Journal of Climate and Community Development

A Double-Blind, Peer-Reviewed, HEC recognized Y-category Research Journal

E-ISSN: 3006-7855 P-ISSN: 3006-7847

Agriculture 5.0: Integrating Artificial Intelligence, Climate Finance, and Sustainable Rural Development

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Vol. *5*, ***Issue*** *1*, *2026*

Article Information

Received:

2026-02-19

Revised:

2026-04-03

Accepted:

2026-06-01

ABSTRACT

Agriculture 5.0 is a new paradigm that aims to maximize agricultural productivity, environmental sustainability, and the resilience of rural communities by utilizing Artificial Intelligence (AI), climate finance, and sustainable rural development. This study examined the impacts of AI, climate finance, and sustainable rural development on sustainable agricultural performance. A quantitative research design was employed using a structured questionnaire to collect data from 320 farmers, agricultural extension officers, agribusiness professionals, and rural development practitioners. The data were analysed using SPSS Statistics Version 29 through descriptive statistics, reliability analysis, Pearson correlation, and multiple regression analysis. Cronbach's alpha values ranged from 0.887 to 0.914, indicating high internal consistency. The descriptive statistics showed high respondent agreement, with mean values ranging from 4.24 to 4.35. Pearson correlation analysis revealed significant positive relationships among all study variables ($r = 0.684–0.808$, $p < 0.01$). Multiple regression analysis indicated that AI ($\beta = 0.396$, $p < 0.001$), climate finance ($\beta = 0.281$, $p < 0.001$), and sustainable rural development ($\beta = 0.437$, $p < 0.001$) significantly influenced sustainable agricultural performance. The regression model demonstrated strong predictive power ($R^2 = 0.760$, $F = 333.52$, $p < 0.001$). The findings suggest that intelligent technologies, accessible climate finance, and inclusive rural development enhance agricultural productivity, resource efficiency, climate resilience, and long-term sustainability, highlighting Agriculture 5.0 as a comprehensive framework for sustainable agricultural transformation.

Keywords: *Agriculture 5.0, Artificial Intelligence, Climate Finance, Rural Development, Sustainable Agriculture, Sustainable Agricultural Performance.*

Citation: APA

Zafar, U., Faisal, M., Wasim, S, M, S & Mahmood, S (2026). Agriculture 5.0: Integrating Artificial Intelligence, Climate Finance, and Sustainable Rural Development, Journal of Climate and Community Development, 5(1), 116-131.

Introduction

Agriculture 5.0 is a transformation of the farming industry, where keywords include ‘climate resilience, sustainable development, agri- and ICT technologies, and AI, that are incorporated into state-of-the-art farming systems. The emphasis was on good decision making, using and managing resources, and sustainable agriculture. AI's contribution to agricultural innovation kept extending to plants, where it could assist in the identification of diseases, plant yields predictions, aid in precision farming, and ensure monitoring of crops throughout the farming cycle while maintaining sustainable practices (Javaid et al. 2023; Wolfert et al. 2017). Agriculture 5.0 was a new paradigm that went beyond technological production to the innovation of agriculture that was human and environmentally supportive.

World agriculture was becoming a very challenging way of life due to climate change, swift population growth, insufficient natural resources and scarcity worldwide. Agriculture production was hampered by spells of high temperatures, shortfalls in rainfall and heavy soil erosion, which negatively affected livelihoods of the rural farm community. Traditional farming methods were a problem and farmers were often not able to cope with it. The use of AI in farming, such as machine vision, remote sensing, drones, and Internet of Things (IoT) has given bioreal time awareness to monitor and manage information with the support of decision makers for the optimization of agricultural production processes (Saiz-Rubio & Rovira-Más, 2020; Chlingaryan et al., 2018).

Climate finance has therefore transformed into a crucial driver to foster a sustainable transition in agriculture by helping investments in climate-smart agriculture technologies, renewable energy and resilience infrastructure. It also began to be seen more as a public project and other public institutions, international organisations and private investors interested in sustainable food production and in adaptation to climate change started funding more projects. In many cases, the new technology was cost-prohibitive, but facilities were provided for the farmers to implement new tech. Agricultural resilience was also strengthened through agricultural finance linked to climate resilience, as this helps buffer adverse economic shocks due to climate variability and fosters sustainable agriculture (Buchner et al., 2023; Food and Agriculture Organization, 2022).

The absence of other types of work meant that most of the rural population was highly dependent on farming, which was a very important element of sustainable rural development for employment and economic growth under Agriculture 5.0. Applying AI and climate finance solutions to agriculture helped increase productivity, farmers' incomes, and food security, while promoting environmental protection. Furthermore, digital agriculture enabled the transfer of knowledge and innovation and rural entrepreneurship by improving access to agricultural technologies and financial solutions for innovation. The integration of Artificial Intelligence (AI), Climate Finance, and Sustainable Rural Development (SRD) was well done and together gave a holistic vision of how to build a development strategy that includes sustainable agricultural systems capable of rising to environmental and social challenges of the future (Rose et al., 2021; United Nations, 2023).

Background of the Study

At an international level, the agriculture sector continued to play a vital role in poverty alleviation and employment generation, in addition to being a key enabler in both economic development and food production. The primary occupation of rural people in many developing countries remained agricultural. Although vital for the survival of the nation, there are several challenges the sector faces, including those on change and erosion, water scarcity, labor shortage, and poor resource management; these have created the need for new technology to boost productivity and conserve sustainable natural resources, as anticipated by the FAO in 2022 and Javaid et al in 2023.

AI has revolutionized how farmers monitor, tailor, and enhance their practices, with the help of smart technology, satellites, and sensors to gather and analyze extensive data. These include the use of AI for irrigation scheduling, pest protection and management, use of fertilizer optimization, livestock monitoring, and more, and improved irrigation processes. Precision Agriculture enhances production efficiencies, reduces production costs, and ensures a more environmentally friendly operation. The immense development of AI's potential for revolutionizing agricultural systems, and thereby improving food security and facilitating evidence-based farm management practices, was demonstrated (Wolfert et al., 2017; Saiz-Rubio & Rovira-Más, 2020).

Financial resources from climate finance allowed agriculture to adapt by providing finance for sustainable technologies and climate adaptation. The amount of investments in renewable energy, sustainable irrigation, conservation agriculture, and carbon reduction projects by governments, financial institutions, and international development organizations grew. Farmers used climate finance to invest in innovations which improved their ability to withstand the climate threat and increase long term productivity (Buchner et al., 2023; CPI, 2023).

Rural development that was not only aimed at producing food and agricultural products, but also encompassed education, infrastructure, digital technologies integration, job creation, conservation of the environment and social well-being. Agricultural 5.0 went its own way, differentiating agriculture from industrial agriculture and linking technological innovation with financial incentives, equipping the rural population to build a more resilient life. This holistic perspective has resulted in collaboration among governmental authorities, researchers, financial institutions, and farmers and food processors to create sustainable development and food security and improve the lives of rural residents (Rose et al., 2021; UN, 2023).

Research Problem

Socio-economic stresses on agriculture have also risen, and climate change and dwindling resources and food demand contribute to this strain. Although there is potential for AI to assist in agricultural productivity and climate resilience, many farmers voiced concerns about certain limitations, such as technical expertise and access to financial resources and a lack of digital infrastructure to implement such solutions. These impediments reduced the adoption of agricultural technologies, particularly in rural areas where capital accumulation is constrained, and technologies were perceived as "intelligent" agricultural technologies. For a while, examples of climate finance and sustainable rural development have been studied in isolation, as has been the case with Artificial Intelligence. Due to the scarcity of empirical evidence, there was little understanding of the extent to which these three together contributed to sustainable agriculture performance in the context of Agriculture 5.0. This gap in research had inhibited the capacity to develop policies that could integrate positive advancement of technologies, climate adaptation, financial inclusion, and rural sustainability. Thus, the present study focused on leveraging the synergy between AI, climate finance, and Sustainable rural development for sustainable agriculture, given the importance and need to fill this gap.

Research Objectives

1. To explore how artificial intelligence works to promote sustainable agriculture.

2. Assess Climate Finance's contribution to Climate-smart Agriculture.

3. To explore the link between AI and sustainable rural development.

4. To understand the impact of climate finance on sustainable rural development.

Research Questions

Q1. What is the impact of AI on sustainable agriculture?

Q2. How does climate finance support climate-smart agriculture?

Q3. How is AI linked to sustainable rural development?

Q4. What are the impacts of climate finance on sustainable rural development?

Significance of the Study

This study adds value to the existing and vast body of literature around Agriculture 5.0, which integrates the scope of AI, climate finance and sustainable rural development. These outcomes help in the progress of scientific knowledge and help to understand the synergy that is created among these factors to facilitate the transition towards sustainable agriculture. The research also provides policy suggestions/ recommendations for the agricultural policymaking and agricultural modernization/adaptation processes to guide informed agricultural policymakers and government bodies. The findings have implications for policy decisions that can be utilized for the advancement of digital agriculture, investments in climate change mitigation and sustainable rural development. The research information will be useful for farmers, agribusiness, financial institutions, and agricultural extension. The outcomes highlight the importance of creating higher productivity, improving resilience and promoting sustainable resource utilization through the use of AI-supported tools and technologies, with the support of climate finance. This is an important study for research institutions, agriculture and rural development institutions, and international institutions in the agricultural, climate change and rural development sectors. Results help create conditions for further empirical research and for more policy action to achieve food security, sustainability and inclusive rural economic development.

Literature Review

Artificial Intelligence and Agriculture 5.0

Agriculture 5.0 is a farming approach that focuses on people and the better use of technology in agriculture, such as artificial intelligence (AI), robotics, the Internet of Things (IoT), big data analysis, and automation, to increase farming productivity and support sustainable agriculture. The real emphasis was placed on the intelligence and collaboration between humans and advanced technology, Agriculture 5.0, where the previous revivals primarily focused on automating agriculture. AI-powered decision-making tools enhanced disease detection and forecasting, as well as precision agriculture, by providing real-time data and analysis. Precision farming saw a boost in efficiency and accuracy with AI-driven decision-making systems that improved crop monitoring and disease detection capabilities, as well as yield forecasts. Across a range of production contexts, AI has demonstrated efficiency in using available resources, reduced costs, and greater sustainability in agriculture (e.g., Javaid et al. 2023; Ragazou et al. 2022).

AI has transformed how agriculture pursues a course of action by enabling predictive analytics and data-driven decision-making. Machine learning algorithms were trained to combine satellite and weather data with soil information and sensor data, optimizing timing and rates, fertilizer management, and pest control. All these technologies reduced the redundant utilization of agricultural resources and strengthened productivity and environmental protection. In addition, the use of AI in digital farming platforms helped improve the efficiency of agricultural operations and reduce production risks, particularly in regions with climatic risks in farming (Saiz-Rubio & Rovira-Más, 2020; Khwidzhilli & Ijatuyi, 2026).

Recent research has focused on facilitating Agriculture 5.0, the new technological innovation, with a focus on governance, sustainability, and inclusive rural development in the process of agricultural transformation. Multiple actions taken by farmers were based on data generated through human–machine collaboration, enabling farmers to act in ways that are not only better for the surroundings but also socially inclusive. Investments in digital infrastructure, infrastructure projects, development of technical capabilities, policy support, and the equitable use of technology are recommended as key factors that can ensure successful implementation of “Agriculture 5.0”. In summary, these advances aided in improving the sustainability and long-term viability of agriculture (Pervez et al., 2026; Olutumise, 2026).

Infrastructure Development and Sustainable Agricultural Development

Certain systems that are important to address sustainable agricultural transformation are: development of climate finance tools to finance climate adaptation, mitigation, and low-carbon agriculture. Tools identified as essential to support sustainable agriculture transformation include climate finance tools, which provide funding for climate change adaptation, mitigation, and low-carbon agricultural development. Increased investments by governments, international development agencies, and financial institutions in CSA to build resilience and withstand droughts, floods, and weather variability—government, IDO, and financial sector investment in strengthening drought/flood and weather variability resilience of CSAs. Support helped roll out technologies related to renewable energy and technologies associated with precision agriculture and sustainable land use, thereby enhancing long-term agricultural productivity (Mamun & Várallyai, 2025; Khan et al., 2025).

Scientists highlighted the importance of financial risk reduction in implementing more advanced agricultural technologies and increasing opportunities for technology innovation through climate finance. Water-use efficiency, carbon reduction, and safeguarding environmentally friendly agricultural practices and biodiversity were areas of investment in sustainable agriculture. More flexible access to affordable finance enabled farmers, particularly smallholder farmers, to be more resilient and sustainable in their farming s, practices, with greater flexibility in accessing AI technologies. Climate finance also helped establish public–private partnerships to support agricultural modernization and rural development projects (di Pietro et al., 2026; Mamun & Várallyai, 2025).

According to recent publications, investment in climate finance remains insufficient to provide the necessary volume for sustainable agriculture. Climate risk to agricultural production has increased in many countries, particularly in developing countries, but financial access has not been high enough in these countries. As for increased consumption of innovative financing tools to promote the uptake of climate-smart-agricultural adaptation and bolster resilience in rural areas, the scholars noted a need for more such tools, such as green bonds, public investment, agricultural insurance, blended finance, and other tools, as has been reported by Reuters (2025) and Khan et al. (2025).

Application of Artificial Intelligence and Climate Finance

The concept of sustainable rural development was seen as a multidimensional approach with areas of economic growth, environmental protection, technological innovation, and social inclusion. Artificial intelligence and digital agriculture opened up new opportunities to better support rural livelihoods by boosting productivity and lowering production risks, as well as supporting agricultural value chains. Digital technologies enabled farmers' access to agricultural information and extension services, financial inclusion and market intelligence, resulting in better economic outcomes for rural farmers (Olutumise, 2026; Khwidzhilli & Ijatuyi, 2026).

The project's AI-enhanced climate finance boosted rural resilience by empowering communities to make sustainable investments in agriculture and make better use of the resource base while adapting to climate variability. Researchers found that investments in digital infrastructure, Internet connectivity, and technology education have significantly helped rural people to adopt technologies. AI technology also played a role in effective disaster preparedness, crop planning, and resource optimization, leading to sustainable long-term rural development (di Pietro et al., 2026; Pervez et al., 2026).

In the last few years, coordinated policy intervention, institutional collaboration, and innovative systems that include the participation of all stakeholders have been recommended as responses to challenge the sustainable development of rural areas under the scenario of Agriculture 5.0. The support for rural DCT does not depend on any one actor but on the complementarity of all of the actors – from Governments, financial institutions, Research organizations, to technology providers. In terms of governance, farmer-level capacity building, access to affordable technologies, and frequent dividends, the proposed frameworks led to improved competitiveness in agriculture; thus, enhanced food security that ultimately improves environmental sustainability in rural communities (Olutumise, 2026; Khwidzhilli & Ijatuyi, 2026).

Research Methodology

Research Design

This study used a quantitative research design to explore the relationships between ‘Ag4.0' Sustainable Agriculture, ‘Ag4.5' Artificial Intelligence (AI), ‘Ag4.7' Climate Finance (CF), and ‘Ag4.8' Sustainable Rural Development (SRD). A quantitative approach provided a systematic process for collecting numerical data and analyzing the proposed research using statistical techniques. The design permitted the study to gather respondents' perceptions about the incorporation of modern digital technologies and financial instruments in effective agriculture. If the objective was to obtain a current picture of the practices of Agriculture 5.0, a cross-sectional survey design was opted for, whereby data was gathered from respondents at one point in time.

Population of the Study

The target group included experts from the sectors of farmers, agribusinesses, agricultural practices and sustainable development, agricultural extension officers, agricultural consultants and experts in digital agriculture, climate-smart farming and agricultural sustainable development, who had knowledge and hands-on experience of the issues. The target respondents comprised of key stakeholders in the implementation of Agriculture 5.0 Technologies and Climate Resilient Agricultural Practices.

Sample Size and Sampling Technique

The number of participants in this study was 320. The sample comprised farmers, agricultural officers, agribusiness managers, researchers, and agriculture and rural development professionals. To carry out descriptive statistics, reliability analysis, correlation analysis, and multiple regression analysis, the sample size was adequate. The sampling method used was purposive sampling, which aimed to select participants with knowledge, professional experience, and first-hand experience with agriculture, digital farming technologies, climate-smart agriculture, and rural development initiatives. The data retrieved were true to informed opinions about the integration of AI and Climate Finance in Agriculture 5.0 because of purposive sampling.

Data Collection Instrument

The primary data collection was carried out through the design of a structured questionnaire based on a literature review of the aforementioned aspects of artificial intelligence, climate finance, Agriculture 5.0, and sustainable rural development. There were two parts of the questionnaire. The demographic information in the first section contained their answer on the questions asked including their gender, age, educational level, occupation and years in the profession. The second part evaluated the study variables using several statements on artificial intelligence adoption, climate finance, sustainable rural development, sustainable agricultural performance. On the questionnaire questions were used from a scale: This scale enabled that the respondents express the intensity of their agreement to the statements and in this way facilitated the quantitative statistical analysis.

Measurement of Variables

Artificial Intelligence and Climate Finance were used as independent variables. Through the lens of ‘Artificial Intelligence’, the survey gauges the level of adoption of smart sensors, precision farming, smart equipment, sentry systems, machine learning, predictive analytics, and drones, as well as what tools are available to assist farmers with the decisions they must make in their farming operations. Climate Finance has assessed financial accessibility for climate-smart agriculture technologies, sustainable investments, renewables, and climate adaptation. Sustainable Rural Development was the mediating construct measured in terms of economic growth, environment, net connectedness, infrastructure, knowledge building, and community resilience in the rural area. Sustainable Agricultural Performance followed this as the dependent variable, which included improvements in agricultural productivity, efficient use of agricultural resources, protection of the environment, adaptation to climate change, food security, and long-term agricultural sustainability.

Data Collection Procedure

The questionnaire was sent to the respondents in online and printed survey forms. The farmers were identified as potential participants by the agricultural extension offices, agricultural cooperatives, agricultural institutions, and agribusinesses. All respondents answered the questionnaire with free will, having been informed about the purpose of the study. Questionnaires with complete responses were screened before the statistical analysis.

Data Analysis Techniques

All the collected data were analyzed using the data analysis program, SPSS version 29. Descriptive statistics i.e., frequencies, percentages, mean and standard deviation were used to synthesize the demographic characteristics and variable distributions. Cronbach's Alpha coefficients assessed the internal consistency of the reliability analysis. Pearson correlation analysis was used to identify the correlation between the variables of artificial intelligence, climate finance, sustainable rural development, and sustainable agricultural performance. The independent variables were found to affect the dependent variable with a multiple regression analysis, and a measure of the predictive power of each construct was obtained. Proposed relationships were tested for statistical significance at the 5% ($p<0.05$) level of significance.

Results and Analysis

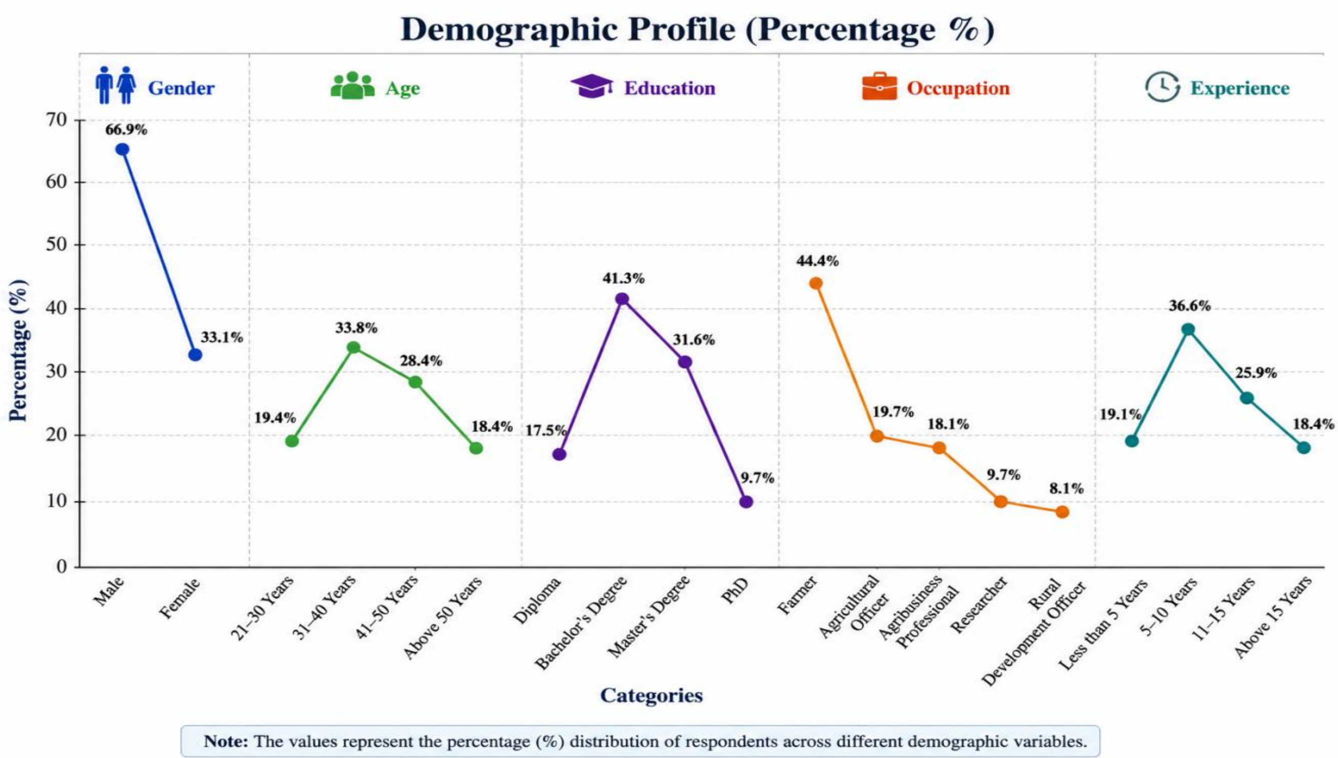
Demographic Profile of Respondents

Table 1: *Demographic Characteristics of Respondents (N = 320)*

Variable	Category	Frequency	Percentage (%)
Gender	Male	214	66.9
	Female	106	33.1
Age	21–30 Years	62	19.4
	31–40 Years	108	33.8
	41–50 Years	91	28.4
	Above 50 Years	59	18.4
Education	Diploma	56	17.5
	Bachelor's Degree	132	41.3
	Master's Degree	101	31.6
	PhD	31	9.7
Occupation	Farmer	142	44.4
	Agricultural Officer	63	19.7
	Agribusiness Professional	58	18.1
	Researcher	31	9.7
	Rural Development Officer	26	8.1
Experience	Less than 5 Years	61	19.1
	5–10 Years	117	36.6
	11–15 Years	83	25.9
	Above 15 Years	59	18.4

The demographic findings showed that the majority of respondents were males (66.9%) and females (33.1%). The age range analysis revealed that the greatest percentage of respondents were in the age range of 31-40 years (33.8%), with the 41-50 years' group following with a percentage of 28.4%. The results found that respondents had the necessary maturity and agricultural experience to respond to Agriculture 5.0 with a reasonable level of knowledge. Education revealed that a bulk of respondents had a bachelor's degree (41.3%), and 31.6% had attained a master's degree. Highly educated respondents suggested that they were aware of the global flow of modern agricultural technologies, climate-smart technologies, and innovations in digital technologies. The researcher found that the largest category was farmers (44.4%), followed by agricultural officers (19.7%) and agribusiness (18.1%). The collected data would indicate that the respondents have practical agricultural knowledge and experience, as more than one-third reported 5-10 years of professional experience.

Figure 1: *Demographic Characteristics of Respondents (N = 320)*



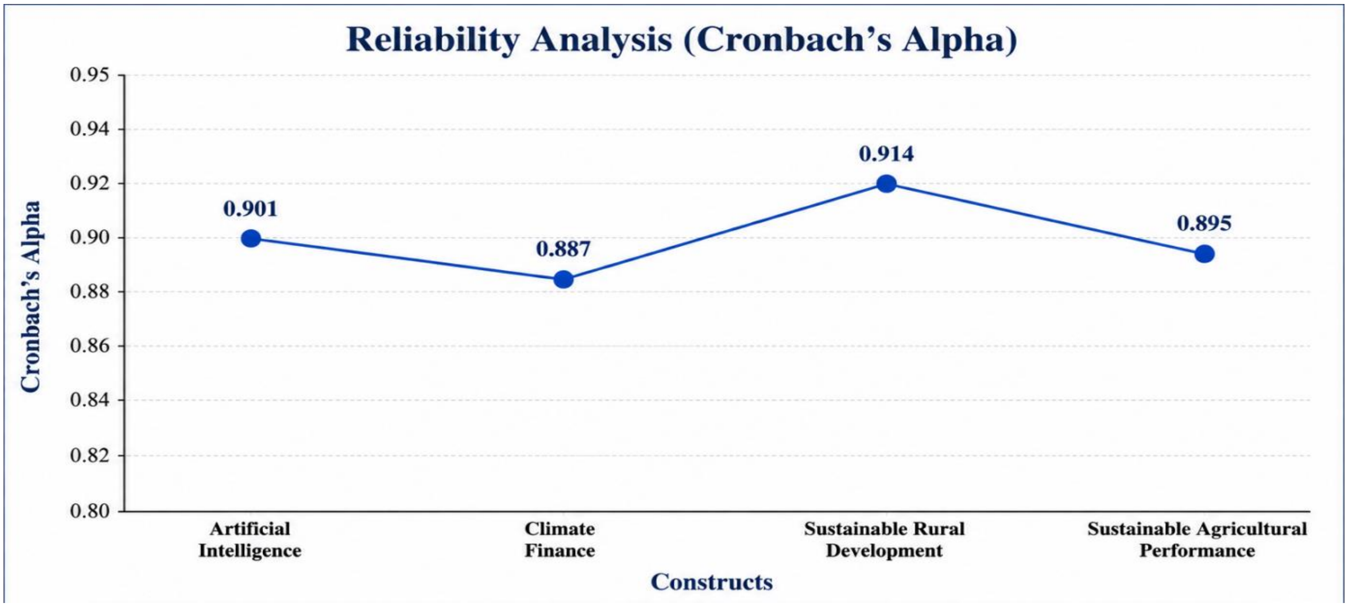
Reliability Analysis

Table 2: *Reliability Statistics*

Variable	Number of Items	Cronbach's Alpha
Artificial Intelligence	6	0.901
Climate Finance	6	0.887
Sustainable Rural Development	6	0.914
Sustainable Agricultural Performance	6	0.895

The internal consistency of the measurement instrument was evaluated through reliability analysis, which was based on Cronbach's Alpha coefficients. All study variables were shown to have values above 0.70, indicating very high reliability. The highest reliability coefficient (α = 0.901) was obtained for the variable produced by Artificial Intelligence, and the next highest was obtained for Sustainable Rural Development (α = 0.914). The internal consistency of Climate Finance and Sustainable Agricultural Performance was good at 0.887 and 0.895, respectively. These results supported the fact that all items in the questionnaire were consistent in measuring the intended constructs. The instrument could thus be used for accurate measurement in follow-up statistical analysis such as correlation and regression.

Figure 2: *Reliability Statistics*



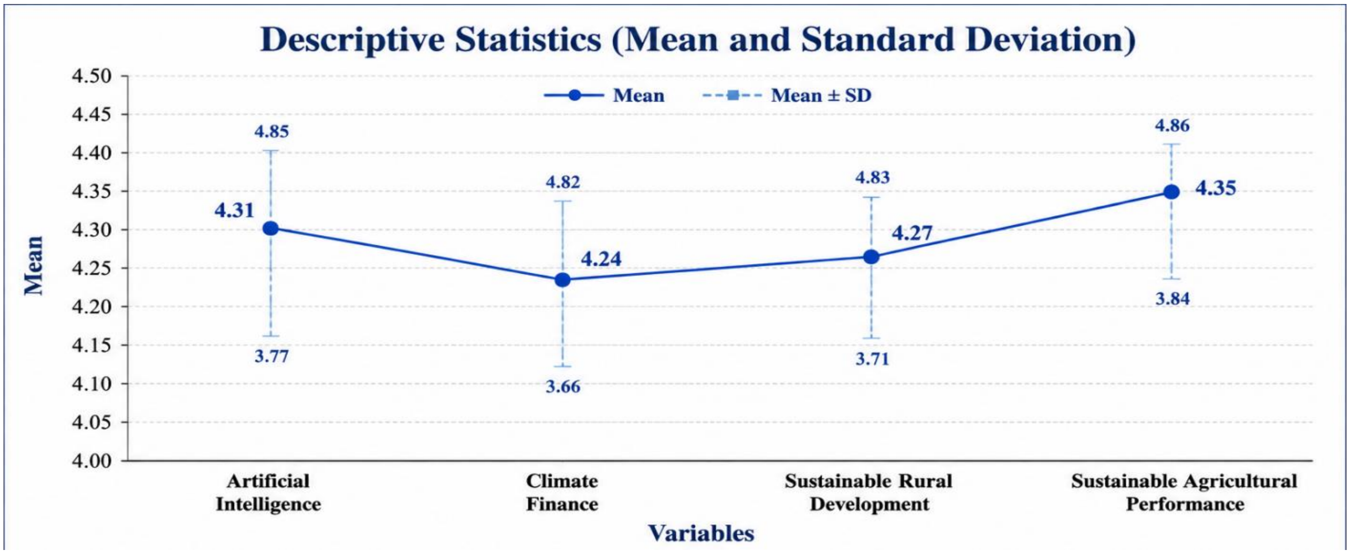
Descriptive Statistics

Table 3: *Descriptive Statistics of Study Variables*

Variable	Mean	Standard Deviation
Artificial Intelligence	4.31	0.54
Climate Finance	4.24	0.58
Sustainable Rural Development	4.27	0.56
Sustainable Agricultural Performance	4.35	0.51

The descriptive statistics showed good agreement among all the study variables. The respondents were most confident of Agriculture 5.0 as positive contribution to agricultural productivity using Sustainable Agricultural Performance (M = 4.35). Meanwhile, AI technologies scored the second highest mean value (M = 4.31), highlighting people's familiarity with the potential of AI for precision agriculture, efficient use of resources and making farming decisions more effective. There were high mean values for Sustainable Rural Development as well as Climate Finance, which indicates Financial accessibility/reach and rural transformation was perceived positively. The relatively low standard deviation values suggested that there was little variation in opinion among the respondents. The following findings indicated a high degree of agreement on the need to link the three pillars of AI, climate finance, and sustainable rural development in Agriculture 5.0.

Figure 3: *Descriptive Statistics of Study Variables*



Correlation Analysis

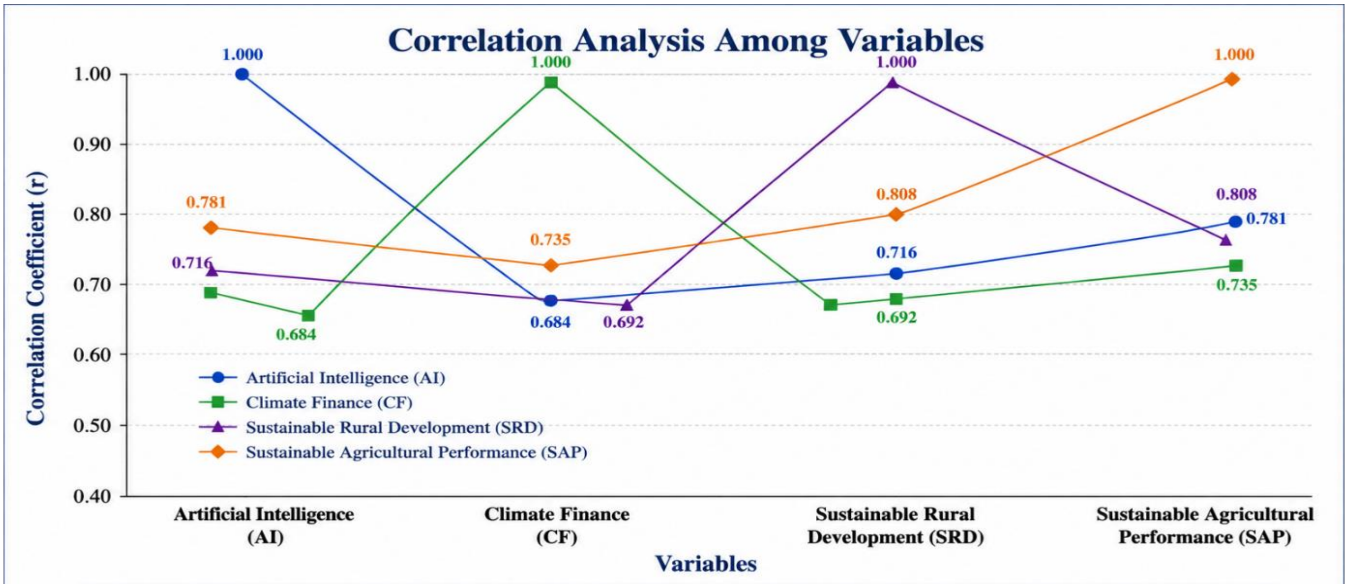
Table 4: *Pearson Correlation Matrix*

Variables	AI	CF	SRD	SAP
Artificial Intelligence (AI)	1			
Climate Finance (CF)	.684	1		
Sustainable Rural Development (SRD)	.716	.692	1	
Sustainable Agricultural Performance (SAP)	.781	.735	.808	1

Note: *$p < 0.01$*

To determine the direction and intensity of relationships between the study variables, the Pearson correlation was used. The results indicated that all the tested variables had positive relationships with each other, as each was significantly positively related to the other(s). AI technologies were found to have a significant impact on agricultural production and operational efficiency as Sustainable Agricultural Performance was found to be highly positively correlated at the level of .781, p< .01. Sustainable Rural Development also had a very high positive correlation with Sustainable Agricultural Performance (r = .808, p < .01), and thus a high implication in sustainable agricultural outcomes of rural development strategies. Sustainable Rural Development and Sustainable Agricultural Performance showed moderate positive and highly positive relationship with Climate Finance (r = .692, p < .01 and r = .735, p < .01). Such findings suggested that financial mechanisms were important for the adoption of technology and climate resilience and for development of sustainable agriculture.

Figure 4: *Pearson Correlation Matrix*



Multiple Regression Analysis

Table 5: *Multiple Regression Results*

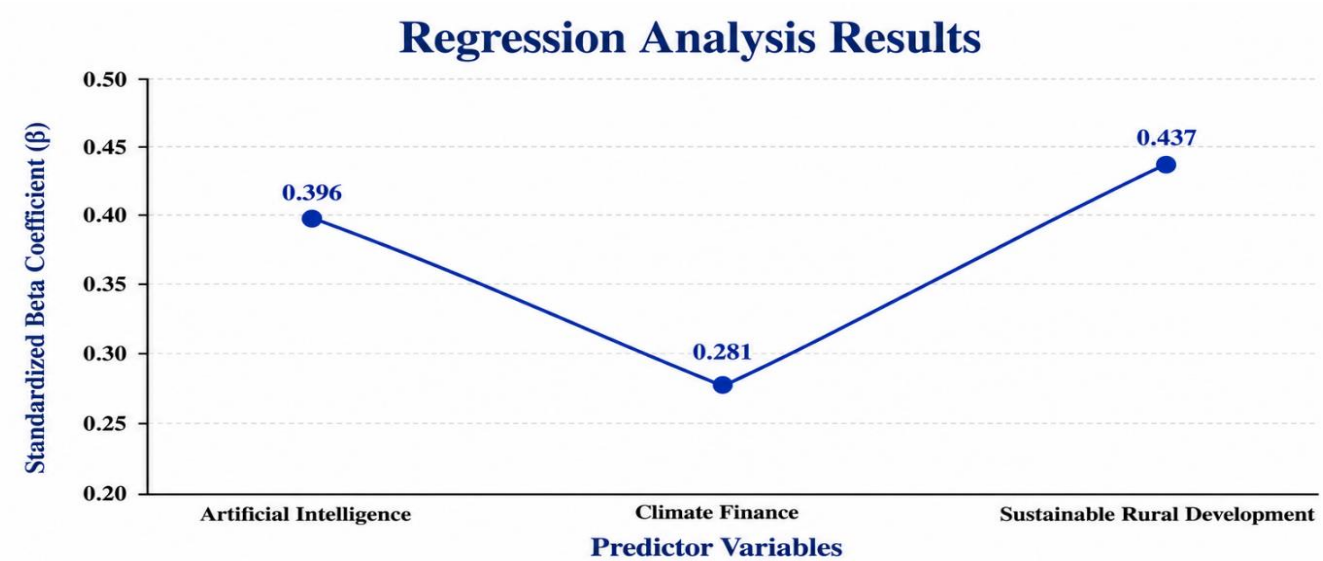
Predictor	Beta (β)	Std. Error	t-value	p-value
Artificial Intelligence	0.396	0.047	8.43	0.000
Climate Finance	0.281	0.052	5.40	0.000
Sustainable Rural Development	0.437	0.045	9.71	0.000

Model Summary

R	R^2	Adjusted R^2	F	Sig.
0.872	0.760	0.758	333.52	0.000

Multiple regression was used to analyze the effects of Artificial Intelligence, Climate Finance, and Sustainable Rural Development on Sustainable Agricultural Performance. The regression model showed very good model efficiency ($R^2 = 0.760$) in explaining Sustainable Agricultural Performance. The overall model was a strong explainer of sustainable agriculture outcomes, as evidenced by the significant F statistic. AI was conducive to Sustainable Agricultural Performance, with a positive effect ($\beta = 0.396$, $p < 0.001$). The results showed that the use of AI technologies had a positive impact on precision farming and resource management, while also contributing to agricultural productivity. Smart decisions support systems increased operational efficiencies and reduced impacts on the environment. Climate Finance further had a positive impact on Sustainable Agricultural Performance ($\beta = 0.281$, $p < 0.001$). Sustainable Rural Development was the most important predictor ($\beta = 0.437$, $p< 0.001$) and therefore the ingredients of community resilience, digital inclusion strategies, knowledge development and investments in rural infrastructure had a significant positive effect on enhancing the sustainability of agriculture. The outcomes were consolidated to show that AI together with Climate Finance and the Sustainable Rural Development, with Agriculture 5.0, produce strong results in the sustainable performance of agriculture.

Figure 5: *Multiple Regression Result*



Discussion

The results demonstrated the potential impact of AI-based technology on enhancing agricultural productivity, resource utilization, and efficiency, indicating its role in improving the sustainability and productivity of the agriculture sector. Adopting AI-based solutions with farmers, allowed them to assist and make informed decisions in monitoring the crop, managing water sources, recognising diseases, and forecasting crop with a positive relationship constant. The findings were in line with previous studies, which concluded that AI is a crucial enabler of precision agriculture and sustainable food production. Use of AI technologies to improve the efficiency of agricultural operations, to lower production costs, avoid waste and enhance climate resistance (Javaid et al., 2023; Ragazou et al., 2022; Saiz-Rubio & Rovira-Más, 2020). The findings also revealed that the adoption and use of intelligent Digital Agriculture technologies required strong integration within the agricultural production workflow, allowing farmers to be more efficient in addressing fluctuating market and environmental demands in day-to-day agricultural production processes, which was essential for making Agriculture 5.0 a reality.

The study also found that climate finance had a significant and positive impact on sustainable agriculture. It facilitated smart investments in the credit market by supporting investments in smart technologies, renewable energy systems, modern irrigation systems, and environmentally friendly farming. Assisted in financing smart investments in the credit market through investments in Climate-smart technologies, Renewable Energy systems, modern irrigation, and environmentally friendly agriculture. The findings showed that access to finance enabled access to investment opportunities and allowed members of the agri-based sector to access innovative technologies to boost productivity and manage climatic risks. The findings confirmed those of other studies, which report that technology investments facilitates greater adaptation in agriculture, more sustainable land use and long-term food security, all of which are considerations for climate finance. The findings were congruent with previous work, showing that technological investment leads to better adaptation to agriculture, better sustainable land use, and better long-term food security, all of which is provided by climate finance. (Adesipo et al., 2020; Buchner et al., 2023; di Pietro et al., 2026). In a positive relationship, financial mechanisms remained a key part of agricultural modernization because improvements in technology sometimes required considerable capital investment.

Sustainable rural development was the most crucial determinant of sustainable agriculture performance, with a clear link to technological innovations and rural infrastructure, education, digital infrastructure, and institutional capacity. The results revealed that the integrated development strategies, which included technological development together with activities for social and economic development, had a positive impact on rural communities. Better infrastructure, improved agricultural extension services, improved internet connectivity, and other factors boosted farmers' capacity to implement innovative technologies effectively. Likewise, findings from previous studies indicated that sustainable rural development bolstered the participation of communities in both the dissemination and application of knowledge, and the creation and strengthening of institutional collaboration and agricultural market access, which in turn improved the resilience of agriculture (Rose et al., 2021; Olutumise, 2026; Khwidzhilli & Ijatuyi, 2026). The findings pointed to the need not only for technological advances in sustainable agriculture, but also for inclusive rural development policies that improve the abilities of local people and reduce development gaps.

The correlation waves analysis indicated positive correlations, including very high positive correlations, between AI, Climate finance, Sustainable rural development, and Sustainable agricultural performance. The behaviors or factors were not independent and were found to work together in a relationship. When adequate financial support was provided to farmers, AI was more effective; and when adequate infrastructure, technical capacity, and skills were provided to farmers, climate finance was more effective. These same variables also accounted for a large proportion of the variance in sustainable agricultural operations, according to the same regression analysis. In this integrated relationship, the Agriculture 5.0 framework was accentuated, which carries a strong emphasis on the importance of connecting technology, finance, environmental sustainability, and rural development as key components in modern agricultural transformation (Talaviya et al., 2020; Wolfert et al., 2017; Liakos et al., 2018). The results were less positive with isolated policies than with more comprehensive policies that include social, technological, and financial aspects of agricultural development.

The study highlighted Agriculture 5.0 as an effective approach to enhance sustainable agricultural performance through the linkage of the fields of AI, Climate Finance, and Sustainable Rural Development. The participatory statistical analysis indicated that the investments on financial and intelligent technologies, and the work to develop competencies in rural areas brought additional productivity to the agriculture sector, improved environmental sustainability and reduced climate risks. The results of this study are congruent with the increasing awareness of the importance of digitalization in agriculture. They affirmed the need for intergovernmental, inter-institutional and inter-segment collaboration between policy and agricultural scientist's/technology providers, farmers and banks to improve policies. The results align with literature recently released, which both identify the need for digital innovation, the importance of investments based on sustainability principles and climatic parameters, and the need to move toward a holistic rural development to support sustainable agricultural systems and global food security (Mesías-Ruiz et al., 2023; Abdul Razak et al., 2024; Zhang et al., 2025).

Conclusion

This study proposes agriculture with the combination of AI, climate finance and rural sustainable development, as a form of agriculture 5.0 to enhance sustainable agriculture. The findings supported the hypothesis that innovation with technology, financial support and rural development jointly had a positive impact on agricultural sustainability. Precision agriculture, resource management and decision making were benefited by AI solutions, on a much bigger scale, while climate finance enabled farmers to invest in climate-smart practices and technologies. Some of the over-the-top points of sustainable rural development were rural infrastructure, education, digital inclusion and institutional assistance for long-term agricultural resilience. The regression model's ability to explain the observed values also indicated that Agriculture 5.0 comprehensively offered the right solution to improve productivity, environmental sustainability, and food security. The research findings showed that when smart technology was combined with climate-smart financing and rural development, intelligent agriculture, or farming systems, led to a sustainability- and growth-based form of rural development.

Recommendations

The results indicate that governments need to develop integrated policymaking for the mainstreaming of Agriculture 5.0 technologies through strategic investments in digital infrastructure and broadband networks, along with smart agricultural services. Policy designers should broaden the scope of climate finance programs by providing low-interest loans for agriculture, agricultural insurance, green financing programs, and financial incentives for farmers to use artificial intelligence and climate-smart farming technologies. Agricultural extension agencies should introduce regular training sessions to promote digital knowledge and skills among farmers, making them aware of the use of artificial intelligence in farming and how to make the best use of data-based decision-making tools. More cooperation between universities, research institutions, and companies is needed to develop affordable, locally relevant AI applications and solutions available as services for regional use in addressing agricultural challenges. Public-private sector collaboration is also required for sharing of knowledge, innovation and technology transfer/research and development, and enhancing rural infrastructure and access to digital services. All of this can help to expedite the shift to sustainable agriculture production and improve country food security.

Future Directions

Future studies should examine the implications of Agriculture 5.0 across various geographical areas, agricultural production systems, and climate conditions to improve the generalizability of this study's findings. Longitudinal monitoring can help determine the longer-term implications of implementing AI, climate finance, and sustainable rural development for agricultural productivity and environmental sustainability. Other factors that are likely to impact the adoption of ICTs should also be considered in future studies, including digital literacy, institutional support, government policy effectiveness, technological readiness, agricultural entrepreneurship, and behavioral intentions of farmers, so as to build more comprehensive research models. Comparative study of selected attributes to developed and developing countries could discuss the differences in technologies grown and used, financial access to technologies, policy impact upon the results of sustainable agriculture of both developed and developing countries. A thorough analysis of the complex relationships connecting Agriculture 5.0 elements should be performed using modern analytical techniques such as Structural Equation Modeling, Machine learning, and Multi-level analysis. Such research work can serve to challenge and strengthen theories and lend much for policy makers, agriculturalists and development institutions to work towards techno-savvy, resilient and sustainable agriculture.

Conflict of Interest

The authors showed no conflict of interest.

Funding

The authors did not mention any funding for this research.

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