Review Article

Using GIS or Geo FIS Tools for Decision-Support for Precision Agriculture: A Review

Abstract

Agriculture is a multifaceted discipline, encompassing a vast array of concepts and relationships. Precision farming is an agricultural production approach that acknowledges in-field variability, leveraging technology such as seeding, nutrient replacement, and spraying to local conditions. When practitioners have the means and resources to facilitate this change, the ideas of "precision agriculture" and "smart agriculture" will be completely realized. GeoFIS is an open-source program created with this goal in mind. Satellite-based Global Positioning Systems (GPS) have 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 the information companies provide have created barriers for potential adopters. This review paper provides a comprehensive examination of the global advancements and current state of precision agriculture technologies, with a specific focus on the integration of GeoFIS and GPS in precision agriculture.

Keywords: GeoFIS, 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 genetic engineering and automation, further transforming agricultural practices. 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 to 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, 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 is lagging. 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 health issues an account of excessive agrochemical 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. 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). Precision agriculture can be effectively implemented by refining traditional farming practices to maximize benefits in these unique, localized settings. The paper goal is to introduce the GeoFIS program (https://www.geofis.org/), which was created by a collaborative team from Montpellier SupAgro, INRA, and IRSTEA in France. This platform aims to give users current and trustworthy algorithms to process their precision agriculture data and integrate field experts' knowledge.

Precision Agriculture

Precision agriculture is a decision-making, information-based agricultural system that aims to enhance the farming process by carefully controlling every stage to guarantee optimal agricultural output and ongoing sustainability of natural resources. Three main functionalities for management (practical) applications have been incorporated within GeoFIS to address this. The effectiveness of "precision agriculture" or "smart agriculture" depends on sound decision-making. To enhance the administration of their domains, end users can convert these information levels into decision layers. Firstly, practitioners are provided with a method to delineate within-field homogeneous zones (Step 3.1). Second, although gathering data and information is typically centered on production-related concerns, its application is unrestricted. Both tactical and strategic decision-making can benefit from its application. The technical opportunity index uses the production data to assess a field's suitability for site-specific management given machinery constraints and the observed production variation (Step 3.2). This filter allows end-users to account for the passes of the agricultural machinery in the field and especially the minimum area (kernel) within which it can operate reliably. As the algorithm requires the data to be organized regularly on a grid, interpolating the data might therefore be required as a pre-processing step (Step 2). Decision support therefore requires dedicated data fusion methods to merge multiple information layers into a single decision layer (Step 3.3).

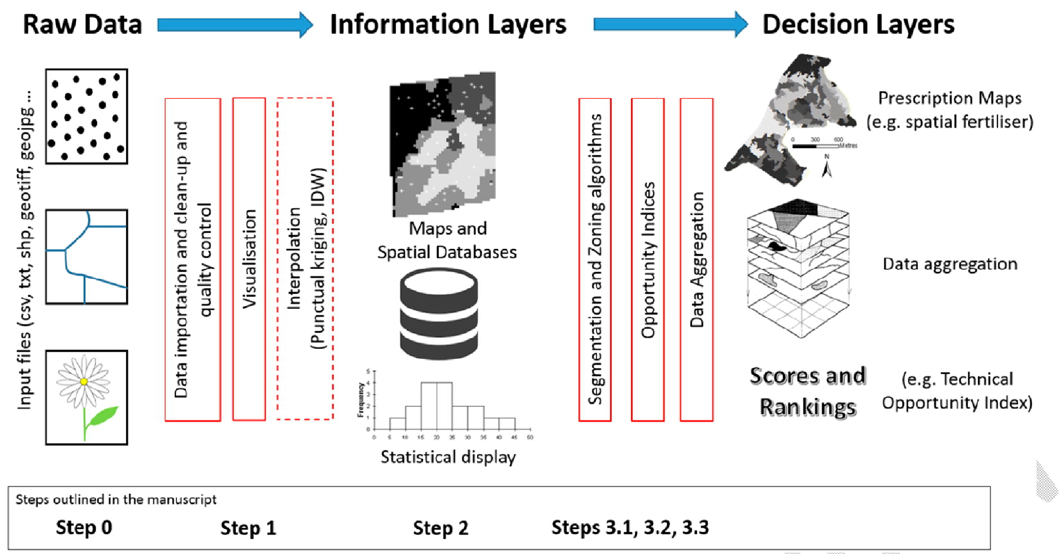

Figure 1. Generic flow of data in precision agriculture with main processing steps from raw data processing to decision-making.

Geo FIS Software

The purpose of GeoFIS is to make it easier to transform geographic data into spatial information and to make spatial decisions. The application is open-source and offers a straightforward interface for creating decision support systems (DSS) using spatial data (Leurox *et. al.*, 2018). GeoFIS deviates from other GIS software, e.g., QGIS, in the sense that specific tools have been implemented to answer the main expectations of agricultural professionals when it comes to processing precision agriculture data. GeoFIS is available in four languages (French, English, Spanish and Portuguese). The interface is designed with a man-machine cooperation objective. The goal is to facilitate the relationships between data, learning algorithms and expert knowledge. Documentation, scientific papers, and video tutorials are available to better understand the implemented function and to facilitate the adoption of the GeoFIS software.

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.

Geographic Information Systems (GIS) 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 helps in creating detailed maps of soil properties (e.g., moisture, texture, pH), which are crucial for optimizing fertilizer application and improving soil health. So, for better, precise and balanced fertilizer management in farm spatial fertility evaluation is very important (Mishra *et. al.*, 2023).

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 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 are 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. 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.

Conclusion

To handle and utilize the growing amount of precision agriculture data and encourage its adoption, free and open-source processing software must be developed. Therefore, the purpose of GeoFIS is to make it easier to transition from spatial data to spatial knowledge and spatial decision-making. 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. As it is, GeoFIS is an excellent tool to promote teaching in precision agriculture. Indeed, GeoFIS has already been used within many higher education institutions in France to teach researchers and professionals how to process spatial data. The user-friendly interface effectively facilitates the understanding of some major precision agriculture concepts.

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