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The Application of Remote Sensing and Geographic Information Systems (GIS) in Precision Agriculture

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Introduction

With the global population now exceeding six billion and projected to grow by another three billion within the next fifty years, the global food landscape is undergoing rapid changes. Limited arable land resources are causing increased pressure on the land currently under cultivation; by 2050, the per capita arable land is expected to decrease from roughly 0.23 hectares in 2000 to about 0.15 hectares (Lal, 1991). The growing population, along with wealthier diets as people climb the economic ladder, is predicted to double or even triple the global demand for food. Simultaneously, the agricultural economy faces instability due to fluctuations in the costs of agricultural inputs and the revenue from farm products. In this context, the introduction of new technologies is essential to boost crop yields, support better field management decisions, reduce the costs of chemicals and fertilizers through more efficient application, maintain accurate farm records, increase profit margins, and reduce pollution. Precision farming has greatly benefited from remote sensing technology, particularly due to the availability of high-resolution satellite imagery, including spatial data.

Precision farming utilizing remote sensing harnesses spectral, spatial, and temporal data to enhance agricultural practices and increase crop yields. Data is collected by remote sensors mounted on satellites, aircraft, unmanned aerial vehicles (UAVs), or ground-based devices. Precision agriculture (PA), a key component of sustainable agricultural systems in the 21st century, involves the use of advanced information, communication, and data analysis techniques in decision-making processes to improve crop productivity while reducing water and nutrient losses and minimizing negative environmental impacts. This management strategy includes the application of resources such as water, fertilizer, pesticide, seed, fuel, and labor more efficiently. According to Berry et al. (2003), emerging technologies are promising tools for optimizing agricultural operations and inputs to enhance production while minimizing inputs and yield losses. These technologies include remote sensing, artificial intelligence (AI), big data analysis, the Internet of Things (IoT), and global positioning systems

(GPS). geographic information systems (GIS).

Application of remote sensing in precision Agriculture

Soil Property Mapping

Soil mapping is vital for the sustainable management of natural resources at local, regional, and national levels. Maps that show crop growth, crop diseases, weeds, crop nutrient deficiencies, and other crop conditions are crucial for the effective operation of variable-rate technology (VRT). VRT enables the adjustment of the rate at which agricultural inputs are applied to the soil.

Crop Monitoring

Precision farming utilizes remote sensing technology to optimize agricultural inputs, thereby enhancing output and reducing losses. Continuous updates on crop status throughout the growing season are essential for effective farming. Monitoring crop growth is key to understanding how crops respond to their environment and to developing efficient management strategies. Remote sensing data is used in precision farming to measure the biomass of various crops, a critical indicator of crop health and development.

Management of Irrigation

Effective irrigation timing and volume are crucial to minimize crop water stress and ensure optimal growth. Remote sensing products are used to develop and test various indices and methods needed for irrigation management. Images from remote sensors are employed to determine crop water requirements and the appropriate timing for irrigation.

Prediction of Yield

Precision farming relies heavily on remote sensing for large-scale crop inventory and production forecasts. There are two primary approaches to estimating agricultural yield using remote sensing: deriving biophysical parameters from remotely sensed data and creating statistical or empirical relationships between crop metrics obtained through remote sensing.

Pest and Disease Control

Pests and diseases can severely impact crop production. Early detection of pests and diseases using remote sensing can help contain and prevent their spread more effectively. Unlike traditional field scouting, which is labor-intensive, time-consuming, and susceptible to human error, remote sensing technology allows for efficient and accurate monitoring of diseases by identifying conditions as they develop.

Identifying Crop Water Stress

Water stress, characterized by a reduction in soil water content or other physiological responses, can severely affect crops. Evaluating crop water status is a top priority in precision farming, especially given changing climatic conditions. Remote sensing provides a wide range of data to detect crop water stress and improve irrigation management.

Geographic Information System (GIS)

GIS is a powerful set of tools for collecting, storing, retrieving, transforming, and displaying spatial data for specific purposes. In the farming industry, GIS's ability to analyze and visualize agricultural environments and workflows has proven to be highly beneficial. A farm's success and profitability often depend on balancing its inputs and outputs, and GIS can help achieve this balance. Spatial data typically come in layers representing topography or other environmental components.

Today, GIS technology is crucial for integrating data from various maps and satellite sources into models that simulate the interactions within complex natural systems. GIS is becoming increasingly important in global agricultural production, aiding farmers in managing their land more efficiently, enhancing productivity, and reducing costs—from mobile GIS applications in the field to the scientific analysis of production data in the farm manager's office. While it is impossible to completely control natural inputs in farming, GIS applications can assist in understanding and managing these factors. This includes estimating crop yields, analyzing soil amendments, and identifying and correcting erosion.

For regional-level agricultural productivity simulation, a spatial crop model is developed by combining the Environmental Policy Integrated Climate (EPIC) model with GIS. An example of this application is the Crop Growth Monitor System, which integrates AVHRR and VGT data for comprehensive monitoring.

Conclusion

Precision agriculture (PA) leverages a variety of technologies to optimize agricultural inputs, enhancing output and minimizing losses. Over recent decades, the adoption of remote sensing technology in PA has grown significantly. The unprecedented availability of high-resolution satellite images—spatial, spectral, and temporal—has facilitated the use of remote sensing in numerous PA applications. These include crop monitoring, irrigation management, nutrient application, disease and pest control, and yield prediction.

Precision farming enables accurate monitoring and adjustment of yield, making farm planning both more complex and more efficient. It provides extensive map data that aids in the creation of long-term cropping plans, assessment of tillage systems, and management of salinity and erosion. By integrating these advanced technologies, precision agriculture ensures more effective and sustainable farming practices.

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