Precision Farming and Fertilizer Recommendation Using Geographic Information System (GIS): A Review

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Abstract
One of the greatest challenges facing farmers is the lack of adequate knowledge of nutrient management aside other agronomic, environmental, and socio-economic issues, resulting in the production of food so insufficient to meet the demand of an ever-increasing population. This challenge has been compounded in recent years by failure of growers to debunk traditional methodologies and embrace scientific researches and innovations. Precision Agriculture (PA) is an emerging technology which has the potential to improve soil fertility management. In traditional agriculture, growers apply the same rate of fertilizers in each field at prescribed times and frequencies, that is, engaging general recommendations for a cultivar or a region. In Precision Agriculture, the agricultural management is tailored to the variability of conditions found in each field and / or within a field. Precision farming implies the use of data and technology-based approach such as Geographic Information System (GIS), Global Positioning System (GPS), and Remote Sensing (RS), to provide better management of natural resources (nutrients, water, herbicides etc) that leads to higher potential of increasing yields and economic returns in agricultural production (Profits). The objective of this review study was to create awareness of the new normal in the management of soil nutrients, and in specific terms, help readers learn about the use of GIS, GPS and RS for fertilizer recommendation and possibly adopt this data and technology approach, with the overall aim of ensuring optimum returns from investment in agricultural inputs.

Keywords: *Precision farming, Fertilizer Application, GIS, Variable-Rate Technology, Data.*

Introduction

With the world's population rapidly growing, the need to find new ways of feeding everyone has become more important than ever before and with global hunger on the rise. Again, FAO (Food and Agriculture organization of the United Nations) has estimated that about 795 million people is undernourished as a result of food insecurity. The vast majority of them (780 million people) live in the developing regions, notably in Africa and Asia [1]. Food production within the developing world therefore, will need to double. Without technology, curbing this menace will be no mean task for producers. According to Matthew [2] producing enough food for the world's population by the year 2050 is a challenge that Farmers and producers will face head on and overcome. This challenge necessitated the development of a GIS-based software package that can be used to help farmers select fertilizer application rates in order to manage soil nutrients, which is a primer for food production. The ease of integration and programming in current digital spatial technology, made it feasible to combine a fertilization model with a GIS platform to develop a GIS-based

Fertilizer Decision Support System that can enable farmers determine precise fertilizer recommendations through an interactive computer interface [3].

Every farmer knows there are differences in soil conditions within a field. This is why some parts of a crop field may give better yield, while the other patches give very little yield, while even when there is uniform application of fertilizer across the field. This can be due to differences in soil physic-chemical properties, topography and vegetal cover. According to findings by Scott [4], micro-differences in physical, chemical, and biological features of soil will affect fertility and nutrient availability. While slope can affect water retention in soil, biological stress can still vary. Weeds tend to occur in the same spot because they are spread by tubers or seeds. The same pattern can also be seen in soil diseases. Hence, the growing conditions for any crop will not be uniform across a growing area. When farmers do not consider these inherent differences and provide nutrients and treatments uniformly, they are providing too many resources to the good patches and not enough resources to the poor patches. Moreover, by adding fertilizers and treatment chemicals at prescribed rates, they are overusing them and unnecessarily adding to the cost of their operations. The idea that differentiates precision farming from traditional farming methods is Variable-Rate Application (VRA). Inputs are given in amounts needed, where needed, and when needed [4].

Precision Agriculture (PA) is an improved farming system where technologies such as Geographic Information System (GIS), Global Positioning System (GPS), and Remote Sensing (RS) are used to improve agricultural practices. GIS applications enable the storage, management, and analysis of large quantities of spatially distributed data. These data are associated with their respective geographic features. For example, water quality data would be associated with a sampling site, represented by a point. A GIS can manage different data types occupying the same geographic space. For example, a biological control agent and its prey may be distributed in different abundances across a variety of plant types in an experimental plot. Although predator, prey, and plants occupy the same geographic region, they can be mapped as distinct and separate features [5, 6]. With such advancements and with new innovative technologies in the pipeline, we can expect to see a rapid increase in food production in the future. Modern farming will change as we know it [7].

Precision agriculture can improve the quantity and quality of agricultural output while reducing input usage (such as water, energy, fertilizers, and pesticides), thereby generating climate benefits, while also increasing time efficiency by performing farming practices remotely. Reducing the use of inputs such as fertilizers and pesticides offers positive environmental effects. Precision farming uses data received from global positioning systems, satellite and aerial imagery, and sensors (for example, sensors for soil conditions, ground water levels, and precipitation detectors) to enable a range of precision agriculture applications. The information and fertilizer rates map created can guide the actual application of fertilizer in the field in such a way that will optimize fertilizer usage and maximize yield production. In the United States, precision agriculture technologies were used on 30 to 50 percent of corn and soybean acreage in 2010–2012. Impacts on farm profits were positive but small, with adoption more likely on larger farms [8]. As precision agriculture technologies become easier to implement they could help improve incomes on smaller farms [9]

In addition to potential productivity gains and cost savings, precision farming via satellite technology enables governments to study how agricultural practices affect the ecosystem, develop better regulations [3], and enforce sustainable land management practices, as in Uruguay [10]. Even though many high-tech precision tools are more accessible for large-scale farms that can afford significant investments in technology, the situation is changing as access to technologies and their delivery become cheaper and more affordable for smallholders. For example, the International Maize and Wheat Improvement Center (CIMMYT) have been testing variable rate fertilizer application kits for smallholder farmers [11].

With the use of GIS, GPS and RS, growers can:(1) create fertilizer variable map from the crop yield data and foliar analysis, (2) use decision support system to create information from the foliar analysis to develop the foliar nutrient maps, (3) estimate the site-specific fertilizer rate requirements, (4) maximize crop production through yield increase and efficient use of fertilizer inputs.

To be able to apply the VRA method, growers need detailed and spatial data about their farms and different variable-Rate Technology (VRT) at each stage.

Basic Elements: Mapping and Managing

In many respects, satellite-navigation receivers are a foundational technology for precision agriculture and have the most widespread adoption of all precision agriculture technologies. Such receivers typically use signals from the US Global Positioning System (GPS) satellite constellation, together with correction signals from a fixed ground-based transmitter to provide the kind of extremely accurate location information that is important for precision agriculture applications. One of the most common uses of GPS receivers in precision agriculture is generating geo-referenced soil maps. Farmers use handheld GPS receivers to mark the precise within-field locations of soil samples, and then correlate soil samples and GPS coordinates in a geographic information systems (GIS) database. Various technologies and techniques are available for measuring soil properties, including laboratory testing of samples, probes that can measure soil's electrical conductivity (to determine water content), and handheld pH meters (many of which integrate or connect to GPS receivers to produce geo-referenced data without requiring the farmer to input such data separately) [12].

Many sensors can also mount on vehicles to facilitate faster testing in large fields. Remote sensors can also take continuous measurements of soil quality indicators and transmit those measurements for incorporation in a central database. GPS and GIS are also used to measure and map indicators of crop health and vigor, and as with soil sampling, a wide range of sensors and methods can be used to conduct such geo-referenced measurements. For example, handheld and vehicle-mounted sensors are available that can measure the chlorophyll content in crop leaves by measuring the light energy reflected off the leaves. Low chlorophyll content can indicate nutrient deficiency, plant diseases, or other problems. Similar sensors are available for measuring other health indicators including crop temperature (which can indicate water deficiencies), sugar content (to help determine the ripeness of fruit), and insect infestation. Farmers can use geo-referenced monitoring data to support site-specific field management practices that vary the application of crop inputs (seed, fertilizer, and pesticide) based on factors like crop vigor and soil fertility [13].

A common technique for site-specific input management is to break down a field into management zones and then calculate the optimal distribution of inputs within each zone. The zone method is popular because it is relatively easy to use with imprecise application systems that disperse uniform amounts of inputs in a broadcast pattern. Calculating required inputs is typically the job of specialized software that often requires expensive licenses. However, inputs can be calculated manually using formulas, assuming the farmer possesses the requisite knowledge [12].

GIS, GPS and RS can help to create fertilizer variable rates map from existing crop yield data and foliar analysis; estimate the site-specific fertilizer rate requirements; and thus, maximize crop production through yield increase and efficient use of fertilizer inputs. By developing the GIS database of the area, information about the studied field can be efficiently utilized for management, forecasting and planning [7].

Emerging Technologies: Variable-Rate Application and Automated Guidance

One of the most significant developments in integrated precision agriculture systems to occur in the past decade was the introduction of variable-rate application systems for fertilizer, seeds, pesticides, and herbicides. Such systems replace conventional fixed-rate application systems on implements or purpose-specific vehicles. Variable-rate systems can allow a farmer to deliver a targeted dose of crop inputs precisely where they are needed [7, 14].

The most basic variable-rate application systems are controller-operated, meaning that a farmer must manually adjust the system's outputs when the vehicle's navigation system indicates that it is entering a new management zone. Increasingly, variable-rate application systems link directly to a vehicle's onboard GPS/GIS systems and modulate input dispersion rates based on mapping data. The most advanced systems use on-the-go sensing and application technology, in which implement- or tractor-mounted sensor arrays measure crop status indicators dynamically and direct spray nozzles or other variable-rate applicators to deliver appropriate inputs to address problems. For example, an herbicide-spraying implement equipped with on-the-go technology can identify weeds using optical sensors and deliver just enough targeted herbicide to kill each weed using articulated spray heads. On-the-go sensing and application systems can also leverage data from mapping databases to improve accuracy and responsiveness, and the sensors' inputs can, in turn, provide valuable information to update those databases to facilitate future decision support [7, 14].

Farmers frequently pair variable-rate application systems with guidance systems that help keep tractors and implements on course within a field, reducing farmer workload while improving the accuracy of variable-rate application. Even without variable-rate application systems, farmers can find guidance systems helpful in navigating fields and determining crossover points between management zones. The most basic guidance systems supplement a navigation map display with a light bar indicator that assists the farmer to keep the vehicle on a predetermined path as precisely as possible. More advanced systems increasingly incorporate active guidance, including automated tractor steering and a separate guidance and steering system for the implement. Basic automated steering systems keep tractors on a very precise straight-line course through a field, but the farmer still needs to turn the tractor around manually to initiate another field pass. The best current systems can both steer and turn a tractor and can achieve extremely high levels of precision, directing massive farm implements that span dozens of crop rows in repeatable patterns with +/- 1 inch tolerance even over rough or sloping fields [12].

Figure 1: GPS Tracking Systems in Tractors
Source: [7].

Technology has also changed the way in which farmers operate their machinery. Telematics for instance allows communication between the farmer and his machinery. If a breakdown happens to occur for instance, the farmer can simply access the on-board diagnostic system of the tractor and the system can find a solution to the problem. It can even be sorted there and then. GPS systems have also been made current in tractors and combines; as a result these machines can more accurately drive themselves through a field than ever before. The farmer only has to tell the on-board computer system the width of the path that the machine will cover and they must drive a short distance marking two points A and B, The GPS then takes over to do the rest. Guidance has proven to be great for tillage as it reduces human-error that may result from overlap, as well as reducing fuel and labour costs. We can expect to see this technology more widely utilized in the near future [15].

Big data, the Internet of things, drones, and artificial intelligence may catalyse precision farming, requiring fewer agrochemical inputs for existing agricultural processes. Some companies are using novel genetic sequencing, along with machine learning, to detect soil quality and help increase crop quality [16].

Machine learning is being applied to drone and satellite imagery to build detailed weather models that help farmers make more informed decisions to maximize their yield (A number of companies provide satellite imagery solutions based on machine learning and artificial intelligence. Examples include https://www.nervanasys.com/solutions/agriculture/, http://www.descarteslabs.com/;https://pix4d.com/,http://gamaya.com/,http://www.bluerivert.com/, http://prospera.ag/, https://www.tuletechnologies.com/ and http://www.planetaryresources.com.). It is also being used with plant genomic and phenotypic data to predict the performance of new plant hybrids (A number of companies provide satellite imagery solutions based on machine learning and artificial intelligence. See https://www.nervanasys.com/solutions/agriculture/).

Robots are increasingly automating farming through the ecological and economical weeding of row crops. Beyond rural areas, Big data and the Internet of things are enabling urban, indoor and vertical farming, which in some cases can improve agricultural productivity and water efficiency with minimal or negligible need for pesticides, herbicides, and fertilizers. A number of these technologies (sensors, artificial intelligence, imaging, and robotics) can be combined for automated precision farming. Figure 2 shows a typical application of Internet of Things (IOT), robots, and artificial Intelligence to farming.

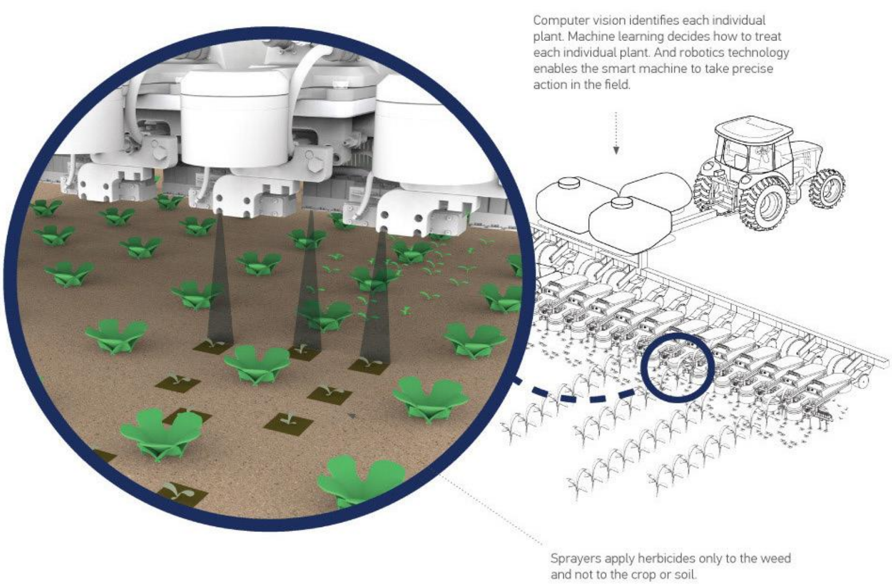

Figure 2: Application of the Internet of things, robotics, and artificial intelligence to farming
Source: [12]

The use of crop sensor technologies (Optical sensing technologies) has the potential to completely transform food production. These smart sensors can read everything from plant health and the water needs of the crop, to nitrogen levels in the soil. The sensors then enable on-the go application of inputs based on real-time field conditions.

Figure 3: Variable rate technology in practice
Source: [7].

These are used to monitor crop health; the process involves measuring light reflectance from the crop that translates into Nitrogen levels. Electronic controllers that are connected to the sensors have the ability to signal fertilizer spreaders to apply the correct amount of nitrogen that may be needed. Variable Rate Technology (VRT) is similar in concept to the two above, It instead provides farmers with a built in prescription GPS map, that identifies what inputs are needed in different areas of the field. By knowing what area of the field is most productive, fertilizer rates can be tailored to increase or decrease at set time in a set place in the field. This technology is hugely beneficial, as it ensures the application rate applied is most effective for that field [17].

Figure 4: use of sensor to adjust fertilizer application
Source: Source: [17].

This high-clearance sprayer makes variable-rate nitrogen applications to corn based on sensor readings- the white camera-like nodules on the outriggers- monitor plant stresses that are frequently related to nitrogen status.

Figure 5: use of Global Positioning System (GPS)
Source: [17].

In Missouri, an agricultural engineer examines corn from this combine's grain flow sensor, allowing precise yield and location data to be correlated with soil samples taken earlier throughout the field. This information will help growers plan best fertilizer rates for the next crop. [18]

Conclusion

Precision farming optimizes output by targeting the fine spatial differences in a farm. The idea that differentiates precision farming from traditional farming methods is variable-Rate Application. Inputs are given in amounts needed, where needed, and when needed. To be able to apply the VRA method, growers need detailed and spatial data about their farms and different Variable-Rate Technology (VRA) at each stage.

It is worthy of note that precision farming with regards to fertilizer application, reduces inputs use and increases yield amounts and quality; reduces soil, water, and air pollution by decreasing the use of chemical fertilizers and pesticides. Precision farming is suitable for big farms, small farms, and organizations working with many growers.

Several studies has revealed that small farms produce more than 80% of the world's food, so it is important to use these smart farming practices at small scale as well. Compact handheld devices, smart sensors, mobile apps, and small drones can bring the benefits of precision faming even to small farmers. Often the benefits to small farmers can mean using just 20% of the fertilizers or any other input such as pesticides, thereby decreasing costs, and improving profits significantly. Large farms use precision farming to help them scout and create field management zones for all or specific operations. Whereas, many of the tools used in precision agriculture are simple and easy to use, some require a little level of expertise. On the whole, the good thing about precision agriculture is that the money and time invested in VRT tools has been shown to provide substantial returns in farms of all sizes, and consistent improvements are expected to provide even greater returns with less input in the future years.

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