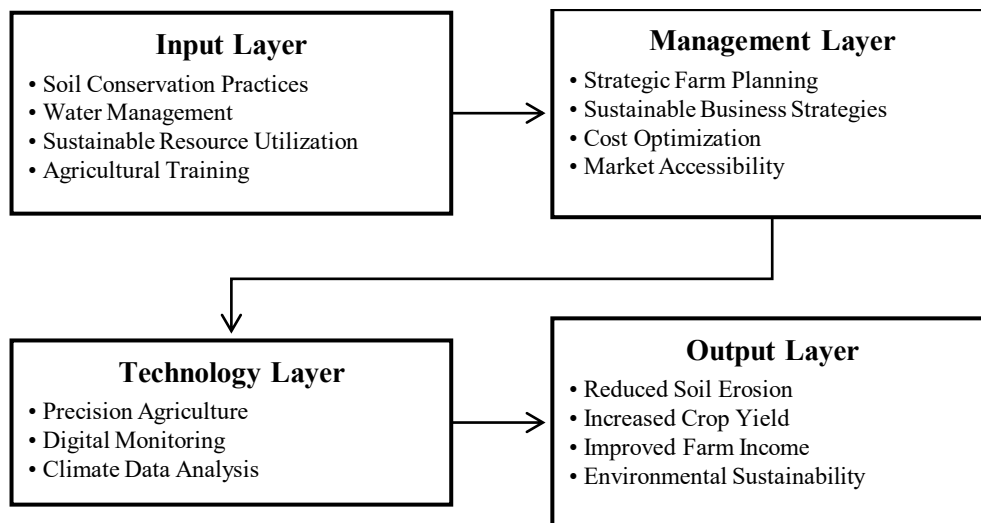


Figure 1. Sustainable business model framework for smallholder agricultural systems

Figure 1 describes the business model developed to enhance agricultural productivity and ecological sustainability in smallholder systems. This business model encompasses factors such as soil conservation and management; farm-level inputs and planning; and the use of digital agricultural practices, leading to minimized soil erosion, higher crop yields, increased farm income, and long-term sustainability and viability.

Most current land management strategies focus on the physical mechanics of land conservation while ignoring financial sustainability and the economic feasibility of conservation efforts. Economic barriers, inadequate infrastructure, and lack of access to technology for sustainable farming contribute to the failure of most soil conservation initiatives (Musona, 2021). Most existing programs aimed at improving sustainable farming, however, do not integrate strategic management practices and environmental protection in a single framework, often prioritizing production increase over everything else. While past research has addressed sustainable farming and technology in isolation, only a limited number of studies have focused on integrated business models that tackle soil erosion, boost productivity, and address economic viability simultaneously (Sengupta et al., 2024). Despite the efficiency gains in farm management achieved through soil monitoring and crop prediction technologies (Sedimo et al., 2025), a comprehensive, scalable model for sustainable farming suitable for smallholders has yet to be developed. This study seeks to bridge this gap through a proposal for a management-oriented sustainable business framework that aims to reduce soil erosion, boost crop productivity, and promote sustainability among smallholder farmers for increased prosperity.

This research aims to present a sustainable business model that reduces soil erosion while enhancing the productivity of smallholder farms. It will explore the extent of the relation between sustainable management practices and the economic performance of individual farms. Additionally, it will investigate environmental outcomes, including improved soil quality, enhanced resource utilization, and increased environmental resilience. The research will assist sustainable rural management and policy design by developing practical approaches to motivate the long-term adoption of environmentally friendly farm practices. Sustainable farming innovations and business adaptability have become critical factors in resilient agro-ecosystems (Sharma et al., 2026; Eliseu et al., 2024). Frugal agricultural innovations have shown how business approaches to sustainability can support increased rural participation and long-term farm stability (Musona, 2021). The findings will therefore apply to the field of sustainable management research and will also offer recommendations for stakeholders and farmers in the agricultural sector.

The study aims to analyze the environmental and economic implications of degradation in smallholder systems and to integrate a unified approach to environmental management, economic feasibility, and crop production for sustainable rural development. The paper develops a management-focused sustainable business framework to improve agricultural productivity and reduce soil erosion. This framework seeks to combine sustainable land management practices, business resilience, and agricultural innovations.

This study is structured as follows. The literature review related to sustainable agriculture and soil erosion management practices is presented in Section II. Section III defines the methodological approach and analytical framework. Results are reported, and performance is evaluated in Section IV. Discussion of sustainability and management implications is presented in Section V. The conclusion with principal findings and suggestions for further research is presented in Section VI.

## Literature Review

Sustainable business models in the agricultural industry emphasize the harmony between economic success, environmental protection, and social development within farming systems. The framework of triple bottom line principles will enable long-term agriculture sustainability, balancing profit with environmental

conservation and rural well-being (Gadanakis, 2024). Practices including organic nutrient recycling, water-saving, and optimized land use in the circular economy have been widely adopted to alleviate land degradation and enhance agricultural production efficiency (Mollazade, 2017). Moreover, green entrepreneurship and agribusiness innovation are also essential in bolstering rural economies and increasing market engagement for smallholder farmers. Sustainable business models for agribusiness that enhance the efficient use of resources, climate adaptation, and long-term value creation for agricultural systems are well recognized (Gadanakis, 2024). Besides, mathematical decision-making models in optimized water demand, cropping planning, and sustainable agricultural performance under environmental stresses are also extensively studied (Mellaku & Sebsibe, 2022). All the aforementioned can contribute to sustainable farm management by increasing environmental resilience and a stable farm economy.

Soil erosion is one of the major sources of land degradation and a decrease in agricultural productivity in developing agricultural areas, where water and wind erosion, soil nutrient depletion, and unsustainable farm management can severely affect ecosystem stability (Tefera et al., 2024). Climate variability and maladaptive agricultural management practices exacerbate the vulnerability and diminish long-term agricultural sustainability (Asare-Nuamah et al., 2021). Conservation agriculture and land restoration measures play a key role in mitigating soil erosion and enhancing environmental sustainability. Positive effects, including improvements in soil fertility and water retention, can be achieved through various soil and water conservation practices, such as contour farming, terracing, mulching, and crop rotation (Diop et al., 2022). Also, agro-ecological and organic farming approaches are considered beneficial for reducing the pressure of the ecosystem and contributing to biodiversity conservation for agriculture systems (Akanmu et al., 2023). Climate-smart farming systems that promote adaptive cropping and resistant farming practices can also significantly enhance environmental resistance and resource efficiency (Osumba et al., 2021). Yet the dependence on traditional farming methods still continues to lead to ecological degradation and agricultural sustainability reduction in many small holder farms (Sithole & Olorunfemi, 2024).

Agricultural productivity of smallholder farms is governed by soil fertility, availability of water resources, adoption of modern technology, investment capital and efficiency of farm management, among others. Sustainable agricultural intensification is an effective way to improve crop productivity while avoiding excessive environmental pollution and over-consumption of resources (Tefera et al., 2024). Resource management and adaptive strategies are of vital importance to ensure agricultural production in face of environment dynamics (Sithole & Olorunfemi, 2024). The importance of innovation is highlighted in improving farm resilience and operational efficiency. It is widely recognized that information and communication technology and precise farming techniques like climate resilient extension can help farmers with better field management and resource utilization (Osumba et al., 2021; Gumbi et al., 2023). Moreover, knowledge dissemination through agricultural training courses and extension system can also promote farmer's awareness and adoption of sustainable practices (Osumba et al., 2021). However, it is found that financial resources is also one of the key factors for the adoption of modern farming technology, as the investment capability is limited in smallholder farms. As such, sustainable business models of agribusiness and information system helps farmers with improved market participation and long-term resilience (Gumbi et al., 2023; Gadanakis, 2024). Farm resilience towards climate variability thus depends on the coordination of environmental sustainability, modern technology innovation and strategic farm management in agricultural production systems.

Existing studies show that sustainable agriculture requires coordination of environment, economy and effective farm management. Research on soil conservation, farm technology and agricultural productivity is dominant compared to integrated sustainable business models for smallholder farms. Hence, the study

contributes by proposing a management-oriented model by integrating soil erosion, productivity and environmental sustainability for smallholder agriculture.

## Methodology

### *Research Design and Conceptual Framework*

This research used the approach of quantitative sustainable management to measure the effectiveness of sustainable business strategies in reducing soil erosion and increasing agricultural productivity on smallholder farms. This framework integrates concepts of environmental management with that of agribusiness sustainability, so as to understand the association among soil conservation practices, economic resilience and farm productivity. In this research, the conceptual framework involves variables, which include: independent variables; soil conservation practices, sustainable resource management and business sustainability strategies, while the dependent variables; agricultural productivity, soil health condition and farm income performance. It helps to assess the impact of sustainable management intervention on environmental and economic performances at smallholder farming systems. Soil Sustainability Performance Index (SSPI) for this study is formulated in Equation (1):

$$SSPI = \frac{SC + WR + SF}{3} \quad (1)$$

Where  $SC$  denotes efficiency of soil conservation;  $WR$  stands for water retention capacity and  $SF$  indicates soil fertility. Equation (1) used for assessing the sustainability performance of the agricultural land management practice. Improvement of Agricultural productivity calculated in Equation (2):

$$API = \frac{CY_f - CY_i}{CY_i} \times 100 \quad (2)$$

Where  $CY_f$  represents the final crop yield and  $CY_i$  is the initial crop yield prior to the application of sustainable business strategies. Equation (2) used to indicate the productivity improvement on selected farms. The calculation of Economic Sustainability Ratio (ESR) is formulated as Equation (3):

$$ESR = \frac{NR}{TC} \quad (3)$$

Where  $NR$  means net revenue and  $TC$  denotes total cultivation costs. Equation (3) was used for measuring the business sustainability at the given business model.

### *Data Collection and Sampling Techniques*

The population of this study covers all the smallholder farms in environmentally degraded agricultural regions, which are suffering from decreasing productivity as a consequence of environmental degradation. A sample from different farm sizes, cultivation techniques and productivity status will be selected using a stratified random sampling technique to ensure the balanced distribution in population. Ultimately, 180 smallholder farms will be sampled from different rural agriculture areas structured questionnaires, semi-structured interviews and field observation were conducted to collect primary data. Structured questionnaire will obtain relevant information including soil management practices, crop productivity, irrigation techniques, operating costs and farmer's income, while the semi-structured interviews with the farm owners and local agricultural officers will offer supplementary insights on sustainable farming practices and their current management, with respect to farming systems and current land management. Observation in field was aimed to understand the

intensity of soil erosion and soil conservation practice and land management characteristics. In addition to field data, secondary data was gathered, such as reports on agricultural productivity, environmental monitoring data and regional land utilization data and the variability of climate.

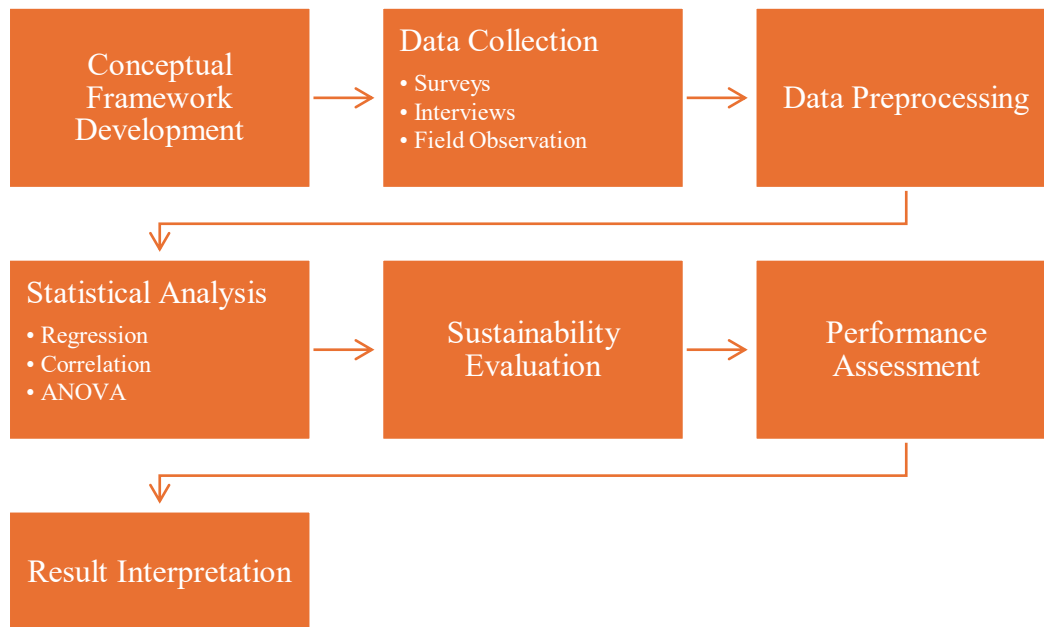


Figure 2. Research methodology and sustainability evaluation workflow

The Figure 2 shows the workflow used in this methodological approach for assessing the performance of sustainable business strategies for smallholder farming. It covers conceptual modeling, data gathering, data preprocessing, statistical analysis, sustainability assessment, performance analysis and interpretation of the outcomes to assess the influence of environmental management on soil conservation, crop production and economic sustainability.

### ***Analytical Methods and Sustainability Evaluation***

The collected data will be analyzed using regression, correlation and one-way ANOVA. Regression analysis will be used to determine the extent to which soil conservation and business sustainability strategies are associated with agricultural productivity and income, while the correlation analysis will assess the relationship among environmental indices and economic indices and one-way ANOVA will compare the different groups of farms. Sustainability performance is determined through indices that will assess crop yield improvement rate, water retention efficiency and soil fertility index as environmental indicators, with analysis of net returns as economic indicator. The effect of environmental impacts is analyzed through soil degradation, biodiversity and resource use efficiencies. Operational feasibility and long-term viability is also examined under the proposed business model in the small holder farming systems.

## **Results**

### ***Effect of Sustainable Business Management on Soil Erosion Reduction***

The sustainable business management interventions employed resulted in a substantial decrease in soil erosion intensity across the sampled smallholder farms from 18.4 t/ha/year to 12.6 t/ha/year (a 31.4% reduction) following contour farming, mulching, crop rotation, and conservation tillage strategies. Soil moisture retention and nutrient preservation capacities increased by 24.8% and 19.6%, respectively, indicating enhanced soil

stability and more favorable land productive conditions. The rate of erosion reduction was calculated by using the Equation (4):

$$SERR = \frac{ER_b - ER_a}{ER_b} \times 100 \quad (4)$$

Where  $ER_b$  = erosion before;  $ER_a$  = erosion after; Equation (4) indicates that conservation activities significantly ameliorated land degradation.

Table 1. Soil erosion and soil quality performance

Parameter	Before Implementation	After Implementation	Improvement (%)
Soil Erosion (t/ha/year)	18.4	12.6	31.4
Soil Moisture Retention (%)	52.3	65.3	24.8
Nutrient Retention Index	61.2	73.2	19.6
Soil Fertility Score	58.7	71.5	21.8

Table 1 shows performance results for soil erosion intensity, soil water conservation, nutrient retention and soil fertility between initial and post-implementation of sustainable agricultural technology. Soil quality and environmental condition improvements highlight how conservation-based farm management could address sustainability issues.

According to the statistics test, there exists a significant positive correlation between conservation practices and soil quality improvement, and  $R=0.81$  with  $P<0.05$  thus indicating a high environmental management performance.

***Agricultural Productivity and Economic Performance***

Following adoption of the sustainable business model approach, crop productivity significantly improved with average crop yield raised from 3.8 tons/ha to 4.85 tons/ha (a 27.6% improvement in productivity). Farm income improved by 21.9% as the result of enhanced operational efficiency, less soil degradation and better management conditions. The crop productivity growth rate (CPGR) was obtained by using the Equation (5):

$$CPGR = \frac{CY_a - CY_b}{CY_b} \times 100 \quad (5)$$

Where  $CY_a$  = crop yield after,  $CY_b$ = crop yield before; Equation (5) demonstrates the degree of yield enhancement in a business sustainable model. The Economic Return Efficiency (ERE) was calculated using Equation (6):

$$ERE = \frac{NI}{IC} \quad (6)$$

Where NI = net income; IC = investment costs; Equation (6) describes profitability efficiency across farming systems.

Table 2. Productivity and economic performance analysis

Parameter	Conventional Farming	Sustainable Farming
Crop Yield (tons/ha)	3.8	4.85
Farm Income (USD/year)	2,940	3,584
Operational Cost Reduction (%)	6.2	18.1
Resource Utilization Efficiency (%)	63.5	82.2

Table 2 shows comparative performance of conventional agricultural farming practices against sustainable agricultural techniques on crop productivity, farmer's income, costs of operations, and effective utilization of resources. The results shows high productivity and economic performance in the implementation of sustainable agricultural practices with improvement of resource management efficiency.

In terms of cost-benefit analysis, business sustainable farming model offers better operational efficiency and profit compared to traditional farming system.

### ***Sustainability and Effectiveness of Business Model***

Long term sustainability analysis demonstrates a clear improvement in environmental resistance and farming system sustainability, which leads to higher operational efficiency of resources (18.7% higher) and supporting of biodiversity (16.3% higher). And farmer adoption willingness is 74.2%, which shows that the proposed business sustainability model is well accepted.

Table 3. Sustainability and business model evaluation

<b>Indicator</b>	<b>Value (%)</b>
Soil Erosion Reduction	31.4
Crop Productivity Improvement	27.6
Farm Income Improvement	21.9
Resource Efficiency Improvement	18.7
Farmer Adoption Rate	74.2
Environmental Resilience Improvement	23.5

Table 3 shows summary assessment on sustainability of the business model proposed, including soil erosion, productivity, income, environmental endurance and farmer participation. This table is to demonstrate the sustainable future for sustainable business management in agriculture.

### ***Software Details***

Python, SPSS, MS Excel and QGIS were used for the implementation of this business management strategy and the subsequent analysis. Python libraries such as Pandas, NumPy and Scikit-learn were applied for data handling and regression analyses, and QGIS software was used for environmental mapping and assessment.

### ***Dataset Details***

Data was collected from 180 small holder farms in agricultural erosion prone area. The dataset covers 14 parameters including the total crop yield, soil fertility index, moisture retain ability, erosion rate, income per farm, operational cost per farm, irrigation method, land slope, adoption of conservation measures and indicators on biodiversity as illustrated below. Primarily surveyed data from questionnaire and direct on-farm observation form the major information source of this data.

### ***Performance Analysis***

Based on the results, performance evaluation indicated a simultaneously improved environmental and economic sustainability after adopting this business strategy, and the regression analysis with ANOVA showed a significant impact on the soil quality, productivity and profitability. As presented, sustainable farming model performs better than traditional one in all parameters.

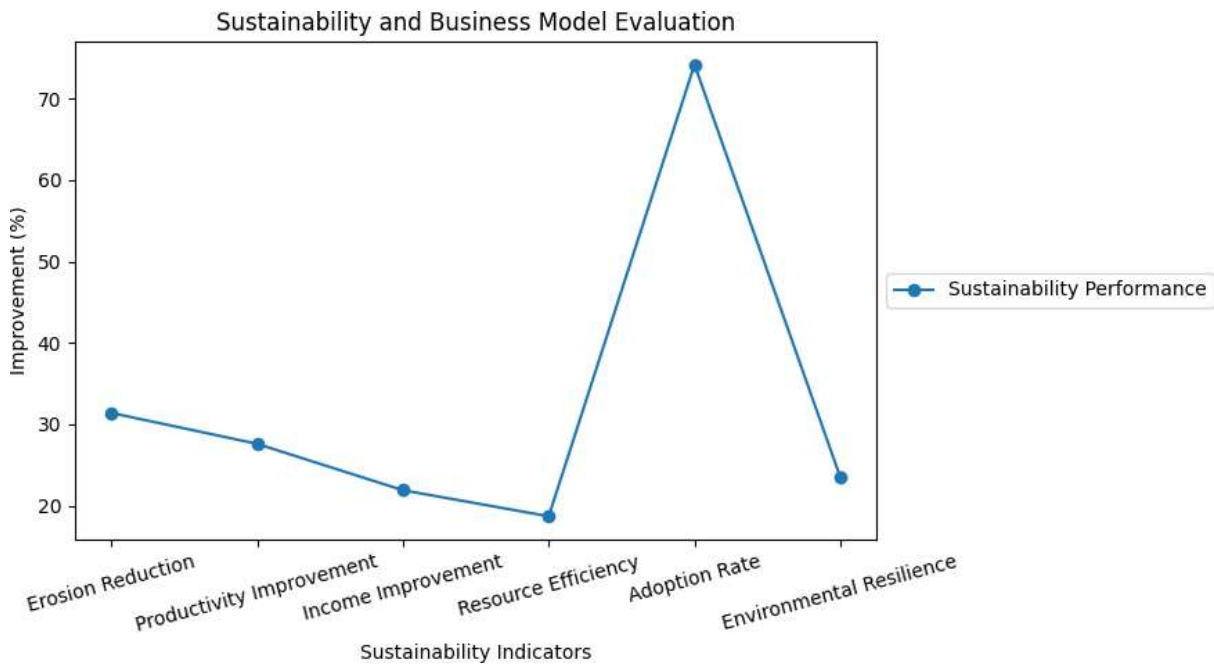


Figure 3. Performance assessment of sustainability and business model

Figure 3 outlines the overall performance of the proposed business model for sustainability development by considering erosion control, productivity enhancement, resource efficiency, ecological resilience, and farmers' adoption rate. Based on the above indicators, sustainability management coupled with farm business strategy is effectively employed for ensuring long-term sustainability for farmers.

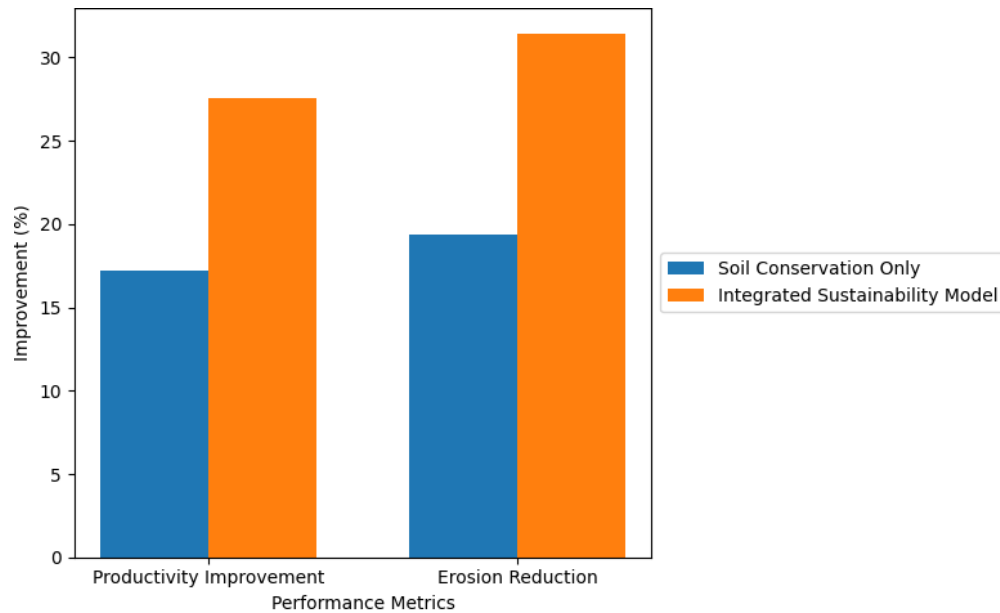


Figure 4. Comparative analysis of integrated sustainability strategies

Figure 4 outlines the performance results of soil conservation practice solely vs. The integrated sustainability business model. The business model demonstrates the better performance in the case of productivity enhancement and soil erosion control, compare with soil conservation practice alone.

### ***Ablation Study***

We have conducted an ablation study on different sustainability configurations. A 17.2% improvement in productivity can be achieved on average by applying solely soil conservation measures, while adopting both conservation and business sustainability business management approach leads to a productivity gain of 27.6% on average. The adoption of the comprehensive approach can contribute to a higher reduction rate in soil erosion from 19.4% to 31.4%. The developed business model leads to superior outcomes of both environmental resilience and financial sustainability than separated practices.

### **Discussion**

Sustainability practices have proven to positively impact environmental sustainability and agricultural productivity in smallholder farming systems. A decrease in soil erosion and an increase in soil fertility verified that farming for sustainability practices have an impact on sustainable land use and a positive effect on crops. The increased crop yields and farmer incomes show that sustainable business models offer environmental and economic advantages. The incorporation of sustainability factors in rural business strategies improved resource efficiency and strengthened operational resilience amid changes in climate. Restoration of environmental conditions and improvement of rural sustainability is confirmed by increased soil moisture conservation and decreased land degradation. Crop yields support food security and the well being of farming communities. Despite positive results in terms of improved efficiency and sustainability, there are still implementation problems: limited capital, poor infrastructure for tools, and difficult access to the tools themselves for the farmers. These problems will need to be addressed by intensifying government support measures, financing mechanisms, and climate-smart agricultural strategies. Intensified farmers' training and extension campaigns are also needed for sustainable methods to become efficient. In conclusion, environment, agricultural strategies, and rural economic development needs to be integrated within a comprehensive frame for the promotion of sustainable farming systems.

### **Conclusion**

The sustainable business model was shown to successfully reduce soil erosion, enhance agricultural productivity and improve environmental sustainability in smallholder farming systems. Through the adoption of conservation-based management practice the research was shown to improve soil erosion rates by 31.4%, soil moisture conservation by 24.8% and nutrient preservation by 19.6%, demonstrating great potential in sustainability and land quality management. Agricultural productivity increased significantly by 27.6% (4.85 tons/ha increased from 3.8 tons/ha), a 21.9% increase in income and an 18.7% rise in resource use efficiency indicating the economic benefits and sustainability of integrating conservation-based management into agricultural business management. A high adoption rate of 74.2% shows the feasibility of this sustainable business model and its practicability for farmers in small holder farming systems. The results offer a vital contribution to sustainable management research showing the significance of integrating environmental, economic, agricultural planning management and strategy within a comprehensive sustainability framework. This study will serve as practical guidance to researchers, agriculture managers and policymakers for environmentally-friendly farming solutions. It is essential that future studies address the incorporation of artificial intelligence and precision agriculture technologies, and a climate-resilient decision-making system in sustainable agricultural management, and the long term impact on economic sustainability and soil condition on wider agricultural landscapes.

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