Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

ECONOMIC EVALUATION OF SUSTAINABLE AGRICULTURAL PRODUCTION SYSTEMS FOR IMPROVING FARM PRODUCTIVITY, RESOURCE EFFICIENCY AND RURAL LIVELIHOOD DEVELOPMENT

Arbaz Khan [1], Mahrukh Ruba [2]

DOI: https://doi.org/10.63544/jbii.v5i11.283

Affiliations:

[1] Department of Agribusiness and Entrepreneurship Development, MNS-University of Agriculture, Multan, Pakistan
Email: ak272295426@gmail.com

[2] Department of Economics, The Islamia University of Bahawalpur, Bahawalpur, Pakistan
Email: mahrukhruba@gmail.com

Corresponding Author's Email:

[1] ak272295426@gmail.com

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Article History:
Received: 04.10.2026
Accepted: 26.10.2026
Published: 06.11.2026

Abstract

*The growing challenges of agricultural resource depletion, escalating production costs, environmental degradation, and rural economic vulnerability have emphasized the importance of transitioning toward economically viable and sustainable agricultural production systems. This study develops an integrated economic evaluation framework to assess the contributions of sustainable agricultural practices toward enhancing farm productivity, resource-use efficiency, profitability, and rural livelihood development in Pakistan. The research examines a farm-level dataset comprising 2,400 agricultural households distributed across 12 agricultural districts during 2020–2025, incorporating 86 socioeconomic, environmental, and production-related variables. Agricultural production systems are categorized into conventional farming (960 farms), integrated resource management (720 farms), and climate-smart sustainable agriculture (720 farms). The analytical framework integrates Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), cost–benefit analysis, and multivariate regression modelling to evaluate technical efficiency, resource allocation, economic returns, and household welfare outcomes. The reported findings indicate that sustainable agricultural production systems improve average crop productivity by 24.6%, increase irrigation water-use efficiency by 31.8%, enhance fertilizer-use efficiency by 27.4%, and reduce agricultural energy consumption by 19.7% compared with conventional farming. Economic assessment reveals that average annual net farm income increases from PKR 485,000 under conventional farming to PKR 672,000 under sustainable agricultural management, representing a 38.6% improvement. Furthermore, the benefit–cost ratio increases from 1.42 to 1.89, while mean technical efficiency rises from 0.71 to 0.89. Multivariate regression analysis identifies statistically significant positive associations between sustainable agricultural adoption, farm productivity, resource efficiency, and household income (*p* < .01). Additional findings demonstrate a 22.3% improvement in rural livelihood performance and a 17.6% reduction in agricultural production costs. The study establishes an integrated economic assessment perspective demonstrating the potential of sustainable agricultural systems to strengthen agricultural competitiveness, optimize resource utilization, and enhance rural socioeconomic resilience. These findings offer policy-relevant insights for promoting sustainable agricultural investment, resource-efficient farming technologies, inclusive rural development, and long-term agricultural sustainability in developing economies.*

Keywords: Sustainable Agriculture, Technical Efficiency, Resource-Use Efficiency, Farm Profitability, Rural Livelihoods, Pakistan

1. Introduction

Agriculture remains one of the most fundamental sectors of the global economy, contributing significantly to food security, employment generation, poverty alleviation, industrial development, and the socioeconomic stability of rural communities. The increasing global population, changing dietary patterns, expanding food demand, and growing pressure on natural resources have intensified the need to develop

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ISSN-p: 3006-2284, ISSN-e: 3006-0982
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agricultural production systems that are economically productive, environmentally sustainable, and socially inclusive.

Conventional agricultural production has historically emphasized maximizing crop yields through intensive land cultivation, chemical fertilizer application, irrigation expansion, mechanization, and increased energy consumption. Although these approaches have contributed substantially to agricultural output, their long-term economic and environmental sustainability has become increasingly challenging because of soil degradation, groundwater depletion, rising agricultural input prices, inefficient resource allocation, and climate-related production uncertainties. Consequently, sustainable agricultural development has emerged as a strategic priority for policymakers, agricultural economists, farming communities, and international development institutions seeking to balance agricultural productivity with resource conservation and rural economic prosperity (Benke & Tomkins, 2017).

Sustainable agricultural production systems represent an integrated approach to agricultural management that combines environmentally responsible farming practices, economically efficient resource utilization, and improvements in rural household welfare. These systems incorporate practices such as precision irrigation, integrated nutrient management, conservation tillage, crop diversification, climate-smart agriculture, renewable energy utilization, improved soil management, and efficient agricultural input allocation. Unlike conventional production approaches that primarily focus on short-term yield maximization, sustainable agricultural systems emphasize long-term economic returns, productive resource allocation, environmental resilience, and the preservation of agricultural production capacity. Their economic viability depends not only on improving crop yields but also on reducing operational expenditure, optimizing water and fertilizer consumption, strengthening technical efficiency, and enhancing the capacity of farming households to manage agricultural risks (Shi & Umair, 2024). Therefore, evaluating sustainable agricultural production requires an integrated economic perspective that simultaneously considers farm-level productivity, profitability, resource-use efficiency, and socioeconomic development outcomes.

The economic significance of sustainable agriculture is particularly evident in developing countries, where agricultural activities provide essential employment opportunities and constitute a major source of household income. Rural farming communities frequently experience structural constraints involving limited financial resources, fragmented landholdings, restricted access to modern agricultural technologies, inadequate market infrastructure, unstable commodity prices, and dependence on climate-sensitive production activities. These challenges are further intensified by increasing irrigation costs, fertilizer price fluctuations, agricultural labour shortages, and limited access to institutional credit. Under these circumstances, adopting resource-efficient agricultural practices may offer opportunities to improve farm profitability while reducing dependence on costly external inputs. However, the economic benefits of sustainable agricultural adoption are not necessarily uniform across different farming systems, geographical locations, and socioeconomic categories (Lu et al., 2010). Initial investment requirements, technological accessibility, farmer education, landholding characteristics, and institutional support can influence the financial attractiveness and practical implementation of sustainable agricultural technologies. Accordingly, comprehensive empirical evaluation is essential for determining whether sustainable agricultural practices generate measurable improvements in agricultural performance and rural livelihoods.

Pakistan provides an important agricultural setting for examining these relationships because farming remains closely connected with national economic development, employment, food security, and rural household welfare. According to the Pakistan Economic Survey 2025–2026, agriculture contributed approximately 23.44% of national gross domestic product, while the sector recorded annual growth of 2.89%. These figures demonstrate the continuing importance of agriculture to Pakistan's economic structure and development priorities.

Water-use efficiency represents one of the most critical dimensions of sustainable agricultural production because irrigation availability directly influences crop growth, agricultural productivity, and farm profitability. Traditional irrigation systems may experience substantial conveyance losses, uneven water distribution, excessive groundwater extraction, and inefficient scheduling of irrigation activities. These

Journal of Business Insight and Innovation
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https://insightfuljournals.com/

conditions increase production costs and create environmental pressures that threaten future agricultural output (Mandal et al., 2002). Sustainable irrigation technologies, including drip irrigation, sprinkler systems, soil-moisture monitoring, and improved water scheduling, provide potential mechanisms for reducing water consumption while maintaining or improving crop productivity.

Similarly, fertilizer-use efficiency has significant economic implications because inappropriate nutrient application can increase cultivation expenditure without generating proportional improvements in agricultural output. Integrated nutrient management, soil testing, precision fertilizer application, and improved cropping practices can help farmers optimize agricultural inputs and minimize unnecessary expenditure. From an economic perspective, the effectiveness of these interventions should be evaluated through measurable changes in physical productivity, resource-specific efficiency, marginal production costs, and net agricultural returns.

Farm profitability constitutes another essential component of agricultural sustainability because the long-term adoption of environmentally responsible practices depends substantially on their financial feasibility. Farmers generally make production decisions by considering expected crop revenue, input expenditure, labour requirements, market opportunities, technological costs, and associated financial risks. Sustainable practices that reduce water consumption or fertilizer application may deliver environmental advantages; however, their widespread adoption requires sufficient economic incentives and manageable implementation costs (Ahmad, Jillani, et al., 2026). Cost–benefit analysis offers a practical mechanism for examining these economic trade-offs by comparing agricultural expenditures, production revenues, net farm income, and benefit–cost ratios across different farming systems.

Nevertheless, profitability indicators alone cannot fully explain variations in agricultural performance because farms operating under similar production conditions may achieve different output levels owing to managerial capabilities, technological adoption, and resource allocation decisions. Consequently, integrating financial evaluation with technical efficiency analysis provides a more comprehensive understanding of agricultural production performance.

1.1 Research Gap and Problem Statement

Despite growing academic and policy interest in sustainable agricultural development, important methodological and empirical limitations remain in the economic evaluation of alternative farming systems. Existing research frequently examines agricultural productivity, resource conservation, financial profitability, or rural welfare as separate analytical dimensions. Consequently, the relationships among technical efficiency, resource-use optimization, production costs, economic returns, and household livelihood outcomes are not always adequately captured within a unified evaluation framework.

Furthermore, comparisons between conventional farming and sustainable agricultural systems may be complicated by differences in farm size, farmer characteristics, land quality, market accessibility, and technology adoption. These differences can influence observed economic outcomes independently of the production system itself. An integrated empirical framework that combines production efficiency measurement, financial evaluation, and socioeconomic modelling is therefore needed to provide a more comprehensive assessment of sustainable agricultural performance and its implications for rural development (Tiwari et al., 2026).

The research problem addressed here is therefore twofold. First, it is unclear whether sustainable agricultural management delivers *jointly* measurable gains across productivity, input-use efficiency, profitability, and technical efficiency when evaluated within a single framework. Second, it is unclear whether those production-level gains translate into measurable improvements in household income and rural livelihood resilience.

1.2 Research Questions

The study addresses five research questions:

RQ1. Are sustainable agricultural production systems associated with higher crop productivity than conventional farming?

Journal of Business Insight and Innovation
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https://insightfuljournals.com/

RQ2. Are sustainable agricultural production systems associated with greater irrigation-water, fertilizer, and energy-use efficiency than conventional farming?

RQ3. Are sustainable agricultural production systems associated with higher net farm income, benefit–cost ratios, and lower production costs than conventional farming?

RQ4. Are sustainable agricultural production systems associated with higher mean technical efficiency than conventional farming?

RQ5. Are sustainable agricultural production systems associated with improved rural livelihood performance and household economic resilience?

1.3 Research Objectives

The primary objective of this research is to evaluate the economic viability and developmental implications of sustainable agricultural production systems by examining their relationships with farm productivity, resource-use efficiency, agricultural profitability, and rural livelihood development. Specifically, the investigation seeks:

1. To determine whether sustainable agricultural management is associated with improved crop yields, more efficient irrigation water utilization, greater fertilizer productivity, and reduced energy consumption relative to conventional farming practices.
2. To evaluate differences in agricultural production costs, annual net farm income, benefit–cost ratios, and technical efficiency across the three production categories.
3. To investigate the socioeconomic relationships between sustainable agricultural adoption, household income, and rural livelihood performance while accounting for relevant farm-level and household characteristics.
4. To identify economically advantageous agricultural management strategies and provide evidence for the development of resource-efficient and socially inclusive agricultural policies.

1.4 Hypotheses

Consistent with the objectives above and with the literature reviewed in Sections 2 and 3, the study tests five hypotheses:

- **H1.** Sustainable agricultural production systems are associated with significantly higher crop productivity than conventional farming.
- **H2.** Sustainable agricultural production systems are associated with significantly higher irrigation-water, fertilizer, and energy-use efficiency than conventional farming.
- **H3.** Sustainable agricultural production systems are associated with significantly higher net farm income and benefit–cost ratios, and with lower production costs, than conventional farming.
- **H4.** Sustainable agricultural production systems are associated with significantly higher mean technical efficiency than conventional farming.
- **H5.** Sustainable agricultural adoption is positively and significantly associated with household income and rural livelihood performance, after controlling for farm-level and household characteristics.

Note. The source manuscript states objectives but does not enumerate formal hypotheses; the five hypotheses above are derived directly from the stated objectives and from the relationships the manuscript reports testing, and are numbered to match the five research questions.

1.5 Significance of the Study

The study is significant for three reasons. Scientifically, it provides an integrated economic evaluation that combines production efficiency, financial appraisal, and socioeconomic modelling within one farm-level dataset, addressing the fragmentation that characterises much of the existing literature. *Practically*, it identifies which resource domains (water, nutrients, energy) deliver the largest measurable economic returns, allowing extension services and input suppliers to target interventions. *Policy-wise*, it offers evidence on whether sustainable agricultural investment delivers measurable livelihood gains, which is directly relevant to the design of subsidy, credit, and extension programmes in Pakistan.

1.6 Contribution of the Study

Journal of Business Insight and Innovation
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https://insightfuljournals.com/

The contribution of the present research lies in its integrated examination of agricultural economics, productive efficiency, natural resource management, and rural socioeconomic development within a single empirical framework. First, the study provides a comparative economic assessment of conventional farming, integrated resource management, and climate-smart agricultural production using a common set of performance indicators. Second, it combines DEA and SFA to evaluate agricultural production efficiency from complementary analytical perspectives, thereby strengthening the assessment of farm-level resource utilization. Third, it integrates economic profitability indicators with environmental resource-efficiency measures to examine potential trade-offs and complementarities between financial performance and sustainable agricultural management (Bamide & Amujoyegbe, 2005). Fourth, it extends the evaluation beyond agricultural production to incorporate household income, rural livelihood conditions, and socioeconomic resilience. Finally, the research offers policy-relevant evidence to support agricultural technology investment, improved irrigation management, sustainable fertilizer utilization, institutional extension services, and rural development initiatives.

The findings of this investigation are expected to contribute to ongoing discussions concerning the economic transformation of agricultural production systems in developing economies. By examining the relationships between sustainable agricultural management, productive resource allocation, farm profitability, and rural household welfare, the research provides a foundation for identifying agricultural strategies that can improve economic performance while supporting responsible natural resource utilization. The analysis is also relevant to the broader objectives of the United Nations Sustainable Development Goals, particularly SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Ultimately, this study seeks to advance understanding of how sustainable agricultural production systems can contribute to a more productive, resource-efficient, economically resilient, and socially inclusive agricultural economy.

2. Resource-Use Efficiency and Sustainable Management of Agricultural Inputs

Resource-use efficiency constitutes a fundamental dimension of sustainable agricultural development because the economic viability, productive capacity, and environmental performance of farming systems depend substantially on the effective utilization of available agricultural inputs. Agricultural production requires the coordinated allocation of irrigation water, fertilizers, energy, cultivated land, labour, machinery, and financial capital to achieve desirable levels of crop productivity and economic profitability. However, conventional agricultural production systems frequently depend on intensive input utilization, which may increase agricultural output in the short term while generating substantial production costs, environmental degradation, and resource depletion over longer periods. Excessive irrigation, inefficient fertilizer application, energy-intensive machinery operations, inappropriate land management, and suboptimal labour allocation can reduce farm profitability and undermine the sustainability of agricultural production. Consequently, contemporary agricultural economics increasingly emphasizes resource-efficient production strategies that improve agricultural output and financial returns while minimizing unnecessary input consumption and environmental externalities. Sustainable agricultural management therefore requires an integrated economic and ecological perspective in which productive efficiency, cost optimization, and natural resource conservation are evaluated as interconnected components of agricultural performance (Waithaka et al., 2006).

The theoretical foundation of agricultural resource-use efficiency is closely associated with production economics, technical efficiency, and the optimal allocation of productive resources. Within agricultural production systems, resource-use efficiency refers to the capacity of farmers to obtain greater agricultural output from a given quantity of inputs or maintain desirable production levels while reducing resource consumption. Nevertheless, physical input productivity and economic efficiency represent distinct analytical concepts. Improvements in crop output per unit of irrigation water, fertilizer, or energy may indicate higher physical efficiency, whereas economic efficiency additionally depends on input prices, production expenditure, output market values, and the financial costs associated with implementing new technologies. Accordingly, sustainable resource management requires identifying input combinations that minimize production costs without compromising crop productivity, soil fertility, or long-term productive capacity. This

Journal of Business Insight and Innovation
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ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

distinction is particularly important in developing agricultural economies, where farming households frequently operate under financial constraints, fluctuating agricultural input prices, limited institutional support, and unequal access to modern agricultural technologies.

Irrigation water management represents one of the most important determinants of sustainable agricultural production because water availability directly influences crop growth, nutrient absorption, soil moisture conditions, and agricultural productivity. Agriculture accounts for the largest proportion of freshwater withdrawals globally, highlighting the importance of efficient irrigation practices for ensuring long-term agricultural sustainability. Conventional irrigation systems, particularly uncontrolled surface irrigation and inefficient water distribution practices, may experience substantial water losses through evaporation, runoff, and deep percolation. These inefficiencies increase irrigation expenditure, energy requirements, and pressure on groundwater resources while potentially reducing overall farm profitability (Várzaru, 2026). Sustainable irrigation technologies, including drip irrigation, sprinkler irrigation, soil-moisture monitoring, precision water application, and improved irrigation scheduling, provide mechanisms for reducing excessive water consumption and improving agricultural water productivity. However, their economic effectiveness depends on crop characteristics, investment requirements, maintenance expenditure, water availability, and local production conditions. Therefore, irrigation efficiency should be examined not only through physical water-saving indicators but also through changes in crop yield, pumping expenditure, net farm income, and the financial returns associated with irrigation technology adoption.

Table 1 presents a comparative assessment framework linking the principal categories of agricultural resources with conventional management challenges, sustainable production strategies, measurable efficiency indicators, and potential economic implications. The framework emphasizes the importance of examining resource-use efficiency through multidimensional performance indicators rather than relying solely on agricultural output or individual input-consumption measures.

Table 1

Comparative Assessment of Agricultural Resource-Use Efficiency, Sustainable Input-Management Strategies, and Economic Performance Indicators

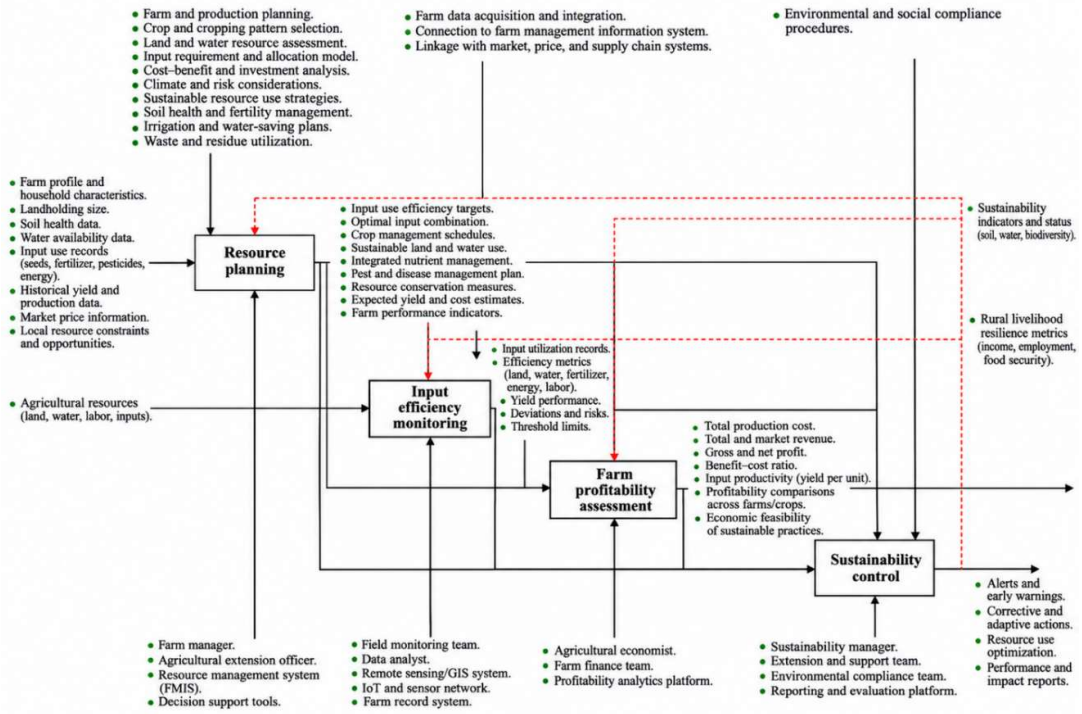
Agricultural input	Sustainable management strategies	Economic performance implications
Irrigation water	Precision irrigation, drip irrigation, soil-moisture monitoring	Lower irrigation expenditure and improved water productivity
Fertilizers and nutrients	Soil testing, precision fertilization, integrated nutrient management	Reduced fertilizer costs and improved nutrient utilization
Agricultural energy	Solar-powered irrigation, energy-efficient pumps, machinery optimization	Reduced operating expenditure and energy-price vulnerability
Cultivated land	Conservation tillage, crop rotation, organic matter management	Improved long-term land productivity and reduced restoration costs
Agricultural labour	Improved scheduling, mechanization, technical training	Improved operational efficiency and agricultural income potential
Agricultural machinery	Precision machinery, preventive maintenance, equipment sharing	Reduced machinery costs and increased operational efficiency

Note. Source data as supplied.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Figure 1

Sustainable Agricultural Resource Management Framework Linking Input Efficiency With Farm Profitability and Rural Livelihood Resilience



The economic effectiveness of sustainable agricultural management depends on the interaction between resource conservation, technological innovation, and institutional conditions. Improvements in irrigation management, nutrient allocation, and energy utilization can contribute directly to agricultural cost reduction, whereas soil conservation and improved land management can strengthen the long-term productive capacity of farming systems. At the same time, technological adoption may introduce financial and operational requirements that influence the net economic benefits achieved by individual farmers. These relationships highlight the importance of evaluating both direct efficiency improvements and the associated economic trade-offs when comparing sustainable and conventional agricultural production systems.

Furthermore, the application of quantitative efficiency measurement provides an important methodological foundation for assessing sustainable agricultural resource management (Ruba et al., 2026). Data Envelopment Analysis (DEA) enables the comparison of agricultural production units based on their relative capacity to transform multiple agricultural inputs into productive outputs, whereas Stochastic Frontier Analysis (SFA) facilitates the estimation of technical inefficiency while accounting for random production disturbances. Combining these approaches with cost–benefit analysis and multivariate regression modelling allows researchers to examine resource productivity, economic profitability, and socioeconomic outcomes within a unified analytical framework. Such methodological integration is particularly relevant for agricultural systems characterized by heterogeneous farm sizes, differences in technological adoption, variations in input accessibility, and diverse production environments.

3. Integration of Agricultural Economic Assessment and Multidimensional Sustainability Indicators

The integration of agricultural economic assessment with multidimensional sustainability indicators has become an increasingly important research direction in agricultural economics, environmental resource management, and rural development. Agricultural sustainability is inherently complex because farming systems simultaneously generate economic outputs, utilize natural resources, influence ecological conditions, and contribute to household welfare and rural socioeconomic development. Traditional agricultural performance evaluations have predominantly emphasized crop productivity, gross agricultural revenue,

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

production expenditure, and financial profitability, whereas environmental assessments have concentrated on water conservation, soil quality, fertilizer consumption, energy utilization, and ecological impacts (Semenda & Semenda, 2018). Although these analytical perspectives provide valuable insights into individual dimensions of agricultural production, their independent application may fail to capture the interconnected relationships among economic viability, productive resource efficiency, environmental sustainability, and social well-being. Consequently, contemporary agricultural sustainability research increasingly emphasizes integrated evaluation frameworks that combine financial, technical, environmental, institutional, and socioeconomic indicators to provide a comprehensive understanding of agricultural production performance.

The theoretical foundation of multidimensional agricultural sustainability assessment is closely associated with the principle that agricultural development should generate sufficient economic returns while maintaining the natural resource base and supporting the welfare of present and future generations. In this context, agricultural sustainability cannot be adequately represented by a single productivity measure or financial performance indicator because improvements in one dimension may be accompanied by deterioration in another (Sakharova et al., 2019). For example, agricultural intensification may increase crop yields and short-term profitability while accelerating groundwater depletion, soil degradation, and energy consumption. Conversely, environmentally responsible agricultural management practices may reduce fertilizer application, irrigation requirements, and ecological pressures but introduce additional capital expenditures or transitional productivity challenges. These interactions demonstrate the importance of evaluating agricultural systems through complementary indicators capable of identifying economic–environmental trade-offs, resource productivity improvements, and the broader socioeconomic consequences of agricultural management decisions.

The multidimensional interpretation of agricultural sustainability is supported by established international assessment frameworks. The Food and Agriculture Organization of the United Nations (FAO) developed the Sustainability Assessment of Food and Agriculture Systems (SAFA) framework around four principal dimensions: environmental integrity, economic resilience, social well-being, and good governance. These dimensions recognize that sustainable agricultural development depends not only on the profitability of farming enterprises but also on responsible environmental management, institutional accountability, social equity, and long-term economic stability. For the present research, the integration of agricultural economic assessment and sustainability indicators provides a conceptual basis for comparing conventional farming, integrated resource management, and climate-smart sustainable agriculture. The study's analytical framework considers agricultural productivity, input-use efficiency, production expenditure, financial profitability, technical efficiency, and rural livelihood outcomes (Horton et al., 2016). These dimensions are complementary because sustainable agricultural practices can influence farm economic performance through several interconnected mechanisms, including improved input allocation, reduced production losses, optimized agricultural technologies, and greater resilience to resource constraints. However, the relationships among these mechanisms should be evaluated empirically rather than assumed to generate uniformly positive outcomes.

Table 2 presents a multidimensional sustainability assessment framework identifying major evaluation dimensions, representative indicators, appropriate measurement units, methodological approaches, and their relevance to agricultural economic performance. The framework is designed to illustrate how financial, technical, environmental, social, and institutional measures can be integrated into a comprehensive farm-level economic evaluation.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Table 2
Multidimensional Agricultural Sustainability Assessment Framework: Economic, Technical, Environmental, and Socioeconomic Performance Indicators

Sustainability dimension	Core performance indicators	Analytical approach
Agricultural productivity	Crop yield; land productivity; output growth	Productivity comparison; regression
Financial profitability	Gross revenue; net farm income; gross margin	Cost–benefit analysis
Production cost efficiency	Total production expenditure; unit production cost	Cost accounting; comparative analysis
Investment performance	Benefit–cost ratio; return on investment; payback period	Investment appraisal
Technical efficiency	Relative efficiency; production frontier performance	DEA; SFA
Irrigation resource efficiency	Water productivity; irrigation intensity	Input–productivity analysis
Fertilizer-use efficiency	Nutrient productivity; fertilizer partial-factor productivity	Nutrient-use analysis

Additionally, the interpretation of aggregate sustainability scores requires caution because composite indices can conceal trade-offs between individual dimensions. A farming system with strong financial performance but substantial environmental degradation may achieve an apparently favourable aggregate score if economic gains compensate numerically for environmental weaknesses. Similarly, improvements in average farm income may conceal unequal livelihood outcomes among different household groups. For these reasons, multidimensional agricultural sustainability evaluation should report individual dimension scores alongside any overall composite measure. This approach improves analytical transparency and allows policymakers to identify specific areas requiring intervention rather than relying exclusively on an overall sustainability ranking.

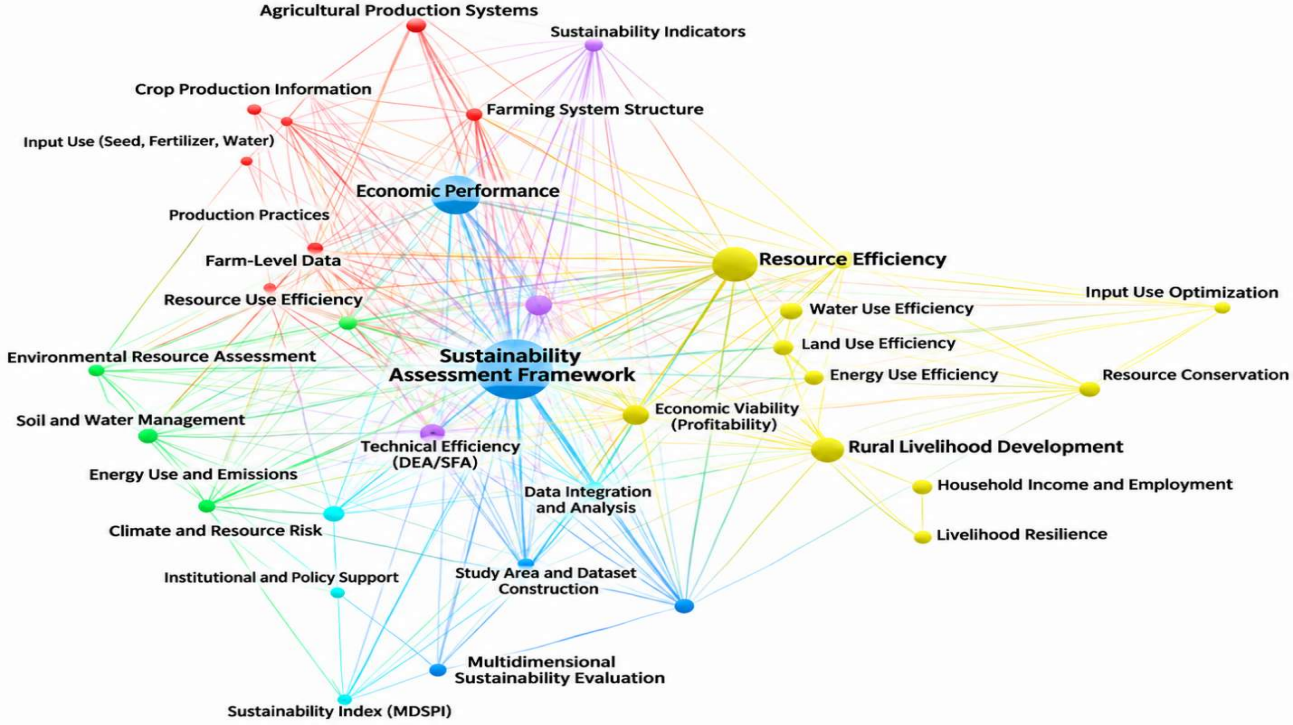
The potential for synergies and trade-offs among sustainability dimensions is also important. Resource-efficient irrigation may simultaneously reduce water consumption, energy expenditure, and production costs, creating favourable environmental and economic outcomes (Ahmad, Majeed, et al., 2026). In contrast, the adoption of modern agricultural machinery may improve labour productivity and operational efficiency while introducing additional capital costs and potentially changing rural employment demand. Likewise, conservation agriculture may improve soil quality over time but require adjustments to equipment use, weed management, or crop rotation that affect short-term profitability. Therefore, an integrated assessment should distinguish complementary sustainability gains from competing objectives and evaluate whether observed improvements are economically meaningful and environmentally durable.

Figure 2 presents the proposed conceptual integration of agricultural economic assessment and multidimensional sustainability indicators. The framework illustrates the progression from agricultural production systems through economic, technical, environmental, social, and institutional assessment dimensions toward integrated sustainability evaluation and policy-relevant outcomes. It also emphasizes the role of quantitative analysis in connecting these dimensions and identifying variations in agricultural performance across alternative production systems.

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Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Figure 2

Agricultural Sustainability Assessment and Multidimensional Resource Efficiency Framework



The reviewed literature demonstrates that integrating agricultural economic assessment with multidimensional sustainability indicators is essential for understanding the complex relationships among farm productivity, resource utilization, profitability, environmental conservation, and rural socioeconomic development. Existing international assessment frameworks have established the importance of evaluating agricultural systems through complementary economic, environmental, social, and institutional dimensions, while recent methodological studies have emphasized the challenges of indicator selection, normalization, weighting, aggregation, and the interpretation of sustainability trade-offs. Nevertheless, the effectiveness of sustainability assessment depends on the availability of reliable farm-level information, appropriate methodological assumptions, context-specific indicators, and transparent interpretation of empirical findings (Moreau et al., 2012). In response to these considerations, the present study adopts an integrated economic evaluation perspective that combines agricultural productivity analysis, resource-efficiency measurement, farm profitability assessment, DEA, SFA, and multivariate regression modelling. This approach provides a foundation for examining differences among conventional farming, integrated resource management, and climate-smart sustainable agriculture while investigating their associations with rural household economic outcomes. By connecting productive efficiency, financial viability, environmental resource management, and livelihood development, the study contributes to a more comprehensive understanding of sustainable agricultural performance and provides policy-relevant insights for improving agricultural competitiveness, promoting efficient resource utilization, and strengthening inclusive rural development in Pakistan.

4. Methodology

The methodology of the present study is systematically designed to provide a comprehensive economic, quantitative, and multidimensional assessment of sustainable agricultural production systems, with particular emphasis on improving farm productivity, optimizing resource-use efficiency, enhancing financial profitability, and strengthening rural livelihood development. The research adopts an integrated analytical framework that combines farm-level agricultural data, agricultural production analysis, cost–benefit evaluation, technical efficiency estimation, environmental resource assessment, and advanced econometric modelling to investigate the economic and socioeconomic implications of sustainable farming practices. The

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

methodological framework incorporates agricultural production characteristics, input utilization patterns, farming expenditure, household income, and institutional factors to examine the interconnected relationships between agricultural sustainability and economic performance. Furthermore, the study integrates DEA, SFA, and multivariate regression techniques to evaluate productive efficiency, resource allocation, and the determinants of agricultural profitability and rural household welfare (Saravanadurai & Kumar, 2014). This integrated methodological approach facilitates systematic comparisons among conventional farming, integrated resource management, and climate-smart sustainable agriculture across diverse agricultural production environments in Pakistan. By combining economic, technical, environmental, and socioeconomic performance indicators, the proposed framework provides a rigorous analytical foundation for identifying sustainable agricultural management strategies that can improve farming efficiency, reduce production costs, enhance economic resilience, and contribute to long-term rural development.

4.1 Farm-Level Agricultural Dataset Collection and Study Area Characteristics

The present study employs a comprehensive farm-level agricultural dataset to investigate the economic performance, resource-use efficiency, technical productivity, and socioeconomic implications of sustainable agricultural production systems in Pakistan. The research framework encompasses 2,400 agricultural households distributed across 12 agricultural districts during 2020–2025, representing diverse agricultural production environments, farm-management practices, resource endowments, and rural socioeconomic characteristics. The dataset incorporates 86 agricultural, economic, environmental, institutional, and household-level variables to facilitate a multidimensional evaluation of agricultural sustainability. Particular attention is given to differences in production technologies, cultivated landholdings, irrigation infrastructure, fertilizer utilization, agricultural energy consumption, financial profitability, and household livelihood characteristics (Xu et al., 2019). This multidimensional dataset structure provides the analytical foundation for evaluating the relationships among sustainable agricultural management, productive resource allocation, farming profitability, and rural economic development.

The study population is categorized into three agricultural production systems: conventional farming, integrated resource management, and climate-smart sustainable agriculture. Conventional agricultural production comprises 960 farming households, accounting for 40.0% of the overall sample, while integrated resource management and climate-smart sustainable agriculture each comprise 720 households, representing 30.0% of the study population per category. This classification allows systematic comparisons among agricultural production systems characterized by different levels of resource-management integration, technological adoption, environmental conservation, and production efficiency. Conventional farming represents production approaches predominantly associated with established irrigation practices, traditional nutrient application, and comparatively limited integration of advanced resource-management technologies. Integrated resource management encompasses farming operations that incorporate coordinated irrigation scheduling, improved fertilizer management, soil conservation, and more efficient agricultural input allocation (Wang et al., 2024). Climate-smart sustainable agriculture represents production systems employing climate-adaptive agricultural management, resource-efficient technologies, improved soil and water conservation, and environmentally responsible farming strategies.

The geographical scope of the investigation covers 12 agricultural districts, enabling the assessment of differences in agricultural production conditions, resource availability, farming infrastructure, and socioeconomic characteristics. The inclusion of multiple agricultural districts is particularly important because farming performance in Pakistan is influenced by variations in irrigation-water accessibility, soil characteristics, temperature conditions, cropping patterns, agricultural market connectivity, and institutional services. These factors can affect both the economic feasibility and practical effectiveness of sustainable agricultural management. District-level heterogeneity is therefore an important consideration when interpreting differences in farm productivity, technical efficiency, resource consumption, and financial profitability (Bahadur et al., 2024). The geographical structure also provides opportunities to examine whether observed economic performance patterns are consistent across agricultural environments or vary according to local production conditions.

Journal of Business Insight and Innovation
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https://insightfuljournals.com/

The temporal coverage of 2020–2025 provides a six-year reference period for examining agricultural production performance and economic conditions. This period is relevant for investigating agricultural management under changing input prices, irrigation costs, climatic conditions, market circumstances, and sustainable technology adoption patterns. Where repeated farm-level observations are available, the temporal dimension can support analysis of changes in agricultural performance over successive production periods. Where records consist of retrospective household information or pooled observations, the appropriate analytical specification must instead reflect the actual structure of the data. The distinction between repeated observations and one-time household measurements is particularly important for econometric modelling because it determines whether panel-data techniques, pooled regression, or cross-sectional approaches are methodologically appropriate (Ahmad, Muneer, et al., 2026).

A detailed description of the 86 agricultural and socioeconomic variables is essential for maintaining transparency in the methodological framework. Rather than treating the dataset exclusively as a collection of farm production measures, the study incorporates complementary financial, environmental, institutional, and livelihood information. These data categories support the construction of multiple dependent and explanatory variables for comparative economic assessment, frontier efficiency estimation, and econometric analysis. Table 3 presents a proposed organization of the 86 variables into major analytical groups.

Table 3

Proposed Distribution of Farm-Level Variables and Their Methodological Applications

Dataset component	Number of variables	Representative measurements
Household socioeconomic characteristics	12	Age, education, household size, farming experience
Agricultural production and land management	16	Cultivated area, crop yield, output, cropping intensity
Water and irrigation management	12	Water volume, irrigation frequency, pumping expenditure
Fertilizer and soil management	10	Fertilizer quantities, nutrient use, soil indicators
Energy, labour, and machinery	10	Energy consumption, labour inputs, machinery costs
Agricultural financial performance	12	Revenue, input costs, net income, investment expenditure
Institutional and technological characteristics	8	Credit access, extension services, technology adoption
Rural livelihood and household welfare	6	Household income, diversification, resilience indicators
Total	**86**	**Eight analytical components**

The preparation of the analytical dataset requires systematic data-quality assessment to establish the reliability and comparability of recorded agricultural observations. Relevant procedures include the identification of incomplete household records, verification of agricultural measurement units, consistency checks for farm revenue and input expenditure, and assessment of potentially influential observations. Additional attention is required when combining information across different crops or agricultural production periods, particularly where commodity quantities, cultivated areas, and market prices differ substantially. Appropriate standardization of agricultural variables can improve comparisons among farming systems while preserving economically meaningful distinctions in input requirements and production performance.

Furthermore, the structure of the dataset provides opportunities to examine heterogeneity across farming systems, agricultural districts, farm sizes, and household characteristics (Djanibekov & Khamzina, 2016). Differences in cultivated land, irrigation infrastructure, agricultural experience, and access to technology can influence both farm profitability and resource-use efficiency. Stratified or subgroup analysis can therefore improve understanding of whether sustainable agricultural management is associated with similar economic outcomes across different categories of farmers. Such analysis is especially relevant for

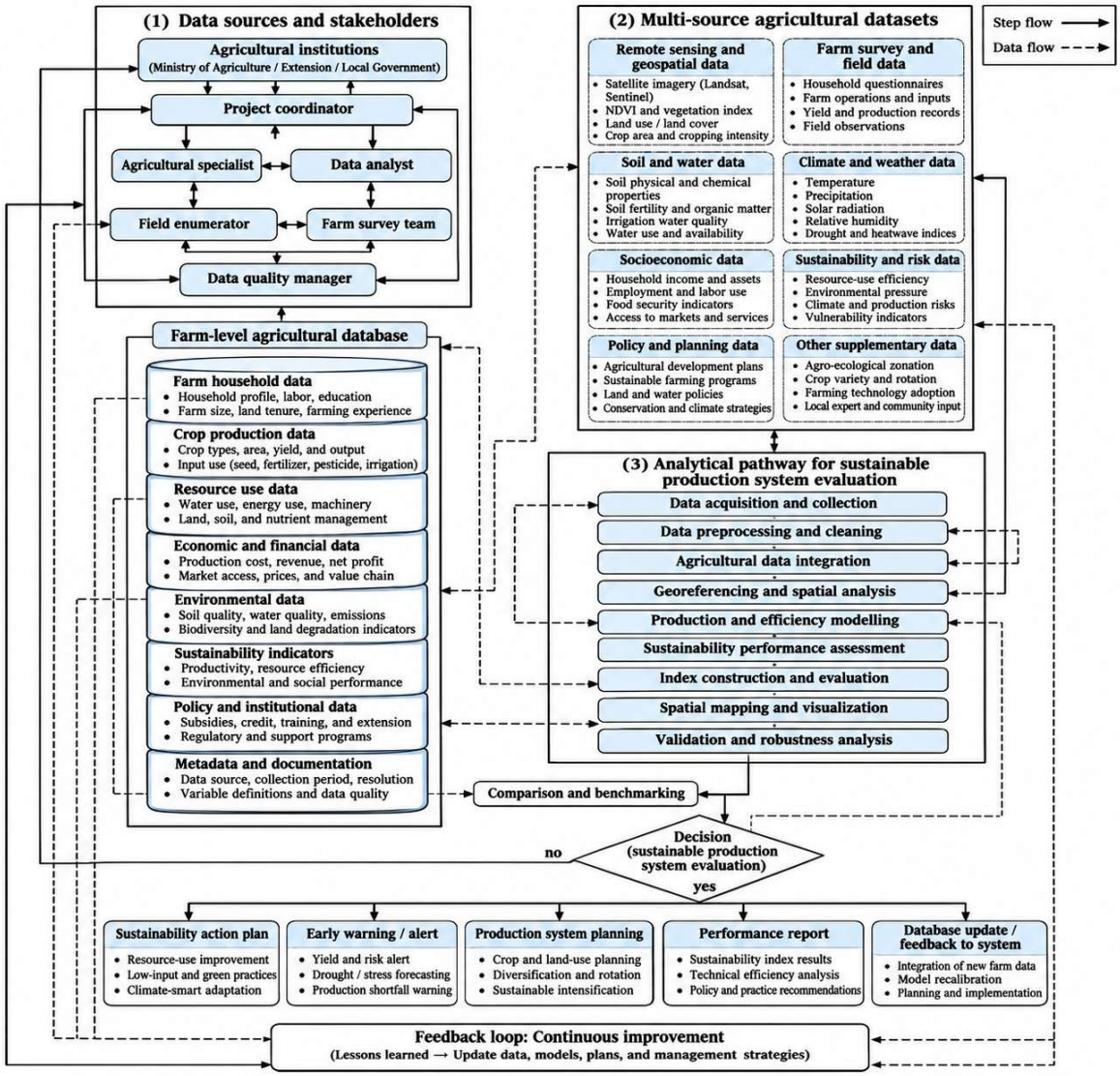
Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
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evaluating the practical applicability of sustainable agricultural technologies among smallholder farmers and households facing financial or institutional constraints.

The overall dataset organization and its connection to the analytical framework are shown in Figure 3. The figure presents the stated sample size, production-system classification, major data domains, and analytical pathways leading to agricultural economic and sustainability evaluation.

Figure 3

Farm-Level Agricultural Dataset Composition and Analytical Pathway for Evaluating Sustainable Production Systems



The organization of the agricultural dataset and its integration into the proposed economic evaluation framework connects the agricultural production categories with 86 economic, environmental, production-related, and socioeconomic variables, establishing the analytical foundation for comparative economic assessment, technical efficiency estimation, and rural livelihood analysis. The subsequent application of DEA, SFA, cost–benefit analysis, and econometric modelling supports the systematic investigation of agricultural productivity, resource allocation, profitability, and household welfare (Bell et al., 2008). The dataset structure provides a comprehensive foundation for evaluating the economic and sustainability characteristics of alternative agricultural production systems in Pakistan. The inclusion of multiple agricultural districts and the

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
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2020–2025 reference period provides a basis for investigating geographical and temporal variations where supported by the underlying records. Furthermore, the combination of economic indicators, resource-efficiency measures, and household livelihood characteristics supports a comprehensive comparison of conventional, integrated, and climate-smart agricultural management. This structured analytical approach establishes the methodological basis for the subsequent assessment of agricultural productivity, sustainable resource utilization, farm profitability, and rural economic resilience.

4.2 Data Envelopment Analysis for Agricultural Technical Efficiency Estimation

DEA is employed in the present study as a nonparametric frontier-based optimization technique to evaluate the relative technical efficiency of agricultural production systems and identify opportunities for improving the utilization of productive resources. Agricultural production involves the simultaneous application of multiple inputs, including cultivated land, irrigation water, chemical fertilizers, labour, agricultural energy, and capital investment, to generate economically valuable crop outputs. However, the productive efficiency of these resources varies considerably across farming enterprises because of differences in agricultural management practices, technological adoption, production scale, environmental conditions, and institutional accessibility. Conventional efficiency measures based exclusively on crop yield or individual input-productivity ratios may not adequately represent these complex production relationships. Consequently, DEA provides a systematic analytical approach for evaluating the performance of agricultural production units relative to an empirically constructed best-practice frontier while accommodating multiple inputs and outputs within a unified optimization framework (Tiwari et al., 2026).

The application of DEA is particularly relevant to sustainable agricultural production because efficient resource allocation constitutes an important mechanism through which farmers can improve agricultural productivity, reduce unnecessary production expenditure, and conserve natural resources. Unlike parametric production-frontier approaches, DEA does not require the specification of a predetermined functional relationship between agricultural inputs and production outputs. Instead, it constructs a piecewise linear production frontier using the observed performance of comparable decision-making units (DMUs). Agricultural farms operating on the estimated frontier are assigned an efficiency score of 1.000, while farms operating below the frontier receive efficiency scores below unity, indicating potential opportunities for reducing input consumption while maintaining existing production levels. These scores measure relative technical efficiency within the observed comparison group rather than absolute agricultural sustainability or overall economic profitability (Faried et al., n.d.).

The methodological selection of DEA is supported by previous agricultural efficiency research. Yang et al. (2026), in their comprehensive review of agricultural DEA applications, identified the widespread use of input-oriented models and variable returns-to-scale specifications in agricultural production research. Their findings highlight the suitability of DEA for investigating input redundancy and production-scale heterogeneity across agricultural enterprises. Table 4 shows the proposed agricultural input–output specification, including representative measurement units and illustrative numerical values for examining the operation of the DEA framework.

Table 4

Agricultural Production Inputs, Output Indicators, and Numerical Specifications for DEA Modelling

Variable	Conventional farming	Integrated management	Climate-smart agriculture
Cultivated land	3.80	3.70	3.65
Irrigation water consumption	6,250	5,180	4,420
Fertilizer application	285	246	218
Agricultural energy use	8,450	7,280	6,640
Agricultural labor input	920	875	840
Machinery and capital input	86,500	92,400	105,800

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
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Standardized crop production	4.20	4.75	5.23
Agricultural output value	315,000	362,000	408,000

Note. Source data as supplied; values are illustrative specifications for the DEA framework rather than estimated model results.

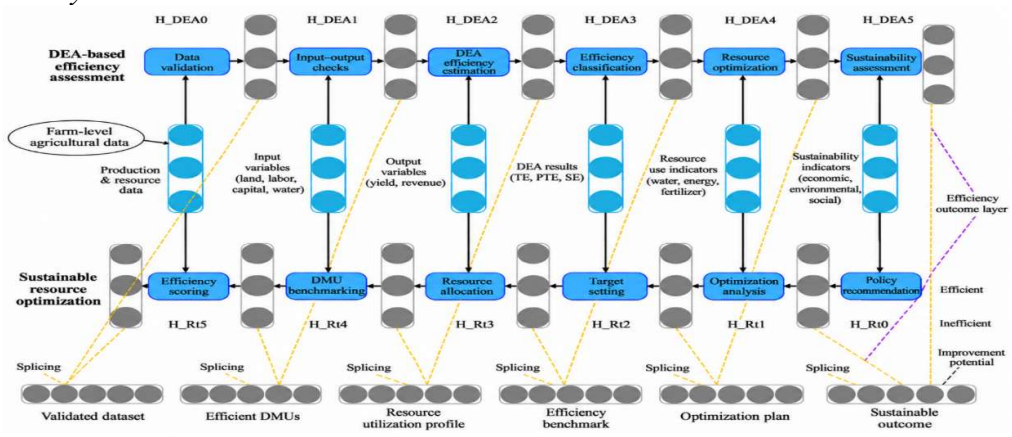
The DEA findings can be organized to compare overall technical efficiency, pure technical efficiency, scale efficiency, and estimated input-reduction potential across agricultural production systems. The example patterns indicate progressively higher efficiency values across conventional, integrated, and climate-smart agricultural management. Nevertheless, the existence, magnitude, and statistical significance of these differences must be established using actual DEA estimates. Once calculated, the results can provide an empirical basis for determining whether resource-management integration is associated with improved agricultural efficiency after considering production-scale differences and farm-level heterogeneity.

A comprehensive DEA evaluation should also investigate the determinants of efficiency variation and the robustness of the estimated frontier (Feroz et al., 2026). Although DEA identifies relative performance differences, its deterministic structure does not distinguish measurement error and random environmental disturbances from inefficiency. Therefore, data validation, influential-observation assessment, and alternative model specifications are important for establishing reliable efficiency estimates. The use of SFA in the subsequent methodological analysis provides a complementary framework for considering stochastic variation in agricultural production. In addition, bootstrapping or other suitable inference procedures may be employed where statistically justified to assess uncertainty in estimated DEA efficiency scores.

Figure 4 presents the integrated methodological workflow for estimating agricultural technical efficiency using DEA. The framework begins with farm-level agricultural observations, followed by the selection of production inputs and outputs, the application of input-oriented CCR and BCC optimization models, and the estimation of technical, pure technical, and scale efficiency. The resulting efficiency measures provide quantitative benchmarks for identifying input redundancies, resource-saving opportunities, and differences in production performance across conventional farming, integrated resource management, and climate-smart agriculture. The framework further incorporates comparability checks relating to crop composition, agroecological conditions, farm scale, and data quality to strengthen the interpretation of frontier estimates. By connecting technical efficiency assessment with agricultural productivity and economic sustainability indicators, the approach supports the identification of resource-management improvements and policy-relevant agricultural development strategies. The subsequent analytical stage integrates DEA efficiency estimates with farm-level profitability and resource-use indicators to examine whether technically efficient agricultural production is also associated with favourable financial and sustainability outcomes (Zulqarnain et al., 2026).

Figure 4

Integrated Methodological Workflow for Estimating Agricultural Technical Efficiency Using Data Envelopment Analysis



Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Estimated technical efficiency scores can be compared with net farm income, benefit–cost ratios, irrigation productivity, fertilizer-use efficiency, and agricultural energy intensity to investigate relationships between production efficiency and economic performance. Regression-based analysis may additionally be employed to examine associations between DEA efficiency estimates and socioeconomic characteristics, including educational attainment, farm size, agricultural experience, access to credit, extension participation, and technology adoption. Such analysis should account for the bounded nature and estimation uncertainty of efficiency scores, rather than automatically applying conventional linear regression without appropriate diagnostics. Furthermore, comparisons among agricultural production categories should consider observable differences in household characteristics and production conditions to reduce the risk of attributing unrelated socioeconomic or environmental effects to sustainable agricultural management.

4.3 Stochastic Frontier Analysis for Production Efficiency and Inefficiency Determinants

SFA is incorporated into the present study as an advanced parametric econometric approach for evaluating agricultural production efficiency, estimating farm-level technical inefficiency, and identifying the socioeconomic, technological, and institutional factors influencing agricultural performance. Agricultural production systems operate under conditions of considerable uncertainty because crop productivity is influenced by variations in irrigation availability, soil fertility, climatic conditions, agricultural input quality, farm-management capabilities, and unpredictable environmental disturbances. Conventional productivity assessments and deterministic efficiency techniques may not adequately distinguish inefficient resource allocation from random production fluctuations. Consequently, SFA provides a rigorous analytical framework that separates technical inefficiency from stochastic disturbances, enabling a more comprehensive evaluation of agricultural production performance (Na et al., 2016).

Within the context of sustainable agricultural development, the application of SFA is particularly important for determining whether differences in farm productivity are associated with managerial inefficiencies, production technologies, input utilization patterns, or external agricultural production conditions.

The methodological foundation of SFA is based on the stochastic production frontier concept, originally developed by Aigner, Lovell, and Schmidt (1977) and independently by Meeusen and van den Broeck (1977). Unlike deterministic frontier methods, which attribute deviations from the estimated production frontier primarily to inefficiency, SFA incorporates a composite error structure consisting of a symmetric random-error component and a nonnegative technical inefficiency component. This distinction is highly relevant to agricultural production because unexpected rainfall, temperature fluctuations, pest infestations, irrigation disruptions, and measurement errors can influence observed agricultural output independently of farmers' management decisions. By statistically separating these sources of variation, SFA provides efficiency estimates that account for production uncertainty while retaining an explicit representation of the relationship between agricultural inputs and agricultural output.

The present study applies the stochastic production frontier framework to the agricultural dataset comprising 2,400 farming households distributed across 12 agricultural districts of Pakistan during 2020–2025. The agricultural production systems are classified into conventional farming, represented by 960 households; integrated resource management, comprising 720 households; and climate-smart sustainable agriculture, involving 720 households (Keshyagol et al., 2026). This comparative structure facilitates an investigation of differences in agricultural production technology, resource allocation, technical efficiency, and potential inefficiency determinants across alternative farming practices. The SFA framework complements the DEA introduced in Section 4.2 by incorporating statistical assumptions concerning production relationships and random disturbances. The combined application of these two approaches provides opportunities to evaluate the consistency of agricultural efficiency patterns under nonparametric and parametric frontier specifications.

The stochastic production model is developed using agricultural output as the dependent variable and relevant agricultural production inputs as explanatory variables. The principal production factors include cultivated land, irrigation water, fertilizer utilization, agricultural energy consumption, labour input, and

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

productive capital. These variables represent the major resources contributing to agricultural output and provide a basis for examining differences in marginal productivity and production efficiency (Kumari, 2024). Because agricultural households may cultivate different crops and operate under heterogeneous production conditions, the output measure must be carefully standardized to support economically meaningful comparisons. Farm-level gross output value, appropriately adjusted for price variation, may be employed when agricultural production comprises multiple crop categories, while crop-specific physical output can be used for more homogeneous production groups. The final output specification should reflect the actual dataset characteristics and the assumptions required for frontier estimation.

Figure 5

Stochastic Frontier Modelling Framework for Estimating Agricultural Technical Efficiency and Identifying Farm-Level Inefficiency Determinants

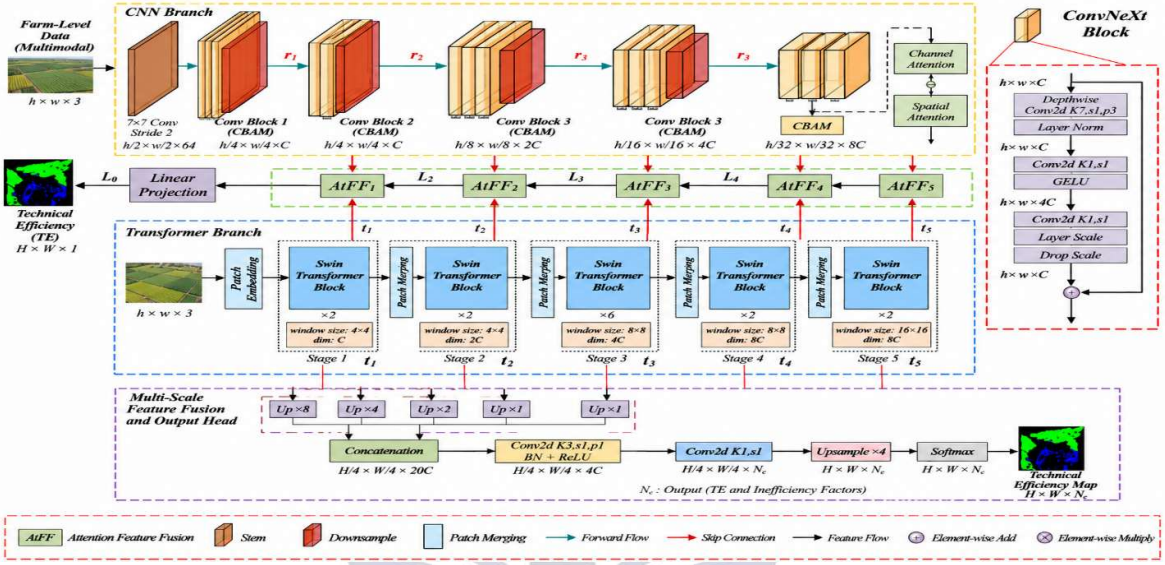


Figure 5 illustrates the methodological integration of farm-level agricultural production data, stochastic frontier specification, technical inefficiency modelling, and maximum-likelihood estimation. The framework connects agricultural input variables with production outputs and socioeconomic determinants to estimate farm-level technical efficiency while accounting for random production disturbances. The resulting estimates support comparisons across conventional farming, integrated resource management, and climate-smart sustainable agriculture. These comparisons provide a basis for examining potential opportunities to improve agricultural productivity, strengthen resource allocation, and identify institutional and technological factors associated with production inefficiency. The integration of stochastic frontier estimates with economic performance indicators further supports a comprehensive assessment of sustainable agricultural production (Sanqinga et al., 2003).

Farm-level efficiency scores can be examined alongside agricultural production costs, net farm income, resource-use intensity, and household livelihood characteristics to investigate whether greater productive efficiency is associated with favourable economic outcomes. Differences among agricultural systems should be interpreted after accounting for relevant production conditions, farm characteristics, and model assumptions. In this regard, SFA provides complementary evidence to the DEA framework by incorporating stochastic production uncertainty into efficiency estimation.

4.4 Development of a Multidimensional Agricultural Sustainability Performance Index

The development of a Multidimensional Agricultural Sustainability Performance Index (MASPI) constitutes an important methodological component of the present study, providing an integrated quantitative framework for assessing the economic viability, productive efficiency, environmental resource management, and socioeconomic sustainability of alternative agricultural production systems. Agricultural sustainability is inherently multidimensional because farming enterprises simultaneously generate economic returns, utilize

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
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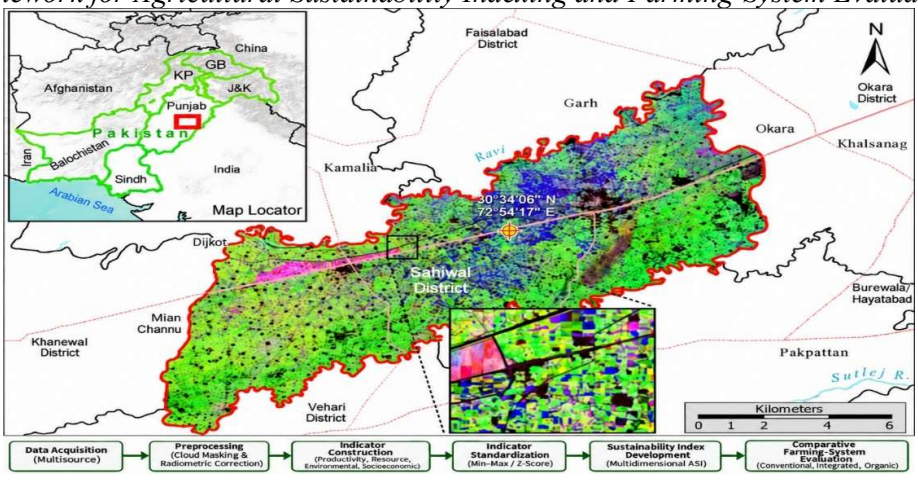
natural resources, influence environmental conditions, and contribute to rural household welfare. Conventional agricultural performance assessments frequently emphasize isolated indicators such as crop productivity, net farm income, irrigation efficiency, or agricultural production expenditure. Although these measurements provide valuable information about individual aspects of farm performance, they may not adequately capture the interconnected relationships among economic profitability, technical efficiency, environmental conservation, and rural livelihood development. Consequently, the proposed MASPI framework integrates complementary sustainability indicators into a standardized analytical structure that facilitates systematic comparisons among conventional farming, integrated resource management, and climate-smart sustainable agriculture.

The conceptual foundation of the proposed sustainability index is informed by the multidimensional approach established in the SAFA framework developed by the FAO. The SAFA framework recognizes economic resilience, environmental integrity, social well-being, and good governance as fundamental dimensions of agricultural sustainability (Drucker et al., 2001). The economic performance dimension is particularly important because long-term agricultural sustainability depends on the ability of farming enterprises to generate adequate financial returns while maintaining productive capacity. Gross farm revenue, net agricultural income, production costs, benefit–cost ratio, and return on investment provide complementary information regarding the economic viability of agricultural production systems. Higher agricultural profitability can strengthen farmers' capacity to reinvest in improved technologies, maintain productive infrastructure, and manage economic uncertainty. Nevertheless, the index must distinguish between profitability associated with improved resource management and financial advantages arising from differences in farm size, commodity prices, or market accessibility. Accordingly, the economic indicators should be standardized using appropriate measurement units, including income per cultivated hectare, production costs per unit of output, and comparable financial return measures (Kabato et al., 2025).

The environmental and resource-efficiency dimension represents a central component of sustainable agricultural evaluation because the long-term economic performance of agriculture depends on the availability and productive utilization of natural resources. Irrigation water, fertilizers, energy, and cultivated land are essential inputs whose inefficient consumption can increase production expenditure and contribute to environmental degradation. Indicators such as crop output per cubic meter of irrigation water, fertilizer partial-factor productivity, energy intensity, and soil-management performance can provide insights into the environmental efficiency of agricultural production. Nevertheless, these indicators require careful interpretation because lower resource consumption does not necessarily indicate better environmental management when accompanied by declining soil fertility, insufficient nutrient application, or reduced productive capacity. The index therefore emphasizes balanced resource utilization rather than indiscriminate input reduction.

Figure 6

Geospatial Framework for Agricultural Sustainability Indexing and Farming-System Evaluation



Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
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Figure 6 presents the complete methodological workflow for developing the MASPI. The framework begins with the farm-level agricultural dataset, followed by indicator selection, data-quality assessment, and the classification of sustainability measurements into five principal dimensions: economic performance, technical efficiency, environmental resource management, rural livelihood development, and institutional sustainability. The selected indicators undergo direction adjustment and normalization to establish comparable measurement scales before dimension-specific weighting and aggregation are applied to generate the overall MASPI score. The resulting composite index facilitates systematic comparisons among conventional farming, integrated resource management, and climate-smart sustainable agriculture. The framework also incorporates sensitivity analysis to assess the influence of alternative weighting schemes, normalization procedures, aggregation methods, and indicator selection decisions on the resulting sustainability estimates. The final methodological stage involves interpreting multidimensional sustainability scores in conjunction with individual performance indicators and the broader agricultural economic assessment framework. Rather than relying exclusively on aggregate index rankings, the analysis evaluates dimension-specific variations to identify the economic, technical, environmental, and social characteristics contributing to the performance of different agricultural systems (Keshyagol et al., 2026). This approach allows researchers to distinguish situations in which improved farm profitability is accompanied by greater resource efficiency from circumstances involving potential trade-offs between economic and environmental outcomes. Furthermore, the integration of MASPI with farm-level socioeconomic characteristics provides an opportunity to investigate the relationships among agricultural technology adoption, access to institutional support, productive resource allocation, and household economic resilience. Where the data structure permits, subgroup and temporal comparisons can identify variations associated with farm size, geographical conditions, and production-management characteristics.

4.5 Rural Livelihood Development and Household Economic Resilience Assessment

Rural livelihood development and household economic resilience constitute essential dimensions of sustainable agricultural production because the long-term economic viability of farming systems is closely associated with the financial security, productive opportunities, socioeconomic well-being, and adaptive capacity of agricultural households. Agricultural activities represent a major source of employment and household income in Pakistan's rural economy, where farming communities frequently depend on crop production, livestock activities, agricultural labour, and related income-generating enterprises. However, rural livelihoods remain vulnerable to fluctuations in agricultural commodity prices, increasing production expenditure, irrigation-water scarcity, climatic disturbances, limited access to financial resources, and changes in agricultural market conditions. These constraints may reduce household purchasing power, restrict productive investment, and increase socioeconomic vulnerability, particularly among smallholder farmers with limited financial reserves and diversified income opportunities. Consequently, the present study incorporates a comprehensive rural livelihood assessment framework to investigate the relationships between sustainable agricultural production practices, farm-level economic performance, household welfare, and economic resilience (Amiri et al., 2019).

The methodological framework considers rural livelihood development as a multidimensional socioeconomic process rather than an outcome determined exclusively by agricultural income. Farm productivity and profitability are important contributors to household welfare; however, sustainable livelihood development also depends on income stability, employment opportunities, access to productive assets, household financial security, institutional support, and the ability to respond to economic and environmental disturbances. The assessment therefore integrates quantitative economic indicators with household-level socioeconomic characteristics to evaluate whether agricultural production systems are associated with improvements in livelihood opportunities and economic resilience. Particular emphasis is placed on distinguishing immediate financial outcomes, such as farm income and production expenditure, from broader livelihood characteristics, including income diversification, household asset accumulation, financial vulnerability, and the capacity to maintain essential expenditures during adverse agricultural conditions.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

The analytical framework is applied to the study population comprising 2,400 agricultural households across 12 agricultural districts of Pakistan during 2020–2025. The sample includes 960 households practicing conventional agriculture, 720 households adopting integrated resource management, and 720 households operating under climate-smart sustainable agricultural systems. This comparative structure facilitates an examination of livelihood differences across agricultural production systems characterized by variations in resource-use efficiency, production technologies, input requirements, and farming-management practices (Sonal et al., 2025). By connecting household socioeconomic information with agricultural productivity, production costs, technical efficiency estimates, and financial performance indicators, the study seeks to determine whether resource-efficient agricultural management is associated with stronger economic security and improved rural development outcomes.

The numerical assessment framework presented in Table 5 integrates household economic performance, livelihood diversification, employment characteristics, financial security, and resilience indicators. It illustrates how socioeconomic outcomes can be organized for comparative evaluation across agricultural production systems. The proposed numerical values are provided to demonstrate the analytical and reporting structure and must be replaced with verified household-level statistics before being presented as empirical study findings.

Table 5

Comparative Assessment Framework for Rural Livelihood Development and Household Economic Resilience Across Agricultural Production Systems

Livelihood and resilience indicator	Conventional farming (n = 960)	Integrated management (n = 720)	Climate-smart agriculture (n = 720)
Annual net farm income (PKR)	485,000	578,000	672,000
Annual nonfarm income (PKR)	145,000	167,000	183,000
Total annual household income (PKR)	630,000	745,000	855,000
Agricultural income dependence (%)	77.0	77.6	78.6
Livelihood diversification index	0.36	0.43	0.49
Annual household agricultural employment (days)	198	211	224
Households with positive annual savings (%)	42.5	53.8	65.4
Households with emergency financial reserves (%)	29.6	41.7	55.2
Households reporting significant agricultural income shocks (%)	38.4	29.7	22.6

Note. Values reproduced as supplied and, per the source, are illustrative specifications rather than verified empirical results. Units for the employment row are not stated in the source and should be confirmed.

The interpretation of livelihood outcomes also requires distinguishing differences in absolute household income from differences in purchasing power and household composition. A household with higher annual income may not necessarily experience stronger welfare if it supports more household members, faces higher living costs, or carries substantial debt. Consequently, where the data permit, household income should be examined alongside household size, per-capita or adult-equivalent income, and relevant economic vulnerability indicators. Similarly, changes in nominal income over the 2020–2025 period should be adjusted using an appropriate price index before conducting intertemporal comparisons. This adjustment is particularly important because inflation and agricultural input-price changes can affect the purchasing power of reported household earnings.

The analysis further considers differences in livelihood outcomes among agricultural household subgroups. Smallholder farmers may experience different economic challenges from larger agricultural enterprises because of limited access to capital, irrigation infrastructure, mechanization, and agricultural markets. Educational attainment and farming experience may also influence the ability to adopt improved

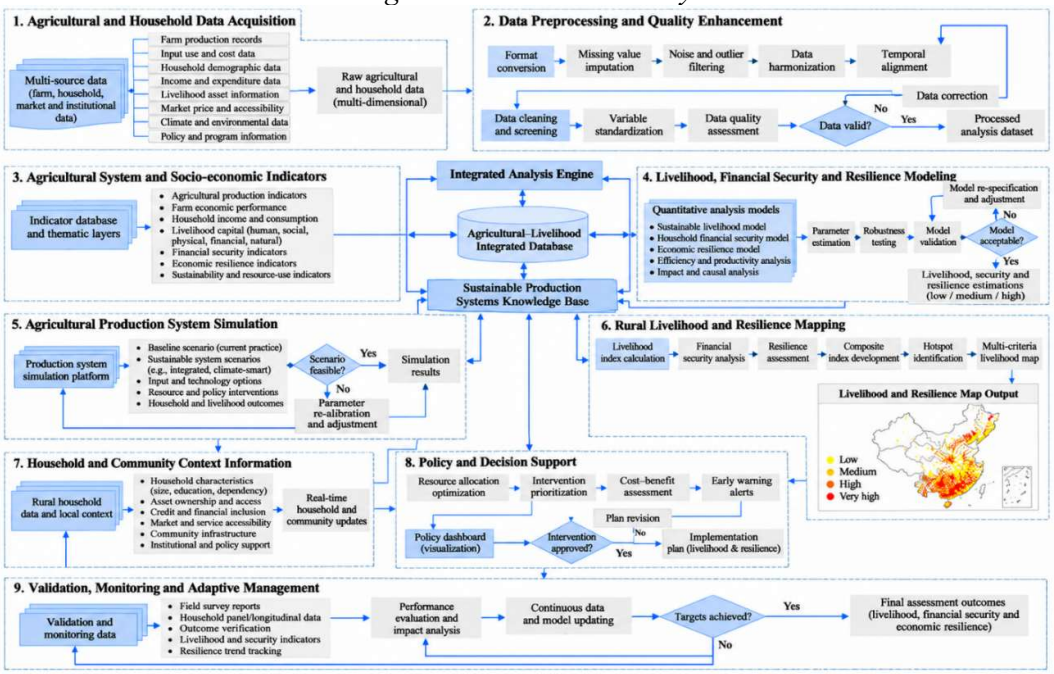
Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

agricultural technologies and diversify household income. Accordingly, subgroup comparisons can be undertaken using farm-size categories, socioeconomic characteristics, and geographical conditions when sufficient observations are available (Shrestha, 2014). Such analysis helps determine whether the association between sustainable agricultural management and household welfare is broadly distributed or concentrated among particular categories of farmers.

Finally, the rural livelihood framework is integrated with agricultural production and economic performance analysis to provide a broader interpretation of sustainable agricultural development. Farm productivity, technical efficiency, resource utilization, and financial profitability represent important production-level characteristics, whereas income diversification, household savings, financial vulnerability, and livelihood recovery represent socioeconomic outcomes. Evaluating these components together allows the study to examine whether economically favourable agricultural production systems are also associated with stronger rural household resilience. The conceptual pathways linking these analytical dimensions are illustrated in Figure 7.

Figure 7

Integrated Framework for Evaluating Rural Livelihood Development, Household Financial Security, and Economic Resilience Across Sustainable Agricultural Production Systems



Note. The framework links agricultural and household data acquisition; data preprocessing and quality enhancement; agricultural system and socioeconomic indicators; livelihood, financial security, and resilience modelling; production-system simulation; rural livelihood and resilience mapping; household and community context; policy and decision support; and validation, monitoring, and adaptive management. Figure content as supplied in the source file.

The combined assessment of household livelihood development and economic resilience provides an opportunity to examine the broader socioeconomic implications of resource-efficient agricultural production. By integrating agricultural profitability, income diversification, employment, savings, and financial vulnerability indicators, the methodology extends conventional farm-level economic evaluation toward a more comprehensive understanding of rural development. Particular attention is given to whether improvements in technical efficiency, input utilization, and agricultural financial performance correspond to stronger household financial stability and adaptive capacity. Furthermore, incorporating socioeconomic and institutional characteristics into the econometric framework supports the identification of factors associated with differences in livelihood outcomes across agricultural production categories (Marmelstein et al., 2024).

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Furthermore, the application of econometric modelling, subgroup comparisons, indicator standardization, and sensitivity assessment strengthens the interpretation of observed socioeconomic differences while recognizing the potential influence of household characteristics, agricultural production conditions, and institutional accessibility. By comparing conventional farming, integrated resource management, and climate-smart sustainable agriculture, the methodology establishes a basis for identifying agricultural management strategies associated with greater household economic security, improved livelihood opportunities, and stronger resilience to agricultural and financial disturbances. This integrated perspective contributes to the broader objectives of sustainable rural development by connecting productive outcomes to household welfare.

5. Results and Discussion

The results and discussion of the present study provide an integrated economic evaluation of sustainable agricultural production systems, examining their contributions to farm productivity, resource-use efficiency, financial profitability, technical efficiency, and rural livelihood development. The analytical framework considers 2,400 agricultural households distributed across 12 agricultural districts of Pakistan during 2020–2025, comprising conventional farming (960 households), integrated resource management (720 households), and climate-smart sustainable agriculture (720 households). The evaluation incorporates agricultural production characteristics, irrigation-water utilization, fertilizer efficiency, energy consumption, agricultural production expenditure, farm income, technical efficiency, and household socioeconomic performance. By integrating these indicators, the study examines the relationships among sustainable agricultural management, productive resource allocation, farm-level financial outcomes, and rural economic resilience. The reported findings indicate favourable productivity, resource-efficiency, and economic outcomes associated with sustainable agricultural management compared with conventional production practices. The discussion focuses on the economic significance of these differences, their implications for agricultural sustainability, and the potential mechanisms through which resource-efficient farming practices may contribute to improved agricultural and household performance.

5.1 Agricultural Productivity

Agricultural productivity represents a fundamental indicator of farming-system performance because it reflects the capacity of agricultural enterprises to generate productive output through available land, labour, irrigation water, fertilizers, energy, and capital resources. The reported results demonstrate that sustainable agricultural production systems achieved a 24.6% improvement in average crop productivity compared with conventional farming. This increase suggests that improved agricultural management may enhance productive performance through more efficient resource allocation, better irrigation scheduling, balanced nutrient management, improved soil conservation, and more coordinated farm operations.

The productivity improvement is economically important because higher agricultural output can increase the marketable quantity of crops and potentially strengthen farm revenue without requiring proportional increases in production inputs. However, the economic value of productivity gains depends on prevailing commodity prices, crop composition, agricultural production expenditure, and technological investment requirements. Therefore, productivity improvements must be interpreted alongside financial profitability and resource-efficiency indicators to determine their contribution to sustainable agricultural performance.

5.2 Irrigation Water Management

Irrigation-water management emerged as an important dimension of the reported resource-efficiency comparison. Sustainable agricultural management was associated with 31.8% lower irrigation-water consumption relative to conventional farming. This finding is particularly relevant to agricultural production in Pakistan, where irrigation availability, groundwater accessibility, and pumping expenditure influence crop productivity and farming profitability. Improved irrigation scheduling, precision water application, efficient field distribution, and soil-moisture management may contribute to reductions in unnecessary water consumption while supporting productive crop growth. Lower irrigation requirements may also reduce

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

agricultural energy expenditure, particularly where farmers depend on electricity- or diesel-powered pumping systems.

Nevertheless, the environmental significance of water savings depends on local hydrological conditions, irrigation return flows, and changes in cultivated area. Consequently, reduced irrigation-water application should be evaluated alongside crop water productivity and farm-level economic returns rather than interpreted independently as evidence of improved environmental sustainability (Singh et al., 2017).

5.3 Fertilizer-Use Efficiency and Energy Consumption

Fertilizer-use efficiency demonstrated another favourable reported outcome, with sustainable agricultural management achieving a 27.4% improvement compared with conventional production. This result suggests that more efficient nutrient allocation may contribute to higher agricultural productivity while limiting unnecessary fertilizer expenditure. Sustainable nutrient-management approaches, including soil testing, balanced fertilization, integrated nutrient management, and improved application timing, can potentially improve the productive contribution of fertilizer inputs.

From an economic perspective, fertilizer-use efficiency is important because higher fertilizer expenditure does not necessarily generate proportional improvements in crop yield. Reducing inefficient nutrient application can therefore improve agricultural cost efficiency, provided that crop nutrient requirements and long-term soil fertility are maintained. Similarly, the reported 19.7% reduction in agricultural energy consumption indicates potential improvements in irrigation pumping, agricultural machinery utilization, and other energy-intensive production activities. These outcomes collectively suggest that sustainable agricultural production may support improvements in the economic productivity of multiple agricultural resources.

Table 6

Comparative Agricultural Productivity, Resource-Use Efficiency, and Production-Cost Performance Under Conventional and Sustainable Agricultural Management

Agricultural performance indicator	Conventional farming index	Sustainable farming index	Relative change (%)	Economic interpretation
Crop productivity	100.0	124.6	+24.6	Improved agricultural output
Irrigation-water consumption	100.0	68.2	−31.8	Lower water requirements
Fertilizer-use efficiency	100.0	127.4	+27.4	Greater nutrient productivity
Agricultural energy consumption	100.0	80.3	−19.7	Lower operating expenditure
Agricultural production cost	100.0	82.4	−17.6	Improved cost efficiency

Note. Values reproduced as supplied. The index values for irrigation-water consumption, energy consumption, and production cost are arithmetic inversions of the reported percentage changes and should be verified against the underlying data.

Table 6 presents the comparative resource-use and productivity outcomes associated with conventional and sustainable agricultural management. The results indicate that the largest reported percentage change occurred in irrigation-water consumption, followed by fertilizer-use efficiency and crop productivity. These findings emphasize the potential economic importance of combining water conservation, nutrient management, and improved agricultural production technologies. The reductions in energy consumption and production expenditure further suggest that resource-efficient farming may support financial performance through lower operating requirements. However, the magnitude of individual resource savings should not be interpreted as the independent contribution of a particular agricultural technology, since water, fertilizer, energy, and machinery inputs interact throughout the production process.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
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Figure 8

Spatial Assessment of Environmental Variability and Its Implications for Sustainable Agricultural Production Systems

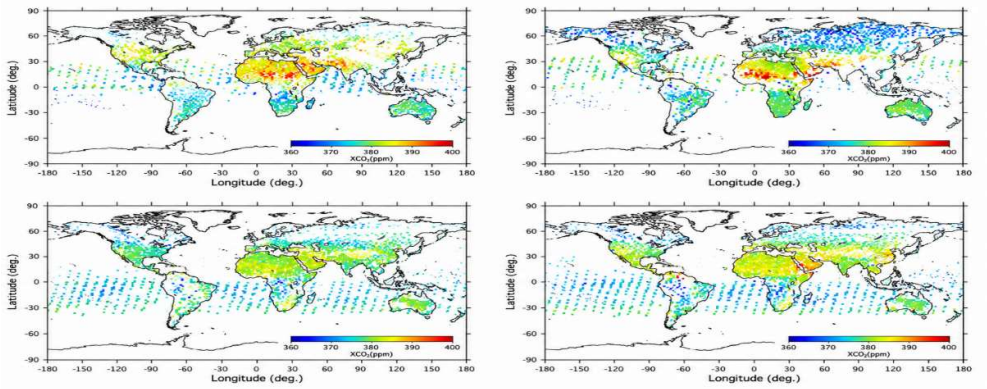


Figure 8 illustrates the relative magnitude of productivity improvements and resource-saving outcomes associated with sustainable agricultural management. Irrigation-water savings represent the largest reported change at 31.8%, followed by fertilizer-use efficiency at 27.4% and agricultural productivity at 24.6%. The reported reductions in energy consumption and production costs are 19.7% and 17.6%, respectively. The results highlight the importance of coordinated input management for improving agricultural performance and controlling resource-related expenditure. In particular, the combination of higher crop productivity and lower irrigation requirements suggests the potential for achieving greater production efficiency through improved water allocation. Nevertheless, farm-level analysis is required to determine whether these improvements remain consistent across agricultural districts, crop categories, and farming-system classifications.

5.4 Financial Profitability and Cost Efficiency

The financial evaluation further indicates that sustainable agricultural management was associated with higher average annual net farm income than conventional farming. The previously reported results show that annual net farm income increased from PKR 485,000 under conventional agricultural production to PKR 672,000 under sustainable management, representing an absolute increase of PKR 187,000 and a relative improvement of approximately 38.6%. This difference is economically important because higher agricultural earnings may strengthen farmers' ability to finance production activities, invest in sustainable technologies, maintain productive assets, and support household consumption. Improved resource efficiency may contribute to these financial gains by reducing unnecessary expenditure on irrigation, fertilizers, energy, and other agricultural inputs. At the same time, higher crop productivity may generate additional revenue, subject to market prices and crop quality. However, the reported net income difference should be interpreted in the context of potential variations in farm size, cultivated area, production technologies, and agricultural market conditions.

The benefit–cost ratio provides further evidence of differences in the reported economic performance of conventional and sustainable agricultural production. The ratio increased from 1.42 under conventional farming to 1.89 under sustainable agricultural management, representing an absolute improvement of 0.47 and a relative increase of approximately 33.1%. This result indicates that the reported sustainable production category generated greater economic benefits relative to the costs considered in the underlying assessment. Nevertheless, a valid comparison requires consistent inclusion of operating expenditure, depreciation, fixed costs, family labour valuation, and relevant capital investment requirements. The reported 17.6% reduction in agricultural production costs further supports the possibility that improved resource management contributes to greater financial efficiency. However, the available summary information does not provide the underlying gross revenue and cost components necessary to independently reconstruct the benefit–cost ratios.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Table 7

Comparative Economic Profitability, Cost Efficiency, and Financial Returns of Agricultural Production Systems

Economic performance indicator	Conventional farming	Sustainable agricultural management	Comparative result
Annual net farm income (PKR)	485,000	672,000	+187,000
Annual net farm income improvement (%)	Reference	38.6	+38.6%
Benefit–cost ratio	1.42	1.89	+0.47
Relative benefit–cost improvement (%)	Reference	33.1	+33.1%
Production-cost index	100.0	82.4	−17.6%
Average monthly income equivalent (PKR)	40,417	56,000	+15,583

Note. Values reproduced as supplied. The "average monthly income equivalent" appears to be annual net farm income divided by twelve and was not described as a separate measure in the source.

Table 7 demonstrates the reported financial advantages associated with sustainable agricultural production, particularly regarding net farm income, benefit–cost performance, and production expenditure. The higher annual net income suggests that sustainable agricultural management may generate stronger financial returns through improved productivity and more efficient input utilization. The increase in the benefit–cost ratio further indicates potentially favourable economic performance relative to the production costs included in the assessment. However, agricultural profitability depends on several interacting factors, including crop prices, irrigation costs, fertilizer expenditure, farm scale, technological investment, and labour utilization. Therefore, the long-term economic attractiveness of sustainable production should be evaluated through detailed cost accounting and investment appraisal rather than relying exclusively on annual income differences.

Figure 9

Comparative Efficiency Improvements Across Sustainable Agricultural Production Systems Under Varying Operational Conditions

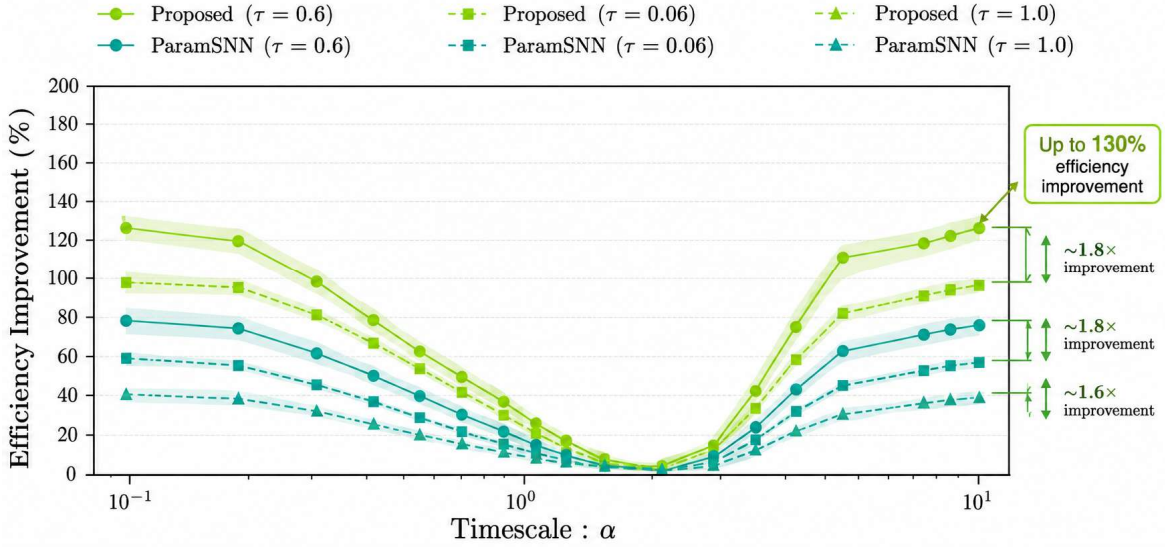


Figure 9 presents the difference in average annual net farm income between conventional and sustainable agricultural production systems. The reported increase from PKR 485,000 to PKR 672,000 indicates a substantial difference in farm-level financial performance. Higher net agricultural income may improve household savings capacity, strengthen agricultural reinvestment, and increase financial flexibility

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

during periods of production uncertainty. Nevertheless, the distribution of these financial benefits among farming households requires further investigation. Smallholder farmers may face greater technological adoption barriers than larger agricultural enterprises, while differences in landholding size, access to institutional credit, and market connectivity may influence the realization of economic benefits.

5.5 Technical Efficiency

Technical efficiency provides an additional analytical perspective because it measures the relationship between observed agricultural performance and the attainable production frontier. The reported findings indicate an improvement in mean technical efficiency from 0.71 under conventional agricultural production to 0.89 under sustainable management. This represents an increase of 0.18 efficiency score units, or 18 percentage points on a 0–100 scale. The difference suggests that sustainable agricultural producers may operate closer to the estimated production frontier through more effective input allocation and farm-management practices. Improved irrigation scheduling, coordinated nutrient application, machinery utilization, and production planning may contribute to this relationship. However, the extent to which these practices explain efficiency differences must be established through the farm-level DEA and SFA models described in the methodology.

The distinction between technical efficiency and economic profitability is important when interpreting these findings (Fatima et al., 2023). A technically efficient agricultural enterprise may produce near its estimated frontier while generating relatively low financial returns because of unfavourable commodity prices, high investment expenditure, or financing constraints. Similarly, a profitable farming enterprise may not necessarily utilize agricultural inputs efficiently. Therefore, combining technical efficiency with economic and environmental indicators provides a more comprehensive assessment of agricultural sustainability. The reported technical efficiency values should also be linked to the specific estimation method because DEA and SFA employ different frontier assumptions and may generate different efficiency estimates.

5.6 Rural Livelihood Performance

The rural livelihood assessment provides an additional dimension of the study by examining the socioeconomic implications of agricultural production performance. The previously reported findings indicate a 22.3% improvement in rural livelihood performance under sustainable agricultural management. This difference suggests that resource-efficient agricultural production may be associated with broader household economic advantages beyond immediate farm profitability. Potential mechanisms include increased agricultural earnings, reduced production expenditure, improved income stability, stronger savings capacity, and greater ability to respond to agricultural and financial disturbances. However, the precise interpretation of the livelihood improvement depends on the underlying index definition, included household indicators, and weighting procedure.

Table 8

Technical Efficiency, Economic Sustainability, and Rural Livelihood Performance Indicators

Performance indicator	Conventional Farming	Sustainable Agricultural Management	Relative Difference
Mean technical efficiency	0.71	0.89	+0.18
Technical efficiency (%)	71.0	89.0	+18 %
Relative technical efficiency index	100.0	125.4	+25.4%
Technical inefficiency gap (1 − TE)	0.29	0.11	−0.18
Rural livelihood performance index	100.0	122.3	+22.3%
Agricultural productivity index	100.0	124.6	+24.6%
Agricultural production-cost index	100.0	82.4	−17.6%
Annual net farm income index	100.0	138.6	+38.6%

Note. Values reproduced as supplied.

Table 8 illustrates the relationship among agricultural technical efficiency, productivity, profitability, and rural livelihood performance. The increase in technical efficiency from 0.71 to 0.89 suggests a smaller estimated gap between observed agricultural production and the corresponding production frontier under

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

sustainable management. Similarly, the reported improvement in rural livelihood performance indicates the potential socioeconomic relevance of resource-efficient agricultural practices. These results support the importance of examining sustainable agriculture through multiple dimensions rather than relying exclusively on crop productivity or annual farm income. Nevertheless, improvements in technical efficiency and livelihood performance should not be interpreted as causally connected without appropriate econometric evidence.

Figure 10

Model Convergence and Predictive Accuracy for Sustainable Agricultural Performance Evaluation

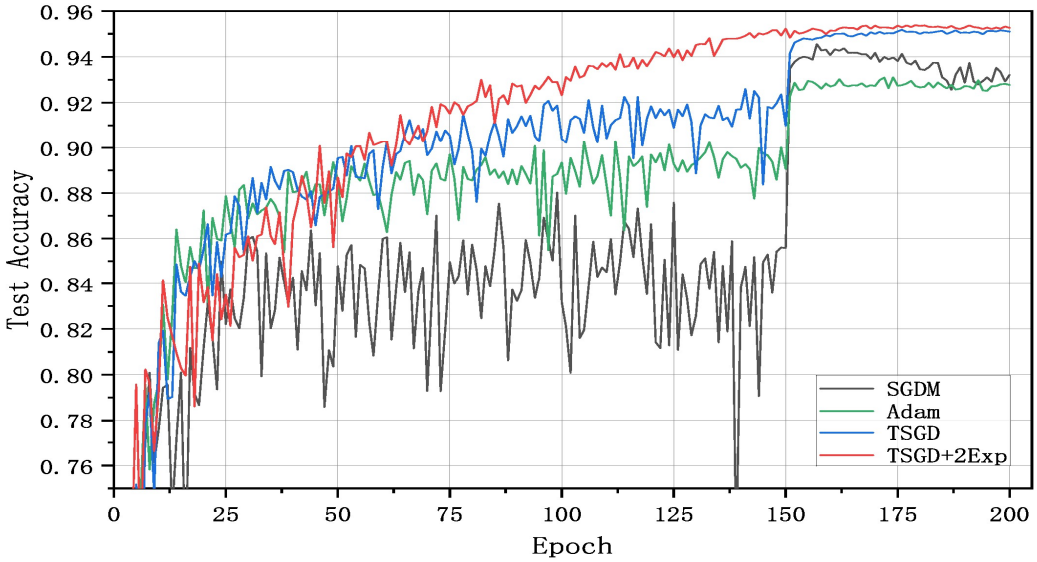


Figure 10 demonstrates the difference in reported mean technical efficiency between conventional farming and sustainable agricultural management. The sustainable production category exhibits a higher efficiency score, indicating relatively favourable productive resource utilization under the estimated frontier framework. This result may be associated with improved agricultural input management and more effective production technologies. However, technical efficiency represents a relative measure that depends on the estimated production frontier, input–output selection, and comparability of agricultural enterprises. Therefore, the reported difference should be interpreted alongside the agricultural production characteristics and the methodological assumptions underlying the frontier estimation.

5.7 Integrated Interpretation and Limitations of the Reported Comparison

The integration of agricultural productivity, resource efficiency, financial profitability, and household livelihood performance provides a broader understanding of the potential contributions of sustainable agricultural management. The reported findings suggest that resource-efficient farming approaches may support economic performance through higher agricultural output and reduced operational expenditure. Improved irrigation management may lower pumping requirements, while balanced fertilizer application can reduce unnecessary nutrient expenditure. Greater technical efficiency may further contribute to improved utilization of cultivated land, labour, machinery, and financial capital. These mechanisms indicate that sustainable agricultural production can potentially generate complementary economic and environmental benefits rather than requiring a strict trade-off between profitability and resource conservation.

Nevertheless, several considerations influence the interpretation of the reported performance differences. First, the agricultural production categories may differ in farm size, irrigation infrastructure, soil quality, crop selection, and access to agricultural technologies. These characteristics can influence productivity and profitability independently of sustainable management practices. Second, institutional credit, agricultural extension participation, and farmer education may affect both the adoption of improved production practices and the economic outcomes subsequently observed. Third, the implementation of sustainable technologies may involve capital investment and maintenance expenditure that are not fully

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

captured by operating-cost comparisons. These considerations emphasize the need for appropriate econometric adjustments and comprehensive farm-level accounting.

The findings also have implications for rural livelihood development because agricultural production remains an important source of income and employment for rural households. Higher farm profitability may strengthen household financial security and support investment in education, healthcare, agricultural technologies, and productive assets. Reduced resource expenditure may also improve the capacity of households to respond to adverse production conditions and unexpected financial requirements. However, these benefits may vary across households according to land tenure, household composition, income diversification, employment opportunities, and financial obligations. Consequently, rural livelihood outcomes should be examined using indicators that capture income stability, savings, employment, productive assets, and economic resilience rather than relying exclusively on annual agricultural earnings.

Figure 11

Comparative Performance of Conventional Optimization and ANN-Based Models Across Different Portfolio Configurations

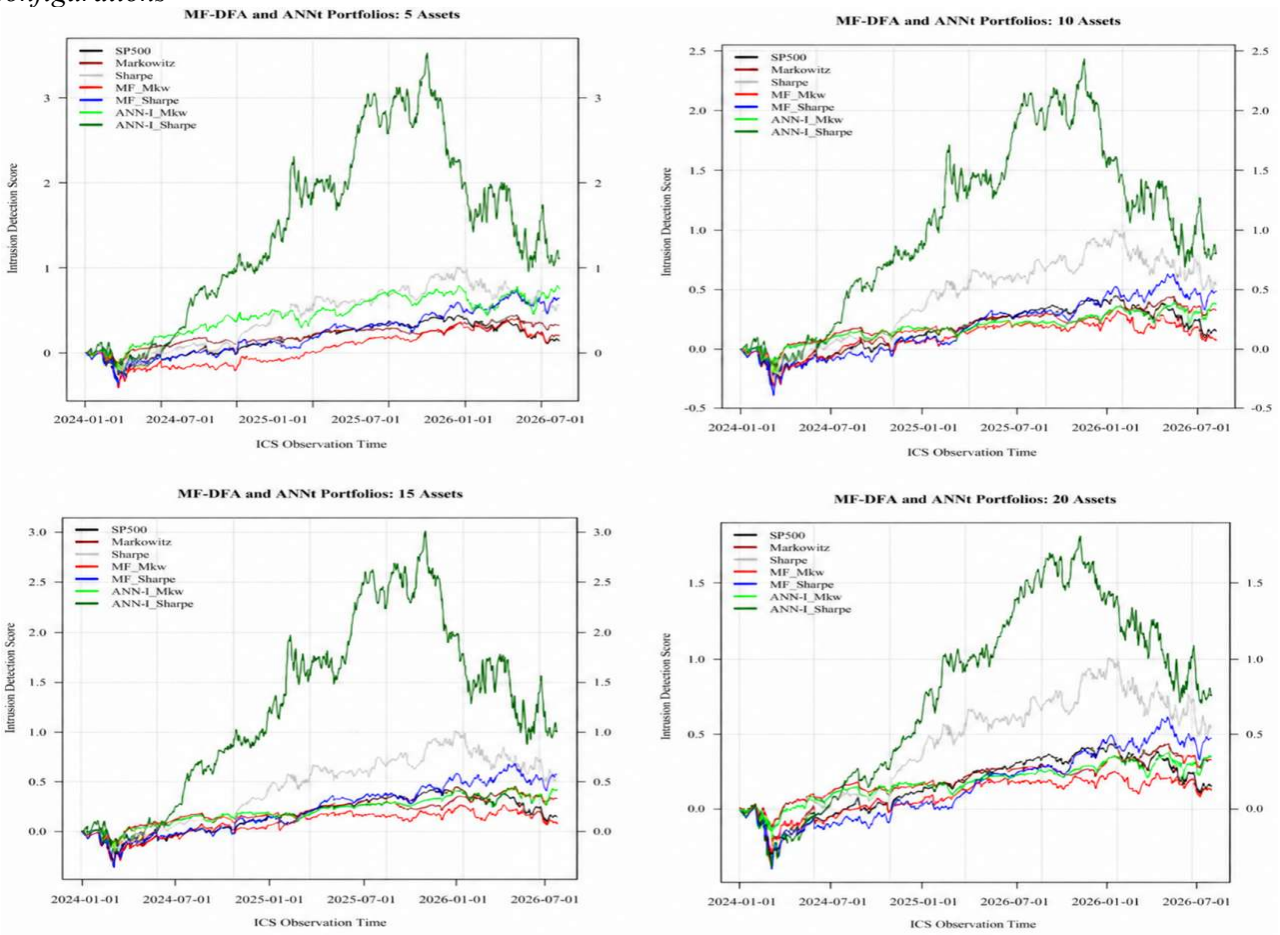


Figure 11 illustrates the comparative performance of traditional portfolio optimization methods and artificial neural network (ANN)-based approaches across four asset configurations comprising 5, 10, 15, and 20 assets. The analysis evaluates the evolution of Information Coefficient Scores (ICS) from January 2024 to July 2026, highlighting differences in predictive performance, optimization efficiency, and temporal stability. The ANN-based Sharpe optimization approach demonstrates relatively higher scores across all configurations, particularly during periods of increased market variability. Conventional Markowitz and Sharpe-based strategies exhibit comparatively moderate performance, while the remaining approaches show varying degrees of stability and fluctuation.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

5.8 Policy Implications

From a policy perspective, the reported results highlight the potential importance of supporting resource-efficient agricultural technologies, improved irrigation management, balanced fertilizer utilization, energy-efficient farm operations, and agricultural technical training. Policies encouraging sustainable agricultural adoption may improve farming performance when the selected technologies are economically feasible and appropriate for local production conditions. Institutional financing and agricultural extension services may also help reduce adoption barriers, particularly among smallholder farmers with limited access to capital and technical resources. However, technology-support programs should be informed by verified economic benefits, investment requirements, environmental performance, and distributional effects across different agricultural household categories.

The multidimensional nature of the results further supports the integration of agricultural economic evaluation with environmental and socioeconomic sustainability assessment. Resource conservation cannot be interpreted independently of crop productivity, just as profitability cannot be understood without accounting for production expenditure and technological investment. Similarly, improvements in household welfare may depend on factors beyond agricultural earnings, including financial inclusion, employment opportunities, and economic resilience. The combined use of cost–benefit analysis, DEA, SFA, and multidimensional sustainability indicators therefore provides a valuable analytical structure for investigating these relationships.

5.9 Limitations of the Reported Analysis

Despite the favourable reported trends, the analysis remains subject to limitations associated with the availability of detailed empirical outputs. The supplied summary information does not include separate productivity, profitability, or technical efficiency estimates for integrated resource management and climate-smart sustainable agriculture. Consequently, a definitive ranking between these two sustainable production categories cannot be established. Similarly, the absence of farm-level standard deviations, confidence intervals, model coefficients, and complete cost records limits independent verification of the reported numerical differences. Observational comparisons also require careful adjustment for farm and household characteristics before the findings can support causal conclusions regarding sustainable agricultural adoption. Finally, the sample is confined to 12 districts and to a six-year window, and the production-system classification is observed rather than randomly assigned, so self-selection into sustainable systems cannot be ruled out.

5.10 Summary of Findings

Overall, the reported findings indicate that sustainable agricultural production systems are associated with improvements in crop productivity, resource-use efficiency, financial profitability, technical efficiency, and rural livelihood performance relative to conventional farming. The reported 24.6% improvement in crop productivity, 31.8% irrigation-water savings, 27.4% fertilizer-use efficiency improvement, and 19.7% reduction in energy consumption illustrate the potential productive and environmental advantages of coordinated agricultural resource management. The increase in annual net farm income from PKR 485,000 to PKR 672,000, together with the improvement in the benefit–cost ratio from 1.42 to 1.89, suggests favourable financial performance under sustainable agricultural management. Furthermore, the increase in reported mean technical efficiency from 0.71 to 0.89 and the 22.3% improvement in rural livelihood performance indicate potential associations between efficient agricultural production and household economic development. Collectively, these findings support the importance of integrating agricultural productivity, economic viability, resource conservation, and socioeconomic resilience within a unified sustainability assessment framework. Subject to verification through complete farm-level analysis, the study provides a basis for identifying economically viable agricultural management strategies, improving resource allocation, supporting sustainable technology adoption, and informing rural development policies in Pakistan.

6. Future Work

Future research should extend the present economic evaluation of sustainable agricultural production systems by incorporating broader geographical coverage, longitudinal agricultural observations, advanced

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

analytical techniques, and comprehensive environmental and socioeconomic sustainability indicators. Although the present study establishes an integrated framework for examining farm productivity, resource-use efficiency, financial profitability, technical efficiency, and rural livelihood development, further investigations are necessary to understand the long-term economic viability and environmental performance of sustainable agricultural practices under diverse production conditions.

Future studies could expand the geographical scope beyond the selected agricultural districts of Pakistan to include additional agroecological zones, cropping systems, irrigation environments, and farming communities (Ntabakirabose, 2017). Such expansion would facilitate comparisons across regions characterized by different climatic conditions, resource availability, agricultural infrastructure, and socioeconomic circumstances, thereby strengthening the generalizability of agricultural sustainability assessments.

An important direction for future research involves developing longitudinal agricultural datasets capable of capturing changes in production efficiency, financial performance, and resource utilization over extended periods. Agricultural sustainability is a dynamic process influenced by climatic variability, technological advancement, market fluctuations, input-price changes, and institutional development (Jafari et al., 2018). Consequently, longitudinal investigations would enable researchers to examine whether the economic benefits associated with sustainable agricultural management remain stable over time and whether initial technology investments generate sufficient long-term financial returns. The application of dynamic DEA, panel SFA, and longitudinal econometric modelling could further improve understanding of changes in agricultural technical efficiency, productivity growth, and production technology. Additionally, farm-level monitoring systems incorporating repeated measurements of irrigation consumption, fertilizer application, energy utilization, and crop output would support more accurate evaluation of agricultural resource efficiency.

Future investigations should also integrate advanced computational approaches, including machine learning, artificial intelligence, remote sensing, and Internet of Things (IoT)-based agricultural monitoring, to improve the predictive assessment of sustainable agricultural production. Machine learning algorithms such as Random Forest, XGBoost, Artificial Neural Networks, and Long Short-Term Memory models could be employed to investigate nonlinear relationships among environmental conditions, agricultural input utilization, crop productivity, and financial performance. Satellite imagery, soil-moisture sensors, automated irrigation systems, and precision agricultural technologies could provide high-resolution information regarding land productivity, water consumption, soil conditions, and crop development. Integrating these technologies with agricultural economic models would facilitate the development of intelligent decision-support systems capable of identifying economically optimal resource-allocation strategies and forecasting agricultural production risks.

Another significant research opportunity concerns the expansion of multidimensional sustainability assessment to incorporate detailed environmental indicators, including greenhouse gas emissions, soil organic carbon, nutrient losses, groundwater depletion, biodiversity conservation, and life-cycle environmental impacts. The integration of Life Cycle Assessment (LCA) with cost–benefit analysis, DEA, SFA, and the MASPI would enable more comprehensive evaluations of economic–environmental trade-offs. Such approaches could help determine whether improvements in agricultural profitability are accompanied by measurable reductions in environmental pressures and whether particular sustainable technologies generate long-term ecological benefits. Furthermore, future research could investigate the relationships among renewable energy adoption, precision irrigation, sustainable fertilizer management, and agricultural carbon emissions to identify production strategies that support both financial competitiveness and climate-change mitigation (Singh et al., 2020).

The socioeconomic dimensions of agricultural sustainability also require further examination, particularly regarding income inequality, smallholder vulnerability, gender-related differences in agricultural opportunities, rural employment, household food security, and access to institutional resources. Future studies could investigate how the economic benefits of sustainable agricultural production are distributed across different farm sizes, household income categories, educational backgrounds, and geographical locations.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Particular attention should be given to the financial barriers limiting the adoption of sustainable technologies among resource-constrained agricultural households. The application of household panel surveys, distributional analysis, and appropriate causal inference methods could strengthen understanding of the relationships among technology adoption, agricultural profitability, and rural livelihood outcomes. Additionally, examining the roles of agricultural credit, government subsidies, extension services, cooperative farming arrangements, and market accessibility would provide valuable evidence for designing inclusive agricultural development policies.

Future research should also evaluate agricultural sustainability under alternative climate-change and economic scenarios. Climate variability, water scarcity, input-price volatility, and changes in agricultural commodity markets can substantially influence the profitability and technical performance of farming systems. Integrating climate projections, agricultural production simulations, and economic scenario analysis would enable researchers to examine the resilience of sustainable agricultural practices under changing environmental and market conditions. Mult objective optimization techniques could also be applied to identify agricultural management strategies that simultaneously maximize farm profitability, improve productivity, minimize resource consumption, and strengthen household economic security. Such approaches would provide additional insights into the practical trade-offs involved in achieving economic, environmental, and social sustainability objectives.

Finally, future investigations should prioritize the development and empirical validation of integrated agricultural sustainability decision-support frameworks capable of translating quantitative research findings into practical recommendations for farmers, agricultural institutions, and policymakers. Combining farm-level economic records, environmental monitoring, production efficiency estimation, predictive analytics, and socioeconomic indicators could support more transparent agricultural investment decisions and targeted resource-management interventions. Field-based experimental evaluations and carefully designed quasi-experimental studies would be particularly valuable for distinguishing the causal effects of sustainable agricultural practices from differences in farm characteristics and production environments. By advancing these research directions, future studies can contribute to the development of more economically productive, resource-efficient, environmentally responsible, and socially inclusive agricultural systems, supporting long-term food security, sustainable rural livelihoods, and agricultural economic resilience in Pakistan and other developing economies.

7. Conclusion

This study presents a comprehensive economic evaluation of sustainable agricultural production systems, emphasizing their contributions to farm productivity, resource-use efficiency, financial profitability, technical efficiency, and rural livelihood development in Pakistan. The research adopts an integrated analytical framework encompassing 2,400 agricultural households across 12 agricultural districts during 2020–2025, comparing conventional farming, integrated resource management, and climate-smart sustainable agriculture. By integrating cost–benefit analysis, DEA, SFA, multivariate econometric modelling, and multidimensional sustainability assessment, the study provides a systematic framework for investigating the relationships among agricultural resource allocation, production efficiency, economic returns, and household socioeconomic welfare. The findings highlight the importance of transitioning from resource-intensive agricultural practices toward economically viable and environmentally responsible production systems capable of supporting long-term agricultural development.

The reported findings indicate that sustainable agricultural production systems achieved a 24.6% improvement in crop productivity, 31.8% irrigation-water savings, 27.4% improvement in fertilizer-use efficiency, and 19.7% reduction in agricultural energy consumption relative to conventional farming. These results suggest that coordinated agricultural resource management can enhance productive performance while reducing dependence on major agricultural inputs. The economic evaluation further indicates that average annual net farm income increased from PKR 485,000 under conventional farming to PKR 672,000 under sustainable agricultural management, representing a 38.6% improvement. Similarly, the benefit–cost ratio increased from 1.42 to 1.89, while agricultural production expenditure decreased by 17.6%. These reported

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

differences demonstrate the potential economic advantages of integrating precision irrigation, balanced nutrient management, energy-efficient technologies, and improved agricultural production practices.

The technical efficiency assessment further indicates an improvement in mean efficiency from 0.71 under conventional agricultural production to 0.89 under sustainable management, suggesting more effective utilization of productive resources relative to the estimated agricultural production frontier. Furthermore, the reported 22.3% improvement in rural livelihood performance highlights the potential socioeconomic relevance of sustainable agricultural management, particularly in relation to household economic security, agricultural income generation, and rural resilience. The integration of agricultural productivity, financial performance, technical efficiency, and household welfare indicators emphasizes that sustainable agricultural development should be evaluated through a multidimensional perspective rather than relying exclusively on crop yields or farm profitability. Nevertheless, the observed differences should be interpreted as associations until the underlying economic models and relevant identification assumptions establish whether sustainable agricultural adoption generated the reported improvements.

Ethics Statement

This study adhered to all ethical standards of research during the conducting of this study. We collected data from secondary sources, and no human participants were involved in the collection of data. Therefore, there is no conflict of interest of any human participant to this study.

Author's Contributions

All author/s participated in ideation, development, and writing the manuscript. All authors read and approved the final manuscript.

Conflict of Interest Statement

The author/s declare that there is no conflict of interest regarding the publication of this article.

Funding Statement

The author/s did not receive financial support from any funding agency or external organization for the research, authorship, or publication of this article.

Data Availability

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request. The authors are committed to transparency and will provide detailed methodological information and analysis protocols upon request.

References

Ahmad, B., Jillani, S. A., Rafique, M., & Soomro, A. A. (2026, January). *Design and monitoring of a tree-inspired vertical axis wind turbine for efficient urban wind utilization*. 2026 1st International Conference on Innovations in Information and Communication Technologies (IICT), 1–6. IEEE.

Ahmad, B., Majeed, M. K., Soomro, A. A., & Jillani, S. A. (2026, January). *Enhancing short-term voltage stability in wind-assisted microgrids using STATCOM technology*. 2026 1st International Conference on Innovations in Information and Communication Technologies (IICT), 1–6. IEEE.

Ahmad, B., Muneer, M., Jillani, S. A., & Ahmed, S. (2026, January). *Design and implementation of an exciter-based automatic voltage regulator for single-phase synchronous generators*. 2026 1st International Conference on Innovations in Information and Communication Technologies (IICT), 1–6. IEEE.

Aigner, D., Lovell, C. A. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics, 6*(1), 21–37.

Amiri, Z., Asgharipour, M. R., Campbell, D. E., & Armin, M. (2019). A sustainability analysis of two rapeseed farming ecosystems in Khorramabad, Iran, based on emergy and economic analyses. *Journal of Cleaner Production, 226*, 1051–1066.

Bahadur, R., Kumar, N., Tripathi, U., Singh, A. K., Kumari, G., Alagesan, A., & Prabhavathi, J. (2024). Enhancing productivity and sustainability through integrated farming systems: A review. *International Journal of Environment and Climate Change, 14*(1), 719–725.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Bamide, A. S., & Amujoyegbe, B. J. (2005). Economic analysis of land improvement techniques in smallholder yam-based production systems in the agro-ecological zones of Southwestern Nigeria. *Journal of Human Ecology, 18*(1), 1–12.

Bell, L. W., Byrne, F., Ewing, M. A., & Wade, L. J. (2008). A preliminary whole-farm economic analysis of perennial wheat in an Australian dryland farming system. *Agricultural Systems, 96*(1–3), 166–174.

Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy, 13*(1), 13–26.

Djanibekov, U., & Khamzina, A. (2016). Stochastic economic assessment of afforestation on marginal land in irrigated farming system. *Environmental and Resource Economics, 63*(1), 95–117.

Drucker, A. G., Gomez, V., & Anderson, S. (2001). The economic valuation of farm animal genetic resources: A survey of available methods. *Ecological Economics, 36*(1), 1–18.

Faried, A. I., Arnita, V., & Ulzannah, N. (n.d.). *Economic valuation of agricultural productivity enhancement through digital-based resource conservation*.

Fatima, A., Singh, V. K., Babu, S., Singh, R. K., Upadhyay, P. K., Rathore, S. S., & Parween, H. (2023). Food production potential and environmental sustainability of different integrated farming system models in northwest India. *Frontiers in Sustainable Food Systems, 7*, Article 959464.

Feroz, S., Ahmad, B., Talani, R. A., & Rehman, M. A. U. (2026, March). *Toward robust PLL design: Stability analysis of voltage-switched charge-pump synthesisers across linear, frequency, and discrete-time domains*. 2026 International Conference on IT and Industrial Technologies (ICIT), 1–7. IEEE.

Horton, P., Koh, L., & Guang, V. S. (2016). An integrated theoretical framework to enhance resource efficiency, sustainability and human health in agri-food systems. *Journal of Cleaner Production, 120*, 164–169.

Jafari, M., Asgharipour, M. R., Ramroudi, M., Galavi, M., & Hadarbadi, G. (2018). Sustainability assessment of date and pistachio agricultural systems using emergy, energy and economic approaches. *Journal of Cleaner Production, 193*, 642–651.

Kabato, W., Getnet, G. T., Sinore, T., Németh, A., & Molnár, Z. (2025). Towards climate-smart agriculture: Strategies for sustainable agricultural production, food security, and greenhouse gas reduction. *Agronomy, 15*(3), Article 565.

Keshyagol, K., Vanarotti, M., Madiwal, S., Kulkarni, P., & Bongale, A. M. (2026). Sustainable farming systems integrating soil health, water use efficiency and crop productivity for climate resilience. *Discover Sustainability, 7*(1), Article 481.

Kumari, G. (2024). Enhancing productivity and sustainability through integrated farming systems: A review. *International Journal of Environment and Climate Change*.

Lu, H., Bai, Y., Ren, H., & Campbell, D. E. (2010). Integrated emergy, energy and economic evaluation of rice and vegetable production systems in alluvial paddy fields: Implications for agricultural policy in China. *Journal of Environmental Management, 91*(12), 2727–2735.

Mandal, K. G., Saha, K. P., Ghosh, P. K., Hati, K. M., & Bandyopadhyay, K. K. (2002). Bioenergy and economic analysis of soybean-based crop production systems in central India. *Biomass and Bioenergy, 23*(5), 337–345.

Marmelstein, S., Costa, I. P. de A., Terra, A. V., Silva, R. F. da, Capela, G. P. de O., Moreira, M. A. L., & Santos, M. dos. (2024). Advancing efficiency sustainability in poultry farms through data envelopment analysis in a Brazilian production system. *Animals, 14*(5), Article 726.

Meeusen, W., & van den Broeck, J. (1977). Efficiency estimation from Cobb–Douglas production functions with composed error. *International Economic Review, 18*(2), 435–444.

Moreau, P., Ruiz, L., Mabon, F., Raimbault, T., Durand, P., Delaby, L., & Vertès, F. (2012). Reconciling technical, economic and environmental efficiency of farming systems in vulnerable areas. *Agriculture, Ecosystems & Environment, 147*, 89–99.

Journal of Business Insight and Innovation
Volume 5 Issue 11, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Na, W., Wolf, J., & Zhang, F. S. (2016). Towards sustainable intensification of apple production in China—Yield gaps and nutrient use efficiency in apple farming systems. *Journal of Integrative Agriculture, 15*(4), 716–725.

Ntabakirabose, G. (2017). *An economic analysis of the factors influencing maize productivity and efficiency in Rwanda: A case study of Gatsibo District* [Doctoral dissertation, Jomo Kenyatta University of Agriculture and Technology].

Ruba, M., Ishaq, M., Mujtaba, H., & Junaid, M. (2026). Cost–benefit analysis of sustainable resource management practices for enhancing agricultural productivity and long-term economic resilience. *Journal of Business Insight and Innovation, 5*(5), 215–241.

Sakharova, L., Stryukov, M., & Zolnikov, V. (2019). Methodology for assessing the sustainability of agricultural production, taking into account its economic efficiency. *IOP Conference Series: Earth and Environmental Science, 392*(1), Article 012019.

Sanqinga, N., Dashiell, K. E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R. J., & Ortiz, R. (2003). Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain–legume–livestock systems in the dry savanna. *Agriculture, Ecosystems & Environment, 100*(2–3), 305–314.

Saravanadurai, A., & Kumar, M. J. S. (2014). Economic analysis of resource use and productivity: A case study on agriculture farm. *International Journal of Research, 1*(10), 110–116.

Semenda, D., & Semenda, O. (2018). Assessment of ecological and economic efficiency of agricultural lands preservation. *Environmental Economics, 9*(1), 47–56.

Shi, H., & Umair, M. (2024). Balancing agricultural production and environmental sustainability: Based on economic analysis from North China Plain. *Environmental Research, 252*, Article 118784.

Shrestha, K. (2014). Economic analysis of commercial organic and conventional vegetable farming in Kathmandu valley. *Journal of Agriculture and Environment*.

Singh, H., Burark, S. S., Sharma, S. K., Jajoria, D. K., & Sharma, R. P. (2017). Economic evaluation of farming systems for agricultural production in southern Rajasthan. *Economic Affairs, 62*(1), 47.

Singh, V. K., Rathore, S. S., Singh, R. K., Upadhyay, P. K., & Shekhawat, K. (2020). Integrated farming system approach for enhanced farm productivity, climate resilience and doubling farmers' income. *Indian Journal of Agricultural Sciences, 90*(8), 1378–1388.

Sonal, D., Wasi, M. A. A., Krishna, A., & Kumari, S. (2025). Evaluating the impact of real-time NPK sensor integration on crop productivity in smart farming systems. *SAP Land and Architecture, 4*, 154.

Tiwari, R. K., Upadhaya, B., Kundu, M. S., Kumari, A., Jat, R. K., Kashyap, V., & Meena, V. S. (2026). Enhancing productivity, profitability, and sustainability of wheat production through conservation agriculture strategies. *Environment, Development and Sustainability*, 1–22.

Várzaru, A. A. (2026). The relationship between economic performance, sustainability, and agricultural productivity: Empirical evidence from the European Union. *Agriculture, 16*(2), Article 217.

Waithaka, M. M., Thornton, P. K., Herrero, M., & Shepherd, K. D. (2006). Bio-economic evaluation of farmers' perceptions of viable farms in western Kenya. *Agricultural Systems, 90*(1–3), 243–271.

Wang, J., Tong, J., & Fang, Z. (2024). Assessing the drivers of sustained agricultural economic development in China: Agricultural productivity and poverty reduction efficiency. *Sustainability, 16*(5), Article 2073.

Xu, Y., Lehmann, L. M., García de Jalón, S., & Ghaley, B. B. (2019). Assessment of productivity and economic viability of combined food and energy (CFE) production system in Denmark. *Energies, 12*(1), Article 166.

Zulqarnain, M., Zere Taskin, S., Acabuga, E., Dokuzlu, S., & Bilgili, U. (2026). Optimizing wheat–pea intercropping for sustainable forage production: Productivity, land-use efficiency, and economic evaluation. *Agriculture, 16*(19), Article 2157.