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Geoinformatics: An Emerging Approach for Sustainable Crop Production and Precision Farming

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A B S T R A C T

India's plant biodiversity is diverse and abundant, embracing a wide range of habitats. The Indian subcontinent is one of the world's eight origin centres and one of the world's twelve mega diversity centres. Agriculture in India is primarily concerned with output, which does not always equate to productivity and profitability. In agriculture, shrinking land, dwindling water, and other related resources are important concerns. As a result, in order to accomplish vertical expansion in agriculture while conserving natural resources, farmer-friendly location-specific production strategies must be promoted. Precision farming strives to make optimal use of resources per unit of time and area in order to achieve targeted agricultural produce production. Geoinformatics is concerned with the application of computer science and geosciences to the solution of complicated scientific problems. It is the science of collecting, analyzing, interpreting, disseminating, and utilizing geographic data. In the handling of big and complex PGR datasets, a Geographical Information System (GIS) can be quite useful. Inventories/mapping, exploration/collection, conservation, and crop extension strategies are some of the primary areas where GIS is used.

Introduction

Agronomic practises and management guidelines have traditionally been created for field application. Tillage, fertilizer, sowing, and pest control treatments are usually applied uniformly at a field scale as a result of this. At the 'within-field' scale, however, farm fields show significant regional diversity in crop output. Such uniform treatment of a field ignores natural and induced continuous variation in soil qualities, and may result in zones being under- or over-treated, resulting in economic and environmental issues linked with inefficient resource inputs. The most serious of these issues are: economically significant yield losses, exorbitant chemical expenses, gaseous or percolatory chemical component release, undesirable long-term chemical component retention, and a less than ideal crop growth environment. Many of these issues can be addressed by Precision Agriculture (PA), which takes the form of Site-Specific Management. The theory entails adjusting resource application and agronomic procedures to site-specific soil conditions and crop requirements. The ability to identify each field site, the ability to gather, evaluate, and analyze agronomic data at an acceptable scale and frequency, and the ability to change input use and farming practises to maximize benefits from each field location are all criteria for PF. In contrast to the "uniform" treatment underlying typical management methods, these acts are collectively referred to as "differential" treatment of field variation. As a result, agricultural production systems are more efficient and have a lower environmental impact. 'Prescription farming, "site-specific farming,' and 'variable rate technology farming' are all terms used to describe this type of farming. For gathering, managing, analyzing, and displaying all types of geographically linked information, a geoinformatics system combines hardware, software, and data. In the form of maps, globes, reports, and charts, GIS allows us to see, comprehend, question, interpret, and display data in a variety of ways that reveal correlations, patterns, and trends.

Tools which promoted precision agriculture

Many technological advancements in the twentieth century, primarily in the areas of information technology and geoinformatics, led to the development of the notion of precision farming. The precision farming system's success is dependent on the integration of these technologies into a single system that can be operated at the farm level with minimal effort. The following are the technological advancements:

Geoinformatics

Geoinformatics appears to have been coined separately by many groups throughout the world to describe a variety of efforts to foster collaboration between computer science and the geosciences in order to address complicated scientific problems. is the art and science of obtaining, analyzing, interpreting, disseminating, and utilizing geographic data. Geoinformatics, often known as geomatics, is a vast field that includes surveying and mapping, remote sensing, geographic information systems (GIS), and the Global Positioning System (GPS) (Geomatics Canada Web Site, 2000).

Global positioning system

The Global Positioning System (GPS) is a satellite-based navigation system that may be used to determine one's location anywhere on the globe. In every weather situation, GPS enables continuous (24-hour) real-time 3-dimensional location, navigation, and timing globally. GPS was originally designed for military use, but in the 1980s, the government decided to make it available to the general public. There are no setup or subscription expenses when using GPS. The system can be accessed by anybody having a GPS receiver, and it can be utilized for any application that requires position coordinates. The public availability of the global positioning system (GPS) has opened up new possibilities for geographical data. The GPS must be used in differentially corrected positioning mode, or DGPS, in order to attain the essential accuracies, which are especially important in precision agriculture. The errors computed by a reference station in a known location are relayed to the mobile user in the DGPS, and error correction is performed to improve accuracy. In agriculture, GPS is most commonly used for yield mapping and variable rate fertilizer/pesticide application. GPS is required to determine the precise location in the field in order to assess spatial variability and site-specific application of the inputs. The GPS's positional (horizontal) precision can be on the order of 20 metres.

Remote sensing techniques

Remote sensing (RS) is the science of inferring information about material objects from measurements taken at a distance without actually touching the objects being studied. Because of its ability to detect geographical variations across time at high resolution, remote sensing holds considerable promise for precision agriculture (Moran *et al.,* 1997). The benefits of using remote sensing technology to acquire geographically and temporally varied information for precision farming have been demonstrated by a number of researchers (Hanson *et al.,* 1995). Satellite-based sensors or CIR video digital cameras on board small aeroplanes can be used to collect remote sensing imagery for precision farming. In their review work, Moran *et al.,* (1997) outlined the applications of remote sensing for precision farming. They discovered that RS may be used as a source of several forms of data for precision farming. However, there are a number of drawbacks to using RS data for mapping, including the need for instrument calibration, atmospheric correction, normalization of off-nadir effects on optical data, cloud screening for data, particularly during the monsoon season, and processing images from airborne video and digital cameras (Moran *et al.,* 1997).

Geographic information system

GIS stands for Geographic Information System, and it is a computerized data storage and retrieval system that may be used to manage and analyze geographical data linked to agricultural yield and agronomic variables. It can incorporate a wide range of data and communicate with other decision-making aids. GIS can visualize studied data in maps, allowing for (a) a better understanding of connections between yield, fertility, pests, weeds, and other elements, as well as (b) decision-making based on such spatial linkages. GIS software comes in a variety of forms, each with its own set of features and pricing.

There are a variety of farm information systems (FIS) that use basic programmes to generate a farm-level database. LORIS is an example of such a FIS. LORIS (Local Resources Information System) is made up of numerous modules that allow for data import, raster file generation using various gridding methods, raster data storage in a database, generation of digital agro-resource maps, and the creation of operational maps, among other things (Schroder *et al.,* 1997).

Spatial decision support system

SDSSs are designed to assist growers in solving complicated spatial problems and making decisions on irrigation timing, fertilizing, and the use of crop growth regulators and other chemicals. Decision support systems and spatial decision support systems have evolved in lockstep (DSS).

Furthermore, in order to successfully enable decision-making for complex spatial situations, an SDSS must allow for spatial data input, storage of complex structures common in spatial data, and output in the form of maps and other spatial forms.

Crop simulation models

Crop simulation models are required to assist consultants, researchers, and other farm advisers in determining the best field management plan for maximum yield or profit. However, efficient application of these tools necessitates their evaluation in optimization disciplines, as well as their integration with other information tools like GIS, geo-statistics, remote sensing, and optimization analysis. Researchers from a variety of countries have developed crop simulation models such as CERES (maize, wheat, rice, sorghum, barley, and millet), CROPGRO (soybean, peanut, dry bean, and tomato), SUBSTOR (potato), CROPSIM (cassava), and CANEGRO (sugarcane). Weather, soil water retention and root growth properties, cultivar, water management, nitrogen management, and row spacing/plant population are all factors that these models take into consideration.

Crop/soil/weather models, data input and administration software, and analytical programmes are also included in decision support systems such as DSSAT for optimizing productivity or profit for homogeneous areas.

Applications of geoinformatics in precision farming

Precision farming is a system engineering approach to crop production that uses "as needed" inputs and was made possible by recent advancements in information and technology such as microcomputers, geographic information systems, remote sensing, positioning technologies (Global Positioning System), and automatic farm machinery control. It is a comprehensive method to managing spatial and temporal variability in agricultural fields at the micro scale, based on integrated soil, plant, information, and engineering management technologies, as well as economics. Precision farming recognizes the conditions for agricultural output that are determined by soil resources, weather, and preceding management. Soil resources and weather vary throughout space and time, as is well known. Because of this inherent flexibility, management decisions should be tailored to the exact time and location rather than being strictly scheduled and standardized. Precision agriculture gives farmers the ability to adapt production inputs to particular plots within a field, potentially lowering input costs, improving yields, and minimizing environmental impacts by better matching inputs to crop needs. The following are the used of geoinformatics:

Agricultural mapping

The use of GIS in agriculture is critical since it aids in the charting of current and future variations in precipitation, crop output, and soil temperature. Scientists and farmers can collaborate on generating more diversified, productive, and efficient agricultural approaches by mapping the current characteristics of a farm. Furthermore, this aids in the increase of food production in a country and can help to reduce food shortages in specific countries.

Soil analysis

Geographic Information Systems (GIS) are also useful in agricultural soil analysis since they aid in determining the type of soil, what plants to grow in it, and how to keep the nutrients in the soil for the benefit of the plants.

Data combination

GIS has been employed in the compilation of vast volumes of data into a data set, along with significant changes in the USDA sectors. GIS systems, for example, are used by countries such as the United States to resolve crop issues, protect crops, and respond to false crop damage claims. Furthermore, the technology has provided farmers with the extra benefit of having access to their crop information throughout the year.

Interaction with farmers

Farmers, particularly in the United States, have benefited from Geographic Information Systems in gaining access to data on their properties. This does not necessitate that they have access to a GIS.

Furthermore, this allows them to interact with the data, ask questions, and obtain trustworthy and important on-ground data that cannot be obtained by satellite use. This, in turn, improves the accuracy of the data produced by the machine by around 90%.

Nutrient determination

Farmers must first evaluate the nutrients in a field before deciding whether or not to add nutrients to the soil. A Geographic Information System is utilized to investigate the various nutrient statuses in a field in order for farmers to determine a specific necessity for external fertilizer application. This aids in the integration of computer software modelling analysis with site investigation to provide a conclusive interpretation of varying outputs and inputs.

Assemble information

A Geographic Information System (GIS) is a tool for combining several layers of data, such as soil moisture, nutrients, elevation, and topography, to create a map that depicts some of the parameters that influence crop output.

Furthermore, the predicted yield is used as a future reference, and economic inputs and outputs are planned around it.

Store geospatial data and produce maps for land inventory

The Geographic Information System's data revealed if the property in question could support agriculture, wildlife, tourism, and forestry, among other things. Agriculture-friendly land is crucial since it aids in the production of crops both locally and globally.

Precision farming

In order to collect data, sensors in tractors, satellites, and fields are essential. In this case, the use of a Geographic Information System (GIS) aids in the transformation of acquired data into useful information that land managers and farmers can understand. This also aids in the making of well-informed choices.

Real-time mapping

Satellites and drones have become increasingly popular in recent decades, and their utilisation has increased dramatically.

Furthermore, framing has encountered numerous obstacles, the most significant of which being the management and availability of water needed for agricultural purposes. Satellite technology aids in the collection of real-time data from the earth's surface, as well as accessing and monitoring the land's condition. Drone technology has also benefited in the collecting of data, particularly local field data such as plant height, disease, flower count, and the presence of weeds, among other things. This advancement in technology has helped to cut down on the amount of time spent walking to and from the field in search of data.

Raising alertness

Farming is one of the agricultural areas that require education, particularly in terms of crop availability. Because of its efficiency in raising food scarcity awareness, the Geographic Information System is useful in this area. The essential support is offered once the impacted area has been located. The root causes of food insecurity are identified, and GIS data is used to protect the impacted communities or places. Farmers may now analyze and comprehend the vast amount of geographic data that is stored on a daily basis thanks to the Geographic Information System. This information is easily shared among farmers, allowing them to learn about which crops are doing well, how fertilizers are being applied, and how natural catastrophes and pollution are affecting productivity.

Historical data comparison

Food supply has decreased dramatically over the world as the world's population has grown. This is a major problem, particularly among today's government agencies, because acquiring the essential food sources to maintain an ever-increasing population has proven to be difficult. According to research, present crop production has to be doubled by 2050 to fulfill future food demands. In real-time analysis and historical data comparison, a Geographic Information System is used.

Analyze and visualize agricultural environments

A farm can only be successful and lucrative if its inputs and outputs are in balance. Because it analyses and visualizes the agricultural environment and the flow of work in various locations, the Geographic Information System has proven useful in this area. This has shown to be advantageous to individuals in the agricultural industry.

Table.1 Some GIS Software used for crop improvement programme

Name of GIS software	Functions
ArcGIS	Tools for building applications (including genetic resources management)
Biomapper	GIS tool kit to model ecological niche and habitat suitability
CLIMEX	Assess the risk of pest establishing in a new location
Degree	Spatial data infrastructures
GARP	Predict and analyse species distribution
DIVAGIS	Maps of species distribution and analysis
DSSAT	Software that combines crop soil and weather data bases into standard formats for access by crop models and application programs.
EcoSim	Null model software for ecologists
EstimateS	Statistical estimation of species richness and shared species from samples
FloraMap	Likely distribution of wild species in nature
GBIF MAPA	Species Richness Assessment (SRA)
Geo Da	Spatial data analysis
GPSphotolinker	Save location and GPS position data to a photo
gvSIG	Manage geographic information
HyperNiche	Multiplicative habitat modelling
Maxent	Species and habitat modeling
Quantum GIS	Spatial data analysis
S-Distance	Spatial decision support system
SAM – Spatial Analysis Macroecology	Statistical tools for spatial analysis
SPADE (Species prediction And Diversity	Spatial data analysis

Fig.1

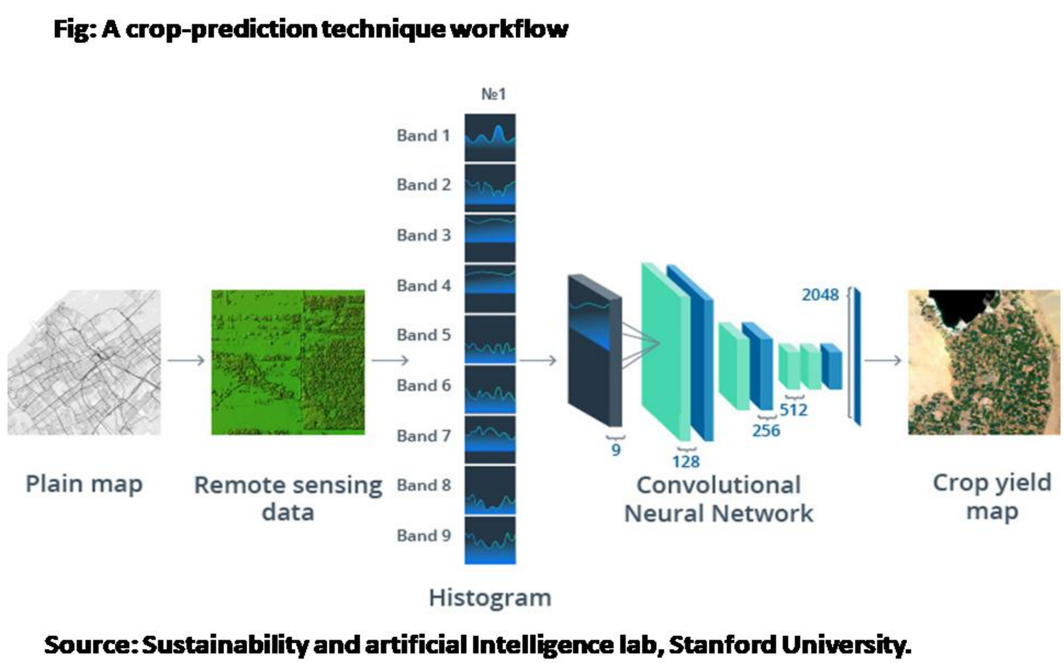
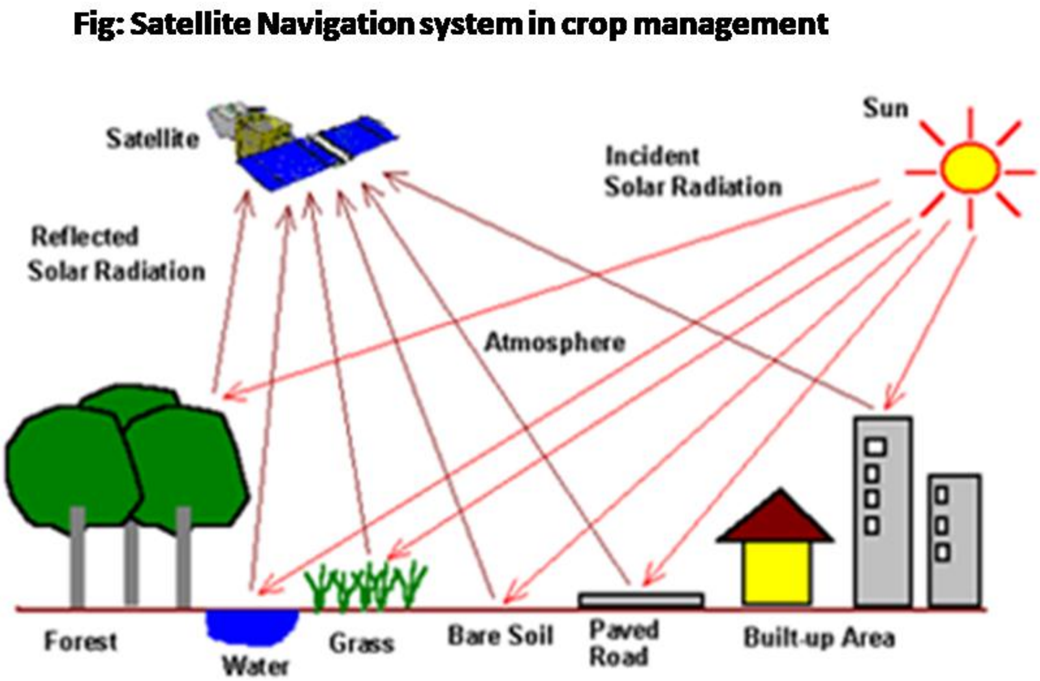


Fig.2



Increase production

In agriculture, GIS is used to help farmers boost their output. Farmers can also save money and better manage their land. This is accomplished by conducting a scientific study of production data held at the farm manager's office.

Limitations of Geoinformatics

Certain obstacles, according to many scientists, have limited the possibilities for site-specific farming in India. The scale of small farms, the diversity of cropping methods, and land tenure/ownership constraints are all factors to consider. The cost of getting site-specific data is prohibitively high. The complexity of tools and procedures necessitates the acquisition of new abilities. Farmers' culture, attitudes, and beliefs, such as opposition to new practises and a lack of awareness of agro-environmental issues, Market flaws are among the infrastructure and institutional restrictions. As a new tale to Indian farmers, geoinformatics must show that it has a positive influence on yields. a scarcity of technical skills on the ground, The initial investment is high. Uncertainty about the returns on new equipment and information management systems that will be purchased.

Future prospects of Geoinformatics

In India, a few private-sector researchers began study on precision agriculture in high-value commodities such as cotton, coffee, and tea. In cotton, remote sensing combined with GIS can help with insect pest management and harvesting precision. At the Indian Agricultural Research Institute in New Delhi, precision farming technologies for a sustainable rice and wheat cropping system are being tested on research farms. In conjunction with the Central Potato Research Institute in Simla, the Space Application Centre (SAC, ISRO) in Ahmedabad has begun an experiment in the Central Potato Research Station Farm in Jalandhar, Punjab, to investigate the function of remote sensing in mapping variability. The National Bank for Agriculture and Rural Development (NABARD) has established a Resource Centre for Precision Farming in collaboration with the MS Swaminathan Foundation in Chennai and the Arava R&D Centre in Israel to develop and spread production technologies based on integrated natural resource management. Precision farming research for capturing variability and variable rate input application is being conducted by the Project Directorate of Cropping System Research, Modipuam, in partnership with SAC and the National Remote Sensing Agency (NRSA), in collaboration with ICRISAT, CRIDA, and ANGRAU. There is also a significant chance for PF for grape and tea to start as a pilot project in Maharastra's Nashik district and Assam's Assam, where these crops are grown in concentrated areas. Agricultural cooperatives play a significant role in the spread of precision farming technologies to small farmers. Precision farming can be viewed as a collection of discrete services such as map development, focused scouting, and so on, and these services can be accommodated within the structure of a progressive agricultural cooperative. Because PF technique necessitates a large number of expensive equipment, farmers' cooperatives and individual farmers cannot afford to purchase them. Again, cooperative farming will overcome the PA's modest field size barrier.

Precision farming is critical for increasing productivity while also reducing environmental degradation. Precision Agriculture success stories have mostly come from industrialized countries, where agriculture is characterized by highly mechanized and automated systems, is driven by market forces, and is professionally managed enterprise. The model of Precision Agriculture that represents the average Indian Agricultural situation is still evolving, taking into account the prevalence of fragmented land holdings, heterogeneity of crops and livestock, and the idea of farm families in rural conditions. Despite the fact that agriculture is a major polluter of the environment, farmers will not adopt precision farming until it generates a higher or comparable profit than traditional farming. While maintaining the ecological integrity of farming systems is critical, it is also critical to provide small and marginalized farmers with access to knowledge and markets. While addressing these difficulties, the Precision Agriculture model for India would give an innovative path for sustainable agriculture in a globalised and liberalized market.

Conflict of Interest

None

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