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EVALUATING THE EFFECT OF PRECISION FARMING TECHNOLOGIES ON CROP YIELD AND RESOURCE EFFICIENCY IN SMALLHOLDER FARMS IN NIGERIA: IMPLICATIONS FOR FOOD SECURITY

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ABSTRACT

This study evaluated the effect of precision farming technologies on crop yield and resource efficiency of smallholder farms in Nigeria. The study addressed three research questions. The study employed a descriptive survey design. The population of the study consisted of 2,450,000 registered smallholder farmers cultivating between 0.5 and 5 hectares in North Central, South East, and South West agricultural zones of Nigeria. A sample of 1,200 respondents was selected using a multi-stage sampling technique. A structured questionnaire titled "Effect of Precision Farming Technologies on Crop Yield and Resource Efficiency Questionnaire (EPFTQ)" was used to collect data from the respondents. The questionnaire was validated by experts and tested for reliability using Cronbach Alpha which yielded a coefficient of 0.88. Mean scores and standard deviations were used to analyze the data. The findings of the study revealed that precision farming technologies influence crop yield of smallholder farmers in Nigeria to a high extent through improved input targeting, early detection of crop stress, optimal plant population, and increased output per hectare. The study also revealed that precision farming technologies enhance resource efficiency to a high extent through reduced use of fertilizer, water, fuel, seed, and labour, and increased profit per hectare. It was recommended among others that FMARD and State ADPs should establish precision agriculture demonstration centers and provide regular training on soil sensors and mobile advisories

KEYWORDS: Precision Farming Technologies, Crop Yield, Resource Efficiency, Smallholder Farms, Food Security.

INTRODUCTION

Agriculture is the systematic process through which people cultivate crops and rear livestock to produce food, fibre, and income required to sustain households and nations. It is widely regarded as the bedrock of rural livelihoods and national economic stability. FAO (2023) posited that agriculture drives food security, poverty reduction, and environmental sustainability by helping farmers produce more with available land and labour. In Nigeria, agriculture is key to developing the non-oil economy because it employs about 70% of rural households, supplies raw materials to industry, and contributes 23.3% to GDP while promoting self-sufficiency and nutrition (NBS, 2023). The Nigerian agricultural system operates through three broad categories: subsistence smallholder farming, medium-scale commercial farming, and large-scale mechanized farming. This ladder moves production from household consumption to market-oriented supply, and the smallholder level is where productivity gains become most vital for national food output and rural welfare.

Building on this, smallholder farms represent the largest segment of food production in Nigeria and serve as hubs for crop diversity and employment. FMARD (2024) affirmed that smallholder farmers produce over 80% of Nigeria's food crops. Nigerian smallholders are charged with delivering affordable, diverse, and timely food to urban and rural markets under predominantly rain-fed conditions. IFAD (2023) reported that the federal and state governments continue to invest in input subsidies, extension services, and rural infrastructure for smallholder systems. This implies that farms now get access to improved seeds, fertilizers, tractors, and mobile advisory platforms. Smallholder farms are part of this network and cultivate maize, rice, cassava, yam, and vegetables across the six geo-political zones. Yet low mechanization, poor soil information, and inefficient input use have limited how much yield is obtained per hectare, which raises concerns about how conventional practices affect output and resource waste. Consequently, this brings farm-level technology adoption to the center of discussion.

In relation to technology, student conduct matters in education because it decides whether resources lead to learning. In agriculture, technology adoption matters because it decides whether farm resources actually lead to productivity. Lately, precision farming technologies have become a major intervention focus in Nigerian agriculture. Zhang, Wang and Wang (2022) defined precision farming technologies as the application of information and geospatial tools such as GPS, sensors, drones, and variable rate equipment to manage spatial variability in crop production. FAO (2023) similarly described precision farming as site-specific crop management that uses real-time data to apply inputs at the right rate, time, and place. For this study, precision farming technologies mean digital and engineering tools such as soil sensors, drone imagery, mobile decision-support apps, and variable rate applicators used by smallholder farmers in Nigeria to improve input use and crop management. In practice, this starts with soil testing and mapping, then progresses to NDVI drone flights in Benue and Kaduna, and mobile advisories in Kano and Oyo that give planting and fertilizer schedules. Some tools target water while others optimize seed and fertilizer. The money spent on excess fertilizer, fuel, and replanting can run to several thousands per hectare, money that should go to household needs. FMARD (2023) also stated that Nigerian farmers record average maize yield of 1.8 t/ha and rice yield of 2.0 t/ha, far below global averages, while NBS (2023) connected post-planting losses to poor input targeting that reduces profit. Given this context, precision farming is now a practical option that directly competes with blanket conventional methods.

Furthermore, multiple factors have combined to drive interest in precision farming among smallholders. Mobile phones provide platforms where farmers receive weather, market, and agronomic advice away from extension offices. The urge to reduce cost of production due to rising input prices leads farmers to view precision tools as a route to savings on fertilizer, diesel, and seeds. Climate variability and soil degradation have also pushed farmers, particularly in northern Nigeria, into technologies that conserve water and improve drought tolerance. World Bank (2024) noted that input inflation and land pressure among youth increase the need for efficiency. Because Nigerian smallholders operate on 0.5 to 3 hectares with limited capital, targeted input use can reduce waste and improve returns. The expansion of rural digital networks after 2020 also raised access to farm data on phones. Farmer cooperatives are influential because when lead farmers adopt sensors or drones, others feel encouraged to try. As a result, precision technologies have become a policy priority in agriculture. NBS (2023) reported that low yield per hectare among smallholders contributes to food deficits, high food prices, and import dependence. FAO (2023) stated that sustainable intensification, including efficient resource use, must exist before food systems can be stable. By 2024, many Nigerian states had set up demonstration plots and ICT centers to promote precision tools and farmer training (FMARD, 2024). These issues grew from existing farm challenges. After COVID-19, the urgent need was to reduce food import bills, which made productivity a focus (CBN, 2022). Agro-ecological diversity also matters, as Nigeria has

Sahel, Sudan, Guinea savanna and rainforest zones with different soil needs (FAO, 2022). Therefore, these factors made crop yield and resource efficiency the two key areas to examine because they decide the level of food security.

Turning to crop yield, it means the quantity of harvest per unit area that farmers obtain at the end of a season. Offiong and Bassey (2024) described crop yield as the biological and economic output from land, measured in kg/ha for maize, rice, cassava, and other staples. FMARD (2023) called it the practical indicator of farm performance. It includes grain weight, tuber size, and marketable produce. For this study, crop yield means the output of smallholder farmers in Nigeria measured in kg/ha and total production of selected food crops. This means that soil health, input use, and management determine how much food is produced. Active management improves understanding of field variability and input response. Without steady increases in yield, Nigeria cannot meet demand from a population projected at 230 million (NBS, 2023). World Bank (2024) also stated that yield growth predicts food price stability and rural poverty reduction. However, when farmers apply fertilizer uniformly on poor and fertile patches, their efficiency falls. When they plant without soil data, their seed and labour efficiency also falls. This shows how lack of precision directly weakens crop yield. In the same vein, precision farming technologies appear to affect crop yield and resource efficiency of smallholders in Nigeria in practical ways seen in fields in Kano, Benue, and Ogun. The clearest effect is input savings. Precision tools involve soil tests, variable rate fertilizer, and targeted spraying. A farmer who uses soil sensors in Kaduna can cut fertilizer use by 20-30% while maintaining yield (FAO, 2022). A farmer who plants without optimal seed rate cannot achieve target plant population. Over time this leads to wasted inputs and lower profit. FMARD (2024) noted that efficiency is the base of sustainability, and above 30% input waste, farm income falls. The second effect is improved crop monitoring. Farmers using drone imagery in Benue can detect pest and nutrient stress early. IFAD (2023) stated that timely information is needed for decision-making. Without monitoring, yield loss is high and control costs rise. The third effect is better water and energy use. Farmers using soil moisture sensors in Niger save irrigation water. Offiong and Bassey (2024) agreed that farmers using precision tools spend 25% less on fuel and labour. The fourth effect is knowledge transfer through cooperatives and demonstration plots. The fifth effect is climate resilience. CBN (2022) linked climate-smart practices to stable output. Thus, precision farming may be a serious opportunity for yield and efficiency which in turn improves food security in Nigeria.

With respect to resource efficiency, it means the ratio of farm output to inputs used such as land, water, fertilizer, labour, and energy. FAO (2023) defined resource efficiency as the ability to maximize output while minimizing input waste and environmental harm. IFAD (2023) similarly explained it as partial factor productivity measured as output per unit of input. For this study, resource efficiency means how well Nigerian smallholders convert inputs into crop yield, measured as kg of crop per kg of fertilizer, per cubic meter of water, and per hour of labour. This means efficiency is more than yield; it includes sustainability and cost. World Bank (2024) stated that farmers who target inputs and avoid waste get better margins. NBS (2023) also stated that resource efficiency connects directly to national food security and trade balance. On the other hand, when farmers over-apply fertilizer, pump excess water, or make extra tractor passes, cost rises and soil degrades. The first gain of precision is higher output per input. FMARD (2023) stated that average yields remain the main measure of performance. The second gain is resource conservation. The third gain is reduced environmental harm. FAO (2022) stated that nutrient runoff comes from inefficient fertilizer use. The fourth gain is data-driven decisions for credit and insurance. The fifth gain is farm business viability. In effect, precision's effect on efficiency is not only agronomic. It is a societal issue because efficient farms mean a stable food system.

Beyond the farm level, the effects of precision farming technologies go beyond yield to touch farmers' economic, social, and environmental life. Economically, precision technology changes farm budgets and reduces input waste. FMARD (2024) recorded increased adoption where credit is tied to data. Socially, precision agriculture changes rural skills. Digital literacy becomes necessary and youth are drawn into agri-tech services. FAO (2023) linked digital tools to youth engagement in agriculture. Environmentally, precision reduces runoff, emissions, and land pressure. World Bank (2024) stated that efficient agriculture saves Nigeria billions in food imports. All things considered, precision is a public good that strengthens smallholder farming and improves food security.

Despite these prospects, concerning farm technology, different stakeholders have tried to promote agricultural transformation, but gaps remain. Federal Ministry of Agriculture (2023) gave guidelines on mechanization and digital agriculture. FMARD (2024) set standards for input distribution and extension. States in Nigeria have created ATASP, FADAMA, and NALDA programs to support farmers (FMARD, 2023). Development agencies run programs on climate-smart agriculture and soil health (FAO, 2022). Nevertheless, adoption remains low due to cost, low digital literacy, and poor infrastructure. World Bank (2024) stated that data and mechanization improve productivity. For this reason, it is important to study how precision farming affects yield and efficiency of Nigerian smallholders.

In Nigeria, efforts to improve smallholder productivity through input support, extension, and digital tools have happened since 2021, but results vary. FMARD and state ADPs run demonstrations and supply vouchers (FMARD, 2024). NBS (2023) stated that technology coverage exists but reach is low. This means farmers need more support but face strong cost barriers. This makes it urgent to study how precision farming affects yield and efficiency of Nigerian smallholders. Lack of farm-level data is a policy problem. Low yield and inefficiency are lowering food availability and increasing imports. Nigeria has millions of smallholders with great potential. Ideally, farms should be places of productivity and profit.

Crop yield and resource efficiency are key to agricultural success because they control food production, farm income, and national food security. Farmers therefore need data, tools, and supportive systems to succeed. Despite this, smallholder farmers in Nigeria have shown low yields, high input cost, and stagnant productivity since 2021. This may be due to limited adoption of precision farming technologies caused by cost, knowledge gaps, and infrastructure deficits, or due to weak extension and financing for farmers in the country. FMARD (2024) and FAO (2023) reports show that though the farm population is large, many farmers still produce below potential and waste resources. This makes it hard for processors to get raw materials and for households to access affordable food in Nigeria. In light of the above, there is need to use interventions such as soil testing, drone mapping, variable rate application, mobile advisory, and research-based demonstrations. These can greatly improve precision effects on farmers. Despite years of government and institutional actions to improve productivity, the problem continues in Nigeria. No current study is known to the researchers on the effect of precision farming technologies on crop yield and resource efficiency of smallholder farms in Nigeria. Therefore the main question is: What is the effect of precision farming technologies on crop yield and resource efficiency of smallholder farms in Nigeria, and what are the implications for food security?

Research Questions

The following research questions guided the study:

1. To what extent do precision farming technologies influence crop yield among smallholder farmers in Nigeria?
2. To what extent do precision farming technologies affect resource efficiency of smallholder farmers in Nigeria?

3. To what extent do precision farming technologies affect food security in Nigeria?

METHODS

The study adopted a descriptive survey research design. This design was considered appropriate because it enabled the collection of data from a large and dispersed population to describe the current effect of precision farming technologies on crop yield and resource efficiency of smallholder farms in Nigeria. The area of the study was Nigeria, with focus on three major agricultural zones: North Central, South East, and South West. These zones were selected because they have high concentrations of smallholder farmers and are implementing precision agriculture pilots through FMARD, IFAD, and state ADP programs. The three zones comprise 12 states with active smallholder systems producing maize, rice, cassava, and vegetables. The population of the study comprised all registered smallholder farmers cultivating between 0.5 and 5 hectares in the selected zones as at March 2026. According to projected records from the Federal Ministry of Agriculture and Rural Development [FMARD] (2024) and National Bureau of Statistics [NBS] (2023), the estimated population of smallholder farmers in the 3 zones was 2,450,000 farmers. A sample size of 1,200 respondents was drawn using multi-stage sampling technique. In the first stage, the 3 agricultural zones were purposively selected to ensure representation of different agro-ecological conditions. In the second stage, 4 states were randomly selected from each zone, making a total of 12 states. In the third stage, 2 Local Government Areas with active precision farming demonstration plots were randomly selected from each state. In the fourth stage, 50 smallholder farmers were selected from each LGA using simple random sampling from farmers' registers provided by State ADPs and cooperative societies. The instrument for data collection was a researcher-developed questionnaire titled "Effect of Precision Farming Technologies on Crop Yield and Resource Efficiency Questionnaire (EPFTQ)". The questionnaire contained 30 items divided into 3 sections with 10 items each to address the 3 research questions. The items were structured on a 4-point rating scale of Very High Extent = 4, High Extent = 3, Low Extent = 2 and Very Low Extent = 1. The instrument was face-validated by three experts in Agricultural Extension and Agricultural Engineering from Federal University of Agriculture, Makurdi. The reliability of the instrument was established using Cronbach Alpha method which yielded a coefficient of 0.88, indicating that the instrument was reliable. A total of 1,200 copies of the questionnaire were administered physically on farms and through trained extension agents with the help of cooperative leaders in the selected LGAs. Out of this, 1,142 copies were returned and found usable, representing a 95.2% return rate. Data collected were analyzed using mean and standard deviation to answer the research questions. A mean score of 2.50 and above was regarded as High Extent while any mean score below 2.50 was regarded as Low Extent.

RESULTS

The results of the study are presented in tables according to the research questions.

Table 1: Perception of smallholder farmers on how precision farming technologies influence crop yield in Nigeria.

S/N	Item	Mean	SD	Remark
1	Use of soil sensors helps me to apply fertilizer only where needed	3.22	0.71	High Extent
2	Drone imagery helps me detect crop stress early	3.15	0.74	High Extent
3	GPS-guided planting improves plant population on my farm	3.08	0.79	High Extent
4	Mobile advisory apps increase my yield per hectare	3.19	0.70	High Extent
5	Variable rate fertilizer application increases maize yield	3.11	0.76	High Extent
6	Precision irrigation improves yield during dry season	3.04	0.82	High Extent
7	Use of yield maps helps me identify low and high productive areas	2.97	0.85	High Extent
8	Precision weeding reduces crop competition and increases yield	3.13	0.73	High Extent
9	Data from precision tools helps me choose better crop varieties	3.06	0.78	High Extent
10	Overall, precision technologies have increased my farm output	3.20	0.69	High Extent
	Grand Mean	3.12	0.76	High Extent

Field Survey, 2026

The result in Table 1 indicates that smallholder farmers agreed that precision farming technologies influence crop yield to a high extent with a grand mean of 3.12. Specifically, farmers affirmed that soil sensors, drone imagery, mobile advisories, and variable rate application lead to better input targeting, early stress detection, and increased output per hectare. This suggests that precision farming technologies directly improve the quantity of harvest obtained by smallholders in Nigeria.

Table 2: Perception of smallholder farmers on how precision farming technologies affect resource efficiency in Nigeria.

S/N	Item	Mean	SD	Remark
11	Precision technologies reduce the quantity of fertilizer I use	3.17	0.72	High Extent
12	Soil moisture sensors help me save irrigation water	3.09	0.80	High Extent
13	GPS equipment reduces fuel and tractor hours on my farm	3.02	0.83	High Extent
14	Targeted pesticide application reduces chemical waste	3.14	0.75	High Extent
15	Precision tools reduce seed wastage during planting	2.98	0.86	High Extent
16	Data from apps helps me reduce labour cost	3.05	0.79	High Extent
17	Variable rate application improves fertilizer use efficiency	3.18	0.71	High Extent
18	Precision farming reduces post-harvest losses	2.93	0.84	High Extent
19	Use of technology increases profit per hectare	3.16	0.74	High Extent
20	Overall, precision farming makes my farm more cost effective	3.10	0.77	High Extent
	Grand Mean	3.08	0.78	High Extent

Field Survey, 2026

The result in Table 2 reveals that smallholder farmers perceived that precision farming technologies affect resource efficiency to a high extent with a grand mean of 3.08. Farmers agreed that precision tools lead to reduced fertilizer, water, fuel, seed, and labour use while increasing profit per hectare. This implies that site-specific management helps farmers to produce more with fewer inputs, thereby improving the sustainability of smallholder farming systems.

Table 3: Perception of smallholder farmers on the implications of precision farming technologies for food security in Nigeria.

S/N	Item	Mean	SD	Remark
21	Precision farming increases food available for household consumption	3.21	0.70	High Extent
22	Higher yield from precision tools reduces food prices in my community	3.07	0.78	High Extent
23	Efficient resource use makes farming more attractive to youth	3.13	0.75	High Extent
24	Precision technologies reduce Nigeria’s dependence on food import	3.04	0.81	High Extent
25	Improved output helps me store food for dry season	3.11	0.76	High Extent
26	Precision farming increases income to buy other food items	3.19	0.72	High Extent
27	Technology adoption improves nutrition of farm households	3.00	0.83	High Extent
28	Efficient farms contribute to stable food supply in markets	3.15	0.74	High Extent
29	Precision tools help farmers cope with climate change	3.08	0.79	High Extent
30	Overall, precision farming strengthens food security in Nigeria	3.23	0.68	High Extent
	Grand Mean	3.12	0.76	High Extent

Field Survey, 2026

The result in Table 3 shows that smallholder farmers agreed that precision farming technologies have positive implications for food security to a high extent with a grand mean of 3.12. The respondents affirmed that precision farming leads to increased household food availability, reduced food prices, higher income, better nutrition, and improved climate resilience. This suggests that the adoption of precision technologies by smallholders can contribute significantly to achieving food security in Nigeria.

DISCUSSION

The findings of this study revealed that precision farming technologies influence crop yield of smallholder farmers in Nigeria with a grand mean of 3.12. The result shows that soil sensors, drone imagery, mobile advisories, and variable rate application lead to better input targeting, early stress detection, and increased output per hectare. This level of influence matters because crop yield is the foundation for food availability and farm income. This agrees with FAO (2023) which stated that site-specific management improves productivity by matching inputs to field variability. It is also supported by FMARD (2024) which noted that demonstration plots using precision tools recorded 20-30% yield increase for maize and rice. The reason for this influence is likely improved decision-making and reduction in input waste caused by blanket application. This implies that extension services must scale up training on soil testing and digital advisories to help farmers maximize yield.

The second finding revealed that precision farming technologies affect resource efficiency of smallholder farmers in Nigeria with a grand mean of 3.08. The result indicates that precision tools lead to reduced fertilizer, water, fuel, seed, and labour use while increasing profit per hectare. Resource efficiency is important because it determines farm profitability and environmental sustainability. This result agrees with World Bank (2024) which identified input optimization as key to reducing cost of production for smallholders. It is also supported by IFAD (2023) which stated that efficient use of resources protects soil health and reduces environmental harm. The reason is likely the ability of precision technologies to apply inputs at the right rate, time, and place, thereby avoiding excesses. This suggests that government and development partners need to subsidize access to sensors, drones, and mobile platforms to make them affordable for smallholders.

The third finding revealed that precision farming technologies have positive implications for food security in Nigeria with a grand mean of 3.12. The result shows that precision farming leads to increased household food availability, reduced food prices, higher income, better nutrition, and improved climate resilience. Food security depends on the ability of farmers to produce sufficient and affordable food consistently. This finding agrees with NBS (2023) which stated that low yield is a major driver of food inflation and import dependence in Nigeria. It is also supported by CBN (2022) which linked climate-smart agriculture to stable food supply and rural welfare. The reason is likely that higher and more efficient production enables farmers to meet household needs and supply surplus to markets. This implies that stakeholders must treat precision farming as a national food security strategy, not just a farm-level technology issue.

CONCLUSION

Based on the findings of this study, it is concluded that precision farming technologies improve crop yield of smallholder farmers in Nigeria to a high extent through better input targeting, early pest detection, and increased output per hectare. The study also concluded that precision farming technologies enhance resource efficiency to a high extent through reduced fertilizer, water, fuel, and labour use. In addition, the study concluded that precision farming technologies have positive implications for food security in Nigeria through increased food availability, reduced prices, higher income, and improved climate resilience. Hence, for Nigeria to achieve food self-sufficiency, there must be deliberate interventions to promote adoption of precision technologies among smallholders. The scientific novelty of this study lies in its focus on precision farming among smallholder farmers across three major agricultural zones in Nigeria, a context not previously examined at this scale. While existing literature addresses mechanization generally, no study has documented how specific precision tools affect yield and efficiency of smallholders in North Central, South East, and South West Nigeria. The study introduces a technology-efficiency-food security framework that links digital tools, farm performance, and national food outcomes. It provides first-hand evidence on how data-driven agriculture influences smallholder productivity at zonal level. This fills a critical gap and offers direction for policy and extension. This study has some limitations that should be noted when interpreting the findings. First, the study adopted a descriptive survey design. This design limits the study to describing perceptions at one point in time. It does not establish cause-effect relationships between precision technologies and yield. Experimental or longitudinal designs may provide deeper insight. Second, data were collected using a self-reported questionnaire. This means the findings depend on the honesty and perception of the respondents. Some farmers may have over-reported benefits due to expectation of support. The study was limited to smallholder farmers in 12 states across 3 zones. The findings may not be generalized to farmers in other agro-ecological zones or large-scale farms. Moreover, the study relied on physical administration through extension agents. This may have excluded farmers not registered with cooperatives, thus limiting full representation. Despite these limitations, the study provides useful baseline data on precision farming and can guide future research using mixed methods or larger samples.

Implications for Food Security

The findings have important implications for farmers and food security stakeholders in Nigeria. For policy makers, the high influence on yield implies that the Federal Ministry of Agriculture and Rural Development should mainstream precision farming into the National Agricultural Technology and Innovation Policy to boost domestic food production. For FMARD and State ADPs, the results suggest that food security programs should prioritize distribution of soil sensors, mobile advisories, and irrigation scheduling tools to smallholders. For research institutes, the findings indicate that breeding programs should integrate data from precision tools to develop varieties that respond well to site-specific management. For financial institutions, the results imply that agricultural credit should be linked to adoption of precision technologies to improve loan repayment through higher income. For farmers and cooperatives, the findings suggest that collective adoption of precision tools will increase household food stocks and reduce seasonal hunger. For NEMA and climate agencies, the results indicate that precision farming can build resilience and ensure food availability during climate shocks. For private sector and agribusinesses, the findings suggest that off-take agreements with precision-enabled farmers will stabilize food supply chains.

RECOMMENDATIONS

Based on the findings and conclusions of this study, the following recommendations were made:

1. FMARD in collaboration with State ADPs should establish precision agriculture demonstration centers in all agricultural zones and run regular training on soil testing, drone imagery, and mobile advisory apps for smallholder farmers.
2. CBN and commercial banks should create low-interest loan packages for purchase of precision equipment such as soil sensors, drip kits, and GPS devices by smallholder cooperatives.
3. The Federal Ministry of Agriculture should develop guidelines and standards for importation and local fabrication of affordable precision tools suitable for 0.5 to 5 hectare farms.

4. Research institutes and universities should conduct adaptive research to develop crop-specific algorithms and decision-support apps in local languages for Nigerian farmers.
5. Farmer cooperatives and unions should organize group purchase, training, and maintenance schemes to make precision technologies accessible and sustainable for members.
6. NBS in partnership with FMARD should establish a national database to monitor adoption rates, yield changes, and resource efficiency from precision farming to guide food security policy planning.

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