Review Article

GIS tools: A Key of Precision Agriculture – A Review

Abstract

Agriculture is a multifaceted discipline, encompassing a vast array of concepts and relationships. Our institute has been conducting research on site-specific farming since 1998. Precision farming is an agricultural production approach that acknowledges in-field variability, leveraging technology such as seeding, nutrient replacement, and spraying to local conditions. Satellite-based Global Positioning Systems (GPS) has empowered farmers to address spatial variability, a crucial aspect of precision agriculture. This review aims to clarify the distinctions between two prominent systems, facilitating further research and development. Unfortunately, misunderstandings among researchers and the complexity of information provided by companies have created barriers for potential adopters. This overview provides a comprehensive examination of the global advancements and current state of precision agriculture technologies, with a specific focus on the integration of GIS and GPS in precision agriculture.

Keywords: GPS, GIS, Computer Application, Precision Agriculture.

INTRODUCTION

The evolution of agricultural production systems has been significantly influenced by the adoption of technological innovations initially developed for other industries. The Industrial Revolution introduced mechanization and synthetic fertilizers to agriculture, enhancing productivity. The Technology Age brought forth genetic engineering and automation, further transforming agricultural practices. Now, the Information Age offers the potential to integrate these technological advancements into precision agriculture (PA), enabling more targeted and efficient farming methods (Whelan *et al*., 1997;Maurya et al., 2024). Precision Agriculture (PA) is a systemic approach aimed at transforming the agricultural paradigm towards a more sustainable, low-input, and high-efficiency model (Shibusawa, 1998). This innovative framework leverages the convergence of various cutting-edge technologies, including:Global Positioning System (GPS), Geographic Information System (GIS), Miniaturized computer components, Automatic control systems,In-field and remote sensing technologies, Mobile computing,Advanced information processing,Telecommunications (Gibbons, 2000). The agricultural sector can now collect and analyze comprehensive data on production variability across space and time. The primary objective of PA is to respond to this variability at a fine scale, enabling farmers to make informed, data-driven decisions (Whelan *et al.*,1997;Krishnababu et al., 2024). Despite numerous technological innovations, the development of agronomic and ecological principles for optimized, localized input recommendations lags behind. As a result, many farmers are hesitant to adopt available precision agriculture (PA) technologies on their farms(Khaspuria et al., 2024). However, the widespread adoption of PA technologies may be driven by factors such as stringent environmental legislation, public concerns about excessive agro-chemical use, and potential economic benefits from reduced inputs and improved farm management efficiency (Naiqian et al., 2002). Ultimately, the success of PA technologies will be measured by their economic and environmental benefits. Remote sensing and Geographic Information Systems (GIS) have revolutionized the mapping of natural resources at both macro and micro levels. However, the complex terrain of hilly states, characterized by diverse landscapes ranging from low-lying hills to high mountain ranges, poses significant challenges to agricultural development and technological adoption.The 20th century witnessed pivotal technological advancements, culminating in the concept of precision farming (Kumar et al., 2016; Shafi et al., 2019). The success of precision farming hinges on integrating these technologies into a cohesive, farm-level system that fosters sustainability.In mountainous regions, precision farming is crucial due to its site-specific nature, differing significantly from flat agricultural areas (Sharma et al., 2020). To optimize agricultural management in these small, site-specific zones, accurate identification of each field location is essential.Precision agriculture can be effectively implemented by refining traditional farming practices to maximize benefits in these unique, localized settings.

What Is GPS?

The Navigation Satellite Timing and Range Global Positioning System (NAVSTAR GPS) is a satellite-based radio-navigation system that provides highly accurate, worldwide, 24-hour, three-dimensional location data, including latitude, longitude, and elevation. Initially designed by the US Department of Defense (DoD) as a military navigation system, GPS is now freely available to civilians, albeit with certain restrictions. The system has achieved full operational capability, comprising a constellation of at least 24 satellites orbiting the Earth in a carefully designed pattern (Gelian et al., 2012). GPS technology has been leveraged by equipment manufacturers to develop tools that enhance productivity and efficiency in precision farming. Many farmers now utilize GPS-derived products to optimize their agricultural operations. GPS receivers collect location data for mapping field boundaries, roads, irrigation systems, and crop problem areas, such as weeds or disease. The high accuracy of GPS enables farmers to create detailed farm maps, precisely measuring acreage, road locations, and distances between points of interest. Furthermore, GPS facilitates accurate navigation to specific field locations, allowing farmers to collect soil samples or monitor crop conditions with precision, year after year (Qian and Zheng, 2006).

What Is GIS?

Conventional Geographic Information System (GIS) software packages, such as ARCVIEW, IDRISI, and SURFER, offer a wide range of functions, but many of these features may not be directly relevant to precision agriculture (PA) applications. Furthermore, these packages are often expensive and require advanced computer hardware that may not be readily available to farmers.To address the growing need for PA solutions at the field level, various commercial GIS packages have been developed, including those offered by AGRIS Corporation, Farm Works TM, Agri-Logic, Inc., John Deere Precision Farming Group, Case Corporation, Rockwell International, and RDI Technologies, Inc. (Ess et al., 1997). Some of these systems enable real-time data acquisition by integrating with Differential Global Positioning System (DGPS) devices or yield sensors. Additionally, researchers like Runquist et al. (2001) have developed specialized field-level GIS (FIS) systems, incorporating analytical functions for spatial data analysis in PA research.

IS (Geographic Information Systems) and Remote Sensing (RS) have become essential tools in modern agriculture, especially for implementing and monitoring farm practices with greater precision. The Geographic Information System (GIS) enables the creation of complex, data-driven views of agricultural fields, facilitating informed agro-technological decisions. The advent of satellite-based Global Positioning Systems (GPS) has empowered farmers to account for spatial variability.The integration of **GPS devices**, whether embedded in smartphones or used as handheld devices, has revolutionized the ability to map agricultural fields accurately. These technologies allow farmers to gather real-time, site-specific data about their fields, enabling them to address challenges with more precise, tailored solutions.The combination of GIS and RS goes beyond just field mapping. When spatial data is linked with web-based applications, it provides a **powerful platform** for monitoring various aspects of agricultural practices, such as:**Crop Monitoring**: GIS and RS help track the growth stages of crops, enabling farmers to make timely decisions regarding irrigation, fertilization, and harvesting.**Disease Management**: With spatial data, it is possible to identify hotspots for disease outbreaks and track the spread of diseases, allowing for early intervention and targeted treatment.**Yield Estimation**: Remote sensing technologies provide insights into crop health, helping farmers estimate yields with greater accuracy, which is important for market planning and resource allocation.**Soil Mapping**: GIS and RS help in creating detailed maps of soil properties (e.g., moisture, texture, pH), which are crucial for optimizing fertilizer application and improving soil health.**Weed Mapping**: Identifying areas with high weed infestation enables farmers to apply herbicides more effectively, reducing chemical use and costs.**Hotspots for Disease Incidence**: GIS and RS can identify regions within a field that are at higher risk for pest and disease outbreaks, helping farmers take targeted actions to minimize losses.

GIS for Precise Farm Management

Managing a farm requires a multitude of responsibilities, including monitoring market trends, optimizing yields, and predicting weather patterns. To mitigate risks and maximize profitability, farmers have transitioned from relying on traditional tools like the Farmer's Almanac to leveraging geospatial analysis and predictive modeling. These advanced tools enable farmers to visualize their land, crops, and management practices in unprecedented detail, facilitating precise decision-making.Access to spatial data has become an essential component of modern farm management. Government agencies, such as the United States Department of Agriculture (USDA) and the European Union, provide valuable online resources that help farmers better understand their land and make informed decisions. By accessing and utilizing this data, farmers can create intelligent maps that inform and improve their farm business practices (Xie and Wang, 2007).

Worldwide applications

Precision Agriculture (PA) research originated in the US, Canada, Australia, and Western Europe in the mid-to-late 1980s. Despite significant research efforts, only a fraction of farmers have adopted PA technologies. The primary method of implementing PA has been through the modification of existing field machinery with the addition of controllers and GPS, enabling spatially-variable applications. To date, the most prevalent application of PA remains the site-specific application of fertilizers (Naiqian*et al.,* 2002). Although many PA experiments have focused on Variable Rate Technology (VRT) applications of fertilizers and herbicides, diverse types of PA technologies have been experimented with globally (Hendrickson *et al.,* 2000).A crucial aspect of Geographic Information System (GIS) database development is referencing to a base map or base data layer. Ideally, the database should be linked to a large-scale, highly accurate base map. However, if a smaller-scale base map is used, it may lead to issues when attempting to visualize the spatial relationships between features digitized from the small-scale map and those captured using GPS. This incompatibility can be problematic if a grower relies on a GIS data layer generated from small-scale base maps as a reference for new data. To avoid such issues, it is recommended to develop an accurate base data layer using geodetic control and photogrammetric mapping (Erstegen, 1998).

GPS and GIS is an important (future) tool for Precision Agriculture

Portable GPS and GIS receivers are now available for rapid mapping of insect infestations in the field. This data can be accurately communicated to field managers, who can then engage custom spray operators to apply targeted chemical treatments only where necessary. Furthermore, spray operators can provide a permanent record of treatment applications, including GPS data on location and timing. Yield monitors can also be connected to GPS receivers to generate detailed yield maps. These maps enable farmers to identify areas requiring specialized treatments, facilitating data-driven decision-making (Smith, 2002).Overall, the role of GIS and Remote Sensing in agriculture continues to expand, offering farmers better tools for site-specific management and improving productivity, sustainability, and profitability. The integration of these technologies with real-time, online platforms also holds great promise for advancing precision farming on a global scale.

Conclusions

The Agrocom ACT system offers an additional advantage through its integration with AgroMap Professional, an Arc View-based GIS application. This software enables the seamless transfer of precision farming data into any Arc View-compatible GIS, facilitating comprehensive data analysis.However, the adoption of precision farming technology is often hindered by the availability and cost of management time. Some precision farming technologies, such as grid soil sampling and Variable Rate Application (VRA) of phosphorus and potassium, require minimal management time, as they can be outsourced or primarily affect logistics. Other standalone technologies, like Variable Rate Technology (VRT) seeding for maize and soybeans, may yield low returns, even without accounting for management time.In contrast, integrated systems appear to offer more promising results. For instance, the Sauder farm trials demonstrate that annual benefits could support the average U.S. managerial salary for nearly three months, potentially covering the time required for managerial tasks. Nevertheless, the willingness of traditional U.S. producers to engage in computer-based analysis and decision-making remains a significant constraint. Many producers prefer an active outdoor lifestyle and are reluctant to dedicate time to computer-based tasks. This reluctance may create opportunities for outsourcing data analysis and recommendation development.

REFERENCE

1- erstegen, J.A.A.M. 1998. Ph.D. thesis, Department of Economics and Management, Wageningen, Agricultural University, Wageningen, Netherlands.

2- Ess, D.R., Parsons, S.D., Strickland, R.M., 1997. Evaluation of commercially-available software for grain yield mapping. ASAE Paper No. 97-1033, American Society of Agricultural Engineers, St. Joseph, MI, USA.

3- Gelian, S,.Maohua, W,. Xiao, Y,. Rui, Y,.Binyun,. Z. 2012. on precision agriculture knowledge presentation with ontology AASRI Conference on Modeling, Identification and Control 3: 732ñ738.

4- Gibbons, G., 2000. Turning a farm art into science an overview of precision farming. URL: http://www.precisionfarming.com.

5- Hendrickson, L.L., Han, S., 2000. A reactive nitrogen management system. Proceedings of Fifth International Conference on Precision Agriculture (CD), July 16-19, Bloomington, MN, USA.

6- Naiqian, Z, Maohua, W, Ning W. 2002. Precision agriculture- worldwide overview. Computers and Electronics in Agriculture, 36: 113-132.

7- Qian P, Zheng Y, 2006. Study and Application of Agricultural Ontology .Beijing:China Agricultural Science and Technology Publishing House.

8- Runquist, S, Zhang, N., Taylor, R., 2001. Development a field-level geographic information system. Computers and Electronics in Agriculture 31: 201-209.

9- Shibusawa, S., 1998. Precision Farming and Terra-mechanics. Fifth ISTVS Asia-Pacific Regional Conference in Korea, October 20-22.

10- Smith, Katherine. 2002. ìDoes Off-FarmWork Hinder ëSmartí Farming? USDA Agricultural Outlook, Sept. p.28-30.

11- Stafford, J.V., 2000. Implementing Precision Agriculture in the 21st Century, Journal agriculture Engineering Research. 76:267-275.

12- Stafford, J.V., Evans, K., 2000. Spatial distribution of potato cyst nematode and the potential for varying nematicide application. Proceedings of Fifth International Conference on Precision Agriculture.

13- Whelan, B.M., Bratney, A.B., Boydell, B.C., 1997. The Impact of Precision Agriculture. Proceedings of the ABARE Outlook Conference, ëThe Future of Cropping in NW NSWí, Moree, UK, July 1997, p. 5.

14- Xie N, Wang W. 2007. Ontology and acquiring of agriculture knowledge.Agriculture Network Information, (8):13-14.

15- Maurya , D. K., Maurya , S. K., Kumar, M., Chaubey , C., Gupta, D., Patel , K. K., Mehta, A. K., & Yadav , R. (2024). A Review on Precision Agriculture: An Evolution and Prospect for the Future. *International Journal of Plant & Soil Science*, *36*(5), 363–374.

16- Krishnababu M E, Devi, B. R., Soni, A., Panigrahi, C. K., Sudeepthi, B., Rathi, A., & Shukla, A. (2024). A Review on Precision Agriculture Navigating the Future of Farming with AI and IoT. *Asian Journal of Soil Science and Plant Nutrition*, *10*(2), 336–349.

17- Khaspuria, G., Khandelwal, A., Agarwal, M., Bafna, M., Yadav, R., & Yadav, A. (2024). Adoption of Precision Agriculture Technologies among Farmers: A Comprehensive Review. *Journal of Scientific Research and Reports*, *30*(7), 671–686.

18- Kumar, A., Dogra, A., &Guleria, J. S. (2016). Sustainable Production Systems for Agriculture Development in Mountains of Himachal Pradesh, India. *Asian Journal of Agricultural Extension, Economics & Sociology*, *14*(1), 1–9.

19- Shafi, U., Mumtaz, R., García-Nieto, J., Hassan, S. A., Zaidi, S. A. R., & Iqbal, N. (2019). Precision agriculture techniques and practices: From considerations to applications. *Sensors*, *19*(17), 3796.

20- Sharma, A., Jain, A., Gupta, P., & Chowdary, V. (2020). Machine learning applications for precision agriculture: A comprehensive review. *IEEE Access*, *9*, 4843-4873.