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BENEFITS OF IMPLEMENTING PRECISION AGRICULTURE TECHNOLOGIES IN NIGERIAN AGRICULTURAL SYSTEM: A REVIEW

***Kutigi, I. B.[1], Musa, J. J.[2], Adeoye P. A.[2], Adesiji, R.[3] and Obasa, P.[2]**

1. Niger State Fadama Development Project, Off Minna-Paiko Road, Behind Farm Centre, Minna.
2. Department of Agriculture and Bioresources Engineering, Federal University of Technology, P. M. B. 65, Minna
3. Department of Civil Engineering, Federal University of Technology, P. M. B. 65, Minna

Corresponding Author email: johnmusa@futminna.edu.ng

ABSTRACT

Precision Agriculture (PA) or Information-based Management of Agricultural Production System (IMAPS) came into existence since the mid-1980s as the process through which the right treatment is given to the agricultural process at the right time. PA was employed mainly for fertilizer application to various soil conditions across agricultural fields at the onset. Since then, different use of PA has been engaged in other areas of agriculture such as farming vehicles and implements, autonomous machinery and processes, product traceability, on-farm research, and software for the overall management of agricultural production systems. To describe precision agriculture, most simplified way is the examination of the five "R"s which are the right time, right amount, right place, right source and proper manner of agriculture inputs like – water, fertilizer, pesticide, etc. The primary constraint of agricultural development in Nigeria is the use of inadequate methods of data and information acquisition on agrarian land potential, crops condition, and farming activities. It can, therefore, be concluded that the lack of decision support systems to be a significant barrier to the adoption of PA. Farmers need decision support systems that enable effective decision making based on accurate and timely data.

Keywords: *Agriculture, Precision, GPS, GIS, Tools.*

1 INTRODUCTION

Availability of food and other agricultural products in adequate supply and quality under environmentally safe conditions and the sustainability of the various resources involved is of paramount importance to researchers (Gebbers and Adamchuk, 2010). Precision Agriculture (PA) or Information-based Management of Agricultural Production System (IMAPS) came into existence since the mid-1980s as the process through which the right treatment is given to the agricultural process at the right time. Sensitization on the variation in soil and crop conditions combined with the various forms of technology such as global navigation satellite systems (GNSSs), geographic information systems (GISs), and microcomputers, serve as the primary drivers. PA was employed mainly for fertilizer application to various soil conditions across agricultural fields at the onset. Since then, different use of PA has been engaged in other areas of agriculture such as farming vehicles and implements, autonomous machinery and processes, product traceability, on-farm research, and software for the overall management of agricultural production systems.

Aside from crop production, PA technology is employed successfully in viticulture and horticulture, including orchards, and in livestock production, as well as pasture and turf management (Gebbers and Adamchuk, 2010). They further stated that application of PA ranges from the tea industry in Tanzania and Sri Lanka to the production of sugar cane in Brazil; rice in China, India, and Japan; and cereals and sugar beets in Argentina, Australia, Europe, and the United States. PA is in three folds that is to optimize the use of available resources to increase the profitability and sustainability of agricultural operations. Second, to reduce negative environmental impact. Third, to improve the quality of the work environment and the social aspects of farming, ranching, and relevant professions.

The idea of precision agricultural practice started several decades ago most especially in developed countries like the State of Israel, the United States of America, Canada, and the Western Europe countries (Junk *et al*. 2013). Precision agriculture is the application of established technologies and principles to manage all areas of an agricultural system for improved quality production of farm products and the environment at large (Pretty, 2008). In the last three decades, this has not only matured but has moved to all other developing countries of which Nigeria is not left out. The connection of PA to the improvement and increment in the level of civilization of humanity and the quest for improved gross domestic product and national cannot be overemphasised. To describe precision agriculture, most simplified way is the examination of the five "R"s which are the right time, right amount, right place, right source and proper manner of agriculture inputs like – water, fertilizer, pesticide, etc. The success of PA is seen through the productivity and profitability of the process. Precision agriculture is the ability of the farmer to manage the differences that may occur during the agricultural process for profitability and sustainability of the farming activities. PA further manages the low input, high yield, and environmentally sustainable conditions. The effect of these variabilities according to Bongiovanni *et al*., (2004) is grouped into yield variability, field variability, soil variability, crop variability, variability in anomalous factors, and management variability.

Every section of the farmland or zones of the country has different production capability, which is connected to the soil type's environmental conditions and other geographic conditions like- such as the slop of the farmland and topography (van Ittersum *et al*. 2013). This makes the lands to respond differently to the crops grown. Yield capacity difference can also mean yield variability. The difference in the field topography (elevation, slope, closeness to a water source) can be termed to be the field variability. The variation for nutrients in the field is termed to be soil variability (Araus and Cairns, 2014). Soil texture to an extent could be called as a variable factor. The plant growth rate and duration are termed crop variability. Other factors affecting the life cycle of the crops include weed infestation, insect infestation, disease condition, and wind damage. These factors are known to affect the performance of the agricultural process. It is therefore essential to understand the variability of these factors and their effect on agriculture. The presence of these factors and the corrective measures are taken to reduce their impact on the farm's aids in achieving the objective of PA. Thus, the introduction of PA helps to make maximum yield and profit from the sales of farm products in spite of yield, field, soil and all another variabilities. The practice of PA is accomplished through the introduction of mitigative measures that control the variabilities.

2. PRECISION AGRICULTURE IN NIGERIA

Agriculture in Nigeria since independence has played a significant role in the country's development at both the food security level and income generation. This sector is an essential occupation of the average Nigerian as about 70% of the population depends on it. The agricultural sector provides bulk employment, income, and food for the rapidly growing population as well as agro-based industries. As a nation, Nigeria is still not self-sufficient in agrarian products as most food crops are imported from other countries. Several governments of Nigeria have introduced different farming programmes and policies targeted at improving agricultural productivity to meet the growing demand by the population and agro-industries (Olaoye, 2014). However, the hydra problems of agriculture in Nigeria and food insecurity have taken great contrary positions because the rate of growth in the area of agricultural production has not in any way met the growing demands of the population. Two significant areas have been identified from the agrarian policies of 2016 which are the inability of products to meet the domestic demand and the failure to achieve the quality required for the foreign market (Lee *et al*. 2012). These policies and programmes are connected to the poor farming methods employed and the lack of essential farming inputs such as fertilizer, herbicides, improved seeds, irrigation crop protection and necessary support from the various agricultural schemes (Toenniessen *et al*. 2008). The advent of industries and urbanization has drastically reduced the farmlands and farming resources largely. Population increase and limited agrarian support resources have in recent times opened up issues like productivity, sustainability, and profitability of agriculture system. Currently, Nigeria is rated as one of the leading producers of grain crops such as rice, maize, sorghum, etc. in Africa. Thus, there is the need for improvement using the conventional process of agriculture and the adoption of technology.

Many challenges oppose the implementation of PA in developing and underdeveloped countries (Scott, 2008). These challenges do not only include the non-availability of the much need technology but many other factors which consist of the lack of electricity supply, insufficient water supply, land allocation methods to farmers, knowledge of PA among the farmers and the government policies (Mustapha *et al*. 2012). With all these challenges it becomes almost impossible for modern agricultural technologies to strive. As one of the developing countries, Nigeria has not started adopting the practice of PA.

Recent developments have shown that PA system when introduced to farmers said that they are farming processes for the future while some others have keyed into it and are making ways regarding the quality and quantity of agricultural products. Precision farming involves the use of specific soil and crop data for improved yield. This process is targeted at optimizing returns on investment by matching farming practice more closely to the crop needs (Okorie, 2018). Nigeria is the most populous black nation and is faced with the adaptation of PA in practice due to cultural and financial reasons. Some of these challenges are due to the types of instruments that are involved which includes Global Positioning System (GPS), Remote Sensing (RS), on the go sensors, etc. Most of the agricultural systems in Nigeria are made up of the so-called hard PA.

3. CHALLENGES OF PRECISION AGRICULTURE

The challenges facing food insecurity, poverty, disease and hunger in Nigeria and many other nations have called for research in this area to forestall these menaces. The primary constraint of agricultural development in Nigeria is the use of inadequate methods of data and information acquisition of agrarian land potential, crops condition and farming activities (Harris and Orr, 2014). The effect of this is the imperfect knowledge and unreliable data acquisition for farm planning and policy formulation. For instance, unguided use of land whose consequence is often the misuse of prime farmland. This has a significant set back on agrarian development. It is worthy of note that substantial agricultural production takes place under traditional systems. This is highly dependent upon natural forces and processes for the maintenance of yield and the quality of produce. Detection, identification, measurement, and monitoring of agricultural phenomena predicated the assumption that agrarian landscape features (such as crops, livestock, crop infestation, and soil anomalies) have consistently identifiable signatures on the type of remote sensing data. These identifiable signatures are a reflection of crop type, state of maturity, crop density, crop geometry, crop vigor, crop moisture, crop temperature, and soil moisture as well as soil temperature (Chong *et al*. 2017). PA-based on the incorporation of information and communication technologies into machinery, equipment, and sensors in agricultural production systems, allows a large volume of data and information generated are inputted into the automation system for processing (Rodrigues, 2013).

Demographic trends, including aging populations and continued migration of people from rural to urban areas, have attracted the attention of researchers, because labor issues may become a scarcity factor in agriculture. According to the UN data, the world's urban population is poised to surpass the rural total for the first time in history. By the time this happens, more than half of the rural population in Nigeria will be living in cities. This kind of population growth is observed mainly in low and middle-income nations like India, China, Nigeria and Brazil (Prince *et al*. 2013). China and India have occupied the first and second positions in the list of countries with the fastest growing 100 cities while Nigeria is not left out in Africa (Seto, 2011). The implications of such dramatic shifts for economic development, urbanization, and energy consumption are immense. In addition to these trends, the intensification of climate change will continue to alter growing conditions, such as temperature, precipitation, and soil moisture, in less predictable ways (Erwin, 2009). PA tools can help reduce these impacts, keep them constant or reduce production costs in agricultural activities, and they can assist in minimizing environmental constraints (Chen, and Yada, 2011).

To meet the growing food grain demand in Nigeria and with the increasing challenge of biotic and abiotic stresses experienced by crops, the introduction, and adoption of modern technology in Nigerian agriculture is inevitable. Agriculture, like other industries, has made entry into the knowledge-based era, leaving its previous resource-based nature in recent times through the various policies governing the importation of agricultural products (Andersen, 2012). Future agriculture will be severely competitive, knowledge-intensive and market driven (Holt-Giménez and Altieri, 2013). Identifying how science frames PA over time, countries and targeted research can help drive new study with the objective of covering areas that have received less attention; this will develop new approaches to understand PA better and illuminate new applications. Some of the challenges in PA includes low technological development; inconsistency and inept implementation of government policies; the level of investment; crop Inputs; farm size management practices; Optimal size zone for soil sampling. Other technical problems include farmland holdings, monocropping system and market imperfection which is regarded as the most important to the farmers as they do not have control over the market forces.

These challenges are real, and they constitute a significant roadblock to the implementation of PA in Nigeria agricultural development. Concerted efforts and careful planning are required to cover these problems. The most significant challenge is perhaps the acquisition of relevant space technology. Remote sensing, Geographic Information Systems, and Global Positioning Systems are expensive tools and are currently very scarce in Nigeria. However, with the successful launch of an earth observation satellite, NigeriaSat-1 in March 2003, by the Nigerian government brought this a step towards the application of space technology to solving some of the socio-economic problems in the country, including the agricultural sector. The satellite will improve the efficiency and reliability of agrarian data collection. Several researchers have expressed in various ways the capabilities and relevance of NigeriaSat 1 in Nigerian agricultural development. Rilwani and Gbakeji (2009) have demonstrated the ability of NigeriaSat 1 in farm planning and management. He integrated data from NigeriaSat 1 with existing soil and topographical map in a Geographic Information System environment to assess the current and potential agricultural land use in the Kadawa sub-sector of the Kano River Irrigation Project.
An alternative to satellite remote sensing that could be adopted in Nigeria is Airborne Videography. This technology provides higher levels of spatial details (between 0.25m and 4m pixel size) than current satellite technology (Woodget *et al*., 2015; Matese *et al*. 2015). This advantage in addition to the flexibility in the frequency and time of coverage make it ideal for the site-specific management of soil and crop conditions.

Some of the tools used in PA includes the yield monitors which have the capability of indicating yield (kg/ha), total kg, ha/hour; hectare worked, and grain moisture content. They are attached to crop harvesting equipment providing information on crop yield; global positioning system (GPS) is a network of 24 satellites orbiting the earth which gives exact satellite time and location to ground receivers. Differential Global Positioning System (DGPS) which is a way of improving the GPS accuracy. This uses the pseudo-range errors measured at a known location to adjust the measurements made by the other GPS receivers within the same general geographic area. Geographical Information System (GIS) are computer soft and hardware's which use feature attributes and location data to produce maps. Remote sensing is a useful tool for collecting lots of information simultaneously from a distance (Zook *et al*. 2010). Remotely-sensed data provide a mechanism for evaluating crop health (Mandal and Maity, 2013). Variable Rate Applicator which has variable rate applicators for the three components which include a control computer, locator and actuator (Chopra *et al*., 2008; Yuan *et al*., 2010; Schumann, 2010).

4. PROCESSES OF PRECISION AGRICULTURE

This is divided into two parts which include:

i. ***Identification and Assessment of Variable components***: This is further broken down into the following segments:

a. Grid soil sampling: Grid soil sampling uses the same principles of soil sampling but increases the intensity of sampling compared to the traditional sampling. Soil samples collected in a systematic grid also have location information that allows the data to be mapped (Morvan *et al*., 2008). The goal of grid soil sampling is to generate a map of nutrient/water requirement, called an application map.

b. Yield map: Yield mapping is the first step to determine the precise locations of the highest and lowest yield areas of the field, and to analyze the factors causing yield variation (van Ittersum *et al*., 2013). One way to determine yields map is to take samples from the land in a 100m x 100m grid pattern to test for nutrient levels, acidity and other factors (Mandal and Maity, 2013). The results can then be combined with the yield map more effective yet more economical placement that produces higher crop yields (Lobell *et al*., 2009). Researchers at Kyoto University recently developed a two-row rice harvester for determining yields on a micro-plot basis (Dixit *et al*. 2014).

c. Crop scouting: In-season observations of crop conditions like weed patches (weed type and intensity); insect or fungal infestation (species and concentrations) crop tissue nutrient status; also can be helpful later when explaining variations in yield maps (Huseth *et al.* 2018).

d. Use of precision technologies for assessing variability: Faster and in real time assessment of variability is possible only through advanced tools of precision agriculture (Zhang and Kovacs, 2012).

ii. ***Variability Management***: The management processes of precision agriculture include:

a. Application rate: Grid soil samples are analysed in the laboratory, and an interpretation of crop input (nutrient/water) needs is made for each soil sample. Then the input application map is plotted using the entire set of soil samples. The input application map is loaded into a computer mounted on a variable-rate input applicator. The machine uses the input application map and a GPS receiver to direct a product-delivery controller that changes the amount and kind of input (fertiliser/water) according to the application map.

b. Yield monitoring and mapping: Yield measurements are essential for making sound management decisions. However, soil, landscape and other environmental factors should also be weighed when interpreting a yield map. Appropriately used, yield information provides essential feedback in determining the effects of managed inputs such as fertiliser amendments, seed, pesticides and cultural practices including tillage and irrigation. Since yield measurements from a single year may be heavily influenced by weather, it is always advisable to examine yield data of several years including data from extreme weather years that helps in pinpointing whether the observed yields are due to management or climate-induced.

c. Quantifying on-farm variability: Every farm presents a unique management scheme. Not all the tools described above will help determine the causes of variability in a field, and it would be cost-prohibitive to implement all of them immediately. An incremental approach is a wiser strategy, using one or two of the tools at a time and carefully evaluating the results and then proceeding further.

d. Flexibility: Small-scale farmers often have highly detailed knowledge of their lands based on personal observations and could already be modifying their management accordingly. Appropriate technologies here might make this task more accessible or more efficient. Larger farmers may find the more advanced technologies necessary to collect and properly analyse data for better management decisions (Baumgart-Getz *et al*. 2012).

5. Benefits of Precision Agriculture (PA)

Precision agriculture within farmland can be managed using different levels of inputs depending on the yield potential of the crop in that particular area of land. Wang *et al.,* (2006) stated that the benefits of precision farming are in two folds:

i. Reduction in the cost of producing a given crop in an area of land and

ii. the risk of environmental pollution from agrochemicals applied at levels higher than those required by the plant can be reduced.

The following are some of the benefits of PA to the farmers:

i. Efficient use of equipment: Information on soil characteristics and weather can be used to plan and improve scheduling of operations, which can increase machinery utilisation rates and lower per- acre costs. Also, GPS based guidance systems can allow farm machinery operators to achieve greater field efficiency under challenging conditions. They can reduce overlap and missed applications of inputs (e.g. spraying), helping fatigued operators maintain higher field efficiency.

ii. Risk reduction: At the field level, PA provides site-specific management that can point out problems with growing conditions, thereby reducing variability in net returns. At the farm level, PA information can be used to improve variety choice, crop rotation, and other agronomic practices that minimise risk. As well, information on crop growth during the season can help you make more informed market decisions.

iii. Management of different products: In the future, precision technology may help farmers differentiate their production within a particular field. For example, you might segregate higher protein wheat for marketing in more rewarding channels. Also, PA technology will allow the additional control that is required when you are managing the production of differentiated products as opposed to the output of regular bulk crops. It will allow documentation of crops conditions and control of inputs to meet the particular requirements of these crops.

Farmers are constantly making important decisions that impact their business success. PA uses a continuous cycle of data collection, data analysis and application to maximise farm profits and protect the environment by managing land and livestock changes over time. The data collection process identifies areas of interest and records the required data. The data analysis process organises, queries and reports on the collected data. The farmer can make effective decisions based on the reports generated (Hochman *et al*. 2009).

iv. Increased farm profitability is an essential benefit of PA for farmers. Some researchers Reviewed some studies of Precision Agriculture published between 1988 and 2005 and found PA to be profitable for 68% of the cases studied (Stoate *et al*., 2009; Ahumada and Villalobos, 2009; Crosson *et al*., 2011; Zhang and Kovacs, 2012). Arable farmers have traditionally used a whole field approach when planting seeds, applying fertiliser and spraying pesticides. PA allows the arable farmer to break a field down into smaller management zones based on crop yield rates and crop production factors such as pest presence, soil types and soil acidity levels. Farmers can use the knowledge gained from management zones to develop management plans and implement processes that ensure the best use of resources to maximise output and profits (Shiferaw *et al*., 2009).

v. Dairy farmers can use PA applications to enhance profitability by monitoring only livestock and making interventions at the right time to optimise outcomes. Sensors can record critical aspects of livestock fertility and alert farmers when an animal is ready to reproduce. Dairy farmers can maximise the number of calves, produce more milk, save time and reduce artificial insemination costs by monitoring their livestock (Hamadani and Khan, 2015).

vi. Time and labour savings are achieved through the automation of repetitive farming tasks. In the dairy sector, robotic milking can record valuable data on milking performance, save time for farmers, reduce the need for external labour, encourage greater production, better animal health and higher quality milk. Auto-steer systems on tractors and harvesters can reduce driver fatigue by automating the navigation of fields with satellite positioning. Automated feeding systems can provide livestock with feed at regular intervals and reduce the workload for farmers. Animals are less stressed with automatic feeding, and lower ranking animals have more access to feed (Grothmann *et al*. 2010).

vii. PA applications can continuously monitor animal health in real-time and alert farmers when intervention is required. Sensors can monitor livestock and their environment to detect changes in livestock positioning, feeding patterns, temperature, humidity and sounds. Pig farmers can monitor the health of their herds by reviewing the sounds produced by the crowd. Early detection of coughing sounds can reduce disease transmission in the group and save money on antibiotic purchases and veterinary fees. Feeding patterns can be monitored for individual animals, and farmers can be alerted when particular animals are eating or drinking less (Banhazi and Black, 2009).

6. APPLICATIONS OF PRECISION AGRICULTURE

Agricultural farmlands are of diverse environments with variable topology and microclimates. Crops grow and produce at different rates depending on factors such as soil quality, access to water and nutrients, altitude and temperature. PA applications are used to increase quality, record production levels, generate yield maps and identify zones requiring additional irrigation or fertiliser (Hochman *et al*., 2013). Drones and satellite imagery are used to analyse the health of the crops using Normalised Difference Vegetation Index (NDVI) to identify areas that require attention. The NDVI uses the visible and near-infrared bands of multispectral imagery to display plant health information. Nutrients are applied to specific areas using the analysed data to reduce water usage and the cost of fertilisers.

Arable farmers in developed countries use high precision positioning systems such as the Variable-Rate Technologies (VRT) and Controlled Traffic Farming (CTF) to drive efficiencies for crop production and protect the environment (Pedersen and Lind, 2017). High precision positioning systems enable the accurate positioning of a farmer's tractor in a field and facilitate the precise seeding of crops, higher planting density and the efficient application of pesticides, nutrients and herbicides. VRT allows farmers to vary the use of fertiliser on specific areas of the field according to the needs of the crop. CTF enables farm vehicles to accurately navigate fields which result in reduced operator fatigue and minimised crop damage (Kroulík *et al*., 2011). Tractors and combine harvesters are large vehicles with the capacity to damage crops with poor operator direction (Shearer *et al*., 2010).

Livestock farmers are using Precision Livestock Farming (PLF) to monitor their herds and environment, detect diseases at an early stage, record growth, food intake and milk production (Meen *et al*. 2015). Farmers can review the variation in performance within their herd and make the necessary input changes to achieve optimal results. Alerts can be set up to notify a farmer when a cow is going to calve. Time savings and better outcomes are obtained by applying technology to herd management (Sarac *et al*. 2010). Horticulture farmers are using machine vision methods to record the size, shape, colour, visible defects, sugar content and acidity of their products (Kondo, 2010).

PA is used in forestry to monitor growth, produce biomass estimates, identify diseased or infested trees, classify different species of trees and determine areas ready for harvesting. Remote sensing imagery captured by satellites and drones are analysed in geospatial systems at regular intervals to produce data that drives planning and decision making (Matase *et al*. 2015). NDVI maps can be used to identify tree health in specific areas. Harvesting machines fitted with high precision positioning systems can record their location and harvesting yields to ensure that a forest is managed appropriately (Suprem *et al*., 2013).

Real-time information from PA applications will lead to changes in the monitoring and trading of crops. Government agencies and the financial markets will be aware of crop yields during the growing season rather than at the end of the season. The pricing for crop markets will become more dynamic with fluctuations occurring as data is received during the growing season (Verchot *et al*., 2007; Peltonen-Sainio *et al*., 2010). Government agencies will be able to forecast crop yields more accurately with the increased volumes of crop performance data (Challinor, 2009; Lin, 2011).

7. REQUIREMENTS FOR IMPLEMENTING PRECISION AGRICULTURE

Key components that can improve the implementation of PA amongst most farmers includes scalability, low cost, support, integration and interoperability with the utilisation of open data standards, rule-based workflows, automated and intuitive data processing methods, user control over analysis and processing functions, systems customised to meet farmer needs and an easy to user interface (Janssen *et al*. 2015). Farmers need systems that can grow over time as more PA applications come to bear. Low-cost systems are required as farmers are not willing to take a risk on expensive applications that may not deliver the expected benefits. Farmers need systems and applications with interfaces that integrate with legacy, current and future operations.

Farming is a diverse industry, and PA applications must be customised to suit the particular needs of the farmer. Specific modules of PA applications can be supplied to the farmers based on their requirements. Rule-based workflows allow farmers to deploy their business knowledge into a PA application. Effective communication is ensured as regards standards and operability of the various forms of technologies. Usability and automated data processing methods help the farmer manage the large volume of data generated by PA applications (Lee *et al.,* 2014; Fountas *et al*., 2015).

The educational status of the farmers as regards PA has in the recent times been emphasised to enable them to understand the potential benefits of the PA technologies and practices (Fountas *et al*., 2015). There are six learning processes which has been identified for stakeholders to improve their agronomic knowledge, information management skills and understanding of PA. These processes include the experience of the idea of spatial data management, spatial variability and maps; the second is that the stakeholders gain an understanding of sensors and how sensors can be used for benefit in farming. Such systems that use sensors were described as GPS, Yield Monitoring Systems, Remote Sensing and VRT systems. The relevant stakeholders are thought IT skills at appropriate levels and become familiar with GIS technology. The fourth step for the stakeholders is the creation of awareness as regards the factors that enable the identification of flexible yield influence elements (Akhtar- Schuster *et al*., 2011). Here, they learn how to analyse yield maps, yield variation patterns and understand the difference between natural and management-induced variation. The final step shows stakeholders how to carry out strategic sampling and on-farm trials to test PA technologies and practices on their farms (Kutter *et al*., 2011; Mariano *et al*., 2012; Eastwood *et al*. 2012).

8. THE ADOPTION OF PRECISION AGRICULTURE

With the adoption of new technologies and its practice, agriculture develops rapidly to meet the competitive demand for its products (Hatanaka *et al*. 2005). The rate and diffusion of PA technology adoption determine the impact on farm production levels. Factors such as the farmer profile, farm type, economic conditions, complexity and cost of the technology influence the diffusion and speed of PA adoption (Aubert *et al*. 2012). Farmers go through a five-stage decision-making process when adopting PA technologies. In the Knowledge stage, the farmer learns about the new technology and its applications. At the Persuasion stage, the farmer develops an opinion on the latest technology. The farmer chooses to adopt the innovation at the Decision stage. The Implementation stage is where the farmer puts the technology into use on their farm. The Confirmation stage is the final stage where the farmer seeks to validate the decision to adopt the technology (Mackrell *et al*. 2009).

Five significant stages of adoption of agricultural technology were identified as the innovators, the early adopters, the old majority, the late majority and the laggards (Läpple and Van Rensburg, 2011). The innovators are adventurous farmers who discover new techniques and pay a premium to evaluate the technologies. Innovators are a small but essential part of a market. Early adopters are influential leaders who observe the innovators' findings and find practical usages for the new technology. They communicate the benefits of the technology to a broader audience. The early majority adopt technologies when they are confident that the product will be useful on their farm and there will be a good return on their investment. The late majority are doubtful of new technology and wait until the technology has achieved widespread adoption before deciding to invest. The laggards are happy to continue farming in the old way and adopt new technologies reluctantly.

PA has not achieved widespread adoption in Nigeria due to high start-up costs, complexity, stakeholder awareness and training, data management issues and the size and diversity of farm structures. The average Nigerian farm is less than 4 hectares, and many farmers cannot afford large investments in technology products. Nigeria with its large arable regions and intensive farming have higher prospects of PA usage (Seck *et al*. 2012). Limited research and investment are on-going to develop PA in Nigeria to ensure higher adoption rates going forward.

9. FACTORS INFLUENCING THE ADOPTION OF PRECISION AGRICULTURE

Research shows the primary driver of PA adoption to be increased profitability and cost to be the primary barrier to PA adoption (Aubert *et al*. 2012). Secondary adoption drivers were environmental compliance, availability of improved information for better decision making and risk reduction. Nigerian farmers have expressed frustration that PA was not a "turn-key" technology as there are many complex interactions to be interpreted to derive the benefits from PA. Current research works should focus on low cost, robust and easy to use PA technology to drive increased adoption (Tey and Brindal, 2012). In their study, they studied the adoption factors for PA and classified the elements found into seven categories; socioeconomic factors, agro-ecological factors, institutional factors, information factors, perception factors, behavioural factors and technological factors. Socioeconomic factors that influence the adoption of PA were found to be the farmer's age, education, farming experience, attitude to risk, market conditions and access to information. Older farmers are less likely to adopt new technologies that require training and investment. Farmers with higher levels of education are more likely to take PA technologies as they often have a more excellent knowledge of best practice farming practices. The risk associated with every investment and the risk-averse farmer is more likely to continue farming traditionally. Market conditions influence the adoption of PA and farmers are more likely to invest in new PA technologies and equipment when market conditions are stable, and the return on investment is high (Tey and Brindal, 2012).

Agro-ecological factors that influence adoption decisions include farm size, income, land tenure, environmental compliance and crop type. Larger farms with steady incomes are more likely to invest in PA. Farmers who are renting land are unlikely to significantly invest in PA technology due to uncertainty regarding future control of the area. Farmers growing crops planted in rows such as corn, cotton and soybeans were more likely to adopt PA than farmers growing vegetables, fruits and minor crops. Environmental compliance is becoming an increasingly important adoption factor as farmers need to meet strict environmental protection measures.

Institutional factors were found to be government organisations and policies, distance from fertiliser and equipment suppliers and the farm's location. Government organisations have a significant role to play in training and educating farmers on the technologies driving PA and the possible PA applications for their farms. Well informed farmers who understand the benefits of PA are more likely to adopt the technologies. Distance from fertiliser and equipment suppliers is another adoption factor as farmers located far from suppliers will be in less contact with sales personnel that can inform farmers of the availability of new PA equipment and possibly convince the farmer to invest in the latest technologies (Tey and Brindal, 2012).

Information factors included the use of consultants and access to information sources. Farmers who work with consultants receive information on the best practices for their farm and are more likely to adopt PA. Access to information sources such as industry and government publications allows a farmer to keep informed of the latest developments with farming. Perception factors were the farmer's view on the importance of PA and the profitability of PA. The farmer's attitude toward PA is crucial as ultimately the farmer is the decision maker who adopts the appropriate technologies for their farm. A farmer who had a bad experience with early PA technologies may be reluctant to invest in new technologies. Behavioural factors included the farmer's behavioural profile and intentions (Tey and Brindal, 2012).

Technological factors found to be essential adoption influences were the complexity of the PA technology, the type of technology to be adopted, farm irrigation structure and the usage of computers on the farm (Tey and Brindal, 2012). Technologies need to be understandable and usable to achieve widespread adoption by farmers. Many farmers are reluctant to adopt complex technologies due to the time and training required for usage. Farmers with previous experience of working with information technology are more likely to take PA technologies as they are familiar with computers. The type of technology influences adoption decisions as there are varying costs associated with different techniques and some technologies may be more familiar to farmers.

Ex-post adoption factors include the farm size, quality of the farm's soils, farmer income, farmer education, access to information, costs savings, desire for higher profitability, land tenure and IT experience. The typical PA adopter was found to be an educated farmer seeking a competitive advantage through better agricultural practices on their large fertile farm. The primary ex-post driver for PA adoption was found to be farm size. Large farms with over 500 hectares can benefit from economy of scale when adopting PA. A secondary driver was the farmer's confidence with technology. Farmers with good technological skills were found to be more likely to take PA. Other ex-post drivers for PA adoption were a high income, the farm's location and the farmer's education (Kassie *et al*. 2011; Paustian and Theuvsen, 2017).

10. CONCLUSION

The adoption of PA has been constrained by some barriers such as cost, complexity and weak or non-availability of rural broadband infrastructure. The accessibility and speed of rural broadband will need to be improved to enhance internet connectivity between farm systems and external providers. PA applications use remote sensing data to identify crop health and development patterns. Remote sensing data is delivered in large files which require fast broadband connections for effective communication. It can, therefore, be concluded that lack of decision support systems to be a major barrier to the adoption of PA. Farmers need decision support systems that enable effective decision making based on accurate and timely data.

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