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GIS-DRIVEN AGRICULTURE: REVOLUTIONIZING NATURAL FARMING PRACTICES: A REVIEW

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ABSTRACT

Incorporating Geographic Information Systems (GIS) into Natural Farming can significantly advance sustainable agricultural practices. This review explores the concept of Natural Farming and the diverse applications of GIS that support it. By integrating detailed spatial analysis and near real-time data, Natural Farming enhances traditional agricultural systems, leading to greater efficiency, productivity, and environmental sustainability. GIS can be applied for land suitability analysis and the management of nutrients, weeds, water, diseases, and pests. One of the major challenges today is increasing food production while minimizing environmental impacts. GIS offers a powerful tool to guide farmers adopting Natural Farming by enabling monitoring, real-time linkage with geodatabases, and improved decision-making for natural resource management. The successful use of GIS techniques in Natural Farming helps improve crop productivity by detecting issues such as pest attacks, nutrient deficiencies, and water stress early allowing for timely and precise corrective actions.

***Keywords* :** Natural farming, GIS, Remote sensing, Agriculture, Geoinformatics.

Introduction

The global population is rising and is projected to increase significantly by the end of 2050. Driven by this population growth, the global demand for food supplies is also expected to rise. FAO (2009) projects that feeding around 9.1 billion people by 2050 will require roughly a 70% increase in global food production relative to 2005–2007 levels. This will necessitate higher crop yields and additional arable land in the future. However, with rapid urbanization, agricultural land is continuously shrinking. Particularly in underdeveloped and developing countries, existing agricultural systems are unable to meet the growing food demand (WHO, 2019; Elahi *et al*., 2022b). Thus, increasing food production without causing environmental harm is the need of the hour.

Furthermore, climate change largely accelerated by human activities has become a critical global issue, significantly affecting natural ecosystems, human communities, and economic systems (Lial Filho *et al*., 2021; Shivanna, 2022). With the growing instability of the global climate system, agriculture occupies a pivotal position at the intersection of this crisis. It is one of the sectors most vulnerable to the adverse impacts of climate change, including rising temperatures, altered precipitation patterns, and increasing frequency and intensity of extreme weather events (Khatun *et al*., 2022; Khatun *et al*., 2024). These climate-induced factors seriously endanger crop yields and food security (Shahzad *et al*., 2021; Abbass *et al*., 2022; Villagran *et al*., 2024).

In response to the rising food demands of a growing global population, intensive agricultural practices have been adopted to some extent. Nevertheless, such measures have exerted significant environmental pressures, including soil degradation, depletion of water resources, biodiversity loss, and pollution resulting from excessive use of chemical fertilizers (Hendricks *et al*., 2019). This challenge calls for action by policymakers and decision-makers

(Godfray *et al*., 2010; Mathenge *et al*., 2022). Under these circumstances, more efficient land use and the sustainable utilization of existing natural resources along with the promotion of *Natural Farming* to minimize environmental impacts offer a potential pathway to meet the ever-increasing global food demand.

Natural Farming is a traditional, chemical-free farming system that integrates crops, trees, and livestock within a functionally diverse ecosystem. The concept of *Natural Farming* was popularized by Masanobu Fukuoka in his 1975 book *The One-Straw Revolution*, in which he advocated a return to nature-based agriculture (De, 2022). The Green Revolution not only transformed India from a food-deficient to a food-surplus nation but also resulted in negative outcomes such as soil degradation, biodiversity loss, and increasing cultivation costs. The injudicious use of chemical fertilizers and pesticides, coupled with declining crop productivity and climate change, has led to unremunerative agriculture. The resulting environmental and economic instability in farming created the need for new models of agriculture (Akhtar, 2018; Duddigan *et al*., 2023; Tatsumi *et al*., 2023).

There is a growing demand for efficient farming practices that are local, resilient, and adaptable (Ravindra *et al*., 2022). Natural Farming envisions ecological and regenerative agriculture by discouraging the use of any chemicals that disrupt soil biomes. It promotes multicropping, year-round soil cover, and the addition of formulations containing cow dung and urine to activate beneficial microorganisms, fostering completely chemical-free farming (Kumar *et al*., 2020). The Natural Farming system is well-suited for small and marginal farmers, utilizing local resources such as desi cow urine, cow dung, lime, gram flour, and soil. The microbial-rich components of Natural Farming enhance soil flora and mineralize macro- and micronutrients, making them available for plant uptake (Choudhary *et al*., 2022).

Natural Farming systems are non-degrading, non-depleting, and resource-conserving. They rely primarily on recycling biomass, restoring natural nutrient cycles biologically, and using plant and livestock inputs directly on the farm. Natural Farming practices include the use of formulations such as *Jeevamrit*, *Beejamrit*, and *Ghana Jeevamrit*, along with components like *Acchadana* (mulching) and *Whapasa* (soil aeration). Preparations such as *Brahmastra*, *Agniastra*, and *Neemastra* are used for pest and disease management, while techniques such as intercropping and the use of soil, straw, and live mulches are integral parts of the Natural Farming concept (Ravisankar *et al*., 2024). Food safety and nutritional security for future generations must be ensured through sustainable and viable approaches. Agroecological systems like Natural Farming have therefore gained even greater relevance in the current context (Datta, 2024).

Most developing economies, including India, remain heavily dependent on agriculture, with food production dominated by small and marginal landholders and subsistence farmers (Cheong *et al*., 2013). Promoting sustainability among these farmers requires access to near real-time and practical information that supports informed decision-making, thereby improving productivity and ensuring long-term resilience. To strengthen subsistence farming and increase market-oriented productivity—thereby enhancing employment and income generation—sustainable production technologies (Alexandratos and Bruinsma, 2012; Misselhorn *et al*., 2012) supported by sound agronomic practices are needed. This can be achieved through the integration of Natural Farming principles with efficient farm management.

Efficient farm management includes the adoption of high-yielding and stress-tolerant crop varieties, climate-resilient cultivation practices, yield forecasting, effective pest management, and biodiversity integration (Lanya *et al*., 2019; Elahi *et al*., 2022a). These innovations in traditional agricultural practices require comprehensive spatial and non-spatial data, supported by advanced geoinformatics, to develop multilayered agricultural datasets that include spatial, topographic, economic, and social dimensions. Such integration enhances understanding of agricultural sustainability, supports evidence-based decision-making, and improves knowledge dissemination.

Geoinformatics is an interdisciplinary field that combines Remote Sensing (RS), GIS, GPS, cartography, computer science, and information technology to collect, manage, analyze, and visualize data for more informed decision-making. It has wide applications across precision agriculture, environmental monitoring, urban planning, and disaster management. Geoinformatics comprises components such as theory, geo-information, geocomputation, technologies/systems, and applications, serving as a powerful tool for managing geographic and spatial data. The various components and subcomponents of geoinformatics (https://geopard.tech/blog/applications-of-gis-geoinformatics-in-agriculture/) are shown in Figure 1 and Figure 2.

Recent advancements in geoinformatics include the integration of technologies such as RS, Geographic

Information Systems (GIS), and the Global Positioning System (GPS). While RS technologies aid in collecting and acquiring imagery of varying resolutions related to crops and soils using sensors mounted on multiple platforms (García-Berná *et al*., 2020; Weiss *et al*., 2020), GIS provides methods for digitizing, analyzing, and visualizing spatial data (Merchant and Narumalani, 2009). From a spatial perspective, agriculture reflects the variability in farmers' access to livelihood resources, local assets, and essential infrastructure and services. Within a GIS, these dimensions can be represented as hierarchically organized spatial layers, each referenced to local geography through GPS-derived coordinates. The resulting spatial layers can be analyzed to derive insights into crop and soil conditions, spatial relationships, and temporal trends, facilitating land-use monitoring, pest surveillance, and biodiversity conservation planning. Furthermore, these datasets can be used to map and analyze spatial constraints affecting agricultural productivity and to generate new spatial insights that support strategies for sustainable agricultural development (Wang *et al*., 2011; Markoski *et al*., 2015; Mathenge *et al*., 2020; Li *et al*., 2021).

The growing complexity of modern agricultural production systems has prompted policymakers to harness the spatial dimension of agriculture through advanced geospatial technologies to optimize productivity and promote sustainable production practices (Clay and Shanahan, 2011; Thakur *et al*., 2017). The incorporation of GIS technologies into agricultural systems has enhanced the capacity to develop advanced frameworks with clear spatial delineation, supporting adaptive agricultural data systems and participatory decision-support platforms (Nie *et al*., 2010). These systems enable real-time interaction with spatially referenced agricultural data, providing accurate geolocation insights that enhance decision-support capabilities. Consequently, several emerging domains have evolved from the application of GIS in agriculture, including precision farming, automated agricultural systems, yield prediction, climate change assessment, and continuous crop monitoring (Dunaieva *et al*., 2018; García-Berná *et al*., 2020; Weiss *et al*., 2020). GIS contributes to water and biomass management by tracking plant growth, supporting carbon storage research, and advancing climate-adaptive farming methods. Numerous studies have demonstrated these applications of GIS (Guerrero *et al*., 2016).

Such systems improve agricultural productivity and contribute significantly to food security. Several reviews have highlighted and synthesized the diverse applications of geoinformatics technologies in the agricultural sector (e.g., Sharma *et al*., 2018; García-Berná *et al*., 2020; Weiss *et al*., 2020; Al-Ismaili *et al*., 2021). Based on an extensive review of the literature, Sharma *et al*. (2018) emphasized the potential of big GIS data to drive transformative solutions to issues such as shrinking arable land, increasing resource demand, and environmental stress. While studies on GIS applications in agriculture (Kingra *et al*., 2016; Gebeyehu, 2019; Ghosh and Kumpatla, 2022) have expanded, their deliberate implementation to advance Natural Farming within an integrated framework remains limited. Existing reviews do not explicitly address how these technologies can facilitate the integration of agriculture's spatial dimension into the concept of Natural Farming.

Thus, this review highlights various applications of GIS in the agricultural sector and discusses how geolocation-based information systems can enhance and promote Natural Farming practices. GIS in Natural Farming uses spatial data such as soil maps, topography, and satellite imagery to create a holistic view of farm conditions, enabling informed, data-driven decisions for optimized resource use and reduced environmental impact. It supports practices such as precision planting, targeted irrigation, and customized nutrient management, which align with Natural Farming principles by enhancing soil health, minimizing chemical inputs, and preserving biodiversity. GIS helps farmers monitor crop health, manage water efficiently, and predict or mitigate risks from natural hazards, ultimately improving productivity and sustainability. Farmers can enhance accuracy, profitability, and adaptability in a rapidly evolving agricultural landscape by adopting GIS-driven strategies (Toromade and Chiekezie, 2024). GIS thus offers multiple valuable applications in Natural Farming, helping farmers manage their land more sustainably and efficiently.

Potential Applications of GIS in Natural Farming

While the key applications of GIS in promoting Natural Farming practices are broadly discussed in the following subsections, the major limitations are summarized in Table 1.

Land Suitability Analysis

Land suitability analysis for a specific crop—or multiple crops is primarily based on multi-criteria decision-making (MCDM) approaches supported by GIS (Topuz and Deniz, 2023; Yang *et al*., 2025). Zolekar and Bhagat (2015) employed a GIS-based MCDM model incorporating remote sensing (RS) imagery to assess agricultural practices in mountainous regions. The importance of various criteria was ranked using correlation analysis and insights from scientific literature. The integration of RS with GIS proved effective for evaluating land suitability.

Currently, researchers are exploring the integrated application of GIS and artificial intelligence (AI) to enhance land-use planning effectiveness (Singha and Swain, 2016). Yohannes and Soromessa (2018) applied MCDM within a GIS framework to determine land suitability for wheat and barley cultivation in Ethiopia. Their findings revealed that existing land-use patterns often overlook the most suitable cultivation areas, emphasizing the need for improved land management measures to increase agricultural efficiency and long-term sustainability.

Shokr *et al*. (2021) integrated topographic information derived from a digital elevation model and RS data with biological, physical, and chemical soil properties in a spatially explicit soil quality model to create detailed soil maps. Abdellatif *et al*. (2021) developed a soil quality index by combining fertility, physical, chemical, and geomorphological indicators. Safnathmol *et al*. (2022) assessed soil quality in Kerala's *kole* lands following the devastating 2018 floods. They analyzed physical, chemical, and biological soil quality indicators using principal component analysis and the weighted additive method to develop a soil quality index. GIS-based thematic maps were then generated to provide information on soil fertility status for paddy cultivation.

GIS supports detailed mapping of soil type, nutrient levels, pH, moisture, and topography, allowing identification of field areas requiring specific management attention (AbdelRahman *et al*., 2025). GIS-based methods can evaluate soil quality at both farm and regional scales (Goswami *et al*., 2021; Louzada *et al*., 2025), with spatial resolution depending on the precision of the sensors used. Overall, GIS aids land suitability assessment by analyzing variables such as soil characteristics, topography, precipitation, and land use to determine optimal crop locations while promoting ecological balance.

Nutrient and Weed Management

Xie *et al*. (2012) demonstrated how GIS can be used to develop a Fertilizer Decision Support System (FDSS) by integrating diverse data sources such as remote sensing imagery, field survey information, and expert knowledge. Using the SuperMap platform, these datasets were combined into a comprehensive spatial soil database, enabling precise mapping of nutrient levels and soil conditions across farm areas. The FDSS provided site-specific fertilizer recommendations, optimizing nutrient application, improving crop yield, and minimizing environmental impact. Its use enhanced fertilizer efficiency, reduced input costs, and promoted sustainable nutrient management.

Dunaieva *et al*. (2018) used GIS to create accurate maps of weed distribution in rice fields, which improved input efficiency and reduced herbicide, fungicide, and labor requirements, thereby lowering production costs. Accurate mapping of weed distribution significantly improves weed control efficiency, reduces crop losses, minimizes herbicide dependence, and optimizes fertilizer use (Golmohammadi *et al*., 2020).

While GPS, GIS, and RS are essential for data collection and analysis, Variable Rate Technology (VRT) applies this information to execute precision agriculture. VRT systems use detailed field data including soil properties, yield records, and pest or weed presence to determine precise application rates for fertilizers, pesticides, and herbicides. This targeted approach reduces input waste and production costs. The integration of GIS, GPS, and VRT provides farmers with powerful tools to visualize field conditions and apply resources more efficiently, thereby increasing productivity (Ghosh and Kumpatla, 2022).

Çolak *et al*. (2025) compared traditional and modern wheat weed management methods and evaluated AI-supported systems, hyperspectral imaging, GIS, and sensor-based technologies. They concluded that integrating AI with these tools provides cost-effective and environmentally friendly solutions. Hence, in the context of Natural Farming, GIS supports optimal nutrient allocation and reduces labor costs associated with weeding.

Disease and Pest Management

GIS plays a vital role in managing crop diseases and pests (Singh *et al*., 2023a; Schieler *et al*., 2024). Santoso *et al*. (2011) used high-resolution satellite imagery to identify the spread and arrangement of oil palm trees affected by basal stem rot, employing various indices to distinguish diseased from healthy plants. RS technologies, including satellite and aerial imagery captured during the crop growth season, have been applied to detect crop diseases in their early and mid-growth stages, enabling management of recurrent outbreaks. Additionally, RS data have been used to assess monetary losses caused by frost (Lou *et al*., 2013).

Bolo and Mpoeleng (2019) used GIS to map bird infestations in Botswana, applying overlay and buffer analyses to delineate pest concentration zones and ecological parameters, thereby supplying crucial spatial information for precision pest management. Yang (2020) demonstrated the use of RS-based precision agriculture to apply fungicides specifically to infected areas, enhancing control efficiency. GIS also supports non-chemical pest control by identifying areas prone to infestations or diseases based on spatial and environmental patterns. The integration of GIS with meteorological models enables forecasting of biotic stress risks, allowing proactive and flexible management (Rano *et al*., 2022).

Integrating GIS with Natural Farming practices for pest and disease monitoring and management can substantially reduce the need for chemical herbicides and pesticides.

Soil Health and Fertility Management

Soil fertility is critical for crop productivity, influencing nutrient and water availability. However, soil fertility is declining due to pollution, waterlogging, overuse of agrochemicals, and erosion. GIS overlays multiple spatial data layers to identify patterns and relationships that inform soil management decisions. It maps soil nutrient status, pH, and moisture, guiding fertilization, irrigation, and land management strategies (Singh *et al*., 2023b; Lanki and Onwu, 2024).

Li and Zhang (2011) applied fuzzy mathematics in a GIS platform using indicators such as soil organic matter, total and available nitrogen (N), phosphorus (P), potassium (K), pH, and cation exchange capacity. Their study revealed that mid- and low-yielding fields had poor fertility closely linked to soil structure. Rezaei *et al*. (2015) examined the combined use of GPS and GIS to optimize precision nutrient application and demonstrated enhanced nutrient efficiency with reduced resource wastage. Bias-correction and assimilation of satellite-derived soil-moisture data, as demonstrated by Sridhar *et al*. (2013), can significantly enhance GIS-based soil-fertility mapping and management frameworks for Natural Farming. AbdelRahman *et al*. (2016) integrated RS and GIS to evaluate soil fertility, using LISS III and IV imagery for land-use classification and applying the RUSLE model to estimate erosion.

Mokarram and Hojati (2017) employed inverse distance weighting in GIS to generate nutrient maps and used ordered weighted averaging for standardization, which served as input to a fuzzy inference system to produce fertility maps. Suleymanov *et al*. (2021) illustrated the use of GIS to delineate nutrient distribution across soil landscapes based on topography, enabling efficient fertilizer use and resource optimization.

The strong link between soil fertility and productivity highlights the importance of GIS-based soil maps for site-specific management strategies, particularly within Natural Farming systems.

Water Management

Long-term climate and diversion analyses in the Snake River Basin illustrate how climatic variability shapes irrigation scheduling and surface-water allocation decisions (Hoekema and Sridhar, 2011). Integrating such hydrologic indicators within a GIS environment can guide Natural Farming water-use strategies. Integrated models that link surface- and groundwater systems, such as the System Dynamics–Snake River Planning Model (Hoekema and Sridhar, 2013), illustrate the potential of combining GIS-enabled simulations with hydrologic feedbacks to optimize irrigation scheduling and aquifer sustainability under varying climatic conditions. Irrigation is essential for meeting agricultural water needs, and GIS combined with RS has proven highly effective in water resource management (Elhag, 2016). Fortes *et al*. (2005) integrated the ISAREG irrigation scheduling model with GIS to improve irrigation planning and salinity management, demonstrating the model’s efficiency during both wet and dry periods.

Although irrigation increases yields, Singh (2016) highlighted soil salinization and waterlogging as significant issues linked to excessive irrigation, emphasizing GIS and RS for monitoring and mitigation. El Behairy *et al*. (2021) used GIS to assess irrigation water quality in Egypt, identifying spatial variations in suitability and heavy metal contamination. Zolfaghary *et al*. (2021) analyzed the feasibility of using treated urban wastewater for irrigation through MCDM and analytical hierarchy process methods, revealing that wastewater suitability depends on crop type, nitrate levels, and aquifer vulnerability.

Tarate *et al*. (2024) reviewed the importance of RS and GIS for water management in India, emphasizing groundwater depletion from intensive pumping. GIS supports irrigation scheduling by analyzing terrain, soil moisture, and drainage to identify drought- or flood-prone zones, ensuring efficient water use and minimizing erosion. By understanding spatial variability, farmers can apply water and organic fertilizers precisely where needed, reducing waste and environmental impacts.

Agricultural Drought Risk Assessment

GIS-based techniques are valuable for modeling and mapping agricultural droughts (Alshaikh, 2015). Sehgal and Dhakar (2016) compared intra-seasonal drought vulnerability during the *kharif* season at a local scale, while Sarkar *et al*. (2020) used rainfall-based indices such as NDVI and SPI for drought characterization. These studies provided crucial insights for drought monitoring and water management.

Hoque *et al*. (2021) integrated fuzzy logic with GIS to model agricultural drought risk in Bangladesh, incorporating hazard, vulnerability, and adaptive capacity indices. Their spatial risk maps aid policymakers in designing targeted drought mitigation strategies. High-resolution hydrologic modeling frameworks have successfully mapped drought dynamics in transboundary basins such as the Mekong (Kang and Sridhar, 2021), offering transferable methodologies for geospatial drought assessment in Natural Farming landscapes. Aziz *et al*. (2022) combined meteorological and soil water-holding data to identify drought-prone areas, supporting policy formulation for drought-tolerant crops. Recent GIS-based vulnerability assessments in semi-arid India highlight the need for localized drought-risk mapping to support Natural Farming adaptation (Kamalamma *et al*., 2023). Alito and Kerebih (2024) emphasized the utility of RS and GIS in estimating spatial and temporal drought extents. John and Philip (2025) developed a drought vulnerability index for semi-arid regions by integrating exposure, sensitivity, and adaptive capacity indicators, producing district-level frameworks for crop insurance and drought response. Thus, GIS demonstrates strong potential in managing natural inputs and mitigating the adverse effects of agricultural droughts.

Climate-Informed Agriculture

Agroecological farming leverages local ecosystems and biophysical factors to promote crop diversification, enhance productivity, and strengthen smallholder livelihoods (Guareschi *et al*., 2020; Aghaloo and Sharifi, 2023). GIS applications in mapping climate risks such as droughts and floods are increasingly widespread. By integrating climatic, soil, and land-use data, GIS identifies vulnerability hotspots and informs tailored adaptation measures (Mălinas *et al*., 2022).

Integrating bias-corrected climate projections and downscaled hydroclimatic datasets within GIS frameworks further strengthens climate-informed decision-making in sustainable agriculture, particularly by improving evapotranspiration and irrigation-demand estimations essential for adaptive water management (Jaksa and Sridhar, 2015). Kadiyala *et al*. (2015) combined GIS and crop simulation models in a web-based tool to assess climate change impacts on groundnut production in India. Kahsay *et al*. (2018) integrated GIS, fuzzy set modeling, and analytical hierarchy process to evaluate sorghum suitability under varying soil, climate, and topographic conditions. Guo *et al*. (2019) analyzed 36 years of data on droughts and floods in China, revealing a sharp rise in climate-related disasters and associated grain losses, underscoring the need for robust drought and flood management strategies.

Seif-Ennasr *et al*. (2020) applied GIS-based MCDM to assess climate change impacts on land suitability, water demand, and crop season duration, revealing reduced suitability and shorter growing periods. Varela *et al*. (2022) demonstrated that integrating GIS-informed risk assessment with agricultural adaptation planning strengthens regional resilience in the Philippines. Giannarakis *et al*. (2022) combined GIS with machine learning to enhance land suitability analysis, highlighting the importance of spatial data for sustainable, climate-resilient agriculture.

Crop Growth and Yield Assessment

Extensive research highlights the value of integrating GIS and RS to improve crop yield prediction accuracy. Accurate assessment of crop growth dynamics and yield forecasting is vital for food security and agricultural policy planning (Al-Gaadi *et al*., 2016; Houshyar *et al*., 2017; Mann and Warner, 2017). Hochman *et al*. (2013) proposed a framework integrating statistical yield data, RS-based crop simulation, and GIS spatial analysis to map wheat yield gaps. Muslim *et al*. (2015) applied the Environmental Policy Integrated Climate (EPIC) model in a GIS environment to simulate rice yields, integrating soil, management, and climatic data.

Al-Gaadi *et al*. (2016) used Landsat-derived spectral indices, such as NDVI and SAVI, at various potato growth stages to model and predict yields. Memon *et al*. (2019) demonstrated that multispectral Landsat imagery effectively quantified wheat straw cover and assessed its influence on rice yields. Hassan and Goheer (2021) showed that MODIS-based vegetation indices combined with GIS modeling allow early and accurate wheat yield estimation.

Mathenge *et al*. (2022) emphasized that GIS- and RS-integrated yield forecasting models are critical for spatially explicit agricultural policymaking. These models inform targeted interventions addressing yield drivers such as management practices, weather variability, water resources, and terrain (Hochman *et al*., 2013; Wang *et al*., 2014). Gumma *et al*. (2024) underscored the importance of accurate crop yield data for national food security and export planning, using machine learning and RS data to generate detailed crop maps and yield assessments.

Assessing crop growth and early-stage yield forecasting are essential for developing food security strategies and projecting agricultural economic outcomes. Recent developments in RS and GIS have greatly improved the precision and efficiency of crop monitoring and yield estimation. Overall, these studies demonstrate the substantial potential of geoinformatics in advancing Natural Farming by promoting data-driven, sustainable cultivation practices.

Discussion

GIS is vital in precision farming because it offers location-specific analysis tools that improve accuracy, efficiency, and sustainability at the farm scale. A major advantage of GIS in precision agriculture is its capacity to produce descriptive, layered maps illustrating attributes related to soil, water, and crops (Mathenge *et al*., 2022). These layers enable spatial analysis of input applications and within-field variability, supporting optimization of resource use. However, its potential remains underutilized in regions with limited access to technology. In the present context, precision farming is increasingly promoted. Precision agriculture is a data-driven approach designed to enhance productivity and maintain long-term environmental sustainability by monitoring and managing each stage of the farming process (Tayari *et al*., 2015). Combining bias-corrected climate data, remote-sensing soil-moisture observations, and hydrologic indices provides a robust geospatial framework to support resource optimization in Natural Farming (Sridhar *et al*., 2013; Hoekema & Sridhar, 2011)

By contrast, Natural Farming emphasizes nature-based inputs with the primary objective of minimizing the harmful environmental impacts of practices such as the use of chemical fertilizers and pesticides. Many farmers remain unfamiliar with Natural Farming practices and how GIS can help strengthen the concept operationally. Developing countries like India are promoting Natural Farming to a significant extent. Integrating Natural Farming with GIS can create a comprehensive agricultural and information-management system that minimizes environmental risks while enhancing overall farm productivity and efficiency at low cost.

GIS has proven valuable for mapping natural resources at both small and large farm scales. Nevertheless, concern is growing that agricultural production systems may struggle to meet rising demand particularly in developing countries—potentially worsening food insecurity. GIS can support regulatory implementation and provide visual representations of how policies may affect the economy (Raihan and Tuspekova, 2022; Boda *et al*., 2023). It has been effectively applied to monitor crop condition, growth periods, and multiple stresses. Studies demonstrate its value in predicting crop yields by analyzing long-term datasets on climate patterns and soil conditions, thereby helping to optimize harvest timing and resource allocation. GIS enhances monitoring and yield forecasting by integrating spatial data with predictive models; its strength lies in improving forecast accuracy through geospatial insights, though regular data updates and locally adapted crop models are required for full effectiveness.

GIS also supports efficient management of biomass and water by analyzing spatial patterns of water availability and biomass productivity, enabling large-scale resource planning. However, the reliability of water-related information can be affected by climatic fluctuations and gaps in monitoring records. GIS can help reduce the impacts of biotic and abiotic stresses by using spatial layers to identify regions vulnerable to pest infestations, salinity, or water stress. It effectively visualizes spatial and temporal stress patterns across regions, though it depends on timely observed or remotely sensed data. By generating spatial representations of erosion risk and land degradation, GIS aids soil conservation and sustainable land management; here again, data reliability may be constrained by regional inconsistencies or limited temporal coverage.

GIS assesses climate risk and vulnerability by pinpointing areas susceptible to floods, droughts, and thermal stress through the overlay of location-specific datasets. It is highly proficient in analyzing and mapping spatial information, but accuracy depends on the robustness of the climate models employed. By facilitating near real-time observation of extreme weather, GIS strengthens early-warning systems. It is also instrumental in evaluating losses to guide recovery initiatives and inform policymakers. However, effective logistics and emergency mapping require the timely incorporation of accurate meteorological information. Furthermore, GIS-based models can evaluate crop suitability under climate change, assisting in crop selection. GIS facilitates sustainable land-use planning by analyzing soil properties, temperature fluctuations, and rainfall data, helping align farming practices with environmental constraints and anticipated climate conditions (Memarbashi *et al*., 2017; Masoudi *et al*., 2021). GIS also supports monitoring and assessment of climate-adaptation strategies by tracking their temporal and spatial impacts. Such evaluation is effective but requires the integration of both spatial modeling and sustained temporal monitoring.

Integrating GIS with Natural Farming can enhance yields, enable targeted crop management, and reduce reliance on agrochemicals. For instance, several studies show that RS imagery can effectively capture spatial variability in wheat production within a farm (Toscano *et al*., 2019). While GIS use in agriculture is well researched, areas such as land-suitability assessment, site monitoring and selection, resource distribution, impact evaluation, and knowledge-based systems are still developing. Moreover, the application of GIS specifically within Natural Farming remains relatively underexplored. As a versatile toolset for storing, accessing, and analyzing spatial data, GIS can be especially valuable for understanding and visualizing Natural Farming environments and processes. Thus, as noted by Mani *et al*. (2021), a farm cannot achieve productivity and success without maintaining a balance between inputs and outputs, and integrating GIS with Natural Farming can help achieve this balance.

Conclusion

GIS integrates diverse spatial datasets such as field boundaries, soil maps, weather records, and satellite imagery into a unified digital map. By analyzing these layers, farmers can identify spatial patterns and relationships among various environmental and management factors. This spatial understanding enables targeted, data-driven decision-making for crop monitoring, resource allocation, and farm planning, thereby aligning with the principles of *Natural Farming*.

Using GIS, it is possible to assess historical weather data and climate models to predict future climatic trends and evaluate their potential implications for agriculture. Such insights enable farmers to adopt adaptive practices, including selecting crop varieties that are less sensitive to climatic variability and adjusting planting schedules accordingly. GIS also supports identifying suitable locations for adopting site-specific strategies that enhance soil quality and biodiversity.

Overall, GIS empowers farmers to optimize resource utilization and tailor *Natural Farming* practices to local conditions. As GIS technologies continue to advance, their role in agriculture will become increasingly critical to meeting growing food demands while ensuring sustainability and resilience in a changing climate. However, the application of GIS in *Natural Farming* remains at a relatively nascent stage. This review of existing literature highlights the potential of geospatial technologies to transform *Natural Farming* systems and reduce the environmental impacts of conventional agricultural practices.

Limitations

The findings presented in this review are based exclusively on literature published between 2010 and 2025. Although this timeframe may have excluded valuable earlier research, the intent of the study was to capture the most recent advancements in the application of GIS in agriculture and to establish a foundation for exploring its potential role in promoting *Natural Farming* practices aimed at reducing the environmental impacts of agriculture. Therefore, the selected body of literature should be viewed as comprehensive but not exhaustive in its coverage of the topic.

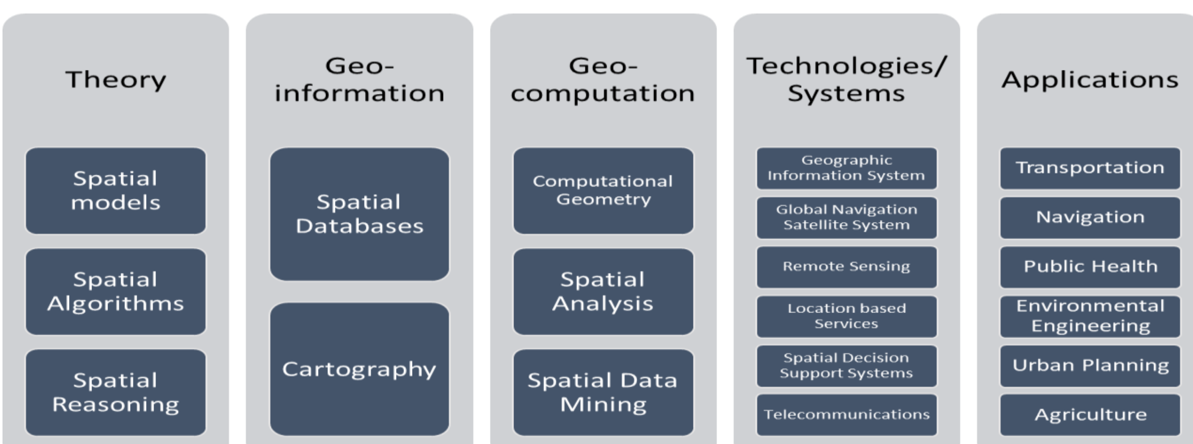

Fig. 1 : Components and sub-components of geo-informatics.

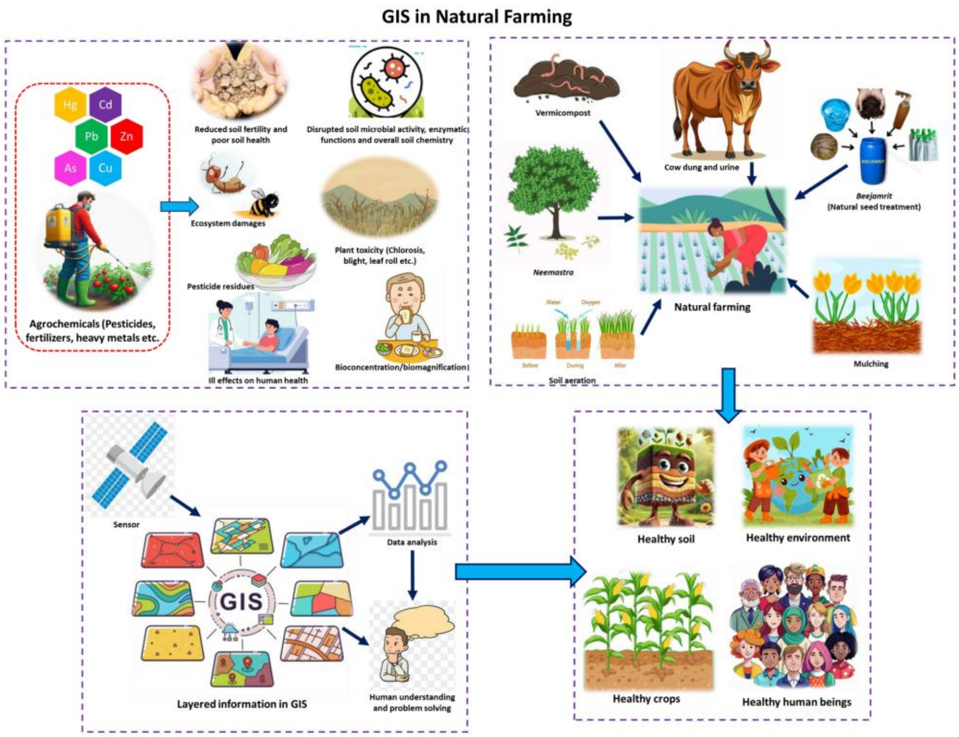

Fig. 2 : GIS in Natural Farming.

Table 1 Limitations of the potential applications of GIS in natural farming

Application of GIS	Limitation
Land suitability analysis	1. Mapping has to be done separately for each crop. 2. Multi-criteria analysis methods are highly subjective in allocating weights.
Nutrient and weed management	1. One has to be cautious when dealing with highly volatile or unstable nutrients. 2. Difficult to map and segregate the weeds using their spectral signatures.
Disease and pest management	1. Due to varied characteristics of various crop diseases and pests, differentiation among them is difficult 2. Requires high skills of the operator/farmer for remote sensing data analysis.
Soil health and fertility management	1. Requires good quality soil datasets. 2. Needs time series data of soil nutrients with high temporal resolution.
Water management	1. Requires consistent and continuously monitored water quality data. 2. Different countries may have different suitability standards.
Agricultural drought risk assessment	1. Very limited number of studies on local-scale agricultural drought risk assessment are available. 2. Requires high resolution remote sensing data.
Climate-informed agriculture	1. Requires spatiotemporal monitoring and modelling. 2. Modelling analyses are largely dependent on the spatial resolution of climate data.
Crop growth and yield assessment	1. Requires good quality input (weather, soil, land use etc.) data. 2. Analyzes long-term data and cannot predict crop yield in real time.

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