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Geospatial Science and Technology Utilization in Agriculture

Dr. Anil Kumar

Associate Professor, Department of Botany, Government PG College, Rishikesh, Dehradun, Uttarakhand, India

ABSTRACT

Since the agrarian revolution during the 18th century, the use of technology to improve the effectiveness and efficiency of farming practices has increased tremendously. Discoveries in the field of science and technology have enabled farmers to effectively use their input to maximize their yield. These advancements have been greatly assisted by the use of sophisticated machineries, planting practices, use of fertilizers, herbicides and pesticides and so on. At the present moment however, the success of large-scale farming highly relies on geographic information technology through what is known as precision farming. Precision agriculture, or precision farming, is therefore a farming concept that utilizes geographical information to determine field variability to ensure optimal use of inputs and maximize the output from a farm (Esri, 2008). Precision agriculture gained popularity after the realization that diverse fields of land hold different properties. Large tracts of land usually have spatial variations of soils types, moisture content, nutrient availability and so on. Therefore, with the use of remote sensing, geographical information systems (GIS) and global positioning systems (GPS), farmers can more precisely determine what inputs to put exactly where and with what quantities. This information helps farmers to effectively use expensive resources such as fertilizers, pesticides and herbicides, and more efficiently use water resources. In the end, farmers who use this method not only maximize on their yields but also reduce their operating expenses, thus increasing their profits. On these grounds therefore, this article shall focus on the use of geospatial technologies in precision farming. To achieve this, the paper shall focus on how geospatial data is collected, analyzed and used in the decision making process to maximize on yields.

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INTRODUCTION

Agriculture faces many challenges today, including climate change, depleted land quality, water shortages, poor water quality, and economic pressures. Farmers, however, do now have greater access to computational and geospatial tools that can also at least help mitigate some of these challenges.

Geospatial technology cannot be successful if the correct data is not collected and analyzed effectively. To achieve this, several techniques have been advanced most of which are based on remote sensing. Remote sensing is essential in dividing a large farm into management zones (Grisso, 2009). Each zone has specific requirements that require the use of GIS and GPS to satisfy its needs. Thus, the first step of precision farming therefore is to divide the land into management zone. The division of this land into zones is mainly based on:

1) Soil types
2) pH rates
3) Pest infestation
4) Nutrient availability
5) Soil moisture content
6) Fertility requirements
7) Weather predictions
8) Crop characteristics
9) Hybrid responses

This information can be accessed by reviewing available records. Most farms usually have records of soil survey maps, historical characteristics of crops, and records that show the cropping practices of the regions. Additionally, aerial and satellite photographs can be used in this process. For example, in the image sample below taken on January 30, 2001, three parameters were analyzed from a Daedalus sensor aboard a NASA aircraft. The individual fields are numbered in each of the images. The top image (mostly yellow) shows vegetation density. The color differences indicate crop density with dark blues and greens for lush vegetation and reds for areas with bare soil (known as "Normalized Difference Vegetation Index", or NDVI). The middle image analyzed water distribution with green and blue areas measuring wet soil and red areas indicating dry soil. The middle image was derived from reflectance and temperature measures from the Daedalus sensor. The last image on the bottom measures crop stress with red and yellow pixels indicating areas of high stress. The data collected from analyzing these different conditions allows the farmer to micromanage the application of water to best address differing soil conditions and vegetation growth.[1]

Technologies used today include GPS tracked monitors that help record information including weather, soil quality, crop progress, or even livestock-related data. In particular, Internet of Things (IoT) devices provide not only real-time data but GPS tracking enables geospatial approaches to assess information, such as volumetric measurements or creating heat maps to measure spatial intensity.

By monitoring closely crops using small devices placed by plants or soils, then farmers are better able to forecast crop health and output prior to harvest. This enables farmers to also better plan in advance.

Fig. An agriculture field

Additionally, one can generate up-to-date aerial and satellite photographs of the farm during different periods of the year or seasons. With this information, the farmer is able to determine the productivity of different management zones. At the same time, the growth and yield patterns of different zones within the farm can also be identified.

Furthermore, such devices help save costs because farmers can plan more exactly how much fertilizer, water, and other measures are needed based on real-time conditions and forecasting. This can help limit waste, particularly from fertilizers, which can have negative consequences for water quality as runoff from farms can greatly increase nitrate and phosphate levels in water.

Increasingly, farming is seen as a major contributor to climate change, in particular carbon released from soils and emissions from livestock has been seen as having negative consequences for our climate. By creating more efficient decisions on when to crop, minimizing the number of livestock and resources needed for agriculture, farmers can at least help to mitigate their impact on climate change emissions

Various remote sensing techniques can be used to increase the effectiveness of this process. The most common remote sensing technique that has been applied over the years is observation with the use of the human eye. With the help of modern technology, any observation that is made using this method is usually geo-referenced into a GIS database.[2] Much of precision agriculture relies on image-based data from remote sensing such as determining the greenness of the field using a technique to determine the productivity/yield of different managemen zones (Brisco et al, n.d.). This technique is based on the relationship that arises from the comparison of the reflection of red light and near infrared light. Data from RADARSAT has also provided farmers with reliable information regarding the parameters that determine soil conditions and crop performance.[3]

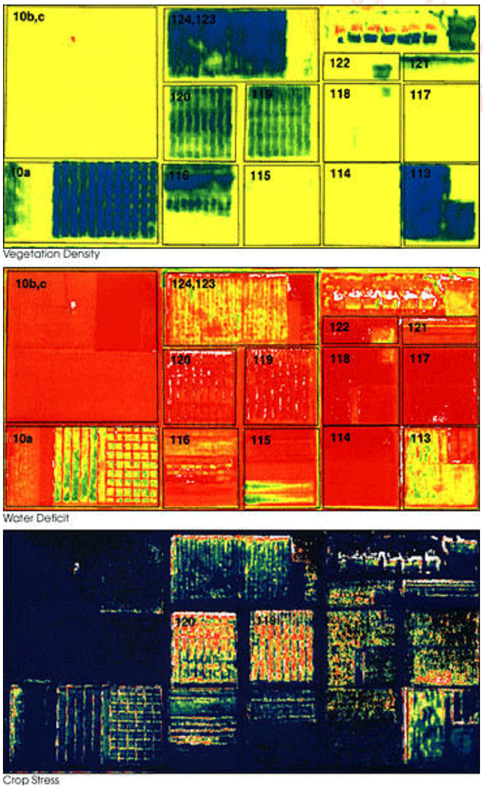
GIS technology has become a vital tool for crop management. Geographic data about soil condition helps farmers to be more efficient in segmenting arable land in order to apply differential rates of fertilizer, and forecasting to determine when, where, and what to plant in what is known as precision agriculture. Satellite and aerial imagery is used to analyze existing conditions of the land, soil samples taken from the fields are used to create a more precise understanding of the condition of a farm. By understanding the condition of the land on a micro scale, farmers and those in the agriculture field can better manage fertilizer and water application, resulting in reduced costs and better crop yields.

The variations in crops grown organically versus conventionally are significant enough to be detected by analysis on satellite imagery. The European Space Agency (ESA) has been working with Ecocert, an organic certification organization, as well as consulting firms Keyobs and VISTA, and Belgium's University of Liège, to develop a methodology to analyze satellite imagery to differentiate crop fields based on whether the crops were grown via organic or conventional methods.

ESA analyzed multi- and hyperspectral imagery from five different satellites, SPOT-4, Kompsat-2, Landsat-5, Proba, and WorldView-2 as part of the study. Using indicators that included crop spectral reflectance, yield forecasts and spatial heterogeneity, ESA was able to predict with an average accuracy of 90% which crops were grown organically versus conventionally. Dr Pierre Ott from Ecocert, concluded, "Accuracy rates of 80% to 100% in discriminating organic from conventional fields are a performance in itself. It seems very promising as far as the potential of future developments is concerned."

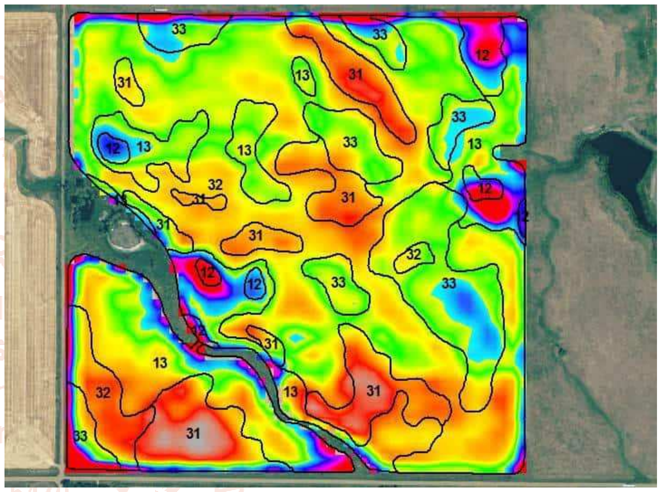
Efforts are ongoing to further refine this methodology so that it can be commercially utilized.

Cornfield classification determinations using a WorldView-2 satellite image acquired on August 10, 2010. The fields in light green are classified as organic (KMO) and the ones shaded dark green are classified as conventional (KM). An accuracy of +90% was obtained on the classification between organic and conventional.



The images were acquired by the Daedalus sensor aboard a NASA aircraft flying over the Maricopa Agricultural Center in Arizona. The top image (vegetation density) shows the color variations determined by crop density (also referred to as "Normalized Difference Vegetation Index", or NDVI), where dark blues and greens indicate lush vegetation and reds show areas of bare soil. The middle image (water deficit) is a map of water deficit, derived from the Daedalus' reflectance and temperature measurements. Greens and blues indicate wet soil and reds are dry soil. The bottom image (crop stress) shows where crops are under serious stress, as is particularly the case in Fields 120 and 119 (indicated by red and yellow pixels). These fields were due to be irrigated the following day.

Discussion



Farmers can use geospatial technologies such as GPS, GIS, and Landsat satellite imagery to assess variations in soil quality for planting crops. This heat map shows soil quality with areas numbered 31 having the highest quality soil in a field for corn productivity.

The data that is collected from remote sensing acts as a source of point data. From the trends and frequencies that have been recorded, this dataset can easily be converted into spatial data that reflects the situation of all management zones within the farm with the use various GIS techniques and tools. Kriging is an example of a method that can be used to convert point data from remote sensing into spatial data (Brisco et al, n.d.). Spatial data can then be used to determine the possible problems that might be present in various management zones. This gives farmers the chance to come up with informed and effective decisions to alleviate the prevailing problems in order to boost the overall production of the farm.[4]

Once point data has been collected, it needs to be stored and analyzed for it to be useful to the farmer. It is at this point that GIS tools come into use. GIS software can be used to develop digital maps that transform spatial information that has been collected on the ground into digital format. At the same time, the point data that had been collected on the field can now be transformed into spatial data to reflect the entire farm. [1] To effectively differentiate points with different values within the management zones, the collected data is normally presented in either raster or vector formats (Brisco et al, n.d.). In raster format, imaginary grids within a map are developed. Points within the map that have different values are assigned different colours. Therefore, from a glance, a user can be able to identify points that have similar characteristics and differentiate them with points that have different characteristics. This form of data representation is useful in spatial modelling to show the relationship that exists within grouped data. Vector format on the other hand uses coordinates from the x-axis and y-axis to assign a specific point within a map. Points that have similar characteristics are plotted and joined together to form a borderline. This form of data presentation is effective in computerized mapping and spatial database management.[5]

Aerial technologies are also helping farmers make better choices by using unmanned aerial vehicles (UAVs) as well as satellite technologies. For instance, the Soil Moisture Ocean Salinity (SMOS) satellite, launched in 2009, is able to collect microwave data from the Earth's surface, which can allow planners and farmers to forecast crop production and assess the likelihood of drought or even flooding prior to events occurring. This enables decisions to be made well in advance, helping to mitigate stresses for crops.[9]

On the other hand, small, cheap drones are often used to provide more fine-scale assessment, including data on plant height, count and biomass estimates, indication of disease, presence of weeds, plant health, field nutrients, and volumetric data using simple cameras that can create photogrammetric data

Powerful modeling tools, such as Decision Support System for Agrotechnology Transfer (DSSAT) and Soil-Water-Air-Plant (SWAP), have also become incorporated with common and open source GIS tools such as GRASS, enabling farmers and analysts to forecast water availability and crop health without great expense.

These tools are increasingly incorporated with high performance computing (HPC) or cloud-based computing, enabling large-scale analyses for large areas in the tens of thousands of hectares to be estimated[8]

For decades, Landsat and other more recently developed multi-spectral satellites, such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), have been used to provide Normalized Difference Vegetation Index (NDVI) data. This allows farmers to monitor the health of their crops and estimate harvest for wide areas.

Once spatial data has been mapped, comparison of the results that are presented with the field notes is essential. This process is conducted to determine any trends and relationships that might be present on the ground. At this point, an area that has high content of nutrients in the soil or a region that is highly infested with parasites might be identified. This distribution can either be in the form of uniform or non-uniform variability. With this information, favourable management techniques can be put in place to increase the efficiency of farming to ensure optimal use of inputs and to maximize the output. Thus, the information that has been provided with the use of remote sensing and GIS can be used to make site-specific decisions with regards to the use of fertilizer, herbicides and pesticides, irrigation and so on. Most importantly, the data that has been generated needs to be stored in a systematic manner for future reference. This is essential, as it will increase the effectiveness and efficiencies of future surveys.[2]

The main reason of collecting this data is for a farmer to have a clear understanding of the needs of different points in the farm to maximize his production. As this need increases, the use of automated farm machinery is inevitable (Sohne et al, 1994). These machines are expected to conduct their work precisely according to the information that has been fed on them. With the use of GIS and GPS, automated farm machineries are now more accurate, safe, eliminate human effort required to drive them and most importantly, increase the productivity of farms.[3]

Results

Many of the key advancements powering the utility of IoT, remote sensing, and simulation applications have to do with improved capabilities in machine learning, in particular deep learning techniques.Deep learning using convolution neural networks (CNNs) has enabled farmers to make better decisions from collected data. For instance, using drone data, CNNs can be used to count the number of livestock or make measurements on crops using visual data.Data from IoT devices can also be assessed, helping to find emerging patterns of crop stress before it becomes too serious. These advancements have helped to make machine and deep learning techniques become increasingly critical for decisions that help save resources while responding to threats.[5]

We have seen many transformations to technologies and techniques used that can benefit agricultural decisions. Farmers have a greater variety of data to choose from to help with decisions needed that not only benefit them but also can have a positive impact on the environment.[7]

Costs and technology access may limit some farmers from benefiting changes occurring for modern agriculture; however, many of these technologies are declining in cost and, in fact, many of the tools, such as GIS and some of the satellite data, are free to use. Improving how agriculture is done will increasingly be more critical as we try to be more effective in how we use landscape resources to mitigate negative impacts on the economy and climate.

Automated farm machineries are operated with the help of Navigation Geographic Information Systems (NGIS). This system is a combination of GPS and GIS systems that enables the machine to:

1. Map Display
2. Path Planning
3. Navigation Control
4. Sensor System Analysis
5. Precision Positioning
6. Data Communication

The system also enhances the management of the automated machines by enabling the user to control its speed, direction, and to monitor the surrounding conditions (Xiangjian and Gang, 2007). For automated machines to conduct their roles effectively and efficiently, they need to be fed with positioning information. This information is usually sent via a GPS receiver that contains precise time, latitudes and longitudes. The machine also received information with regards to the height above ground as well as the height above sea level. With the help of its GPS system, the machine is usually guided through an optimal path. Factors such as the length, traffic characteristics, corners and costs are usually considered while generating the path that shall be followed by the machine. Steering of the machine is determined by the angle that exists between the target points within the path. This ensures that the machines cover all the target points that have been identified from the spatial data from GIS. This therefore ensures that the machine will traverse the farm and spray, deposit or plant the exact amount or quantity of input that is required to maximize the output of a given site as per the findings in the farm.[6]

Trimble is one geospatial vendor for precision agriculture technology. Tractor with Trimble based GPS technology on board.[4]

Conclusions

With the use of remote sensing, GPS and GIS, farmers can be able to understand site-specific needs of their farms. With this information, they are capable of formulating and implementing management techniques that will ensure the optimal use of inputs to maximize their output and profits. Geospatial technologies therefore provide a farmer with an information resource that he/she can use to make informed decisions that guarantee effective and efficient management of the farm to maximize its productivity. Thus, farmers should understand and implement these technologies in conjunction with their experience and expertise to get maximum benefits of their farms.[9]

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