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Geo tech revolution: Transforming agriculture with GIS, GPS, and remote sensing

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Abstract

Precision agriculture is a transformative approach to farming that combines technology and data-driven insights to optimize crop production, reduce environmental impacts and enhance sustainability. It focuses on efficient resource utilization, including nutrients, water, seeds and more. Key components involve Remote Sensing (RS), Global Positioning System (GPS) and Geographical Information System (GIS), enabling farmers to collect and analyze data for better decision-making throughout the farming process, from land preparation to harvest. These technologies improve variable fertilizer management, irrigation scheduling, disease control, weed mapping and yield forecasting.

Precision agriculture faces challenges such as technical expertise, high-resolution data requirements, weather variability and economic constraints, particularly for small-scale farms. To overcome these challenges, we need immediate, short-term and long-term measures, including integrating technologies like AI, IoT and Big Data Analytics, as well as expanding the scope to include livestock and aquaculture sectors are crucial for its broader application. In summary, precision expanding micro-irrigation, improving water storage, adopting laser leveling and furrow irrigation, discouraging manual fertilizer application and promoting drone use for precise agro-chemical application. Developing sensors and algorithms for real-time crop monitoring, agriculture holds significant promise for enhancing agricultural productivity, minimizing resource consumption and bolstering sustainability. Nevertheless, it faces formidable challenges that necessitate innovative solutions and a concerted effort from diverse stakeholders to harness its full potential in the agricultural sector.

Keywords: GPS, GIS, remote sensing, variable rate technology, precision agriculture

1. Introduction

The changing climate every year is creating uncertainties in production pattern from a piece of land so is creating concern about the food security. Prediction models are needed to be site specific to give accurate prediction data and give precise information on the benefit data. Improvement in crop yield by performing better in field management decisions, reduction in chemical and fertilizer costs and more efficient application through information technology, permit more accurate farm records increase profit margin and can reduce pollution. Technology has a great role to play in such aspects. The techniques which are being collaborated with the advanced technology are Global Positioning System (GPS), Geographical Information System (GIS), operational control through Real Time Sensors and on the go sensors, remote sensors, telecommunication, mobile computation and advanced information processing models (Sahu *et al.*, 2019) ^[6]. Indian agriculture stands at a pivotal juncture, facing the dual challenges of feeding a burgeoning population while ensuring sustainability. The integration of GIS, GPS and precision agriculture technologies emerges as the linchpin for achieving this delicate balance, demanding the attention of the global scientific community. Geographic Information Systems (GIS) and Remote Sensing (RS) are helpful tools that can raise agricultural output and efficiency.

A. GIS

Maps and other geographical data, as well as other spatial data, can be managed, stored and analysed using a GIS system (Sahoo and Giri, 2023) ^[7]. GIS is a helpful tool for managing and evaluating agricultural resources. A wide range of geographical and descriptive data formats are

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typically used in GIS applications (Tayari *et al.*, 2015) ^[13]. The GIS is regarded as Precision Agriculture's brain. Because GIS can analyse and process large amounts of data quickly, it is crucial for handling and storing location-specific data (Sahu *et al.*, 2019) ^[8].

B. GPS

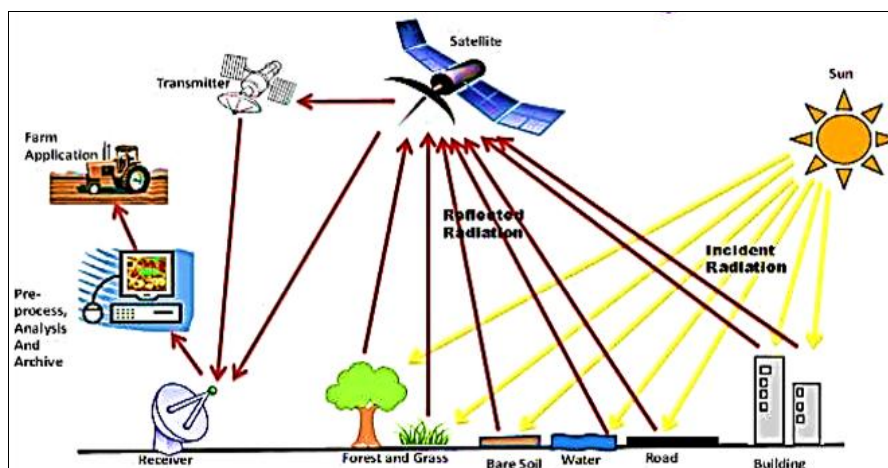
Global positioning systems have metamorphosed into a keystone for precision farming practices in India. This section delves deep into the applications of GPS technology, outlining its utility in land surveying, machinery management and efficient field operations. Such precise management drives enhanced productivity, thereby enticing the attention of the global agricultural research community. GPS is a satellite navigation system operated by the US department of defence that provides global 3D location data (latitude, longitude, elevation) in all weather conditions. It helps farmers gather annual soil samples with accuracy for crop monitoring and to evaluate soil variability at various scales. Additionally, it aids in the generation of data about agricultural land, including field boundaries, acreage, roads, irrigation systems, separations and weed and disease-affected areas (Sahu *et al.*, 2019) ^[8].

C. Remote Sensing

In Remote Sensing (RS), the Earth's surface is seen and monitored using satellite and aerial pictures. This information can be used to determine areas that are under environmental stress, such as water stress and to evaluate the production and health of crops.

A farm or collection of farms can have both visible and invisible features measured by remote sensing, which also converts point measurements of continuous spatial data. This method keeps an eye on the dynamic of soil conditions as well as the surface of plant (Tayari *et al.*, 2015) ^[13]. The process of gathering data through remote sensing involves sensors mounted on aircraft or satellites that pick up reflected energy from the Earth (Sahu *et al.*, 2019) ^[8].

Precision agriculture remote sensing systems, categorized by sensor platform and type, are deployed on satellites, aerial vehicles, and ground-based platforms. Satellite products have been used since the 1970s. Recently, aerial platforms, including aircraft and unmanned aerial vehicles (UAVs), have also found application in precision agriculture. Ground-based platforms, encompassing hand-held, free-standing, and tractor-mounted systems, are referred to as proximal remote sensing systems, situated close to the target surface compared to aerial or satellite-based platforms (Sishodia *et al.*, 2020) ^[11].



Source: Bharteey *et al.*, 2019 ^[1]

Fig 1: Process of remote sensing

D. Precision Agriculture

With the seamless integration of GIS and GPS, Precision Agriculture (PA) is triggering a transformative wave across Indian farmlands. Its immense potential for variable-rate applications, yield monitoring and sustainable crop management is meticulously analyzed. For underscores the socioeconomic and environmental impacts of PA practices in the Indian context, marking it as an essential contribution to the scholarly discourse. By reducing the amount of inputs (such as water, energy, fertilisers, and pesticides) used, precision agriculture increases the quantity and quality of agricultural produce. This improves time efficiency by executing farming practises remotely while also producing benefits for the climate (Udoumoh *et al.*, 2021) ^[15].

Precision farming or Precision Agriculture (PA), is an advanced approach to agriculture that customizes practices for individual pieces of land. It uses technology like computer programs and satellite signals for predicting crop development and improving agricultural efficiency. PA involves data integration for resource application, soil properties, and crop requirements to enhance land management and maximize output through informed

decision-making. PA comprises advanced techniques categorized into diagnostic techniques such as geo-referencing yield monitoring, management zones, and crop input determination, as well as application techniques like laser land leveling, precision planting, and water and nutrient management. Key tools utilized in PA encompass GPS, GIS, yield monitoring devices, soil, plant, and pest sensors, along with variable-rate technologies. Among these tools, GPS and GIS serve as foundational elements. The map-based approach involves the collection and storage of data for fertility assessment, while the sensor-based approach offers real-time monitoring and adaptive input application, even without GPS connectivity (Sahu *et al.*, 2019) ^[8].

Precision agriculture, driven by technologies like GPS and GIS, aims to maximize agricultural output while minimizing resource use, reducing environmental impact and ensuring sustainability. It includes variable rate technologies, electronic maps, yield monitors, and guidance systems. Precision agriculture utilizes remote sensing tools like satellites and drones to collect high-resolution field data for informed decision-making. This approach is applicable to various agricultural production systems

beyond crop farming, including agronomics, livestock farming, aquaculture and agroforestry (Karunathilake *et al.*, 2023) ^[3].

2. Application of GIS, GPS and remote sensing in precision agriculture

Using GPS, whether built-in to smartphones or handheld devices, allows farmers to map their fields and find more accurate and site-specific solutions to their issues. In addition to field mapping, GIS and remote sensing provide very powerful tools that can be used to monitor crop stages, disease management, yield estimation, soil mapping, weed mapping, and hotspots for disease incidences. These tools are particularly useful when spatial content is linked to other web-based applications. Here are some applications of these technologies-

- Assessment of crop growth stages and crop condition
- Identification of Disease, pest and weeds and its management
- Soil fertility, micro and macro nutrients and site-specific fertilizer application
- Precision conservation
- Climate suitability and crop suitability
- Assessment of evapotranspiration (ET)
- Precise space utilization
- Micro propagation/tissue culture
- Site specific irrigation, water resource management and crop water stress monitoring. Source: (Sood *et al.*, 2015; Patel, 2016; Sishodia *et al.*, 2020; Udoumoh *et al.*, 2021; Trivedi *et al.*, 2022) ^[12, 5, 11, 15, 14].

Utilising information from multiple sensors and GPS references, RS and GIS assist in identifying crop maturity, nutrient and water stress, disease-pest and weed infestation. The creation of field management plans for fertiliser application, cultivation and harvesting is made possible by this information integration. GIS and RS in integrated form provide a solution where mapping for the disease incidences can be carried out. Mapping the disease occurrences areas it can be spatially integrated with the agro ecological zones which can help in making simulating the other hotspots for similar infestation in future. GIS is crucial for pinpointing optimal irrigation sites by leveraging natural slopes. Through GIS and remote sensing, experts can identify locations for water storage through use of natural slopes, enabling farmers to set up tanks for rain harvesting. This technology aids in establishing irrigation channels, especially in areas with steep terrain, by identifying potential sites for trapping groundwater and rain runoff. Source: (Sood *et al.*, 2015) ^[12].

The most common use of PA to date is still the application of fertilisers according to the specific site. (Zhang *et al.*, 2002) ^[17]. Even so, the majority of PA experiments focused on VRT herbicide and fertiliser applications (Yousefi and Razdari, 2015) ^[16]. This study exemplified the effectiveness of utilizing multi-spectral remote sensing data to identify diseases during advanced stages and at elevated infection rates. The findings underscore the appropriateness of these methodologies for detecting diseases in situations characterized by late occurrences and high infection rates (Trivedi *et al.*, 2022) ^[14].

Remote sensing images, gathered multiple times throughout a growing season, play a crucial role in assessing key indicators of crop water demand, including ET, soil moisture, and crop water stress. Crop water requirement and precise irrigation scheduling rely on indicators that leverage remote sensing products in optical, thermal and microwave bands. Various indices and techniques, such as the normalized difference vegetation index (NDVI) and soil-adjusted vegetation index (SAVI), derived

from optical images are employed to assess water stress and soil moisture conditions in multiple crops. Traditional ET measurement methods (lysimeters) are typically costly and fail to offer spatially variable ET estimates due to variations in land use, soils, topography and other hydrological processes. Remote sensing data plays a vital part in estimating evapotranspiration (ET), essential for assessing crop water needs and scheduling irrigation. ET estimation methods utilizing remote sensing data can be categorized into three groups: (i) surface energy balance, (ii) crop coefficient, and (iii) the Penman–Monteith method (Sishodia *et al.*, 2020) ^[11].

Monitoring and detecting pests and diseases using Remote Sensing and GIS involves capturing aerial infrared photos and satellite images of chosen crops throughout the growth period. The collected data is then correlated with field values to assess crop development, pest and disease status, field productivity and spatial variations. Additionally, the feasibility of utilizing satellite-derived land surface temperature to drive models for crop and pest development is examined for operational Integrated Pest Management (IPM) programs (Patel, 2016) ^[5].

3. Challenges and limitations

The utilization of remote sensing, geographic information systems (GIS) and precision farming methodologies for agricultural resource management is experiencing rapid growth, primarily driven by advancements in space science and bolstered by computer and communication technologies. To effectively leverage these technologies, several challenges must be confronted (Dige, 2020; Patil *et al.*, 2002) ^[2, 6].

- Automation of land evaluation through GIS techniques
- Cost reduction and time efficiency in RS, GIS and precision farming technologies
- Crop stress detection and quantification of impact on yield
- Decision support systems for biotic and abiotic stress management
- Demonstrating utility and economic viability
- Depth estimation of water reservoirs and groundwater quality assessment
- Effective drought and flood forecasting
- Enhancing yield models precision
- Extending precision farming database to smaller farms and diverse cropping systems
- Human resource development for cutting-edge technologies
- Information retrieval on sub-surface soil horizons
- Integration of remote sensing and precision farming in intercropping scenarios
- Micro-level watershed development with sub-meter contours
- Precise identification and estimation of short-duration crops in fragmented landscapes

4. The way forward

In the future of precision farming, the key thrust involves advancing the integration of Geographic Information Systems (GIS), Global Positioning Systems (GPS) and Remote Sensing technologies. This synergy aims to address the challenges posed by global population growth and the need for sustainable productivity in agriculture. The trajectory of precision farming will be shaped by refining data analytics, machine learning and artificial intelligence to effectively utilize the wealth of information generated by GIS, GPS and Remote Sensing. This evolution is expected to bring forth more advanced sensor technologies, improved connectivity and widespread access to

data-driven insights. Ultimately, this convergence is set to propel agriculture towards a future marked by enhanced efficiency, sustainability and productivity.

A. In Order To Address the Challenges in the Management of Agricultural Resources, Several Steps Need To Be Taken At Different Timeframes

Immediate steps are crucial to enhance India's agricultural resource management. Prioritizing micro-irrigation in water-stressed regions, expanding storage capacities and implementing advanced irrigation systems are paramount. Discouraging manual fertilizer broadcasting and promoting drone usage for precision agriculture are essential short-term measures. Additionally, the focus should be on sensor development, UAV surveys and promoting technology adoption by Precision Agriculture Service Providers. In the mid and long term, collaboration among various stakeholders is key to developing Decision Support Systems integrating AI, IoT, Machine Learning (ML) and Big Data Analytics, facilitating real-time decision-making. Exploring agricultural robotics, extending precision agriculture to livestock and aquaculture, ensures a holistic approach to sustainable agricultural practices in India (Singh, 2022) ^[10].

The establishment of farmer cooperatives due to the high cost of many precision agriculture instruments (GIS, GPS, RS, etc.) and educating farmers on the effects of using uneven amounts of agricultural inputs, such as fertilisers, irrigation, insecticides, and pesticides (Patel, 2016) ^[5]. Remote sensing enables us to track field variations during the growing season in response to management changes. Monitoring tools can capture surface water and groundwater samples to quantify environmental impact through runoff or leaks (Dige, 2020) ^[2].

Prospective approaches towards the implementation of Precision Agriculture (PA) in India need to tackle concerns such as the division of land, the lack of sophisticated technical facilities and specialised PA software, and the financial difficulties encountered by Indian farmers. A solution to India's land fragmentation issue and a step towards PA advancements could be the implementation of "virtual land consolidation" without changing ownership structures (Mondal and Basu, 2009) ^[4].

Future challenges in PA adoption include the need for new skills and mind-set changes. Resistance to PA arises from a preference for traditional practices, with barriers such as high costs and perceived lack of benefits. Large-scale adoption requires timely access to affordable soil and crop yield maps. Despite the benefits of autonomous crop equipment, profitability is crucial for widespread adoption. In developing countries, PA is still considered a concept, highlighting the need for simultaneous public and private sector support (Shaheb *et al.*, 2022) ^[9].

5. Conclusion

In conclusion, the integration of GIS, GPS and remote sensing technologies has ushered in a new era for precision agriculture, offering solutions to the challenges posed by climate change and burgeoning population demands. The applications of these technologies in crop monitoring, disease management and resource optimization underscore their transformative impact on Indian agriculture. Despite the progress made, challenges such as automation, cost reduction and skill development persist, requiring collaborative efforts from stakeholders. The future trajectory of precision farming envisions advanced sensor technologies, improved connectivity and widespread access to data-driven insights, promising increased efficiency and sustainability. Immediate, mid-term and long-term strategies are

proposed to address current issues and foster the widespread adoption of precision agriculture. As the agricultural landscape continues to evolve, the synergy of GIS, GPS and remote sensing remains integral to mapping the future of agriculture and ensuring food security in a changing climate.

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