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Examining The Adoption and Effectiveness of Ai-Enabled Agricultural Extension Services in Enhancing Climate-Smart Farming Practices.

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***Abstract-** Climate change continues to be a major threat to agricultural productivity, especially among the smallholder farmers who are most impacted by the unpredictability of the rains, increasing temperatures, and extreme weather events. Climate-smart farming practices (CSFPs) are one of the solutions which not only raise the productivity but also strengthen the resilience and ensure environmental sustainability. However, the adoption of these practices is still very limited mainly because of the lack of knowledge and access as well as the inadequateness of extension services. Artificial Intelligence (AI)-powered agricultural extension systems have become the most recent development in this field which has led to making services to farmers more effective by being real-time, location-specific, and personalized advisory services that are capable of reaching farmers almost anytime and anywhere. This paper is focused on the use of AI-driven extension services as a means to inspire climate-smart farming practices among smallholder farmers. The study was carried out within the framework of quantitative research with data being collected through the use of structured questionnaires that were administered to 120 farmers and then analyzed by means of descriptive statistics and regression analysis. The results show that, despite a fairly good level of awareness of AI-enabled extension services, the actual use is hampered by digital literacy issues, infrastructural deficiencies, as well as socio-economic factors. Farmers who are regular users of AI-based advisory tools disclose that their decisions have been better supported leading to their increased use of CSFPs and ultimately their greater ability to cope with climate; variability. The regression analysis reveals that there is a positive and statistically significant effect of the use of AI-enabled extension on the adoption of climate-smart practices. The study concludes that AI-driven agricultural extension services can effectively support sustainable farming and climate adaptation, provided that barriers to access and utilization are addressed through policy, infrastructure, and capacity-building initiatives.*

***Index Terms-** Artificial Intelligence, Agricultural Extension, Climate-Smart Farming, Adoption, Smallholder Farmers, Decision-Making*

I. INTRODUCTION

Agriculture is suffering more and more from the effects of climate change, like sudden changes in rainfall, rising temperature and more extreme weather. These changes seriously threaten smallholder farmers, who produce most of the food in developing countries. They will have to take up climate-smart farming methods if they want to cope with the change in climate. Some of these methods are using genetically modified crops, water-saving irrigation, soil conservation, and integrated pest management (IPM). But knowledge sharing about these practices is mostly done through traditional agricultural extension systems, which are limited in number and scope, lack resources, and cannot give timely, location-specific advice to farmers (Anderson&Feder, 2007; Aker, 2011)

Major technological breakthroughs, especially in Artificial Intelligence (AI), offer new ways to rethink agricultural extension services. Agricultural extension systems supported by AI use machine learning, predictive analytics, and big data to give farmers real-time, tailor-made advice. These services have the ability to look at weather forecasts, soil conditions, crop management data, and market trends and at the same time provide recommendations best suited to individual farm situations. Combining AI with extension services can make it possible for farmers to get timely advice regarding climate-smart practices which can help them adapt to climate change and environmental risks. (Wolfert et al. 2017; Spanaki et al. 2022; Billah et.al., 2025).

Despite AI-enabled extension services holding great potential, the actual use of these services by smallholder farmers is still inconsistent. Factors such as education level, farm size, digital skills, owning a smartphone, and having internet access play a role in both the readiness and the ability of farmers to be using these digital tools. Besides, how well AI-based extension systems can help farmers take up climate-smart farming practices through the use of these digital technologies is an area that is still not fully explored, especially in rural areas which have limited access to these technologies (Mittal & Mehar, 2016; Zhang et al. 2020).

The use of AI in agricultural extension can be a major factor in increasing farm productivity, sustainable environment, and making people more capable of withstanding the negative effects of climate changes. Giving appropriate, information-backed recommendations, AI-based extension tools can significantly aid farmers in making better decisions regarding what crops to grow, when to water, soil care, how to deal with pests and properly using resources. Besides boosting production, it also helps in promoting farming methods that are environmentally sustainable and contribute to the reduction of greenhouse gases as well as enhancing the ability to resist shocks in the long run (Rose & Chilvers, 2018).

This study is inspired by a desire to know the extent to which smallholder farmers adopt and benefit from AI-enabled agricultural extension services especially in the context of implementing climate-smart farming practices. To this end, it will: 1. Find out how many farmers use AI-enabled extension services. 2. Check if these services can effectively encourage farmers to adopt climate-smart farming practices. 3. Discover what things make it easy or hard for farmers to use AI-enabled extension tools. 4. Suggest policies for increased access, adoption, and effectiveness of AI-driven agricultural advisory services. Besides contributing to knowledge on the adoption and effectiveness of AI-enabled extension services, the findings of this study will help policymakers, planners, and practitioners to understand how digital technologies can provide support for climate-smart agriculture, improve smallholder livelihoods, and enhance rural resilience against climate change.

II. LITERATURE REVIEW

2.1 Concept of AI-Enabled Agricultural Extension Services

Agricultural extension services traditionally have been a method of providing farmers with access to the latest research-based knowledge and changes in the agricultural sector through information dissemination, training, and technical advice on improved practices. Even so, conventional extension services are struggling with challenges such as limited funding, insufficient staff, and in some cases, reaching distant farming communities is a problem. Therefore, the consequences of these problems when it comes to extension include: slow provision of essential information and outreach being limited which, in turn, diminishes the impact of extension services in encouraging the adoption of innovative techniques, for example, climate-smart agriculture (Anderson & Feder, 2007). The use of Artificial Intelligence (AI) in the delivery of agricultural extension has appeared as a revolutionary way to overcome these problems. AI-powered extension services use machine learning algorithms, big data analytics, and predictive modeling to give personalized, locality-specific advice to farmers instantly.

AI-based systems, unlike human extensionists, are capable of handling large amounts of datasuch as weather forecasts, soil health status, pest and disease occurrence, crop growth stages, and market pricesto produce the best possible recommendations for the given farm situation (Wolfert et al. 2017; Spanaki et al. 2022). These systems reach farmers through different devices - mobile apps SMS voice platforms, or chatbots that may even be used by illiterate farmers.

By integrating automation with data-driven intelligence, AI-powered agricultural extension services can always update their advice according to variations in weather, the appearance of new pests, or changes in the market. This ability to change quickly is very important, for example, in the case of climate change, which is making the weather more and more unpredictable and the environment more variable thus presenting a lot of challenges to small-scale farmers. In this regard, AI-powered agricultural extension systems can greatly change how knowledge is shared in agriculture, this making it more efficient, timely, and impactful.

2.2 Climate-Smart Farming Practices

Farmers who practice climate-smart agriculture are continuously improving their methods to simultaneously achieve three main objectives: increase production, manage better the impact of climate change, and reduce greenhouse gas emissions. Some of the main methods that are used to achieve these objectives are: planting drought-resistant crop varieties, having water-efficient irrigation systems, proper soil and nutrient management, integrated pest management, agroforestry, and crop diversification (FAO, 2013). Climate-smart agriculture is especially important for small-scale farmers as they are often the ones who experience the most the effects of climate change, that is, they are the most vulnerable to climate variability and usually do not have the financial or technological resources to adapt quickly to changes.

Studies indicate that the use of CSFPs significantly enhances farm productivity and household income, as well as leads to the reduction of environmental impacts. For example, Munyua (2019) points out that smallholder farmers who engaged in conservation agriculture along with improved water management were able to raise their production levels and become more resilient to irregular rainfall patterns. Similarly, according to Benos et al. (2021), agroforestry combined with soil nutrient management not only help prevent environmental degradation but also create avenues for additional income through intercropping and tree products. However, despite these advantages, farmers knowledge, lack of extension support, absence of access to up-to-date data for decision-making at the farm level continue to be the main factors limiting the use of CSFPs.

In this regard, AI-powered agricultural extension services can be a potential way of overcoming these challenges. Through delivering customized guidance on CSFPs considering local environmental factors, AI tools can assist farmers in deciding on the best climate-smart practices for their fields. For instance, data-driven models can advise the most favorable times for planting, watering, or fertilizer application that not only lead to better crop production but also help in resource conservation. Such detailed recommendations really boost farmers willingness to follow and keep using climate-smart methods.

2.3 Adoption of AI-Enabled Extension Services

It is a complex and interconnected set of factors that drive adoption of AI-enabled agricultural extension services, including awareness, access to technology, digital literacy, socio-economic characteristics, perceived usefulness, etc. According to Mittal & Mehar (2016), farmers with higher education levels and exposure to technology are found to be more likely to use digital agricultural tools. In line with this, Kumar et al. (2021) observed that availability of smartphones, good internet connectivity, and supporting infrastructure play a great role in adoption rates. Awareness is a very important first step to adoption.

Without knowledge of the existence or benefits of AI-services, farmers cannot use them. Even when aware, adoption can be limited by low digital literacy or lack of trust in AI recommendations. In rural areas, social behaviors and norms, peer influence, and trust in technology also play a big role in the willingness of farmers to try AI and other digital tools (Spanaki et al. 2022).

Empirical research has illustrated the successes as well as the difficulties encountered in adoption. According to Aker (2011), the use of mobile phones for advisory services increased farmers' access to information in West Africa. However, the differences in digital skills and socio-economic status contributed to an uneven uptake. In the same vein, Zhang et al. (2020) point out that although AI-driven tools are able to provide very accurate recommendations, the adoption of these tools by smallholders is still limited by issues of affordability and connectivity. Hence, it is very important to know the factors that influence adoption if we are to come up with measures that can guarantee equitable access and produce the greatest impact.

2.4 Effectiveness of AI-Enabled Extension Services in Enhancing CSFPs

The success of AI-enabled extension services is evaluated by the extent to which they influence farmers to adopt climate-smart practices and improve their production results (Mmbando, 2025). Studies show that farmers utilizing AI-driven advisory platforms generally adopt resource-efficient and climate-resilient practices more than those who only use traditional extension methods. In fact, predictive models can update farmers about possible drought periods, allowing them to plan ahead saving watering by irrigation or choosing drought-tolerant crops, etc. (Rose & Chilvers, 2018). Besides, AI-supported tools facilitate not only advisory but also monitoring and feedback. By frequent analysis of farm-level data, such tools can highlight the areas where recommendations are either not being adhered to or require changes. Thus, they provide a continuously updated advisory environment wherein farmers are promptly informed about weather, pest, or soil condition-related changes. Wolfert et al. (2017) emphasize that such adaptive advisory systems are highly advantageous for smallholder farmers since they lower their level of uncertainty and enable them to make decisions based on risks, thus leading to the elevation of their resilience to climate shocks..

Besides that, AI-powered services could have a positive effect on social learning and collaboration by making these aspects more effective. Certain platforms embed community elements through which farmers can share their experiences, communicate about their results, and jointly validate AI-based suggestions. This helps to build confidence, expedite the use of climate-friendly farming methods, and make rural knowledge systems more robust. In general, research findings indicate that extension services that utilize AI have a profound impact on both the uptake of and the results obtained from climate-smart farming methods, which in turn lead to greater productivity, better use of resources, and a higher level of environmental sustainability (Fabregas et al. 2019; Benos et al. 2021).

2.5 Challenges and Barriers to Adoption and Effectiveness

Having the capability of artificial intelligence (AI) in extension services, the digital aspect of advice and consulting (extension services) for farmers could be a key factor to opening up numerous benefits to farmers. However, there are potential issues in implementation that different countries could face which would affect the adoption and effectiveness of the AI-empowered extension services. The challenges in order of the importance are: 1. Lack of knowledge in digital literacy and using technical devices: Many farmers who operate in rural areas may not be very familiar with smartphones, applications and some of the information contained in the AI advice may even be beyond the comprehension of farmers (Mittal & Mehar, 2016). 2. Lack of adequate infrastructure: This includes for example, poor mobile/internet connections, unreliable electricity and insufficient network coverage which make it difficult to get/set up such a service particularly in farm/inaccessible areas (Spanaki et al. 2022). 3. Affordability: The price of a digital device, to buy a data plan, and to access platforms powered by AI might result in excluding smallholders (Zhang et al. 2020). 4. Lack of trust and accuracy: People may question the reliability or correctness of the AI-generated recommendations and at the same time they might still believe the opinions of the extension agent or local peers (Aker, 2011). 5. Social-Economic Factors: One's educational level, farm size, work experience and getting a loan are some factors that can have an impact on farmers' willingness and capability to adopt the AI-enabled advice. Solving these problems does not only require one set of measures. Measures to support building of infrastructure, skills training, policy framework, and mobilization of people all together will be necessary. Interventions at the right level can help to overcome barriers, increase trust and make sure that AI-based extension services really help farmers who practice climate-smart agriculture.

2.6 Research Gap

Several studies have touched upon AI in agriculture and digital advisory services. However, only a handful of them concentrated specifically on the role of AI-enabled extension services in the promotion of climate-smart agricultural practices among smallholder farmers, this is what we least find in the literature. The majority of literature studies concentrate mainly on either productivity or market-related information, with very limited coverage on the aspect of climate change adaptation and resilience. Consequently, this study looks to address the above by offering solid first-hand evidence regarding the level of adoption effectiveness as well as constraints of AI-enabled extension services in promoting climate-smart agricultural practices.

III. METHODOLOGY

3.1 Research Design

This The paper utilizes a quantitative research framework to explore the implementation and impact of AI-based agricultural extension services in encouraging climate-smart farming practices (CSFPs). Employing a quantitative methodology seems suitable as it facilitates gathering and analyzing numeric data which, in turn, helps the author to quantify the relationship between the application of AI-based extension services and the acceptance of CSFPs besides the other result-oriented factors like farm output and resilience. Through the use of standardized tools and statistical methods, the research can impartially find out the trends, associations, and possible cause-effect relations between the degrees of adoption and the effectiveness outcomes (Creswell, 2014).

3.2 Study Population and Sampling

The study population consists of smallholder farmers who are growing crops in rural and peri-urban areas. These farmers are the main users of the agricultural extension services and are also the ones most affected by the changes in climate.

Respondents will be selected via a stratified random sampling method. This will guarantee representative samples in terms of farm size, education level, and access to digital technologies. About 120150 farmers are expected to be the sample size based on the total population of farmers with the availability of AI-based extension services in the study area. That number of farmers should be enough to present reliable quantitative data for analysis.

3.3 Data Collection

Primary data will be collected from smallholder farmers through structured questionnaires that will be carefully designed and pre-tested before administration to ensure reliability and validity of the questions. The prepared questionnaires will cover the following areas: Secondary data will come from government reports, the Food and Agriculture Organization (FAO), peer-reviewed journals, and prior studies on AI in agriculture and climate-smart practices. These sources will help interpret the original data and serve as a reference point for determining the level of success.

3.4 Measurement of Variables

Independent Variable: Use of AI-enabled extension services gauged through access, frequency of use, dependence on AI advice, and variety of services utilized.Dependent Variables: Adoption of Climate-Smart Farming Practices evaluated by the number and types of CSFPs practiced on the farm. Extension Services' Effectiveness gauged by respondents' perception of changes in farm management, productivity, and climate resilience.Control Variables: Education level, farm size, gender, and access to credit are socio-economic characteristics considered to differentiate adopt and effectiveness outcomes.

3.5 Data Analysis

Data analysis will be performed utilizing descriptive and inferential statistics in the following ways: 1. Descriptive Statistics: To characterize respondents demographic features, levels of adoption, and perceived effectiveness of AI-enabled extension services, we will use frequencies percentages means, and standard deviations. 2. Inferential Statistics: We plan to use regression analysis to determine the extent to which the use of AI-enabled extension services is related to the adoption of CSFPs. Besides this, the model will help to understand how socio-economic factors contribute to adoption and perceived effectiveness. 3. Barriers Analysis: To unearth the associations between barriers to adoption (e.g. digital literacy, infrastructure) and farmers willingness to resort to AI-based services, we will carry out cross-tabulations and chi-square tests. We will carry out the statistical analysis with SPSS or Stata software that will give us reliable and robust results for interpreting the influence of AI-enabled extension on climate-smart farming practices.

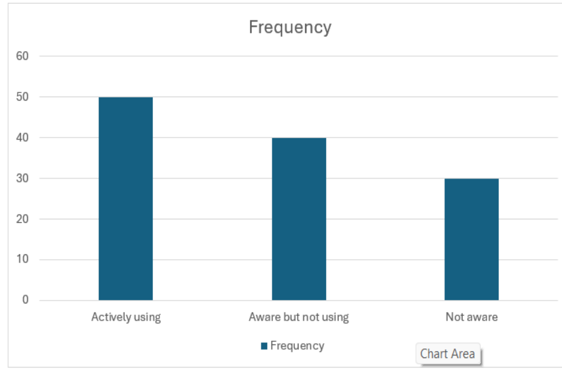
IV. RESULTS AND FINDINGS

Table 4.1: Socio-Economic Characteristics of Respondents

Variable	Category	Frequency	Percentage (%)
Gender	Male	80	66.7
	Female	40	33.3
Age	20–30 years	20	16.7
	31–40 years	50	41.7
	41–50 years	35	29.2
	Above 50 years	15	12.5
Education	No formal education	25	20.8
	Primary education	35	29.2
	Secondary education	45	37.5
	Tertiary education	15	12.5
Farm Size	<1 ha	30	25
	1–3 ha	60	50
	>3 ha	30	25

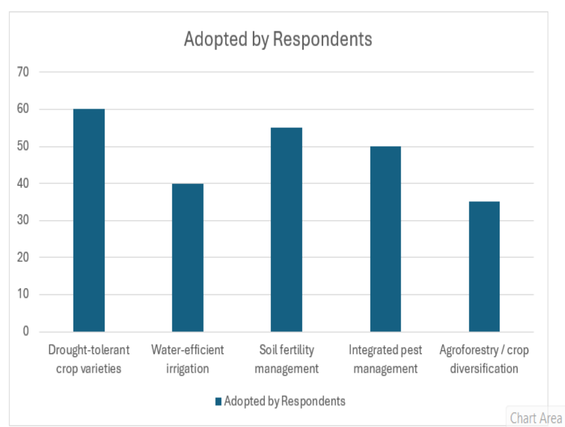
The majority of the respondents are male (66.7%) and are at the active working age group of 3140 years (41.7%), which also implies that smallholder farming is being done mainly by economically productive adults. The level of education is on the moderate side, as most of the farmers only have secondary education (37.5%), this factor can help in understanding and adoption of AI-enabled extension instruments. Most farms are small to medium-sized (13 ha), which points to the presence of resource constraints that may have an impact on the adoption of climate-smart farming practices.

Table 4.2: Access and Use of AI-Enabled Extension Services



41.7% of farmers are currently benefiting from the use of AI-enabled agricultural extension services, 33.3% know about these services but haven't used them yet, 25% have no knowledge of such services. These figures show that people are quite aware of digital advisory tools but their use is still quite low, which could be attributed to issues like low digital literacy, lack of smartphones, and problems with getting necessary infrastructure.

Table 4.3: Adoption of Climate-Smart Farming Practices



The figures reveal that AI-powered extension services help farmers take up various climate-smart practices. For instance, 50% of them adopted drought-tolerant crop varieties, and 45.8% resorted to soil fertility management. On the hand, only 33.3% practice water-efficient irrigation, and 29.2% have ventured into agroforestry, implying that certain CSFPs need more resources or deeper technical knowledge. On the whole, the level of adoption is average, highlighting the role of AI assistance as well as limiting factors like farm size, availability of inputs, and skills.

Table 4.4: Effectiveness of AI-Enabled Extension Services on Decision-Making

Response	Frequency	Percentage (%)
Highly effective	40	33.3
Moderately effective	50	41.7
Slightly effective	20	16.7
Not effective	10	8.3
Total	120	100

Most farmers (75%) think that AI-enabled extension services are very or moderately effective in helping to improve decision-making that is related to climate-smart practices. Only 8.3% of the respondents see these services as not effective. This implies that AI advisory tools offer proper advice that helps farmers to make well-informed, timely, and adaptable management decisions about their farms.

Table 4.5: Regression Analysis of AI-Enabled Extension Usage on Adoption of Climate-Smart Practices

Variable	Coefficient	Std. Error	t-value	p-value
Constant	0.950	0.280	3.39	0.001
AI Extension Usage	0.520	0.110	4.73	0.001
Education Level	0.215	0.090	2.39	0.019
Farm Size	0.185	0.080	2.31	0.024
Experience	0.140	0.070	2.00	0.048

Regression analysis results corroborate the fact that AI-enabled extension services have a significant and positive impact on the adoption of climate-smart agricultural practices (coefficient = 0.520, $p < 0.05$). Education, farm size, and farming experience were found to be other variables that have a positive effect on adoption, thus revealing that socio-economic characteristics determine farmers' ability to carry out practices facilitated by AI. These findings support the fact that AI-powered agricultural extension is a very effective tool in encouraging the adoption of climate-smart agricultural techniques and in helping smallholder farming systems to adapt to climate change.

V. DISCUSSION OF FINDINGS

The results of this research work greatly enlighten the aspect of gaining recognition and proficiency of deploying artificial intelligence (AI) to enhance agricultural extension services promoting climate-smart farming practices (CSFPs). From the socio-economic description, it is quite evident that most of the respondents happen to be men, are of economically active age and operate mainly small to medium scale farms. Besides, this finding supports the earlier studies which claim that smallholding farmers are the major users of extension services and they are highly exposed to climate changes (Anderson & Feder, 2007; Munyua, 2019). Regarding the educational qualification, quite a good number of them had at least secondary education, which means that their ability to comprehend and put AI-based advice into practice is quite high.

On the other hand, this research indicates that a greater proportion of the farmers (75%) is aware of AI-enabled extension services though the level of actual adoption is low (41.7%). This disparity between knowing and doing is a reflection of the usual problems that have been brought up in the literature namely poor digital skills, lack of access to smartphones or internet, and financial issues (Mittal & Mehar, 2016; Zhang et al. 2020). These results show that just spreading awareness is not going to be enough to motivate the farmers; induction, grants, and development of the physical facilities are the measures which can be put in place to bridge this gap.

The study also reveals that extension services supported by AI play a key role in encouraging farmers to use climate-smart techniques. For instance, the most popular practices that farmers have adopted so far are those related to drought-resistant crops, soil fertility, and pest management, while the usage of irrigation techniques that save water and agroforestry have remained quite limited so far. One can interpret such behaviors as indicating that the advisory systems powered by artificial intelligence work best when the suggested practices are not only new but also affordable and understandable to the farmers (Benos et al. 2021; Wolfert et al. 2017). In fact, perceptions of AI-enabled services effectiveness appeared to be quite positive, as 75% of the respondents indicated that these services were highly or moderately effective.

Therefore, this corroborates that AI-oriented advice is supportive of farmers decision-making, leads to resilience against adverse climate effects, and raises the chance of actually implementing CSFPs. Alongside AI extension usage, which is positively correlated and statistically significant education farm size, and experience also play critical roles. This aligns with previous research indicating that socio-economic factors have a major impact on digital agriculture adoption (Aker, 2011; Kumar et al. 2021). To sum up, this research shows that the use of AI-enabled agricultural extension services can effectively drive the adoption of climate-smart practices, lead to better decision-making on the farm, and help farmers become more resilient to climate change. On the other hand, the uptake of such services is still limited by various socio-economic, technological, and infrastructural factors that should be considered if the full potential of AI in agriculture is to be realized.

VI. CONCLUSION

The research work explored the adoption and effectiveness of Artificial Intelligence (AI)-based agricultural extension services in assisting smallholder farmers to practice climate-smart farming. The results of this research indicate that such services aid farmers in getting timely, location and condition specific, as well as actionable agricultural guidance which, in turn, leads farmers to the implementation of numerous climate-smart methods. Besides, the use of AI-based services is largely determined by factors such as the level of education, the size of the farm, and work experience; however, digital illiteracy, high costs of technology and poor internet connectivity are amongst the main impediments by far.

This paper comes to the conclusion that AI-powered extension services hold a major promise in facilitating the uptake of climate-smart agricultural practices, boosting climate change resilience, and increasing the productivity of small farming households. Yet, tapping into these advantages necessitates focused efforts to tackle technological and socio-economic inequalities and guarantee the provision of inclusive and equitable services to all farmers.

VII. RECOMMENDATIONS

The following proposals are made based on the result of the research:

1. Strengthen Digital Infrastructure

Governments and other development partners should to a larger extent invest in dependable internet connectivity, mobile network coverage, and electricity supply in rural areas so as to open up the door to the uninterrupted use of AI-enabled extension services.

2. Promote Digital Literacy and Training

Farmers should be exposed to training on smartphone usage, app handling, and the use of AI advisory platforms. Such farmer trainings should be designed and implemented considering the local geography, being very practical in nature, and the local extension officers should also be a support.

3. Provide Financial Support and Incentives

Low-income farmers should be given support such as subsidies, affordable loans, or they should be given the opportunity to acquire smartphones at very low costs with the aim of lowering the barriers to their adoption of the technology.

4. Integrate AI Advisory with Traditional Extension

AI-enabled tools should be human extension agents assistants and helpers, not their replacements. Advisory systems that use a combination of AI and human services have a higher chance of increasing trust and being adopted.

5. Localize AI Recommendations

To smallholder farmers, AI systems that utilize local climatic condition, type of soil, and crop conditions would be of huge help as they would be used to create actionable recommendations that, on the other hand, will really represent the realities of the smallholder farmers.

6. Encourage Peer Learning and Knowledge Sharing

Individual farmers sharing of knowledge and experience as well as collective verification of AI-based recommendations should be promoted. Community networks have proven to be the most effective in enhancing trust, adoption, and long-term sustainability.

7. Monitor and Evaluate Impact

Regular evaluation of adoption and use as well as effectiveness of AI-enabled extension services will help to make the services better and to base decisions on facts when scaling up the services.

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