Precision Agriculture: Applicability and Opportunities for Nigerian Agriculture

Isioye Olalekan Adekunle

Abstract: Precision Agriculture has evolved from a concept some decades ago into an emerging technology today. The catalyst for the emergence of Precision agriculture has been satellite positioning and navigation. The combination of Global Positioning System (GPS) and mobile mapping provide the agriculturist with a new capability of gathering information for implementing decision-based Precision Agriculture. While adoption of precision farming in wide concept has been modest in Nigeria the potential for using precision agriculture to address environmental, food security and sustainability problems seems not to be attracting political attention in Nigeria conditions. This paper discusses the applicability, opportunities of precision agriculture in Nigeria. It was identified that the small size of farms and fields in most of Nigerian agriculture limits economic gains from currently available precision farming technology. However, the public concerns for the environment and food security may mean that those potential benefits of precision agriculture are beginning to receive attention. Finally it was concluded that it is not impossible to adopt Precision agriculture in Nigeria but research efforts are needed to work out modalities for its adoption in the Nigerian agricultural scenario.

Key words: Precision agriculture • Remote sensing • Global Positioning System (GPS) • Geospatial Information System (GIS) • Mobile mapping

INTRODUCTION

Agriculture is an important occupation in Nigeria with over 70% of her population depending on it directly or indirectly for livelihood. It provides the bulk of employment, income and food for the rapidly growing population as well as supplying raw materials for agro-based industries. World current agricultural production has an average growth rate of 1.8% as compared to the 3% in the 1960s and therefore at a lesser pace than the demographic growth [1].

Nigeria, with a population of 140 million people (provisional result of the 2006 population and housing census), is the most populous country in Africa. Successive governments since national independence in 1960 have introduced a myriad of agricultural development programmes and policies aimed at enhancing agricultural productivity to feed the rapidly expanding population, provide raw materials for the agro-industries and for export income [2] and [3]. However, the agricultural problems in Nigeria and in particular, food insecurity have assumed alarming proportions largely because the rate of growth in the sector has not been commensurate with that of population. The rate of growth of agricultural production in Nigeria should increase appreciably in order to mitigate hunger, starvation, diseases, raw materials dependence on foreign sources and food importation, as well as to improve on the quantity and quality of food per person and the well-being of the farmer and his family. This can be done by increasing agricultural productivity through mechanization and precision farming.

In Nigeria, food security is at the heart of economic and social development priorities. Although the country has been making efforts for many years to stop hunger and alleviate poverty, the threat of food insecurity is still present. Nigeria ranked 20th out of 42 African countries studied on the 2006 Global Hunger Index (GHI); improved to 18th position on the 2009 GHI and 46th out of the 84 developing countries captured globally for the study in 2009 [4].

The need to increase productivity of crops, livestock and fisheries in Nigeria using improved technologies has been identified [4]. The critical analysis of agricultural processes in order to have sustainable agricultural production and also maximize production has
reached advanced stages in the developed countries with the aid of Satellite technologies and Geospatial Information Systems (GIS), which are specially designed computer systems for the proper harnessing, collation, interpretation and analysis of data obtained from these Satellite technologies and from other sources.

To address the problem of misuse of agricultural land and improved productivity in Nigeria, it is necessary to adopt Geoinformatics techniques of Remote Sensing, GIS and Global Positioning System (GPS), which enable the acquisition of relevant and timely data and information on agricultural land and activities. For instance, improvement in remote sensing technology have opened newer possibilities of improving agricultural statistics systems as it offers accelerated, repetitive and spatial-temporal synoptic view in different windows of the electromagnetic spectrum from its vantage point in space [5]. It also has the advantage of wide coverage, provision of permanent record, mapping base, cost-saving and real-time capability [6]. GIS is a potential tool for handling voluminous remotely sensed data and has the capability to support spatial statistical analysis [5] and [6]. GPS is for the determination of accuracy in the location of equipment, soil sampling points, inputs application and adjustment of tillage to suit variability in field conditions, as well as recording yield data across the field [7].

The Satellite Technologies that have over the years impacted sustainable agricultural development and production in the form of improved crop yields are Satellite Remote Sensing and GPS. This agricultural practice that employs the use of the totality of these satellite technologies and GIS is known as “precision farming” or in a more general sense “precision agriculture”.

The objective of this paper was to illustrate the significance of Geoinformatics techniques in agricultural development, examine the situation in Nigeria and consequently make a case for the adoption of Precision Farming techniques in Nigeria.

Overview of Precision Agriculture: Precision agriculture is an agricultural system that has the potential of dramatically changing agriculture in this 21st century. Precision agriculture lends itself to most agricultural applications and can be implemented at whatever levels required. Precision agriculture is based on information technology, which enables the producer to collect information and data for better decision making. Precision agriculture is a pro-active approach that reduces some of the risk and variables common to agriculture. Precision agriculture is more environmentally sound and is an integral part in sustaining natural resources. Precision Agriculture is defined as the technique of applying the right amount of input (fertilizer, pesticide, water etc.) at the right location at the right time to enhance production, decrease input and/or protect the environment [8].

The technology affords the following objectives:

- It allows for the application of fertilizers at variable rates according to variations in fertility levels.
- It allows for the measurement of yield variability in fields.
- It helps to increase yields by reducing variability.
- It allows for soil sample sites to be accurately located within a field and fertility levels mapped.
- It allows for the monitoring of yield as compared to soil test results.
- It accurately pinpoints accurately location of significant soil variability.

Elements of Precision Agriculture: Precision farming basically depends on measurement and understanding of variability, the main components of precision farming system must address the variability. Precision farming technology is information based and decision focused, the components include, (the enabling technologies) Remote Sensing (RS), GIS, GPS, Soil Testing, Yield Monitors and Variable Rate Technology.

Precision farming requires the requisition, management, analysis and output of large amount of spatial and temporal data. Precision farming is concerned with spatial and temporal variability and it is information based and decision focused, it is the spatial analysis capabilities of GIS that enable precision agriculture. GPS has greatly enabled precision farming and is of great importance to precision farming, particularly for guidance and digital evaluation. Modelling position accuracies at the centimetre level are possible in DGPS receivers. Accurate guidance and navigation systems will allow for farming operations at height and under unfavourable weather conditions.

In Nigeria, all these technologies are available and they can be implemented through agricultural training centres by giving training to agriculture officers in these technologies.
Processes of Precision Farming: The processes of Precision Farming include field data collection, Data Analysis and Decision Making and data management.

Field Data Collection: The initial processes of site characterization and site selection for precision farming will be achieved with the aid of Satellite Remote Sensing, which will provide invaluable data about soil, environment and traditional land use and practices. These data, which include topography, slope and aspect, hydrology and drainage systems, landuse types and boundaries, prevailing weather and climatic conditions and soon, now form part of the basic inputs for the GIS, which will help in management of database which consists of many layers of spatial data, each of which has precise control of ground position in the fields. Along with satellite data contained in the GIS, other layers to be incorporated are physically measured inputs such as water content, particle size distribution and rooting volume. While some of these inputs will be interpreted from soil maps, conventional soil survey maps are not accurate enough for precision farming, thus there is a need for intensive soil sampling and soil map generation for each field. Layers with chemical inputs will be nutrient levels, cat-ion exchange capacity, pH, salinity, pollution potential and plant tissue element levels will also be collected. Measured biological data that will be included as layers will be yield quantity; yield quality, disease distribution, insect distribution, crop distribution and organic matter content.

Data Analysis and Decision Making: Data manipulation will include rectification functions to correct the geometry of the digital image data, such as scanned satellite images and digital images. To aid image interpretation, both spatial and spectral enhancements will be performed. Classification of the digital images, using statistical classifiers, in both supervised and unsupervised modes provides information on crop or insect infestations, soil types, vegetation types and plant stress may be implemented with aid of GIS Visualization of images, including multiple image display, will provide a well defined and appropriate tool for management of farm input resources. Using GIS analytical functions such as Boolean Overlay, Cluster analysis, Clumping functions, Reclassification, Indexing and Spatial searching, new data layers may be created, which will show areas of the farms that need attention. With the aid of GIS modelling capability an expert system will be developed and customized to suit site’s specific needs. This will help to make decisions concerning application of inputs and its effects on yields. Development of spatial models will allow for production of maps of fertility and pests, which will be used to implement Variable Rate Technology (VRT) applications. The models include raster, vector and tabular data, as well as scalars, matrices and a variety of analytical functions from simple arithmetic to principal components.

The GIS modelling functions will be use to develop pollution models and would be integrated with the GIS data layers. Identifying the precise positioning of the data layers will allow study area to determine locational coincidence among the yield rates and the various fertility and pest-control inputs. The locational coincidence will then be used to create maps, which will guide VRT applications to enhance production and reduce investment.

One of the major advantages of this technology is that the process is cyclic, inputs and yield measurements resulting in VRT, using the yield maps from one crop season as input while the fertilizer, pesticide, herbicide and soil fertility from the GIS will be used to predict required inputs to increase yields for the next crop season. The potential benefit of the integration of these technologies is to improve agricultural production while simultaneously reducing environmental degradation. This is one of the greatest contributions of GIS technology to human population.

Data Management: GIS provides the capability to integrate diverse datasets and precision farming requires data of many different types from the different sources. Data management is needed to ensure compatibility of the various data sources and this will concentrate on four data aspects: Control, Sampling, Resolution and Generalization.

Control: Because location in the field is the key to precision farming data management, each collected data set is precisely registered to a standard set of control. The approach is to establish Ground Control Points (GCPs) within each field and to use these GCPs to establish the locational coordinates for each data layer gathered. The GCPs will be established by precise Differential Global Positional Systems (DGPS) techniques to a horizontal and vertical accuracy of 0.1m. A minimum number of GCPs will be determined based on field size and shape with an absolute minimum of four points. The GCPs will be targeted to appear in all satellite images.
Sampling: Once established, the GCPs will be used to collect precise data, which will be introduced into the common GIS database. While the GCPs account for locational correspondence among data layers, other factors such as precision of the collected data and variable types and rates of data can introduce inaccuracy. To facilitate management, standard sampling methods will be developed to ensure that point data collected for one layer can be effectively combined with point data from another layer.

Interpolation is critical but only produces results adequate for overlay in a GIS of the original samples. For data requiring random samples over a field, a procedure called systematic stratified unaligned random sampling will be used. This procedure has been demonstrated to maintain systematic coverage of a target area while providing randomness in sub areas, allowing statistical testing to be used.

Resolution: The resolution of data collection for different data types is established to facilitate data management and analysis. Ultimately, the resolution is a product of the crop being managed, but various types require different scales of analysis. For example, insect pests may cause crop damage with small infestations while, to cause equivalent damage, weed pests or soil infertility may need to cover much larger areas. Collecting the data at the appropriate resolution facilitates use in the GIS in which all data layers are eventually reconciled to a common resolution.

Generalization: Many of the data layers will be collected on a grid or raster pattern. These datasets are directly used in raster-based GIS software requiring only re-sampling to a common raster cell size. The layers will be maintained in their initial form for manipulation and analysis. Other data, such as point samples, will be entered directly in vector-based GIS software and interpolated to provide correspondence with the raster data model.

While interpolated data will be used in some analysis and presentation procedures, the original points will be maintained in the GIS databases. Data collected as lines of attribute or response values, such as yield rates, also require interpolation to yield raster cells matching the other datasets. Any data collected by interpretation of aerial photographs will require digitizing and processing to convert to a raster format.

In essence, all datasets undergo transformation to support analysis in a GIS in raster or vector formats and conversion between the forms is essential.

Precision Agriculture in the Nigerian Scenario: The first thing that comes to mind is that, this system is not for developing countries, especially Nigeria, where the farmers are poor, farming is mostly subsistent and the land holding size is small. However, this is far from the truth as this approach has a large potential for improving the agricultural production in developing world. Imagine this situation where a farmer goes to his field with a GPS-guided tractor. The GPS senses the exact location of the tractor within the field. It sends signals to the computer fixed on to the tractor, which has a GIS, storing the soil nutrient requirement map in it. The GIS, in consultation with a Decision Support System would decide what the exact requirement of fertilisers for that location is. It then commands a variable rate fertiliser applicator, which is again attached with the tractor, to apply the exact dosage at the precise location of farm. Hence, this is what precision farming means to large growers in the highly developed parts of the globe.

To make it clearer, Precision Farming is the system of matching of resource application and agronomic practices with soil attributes and crop requirements since they vary across a field. It therefore, implies that precision farming can be adopted and practiced at the level of technological advancement of a country.

Increased efficiency in management systems is a key aspect of precision farming, especially in smallholder systems where funds to buy large amounts of external inputs are often in short supply. The approach carries many clear messages with emphasis on efficient fertilizer usage. Smallholders should also try to determine the type of system required and manage it as specifically as possible. It is worth stressing the fact that smallholders often do not need equipment. They know the variability of their soil very well, they observe crop variability and they can manage their fields on a site-specific basis even if they rely on manual labour and do not make major investments.

Agricultural research institutions in Nigeria must work more closely with their counterparts in and outside the country, to develop technology transfer initiatives and with policy-makers in their own countries, to convince them of the value of what they do and to advocate for policies that help farmers make use of the best available technologies and management strategies to increase crop yields.

Today in Nigeria, we have over 15 national agricultural research institutes conducting applied research in agriculture and related activities, more than 30 universities training specialists in various fields of agriculture and carrying out basic research, also more
than 50 colleges of agriculture and polytechnics training middle level manpower in the different fields of agriculture, agricultural productivity. This represents a great potential for agricultural research in the country. There is, therefore the need for researchers to use improved technologies within our reach, which offer a wide range of applications in order to effectively harness human, natural and man-made resources for sustainable agricultural production and improved crop yields in Nigeria.

Although there have been researches into the development of improved, hybrid crop species through the various specialized research centers in the country, such as the International Institute of Tropical Agriculture (IITA), Cocoa Research Institute of Nigeria (CRIN) etc, very little have been done in terms of transferring their research findings into agricultural realities, which should transmute into food security for the country.

Furthermore, the existence of the National Fertilizer Company (NAFCON) and other fertilizer manufacturing companies are meant to improve agricultural practices and subsequent agricultural yields for which they were established. The applications of these fertilizers have, on the contrary caused soil and environmental depletion and degradation, which have in turn led to decreased agricultural yields. This is due to the fact that the applicants of these fertilizers and chemicals have applied them inappropriately because of the lack of basic and adequate knowledge of the soil compositions and environmental constituents.

Precision farming, though in many cases a proven technology is still mostly restricted to developed (American and European) countries. Except for a few, there is not much literature to show the scope of its implementation in Nigeria. There are many obstacles to adoption of precision farming in developing countries in general and Nigeria in particular. Some are common to those in other regions but the others which are specific to Nigerian conditions are as follows.

- Small farm size
- Heterogeneity of cropping systems and market imperfections
- Land ownership, infrastructure and institutional constraints
- Lack of local technical expertise
- Knowledge and technical gaps
- Data availability, quality and costs

**Opportunities for Precision Agriculture in Nigeria:** Despite the many obstacles listed earlier, business opportunities for precision farming technologies including GIS, GPS, RS and yield monitor systems are immense in many developing countries. The scope for funding new hardware, software and consulting industries related to precision agriculture is gradually widening. In Japan, the market in the next 5 years is estimated at about US $ 100 billion for GIS and about US $ 50 billion for GPS and RS [9].

Precision farming is useful in many situations in developing countries like Nigeria. Rice, wheat, sugar beet, onion, potato and cotton among the field crops and apple, grape, tea, coffee and oil palm among horticultural crops are perhaps the most relevant. Some have a very high value per acre, making excellent cases for site-specific management. For all these crops, yield mapping is the first step to determine the precise locations of the highest and lowest yield areas of the field. Researchers at Kyoto University recently developed a two-row rice harvester for determining yields on a micro plot basis [10].

In Nigeria precision technologies can help growers in scheduling irrigation more profitably by varying the timing, amounts and placement of water. For example, drip irrigation; coupled with information from remotely sensed stress conditions (e.g., canopy temperature) can increase the effective use of applied water there by, reducing runoff and deep percolation considerably.

Pests and diseases cause huge losses to Nigerian crops. If remote sensing can help in detecting small problem areas caused by pathogens, timing of applications of fungicides can be optimized. Recent studies in Japan show that pre-visual crop stress or incipient crop damage can be detected using radio-controlled aircraft and near-infrared narrow-band sensors. Likewise, airborne video data and GIS have been shown to effectively detect and map black fly infestations in citrus orchards, making it possible to achieve precision in pest control. Perennial weeds, which are usually position-specific and grow in concentrated areas, are also a major problem in developing countries [11]. Remote sensing combined with GIS and GPS can help in site-specific weed management. Although comprehensive cost-benefit analysis has not been done yet, the possible use of precision technologies in managing the environmental side effects of farming and reducing pollution is appealing.
In so far as dairy farming in Nigeria is concerned, precision farming techniques can help in improving efficiency of methods, timing and rate of application of animal wastes leading to high application efficiency and low environmental pollution. While considering soil and climatic conditions. For instance, factors determining the risk of Nitrate (NO$_3^-$) leaching, release of Nitrous Oxide (NO$_2$) through denitrification and contamination of surface and ground water by runoff can be mapped and analysed. Likewise, poorly managed areas in grass lands can be identified and the optimum period for cutting on a plot basis determined. Nutrient stress management is another area where precision farming can help Nigerian farmers. Most cultivated soils in Nigeria have high spatial variation in PH. Detecting nutrient stresses using remote sensing and combining data in a GIS can help in site-specific applications of fertilizers and soil amendments such as lime, manure, compost, gypsum and sulphur. This in turn would increase fertilizer use efficiency and reduce nutrient losses.

**Strategies for the Implementation of Precision Agriculture in Nigeria:** Precision farming is still only a concept in many developing countries and strategic support from the public and private sectors is essential to promote its rapid adoption. Successful adoption, however, comprises at least three phases including exploration, analysis and execution. Data on crop yield, soil variables, weather and other characteristics are collected and mapped in the exploratory stage, which is important for increasing the awareness among farmers of long term benefits. The approaches to data collection and mapping must, therefore, reflect local needs and resources.

In the analysis stage, factors limiting the potential yield in various areas within a field and their interrelationships are examined using GIS-based statistical modelling. Quantitatively important yield variation may occur over distances as short as 10m [12], however, only some factors such as soil structure, water status, pH, nutrient levels, weeds, pests and diseases can be controlled but not the others (soil texture, weather, topography). After determining the significance of each source of variability to profitability of a particular crop and relative importance of each controllable factor, management actions can be prioritized. It must be remembered that in some low yielding areas, the reason for poor yields may be the lack of sufficient soil nutrients in the first place. In such cases, application beyond just replenishment is necessary.

Lastly, execution phase includes variable application of inputs or cultural operations in most developing countries. However, it is not always necessary and/or possible to use variable rate applicators. Efforts must, therefore, initially focus on limiting indiscriminate use of inputs in conventional methods. Once the economic and environmental benefits are known widely, variable rate technology would be rapidly implemented at least in high value crops.

To spur adoption of precision farming methods in Nigeria, pilot demonstration projects must be conducted at various growers’ locations by involving farmers in all stages of the project. The pilot projects must attempt to answer the grower’s needs and emphasize the operational implementation of technology and complete analysis of the costs and savings involved. Documentation of pilot projects would help in examining the operational weaknesses and identification of remedial measures. The projects can be used to train innovative farmers and early adopters, expose the neighbouring non-participating farmers to the new technologies and show the usefulness of the technology for short and long-term management.

The role of agricultural input suppliers, extension advisors and consultants in the spread of these technologies is vital. For instance, public agencies should consider supplying free data such as remotely sensed imagery to the Universities and Research institutes involved in precision farming research. Also, professional societies of agronomy, agricultural informatics and engineering must provide training guidance in the use of technologies. The involvement of inter-disciplinary teams is essential in this. Small farm size will not be a major constraint, if the technologies are available through consulting, custom and rental services.

The role of agricultural cooperatives is important in dissemination of precision farming technologies to small farmers. If precision farming is considered as a series of discrete services: map generation, targeted scouting, it is possible to fit these services within the structure of a progressive agricultural cooperative in Nigeria. Changes in agricultural policies are also necessary to promote the adoption of precision farming. There are basically two policy approaches: regulatory policies and market based policies. The former refer to environmental regulations on the use of farm inputs and later refer to taxes and financial incentives aimed at encouraging growers to efficiently use farm inputs. In most developing countries like Nigeria the lack of penalties for pollution generation has partly contributed to an excessive use of inputs.
In most developing countries, the pollution effects of agriculture have been largely ignored so far because of inability to effectively monitor such effects. The advent of precision farming and the computerization of input and output flows now enable such monitoring. Higher taxes on pollution farms are often recommended, but there is strong opposition to the implementation of the polluter-pays-principle concept in most countries including Nigeria. When the price elasticity of input use is low and the input costs are only a small part of the total production expenditure, as in the case of fertilizers and pesticides. Very high taxes are required to reduce their use adequately. Given the unfeasibility of such high taxes, a hybrid policy may be implemented for controlling pollution.

At the research level, many issues remain to be resolved. Although some progress has been made at the National Agricultural Extension and Research Liaison Services (NAERLS) and the National Programme on Agriculture and food Security (NPAFS) towards an annual agricultural performance survey in Nigeria [13], it is planned that from 2011 all annual agricultural performance survey will be done in GIS platform, creating large agricultural geo-databases for the country.

The development of standards for the hardware and software (image transfer formats and GPS transfer formats, map projection formats) is another issue. Crop models and decision support systems must be improved by considering local resources. Data for calibration of models must be made available to increase their accuracy and/or predictability.

The ability to finance a creative information venture in agriculture will affect the speed of diffusion of precision farming technologies. Commercial banks, as well as other sources of funding, have to be educated regarding the potential of precision farming. In many developing countries, it may be worthwhile to develop programmes of subsidized credit to encourage precision farming.

The implementation of precision farming in Nigeria should have two different strategies—one for the low input subsistent agriculture and the other for input intensive profit making agriculture. In case of the former the increase in productivity is the prime concern. Here, the system has to be converted to information based agriculture, where farmer has spatial information about the soil and crop. This information can be used for efficient input application. Since the field sizes are small in this situation, individually bounded field or a group of fields can be considered as a unit for variable rate application. However, for the latter case, the field sizes are large and the farmers are rich, input for farming is high and thereby causing ecological imbalances in many places. Thus the input use efficiency is the prime concern here, apart from enhancing the productivity. Here, remote-sensing data can be used to identify the spatial and temporal variability and necessary actions can be adopted using sophisticated instruments like variable rate applicators. This situation will also benefit from GIS based Decision Support Systems for better management of agriculture.

Concluding Remarks: Precision farming in many developing countries including Nigeria is in its infancy but there are numerous opportunities for its adoption. We believe that progressive Nigerian farmers, with guidance from the public and private sectors and agricultural associations, will adopt it in a limited scale as the technology shows potential for raising yields and economic returns on fields with significant variability and for minimizing environmental degradation. The support from governments and the private sector during the initial stages of adoption is, therefore vital. It must be remembered that not all elements of precision farming are relevant for each and every farm. For instance, introduction of variable rate applicators is not always necessary. Likewise, not all farms are suitable to implement precision farming. Some growers are likely to adopt it partially, adopting certain elements but not others. Precision farming cannot be convincing if only environmental benefits are emphasized. On the other hand, its adoption would be improved if it can be shown to reduce the risk. We must be cautious, however, not to oversell the technologies without providing adequate product support. The adoption of precision farming also depends on product reliability, the support provided by manufacturers and the ability to show the benefits. Effective coordination among the public and private sectors and growers is, therefore, essential for implementing new strategies to achieve fruitful success.

Finally, it must be noted that boosting agricultural research in the developing world is the key to ensuring food security. This could only be achieved if agriculture is led by a viable, innovative and productive research system in the country. With nearly a billion people suffering from chronic hunger, global food security
remains a major concern, despite being a key goal of the UN Millennium Development Goals (MDGs). The government must accord high priority to agriculture research and development to meet the challenges of food security, poverty reduction, improve quality of life for rural masses and export competitiveness in the global markets.

Government must provide the necessary incentive structure to the agricultural scientists to exploit their creative potential to the well-being of the Nigerian people in order to achieve growth in the agriculture sector with emphasis on high value agriculture, improved productivity, profitability and exports.

There is urgent need for continuous capacity building to take advantage of cutting-edge agricultural technologies, such as Precision Farming, which have the potential to increase crop yields without unduly stressing the environment. The capacity building must be programmed in such a way to bridge the gap, which delays the transfer of technologies to the developing world and the gap between developing world research communities and farmers working in the field.

REFERENCES