

# **GEOGRAPHIC INFORMATION SYSTEM(GIS) APPLICATION IN SOIL FERTILITY MANAGEMENT: A REVIEW**

## ***Abstract***

As the global population expected to reach 10 billion by 2050 and arable land decreases, innovative soil management strategies are required to maximize agricultural productivity while preserving natural resources. GIS, as a powerful technology, offers a comprehensive solution by enabling the collection, storage, analysis, and visualization of spatial data for agricultural purposes. By integrating GIS with sensors, communication technologies, and data analytics, precision agriculture is possible, allowing for efficient use of agricultural inputs and reduced environmental impact. GIS technology facilitates the simulation and modeling of biological ecosystems, providing valuable insights for sustainable soil management. It has diverse applications in agriculture, ranging from soil nutrient mapping to yield estimations and runoff detection. GIS works by overlaying various layers of information onto digital maps, allowing for the identification of relationships and patterns that are crucial for optimizing soil fertility. Detailed maps created through GIS highlight the distribution of soil nutrients, pH levels, and moisture content, enabling informed decision-making on fertilizer use, irrigation techniques, and land management practices. By harnessing the power of GIS, farmers and land managers can make data-driven decisions that maximize agricultural productivity, conserve resources, and protect soil health for future generations. The integration of GIS with other technologies further enhances its effectiveness in soil fertility management. Overall, GIS is a valuable tool for understanding and managing soil fertility, contributing to sustainable agriculture and food security.

Keywords: Soil fertility management, Geographic information system, Food security, Soil fertility maps.

## **1.1: Introduction**

Geographic Information System (GIS), a key foundational technology, is a powerful system comprising tools for the collection, storage, and retrieval of data, as well as analyzing, transforming, and displaying the spatial data for a specific purpose (Burrough *et al.*, 1998; Gomiero 2013).

We need to produce almost 50% more food to meet the world's need because the population is predicted to reach 10.0 billion in 2050 if it continues to increase (FAO 2017). The issues of climate change, the finite amount of arable land that can be expanded, and the depletion of water supplies must all be addressed in order to achieve this aim. In order to maintain soil health, save water resources, and protect biodiversity, the projected food production must also include sustainable agricultural management techniques (Gomiero 2016).

There is an unprecedented demand for crop growth and health monitoring, as well as prompt interventions to maintain or increase agricultural output while minimizing input and resource waste, in light of these obstacles and limits in reaching our food production targets (Gomiero 2016). We can complete these duties because to advancements in sensors, communication technologies, computer systems, and potent data analytics. Achieving food security requires technologies that can boost and sustain production, minimize environmental losses, and facilitate the efficient use of agricultural inputs (Çakmakçiet al., 2023). Precision agriculture is an integrated information and agricultural management system composed of various existing and emerging technologies, including remote sensing (RS), geographic information systems (GIS), and the global positioning system (GPS) (Delgado et al., 2019). To enhance agricultural output and protect the environment, precision agriculture involves obtaining timely geospatial data on the needs of the soil, plants, and animals as well as recommending and administering remedies for particular places (Çakmakçı et al., 2023).

GIS technology is increasingly being used to create models that simulate the dynamics of complicated biological ecosystems (Yang *et. al.*, 2004). In addition to maps, GIS enables for the development of visuals, animations, and other cartographic outputs (Bingfng and Chenglin, 2000).

Additionally, GIS is having an impact on a wide range of fields, such as industry, finance, health services, forestry, food, geography, environmental sciences, and natural resources (Soomro 2015). The use of GIS technologies for a variety of local, regional, national, and international agricultural applications has grown significantly in recent decades (Gebeyehu 2019). In order to gain a thorough understanding of a particular farm or region and to provide intervention or corrective actions for the crops and/or soils, these applications typically entail the use of GIS in

conjunction with partner technologies like remote sensing, GPS, and data analytics (Kingra et al., 2019). Another benefit of GIS is that the same data can be used for multiple applications or objectives because they are linked to a common referencing system. We can also incorporate new data and, when combined with the existing data, conduct a collaborative analysis to generate new insights (Kazemi and Akinci 2018).

Geographic Information Systems (GIS) are becoming increasingly important in agricultural production worldwide. From mobile GIS in the field to scientific production data analysis at the farm manager's office, GIS helps farmers increase productivity, reduce costs, and better manage their land (Bingfng and Chenglin, 2000). Although it is challenging to fully control natural inputs in agriculture, GIS applications like runoff detection and remediation, soil supplement evaluations, and agricultural yield estimations may be able to assist us in better understanding and managing the soil for the best crop production (Çakmakçiet al., 2023).

## **2.0: How GIS Works**

Computer programs known as Geographic Information Systems (GIS) are used to collect, store, verify, and present data pertaining to locations on Earth's surface (U.S. Geological Survey, 2022). By linking data to a map and combining location data—which tells us where things are—with descriptive information—which tells us what they're like—they assist people and organizations in understanding spatial patterns and linkages (NGE, 2022). It is essential to comprehend the fundamentals of GIS and how they operate in order to optimize soil fertility.

Fundamentally, GIS allows us to superimpose many layers of data onto a computerized map, including soil types, topography, climatic patterns, and land use (Li and Ahmed 2019). This allows us to see connections, patterns, and trends that would otherwise be hard to notice (Ghosh and Kumpatla 2022).

The basis of GIS is geographic referencing, which associates each data point with a specific location on Earth's surface (Yao et al., 2020). This geospatial context allows us to manage, store, and analyze data in a way that is both aesthetically pleasing and spatially accurate (Ravi and Shah 2018).

The distribution of soil nutrients, pH levels, moisture content, and other pertinent variables can all be highlighted in great detail on maps made with GIS (Ghosh and Kumpatla 2022). We may

learn more about the best ways to use fertilizers, irrigation methods, and land management strategies by combining this spatial data with historical knowledge and crop-specific requirements (Singh 2022). In order to comprehend the possible effects of various farming techniques on soil fertility, GIS can also model and simulate scenarios (Patel & Kumar 2022). Farmers and land managers can limit environmental degradation, maximize land productivity, and make well-informed decisions thanks to this predictive capability (Li et al., 2021).

We can significantly improve our understanding of soil fertility by utilizing the abundance of information that can be unlocked by utilizing GIS (Liet al., 2020). It gives us a thorough and spatially explicit picture of our land, empowering us to make data-driven decisions that maximize farming productivity, preserve resources, and manage our soils in a sustainable manner for future generations (Shah et al., 2019).

### **2.1: Application of GIS in Soil Fertility**

According to Patel and Singh (2020), productive agriculture depends on healthy soil. It speaks to the soil's capacity to supply necessary nutrients and encourage the growth of healthy plants (Adams 2022). It is critical for growers and farmers to comprehend the importance of soil fertility and how it directly affects crop productivity and the sustainability of agriculture as a whole (Thompson 2016). Plants struggle to grow and thrive in soil that is deficient in essential nutrients (Davis 2019). Reduced yields, heightened vulnerability to pests and diseases, and generally subpar crop quality can result from this (Ahmed et al., 2021). However, as Rodriguez & Cooper (2022) argue, well-fertile soil offers a rich foundation for robust plant growth, which results in increased yields, improved crop quality, and a more sustainable farming system.

Numerous elements contribute to soil fertility, such as organic matter, pH, nutrient concentration, and soil structure (Gonzalez 2020). According to Young (2017), every one of these elements is essential to establishing the ideal environment for plant growth. For plants to develop, certain nutrients like potassium, phosphate, and nitrogen must be present in sufficient amounts (Li & Zhou 2018).

Clark (2020) emphasizes that there is no one-size-fits-all method for understanding soil fertility. The needs and content of nutrients vary throughout soil types (Patel 2019). According to Kumar (2021), this is where Geographic Information Systems (GIS) are useful. Farmers and

agronomists can use GIS technology to map and evaluate soil features, which helps them plan crops and manage nutrients more effectively (Ravi & Singh 2017).

Farmers can use GIS to produce comprehensive maps of soil fertility that show differences in nutrient levels in different areas of their fields (Wu et al., 2019). Zhou & Li (2020) have shown that this information can subsequently be utilized to strategically apply soil amendments or fertilizers, ensuring that each area receives the right nutrients based on its unique requirements. Shah emphasizes that this precise method dosage decreases input costs, lessens the environmental effect of excess nutrient application, and maximizes crop output (2022).

According to Clark (2020), farmers can optimize nutrient management practices, increase crop yields, and contribute to a sustainable and effective agricultural system by utilizing technologies such as GIS and understanding the fundamental importance of soil fertility.

## **2.2: Role of Geographic Information Systems (GIS) in Maximizing Soil Fertility**

According to Kumar & Ravi (2022), Geographic Information Systems (GIS) are essential for optimizing soil fertility. They offer a potent instrument for deciphering and assessing the intricate connections between geographical features, climatic patterns, and soil properties. (The Shah, 2022).

According to Patel & Rana (2018), GIS enables farmers and other agricultural professionals to gather, store, handle, and evaluate vast amounts of spatial data pertaining to soil fertility. A comprehensive picture of the soil landscape is provided by GIS, which integrates multiple layers of data, including topography, nutrient levels, soil composition, and organic matter content (Li et al., 2021).

According to Wu & Shah (2019), one of the main benefits of GIS is its capacity to produce precise and thorough maps that show the geographical distribution of soil attributes. According to Singh (2017), these maps help farmers identify regions with different fertility levels and make well-informed decisions about irrigation, crop selection, and nutrient management.

Moreover, as shown by (Zhou et al., 2022) GIS may be used to track changes in soil fertility over time. Farmers can evaluate the success of their management techniques and pinpoint areas in

need of more care or development by superimposing historical data with current information (Ahmed & Kumar 2020).

According to Young & Li (2022), the integration of GIS with other agricultural technology is another crucial feature. For instance, farmers can obtain real-time data on soil moisture, temperature, and nutrient levels by integrating GIS with precision agricultural techniques like remote sensing (RS) and global positioning system (GPS). By using this information, herbicides, fertilizers, and water resources may be applied precisely and strategically, reducing waste and increasing agricultural output (Patel et al., 2019).

Shah (2022) asserts that Geographic Information Systems (GIS) offer a priceless tool for optimizing soil fertility. Farmers can apply sustainable agricultural techniques, allocate resources optimally, and make well-informed decisions by evaluating and displaying spatial data (Singh & Kumar 2021). Using GIS technology enables farmers to increase output, cut expenses, and support the farming sector's overall sustainability (Ravi et al., 2022).

### **2.3: Key Data Layers and Variables used in GIS for Soil Fertility Mapping**

Geographic Information Systems (GIS) are essential for understanding the spatial distribution of soil characteristics and nutrients in order to maximize soil fertility (Patel & Shah 2022). Researchers and farmers can produce precise maps of soil fertility that offer important insights for efficient agricultural management by leveraging several data layers and factors in GIS (Singh et al., 2020).

Elevation data is one of the most important data layers utilized in GIS for mapping soil fertility, according to Wu & Kumar (2021). Elevation can have a big impact on how nutrients are distributed and how soil forms (Zhou & Ravi 2017). Researchers can evaluate how water moves and accumulates in the landscape by identifying high and low elevation places by studying elevation data (Young 2018). Understanding how nutrients are moved and deposited across the field requires knowledge of this information.

### **2.4: Techniques for Creating Soil Fertility Maps Using GIS Software**

A potent method that can significantly improve your understanding of your land and assist maximize its fertility is the creation of soil fertility maps using GIS software (Kerry et al., 2010). Using GIS software, you may produce precise and in-depth fertility maps by analyzing and visualizing different geographical data layers, including topography, vegetation, soil samples, and climate (Hengl et al., 2004).

Gathering soil samples from various points on your property is one method for producing maps of soil fertility (Mallarino & Wittry, 2004). Numerous soil characteristics, including pH, organic matter content, nutrient levels, and texture, can be examined in these samples (Havlin et al., 2005). You can build a spatial database of soil attributes by georeferencing these samples and entering the data into your GIS program (Kravchenko et al., 2002).

Once you have the data from the soil sample, you may make a continuous fertility map in the GIS program by using interpolation techniques (Oliver & Webster, 2014). To estimate values at unknown sites, interpolation techniques like inverse distance weighting and kriging use known soil sample points (Goovaerts, 1999). By doing this, you may create an extensive fertility map that illustrates the spatial distribution of soil qualities throughout the whole area of your property (Kerry et al., 2010).

To improve your fertility maps even more, you can use GIS software to overlay additional spatial data layers (Mulla & Schepers, 1997). Digital elevation models, for instance, can be used to examine how aspect and slope affect soil fertility (Moore et al., 1993). In order to evaluate how temperature and precipitation patterns impact soil nutrient availability, you can also incorporate climatic data.

Through the application of GIS software and these methodologies, one can acquire significant insights into the fertility patterns of their soil and subsequently make well-informed judgments for soil management strategies, crop rotation, and fertilizer (Kitchen et al., 2005). By focusing on certain regions for improvement and optimizing nutrient distribution, this data-driven strategy helps to increase the land's overall fertility (Sudduth et al., 1997).

## **2.5: Geographic Information Systems (GIS) Models Used in Soil Fertility Management**

According to Feng et al. (2018), GIS makes it possible to create predictive models for fertilizer management and soil fertility. GIS can help forecast future trends in soil fertility by combining

geographical information with historical data analysis (Smith et al., 2017). With long-term planning, this predictive ability enables farmers to organize and carry out proactive steps to preserve or enhance soil fertility.

### ***2.5.1. Land Suitability Assessment***

The ability of the soil to supply necessary nutrients and promote healthy plant growth is known as soil fertility, and it is the foundation of successful agriculture (El-Seedy et al., 2022). In order to maximize the benefits of natural resources, we must optimize their usage in this period of feeding billions of people while the amount of arable land is decreasing. GIS offers a great platform for evaluating a piece of land's suitability for a certain use.

Researchers most often choose the multi-criteria decision-making (MCDM) technique based on GIS for land use planning. The distribution of soil types, soil textures, buried deep underground water levels, soil fertility, soil pollution, slopes, hydraulic conductivity of soil (Ks), soil texture (ST), depth to water-table (DTW), electrical conductivity of groundwater (ECw), topography, climate, and satellite data are just a few of the features that researchers can use to identify the various interactions, dependencies, and effects of these interacting factors on sustainable land use.

Using IRS P6 LISS-IV images as input, Zolekar and Bhagat (2015) evaluated agricultural practices in hilly areas using a GIS-based MCDM model. Correlation analysis and recommendations from scientific literature were used to determine the ranking of influential criteria. The evaluation of land suitability benefited from the combined use of GIS and remote sensing.

Pan and Pan (2011) used two-step, three-scale analytic hierarchy processes (AHP) to assess crop suitability using a geographic information system (GIS). They have underlined how crucial it is to choose relevant evaluation elements, recommended taking into account characteristics that significantly differ, managing land use, and avoiding causation. After using this feature selection method, the AHP output showed spatial distinctness. On the basis of land suitability maps, the authors have suggested suitable land use. El Baroudy et al. (2016) chose the characteristics in a different study in order to assess the suitability of the land for the wheat crop based on growth requirements.

Citrus crop site appropriateness was assessed using the Analytic Network Process (ANP) model, which evaluated the interdependence of strategic input features (Zabihi et al., 2015). Important variables for optimizing yield and reducing production loss were found using the ANP in conjunction with the GIS-MCDM.

In calcareous and saline-sodic soils, AHP combined with geostatistics has demonstrated its value in mapping the suitability of land for maize agriculture (Tashayoet al., 2020). Planning for land reclamation with appropriate conservation techniques is made possible by these potent GIS tools. A GIS model and integrated fuzzy membership were utilized to assess arable land that might be used for farming. For fuzzy membership categorization, topography and eight soil metrics were used, and significant soil factors related to agricultural productivity were taken into account. In contrast to traditional categorization methods, fuzzy membership made it possible to consider partial memberships. In contrast to the usual practice of growing finger millet, this self-adaptive technique showed that the soil was more suited for groundnut production. The experiment's findings demonstrated that, when applied correctly, a GIS-based decision system can outperform conventional wisdom and increase land production (Mendas and Delali, 2012).

More technology is required because natural resources and land are running out while the demand for food production is rising quickly. A map of land suitability for tobacco production was created by using the fuzzy set model, AHP, and GIS (Zhang et al., 2015). The benefit of utilizing fuzzy membership functions for land suitability analysis has been shown by this study once more. The ability to precisely and logically assign weights to the input factors is possessed by AHP. ArcMap was used to create the maps.

The issues brought on by the traditional land suitability assessment process's subjectivities, uncertainties, and hierarchical features were mitigated with the help of the integrated application of fuzzy, AHP, and GIS. GIS is an effective tool for processing maps, defining the study area, manipulating geographic data, and presenting the findings of a land suitability evaluation. When used to land suitability analysis, the integration of fuzzy set and AHP approaches with GIS offers a precise and potent combination. Scholars argue that one of the greatest strategies for land suitability analysis is to combine fuzzy logic with other decision-making techniques (Mendas and Delali, 2012). In addition to GIS, scientists are investigating artificial intelligence to facilitate effective land use planning (Singha et al., 2016).

### ***2.5.2 Soil Health and Fertility Management***

Productivity is directly correlated with soil fertility. It regulates the crop's access to water and nutrients. Numerous problems, including pollution, sealing, overgrazing, waterlogging, excessive use of agricultural pesticides, and erosion, have contributed to the degradation of soil fertility (Parnes 2013). Determining the fertility and health of the soil is essential for organizing efficient site-specific management or precision farming strategies (Velayutham and Bhattacharyya 2000). The assessment of soil fertility status makes significant use of features such as soil macronutrients (N, P, and K), micronutrients (Zn, Mn, and Fe), pH, soil organic carbon (SOC), water holding capacity, erosion status, and moisture content (Wang and Cao, 2011; Yang et al., 2019). The most widely used geospatial analysis techniques that give decision-makers access to the spatiotemporal variability of soil health and fertility status are spatial interpolation, Multi-Criteria Decision Analysis (MCDA) (Malczewski 1999; Feng et al., 2012), and Ordered Weighted Averaging (OWA) (Malczewski and Rinner, 2005).

According to Kusreet al. (2018), the regional variation in soil erosion provides a clear picture for agricultural planning, and the status of soil erosion is a crucial criterion for assessing soil quality. It was shown that the Inverse Distance Weighted (IDW) method's geospatial maps of soil erodibility are an excellent tool for supporting land use planning at the sub-watershed level.

In order to evaluate the soil fertility status, AbdelRahmanet al. (2016) utilized remote sensing and GIS technology. In order to determine the geographical variance of soil erosion and nutrient availability, they gathered soil nutrient field data, employed a geostatistical model, and classified land uses using LISS III and IV images using the RUSLE approach. In a different work, Mokarramet al. (2017) generated soil nutrient maps using the IDW model, homogenized the maps using the OWA technique, and then used the homogenized maps as input for a fuzzy inference system to map soil fertility. Based on fuzzy mathematics, it was determined that the soil fertility of mid- and low-yielding fields was low and directly correlated with the configuration of the soil profile. The indicators used in the fuzzy mathematics were soil organic matter (SOC), total N, total P, total K, available N, available P, available K, pH value, and cation exchange capacity (Li and Zhang, 2011). Crop productivity and soil fertility are well correlated, and field-specific crop suitability can be predicted in advance using GIS-based soil mapping and fertility status.

### ***2.5.3 GIS and Crop Production***

Farm productivity can be substantially improved by combining data from GPS technology and remote sensors with soil maps. Data on crop health, soil temperature, moisture content, soil nutrition, and the presence of invasive plants and pests can all be gathered by remote sensing. With the use of GIS software and this data, different fertilization rates may be created throughout a field to increase the amount of fertilizer applied to the areas that require it most. Because of this, farmers are able to use less fertilizer, which saves them money and lessens the negative impacts of excessive fertilizer runoff. Watering rates and the application of pesticides and herbicides can be done using the same system (Daniel 2022).

A GIS-enabled cloud technology for a decision support system for managing soil fertility was proposed by Leena et al. (2016). This method may prescribe fertilizer depending on crop response and soil test results. Farmers may maximize production and optimize fertilizer usage with the aid of this advice system. For government organizations, this system-generated regional diversity in nutrients serves as an excellent e-governance solution. In order to maximize the usage of the acidic soil, (Mishra et al., 2014) advised using paper mill sludge to lower soil acidity and cultivate groundnuts and pulses. GPS- and GIS-based soil fertility maps are excellent instruments for comprehensive soil health monitoring. These geospatial soil maps have shown to be a useful tool for decision assistance when it comes to problems with soil degradation-related agricultural production. In order to demonstrate the efficacy of the soil fertility index (SFI), Tunçayet al. (2001) employed the SFI based on the following variables: pH, EC, OM, CaCO<sub>3</sub>, N total, P<sub>avb</sub>, K<sub>exc</sub>, Ca<sub>exc</sub>, Na<sub>exc</sub>, Mg<sub>exc</sub>, and accessible micronutrients (Fe<sub>avb</sub>, Cu<sub>avb</sub>, Zn<sub>avb</sub>, Mn<sub>avb</sub>). This work showed how the soil fertility model may be validated by combining crop production estimated from Sentinel 2 images. The collection, storage, analysis, visualization, and interpretation of non-spatial data for the soil fertility index (SFI) have been made easier by developments in observatory systems, such as remotely sensed data with fine-to-coarse spatiotemporal resolutions, and in process-based and data-driven modeling techniques (Li et al., 2012).

For the purpose of characterizing soil fertility, Li et al. (2012) combined the soil nutrient space mutation distribution with weighted space fuzzy clustering. The fertilizer suggestion algorithm is optimized with the use of this data. Crop residue management, nutrient management, soil tillage, pest management, and other agricultural practices have an impact on soil fertility and quality as well as ecosystem goods and services (Lal 2015; El-Naggar et al., 2019). To stop the

deterioration and loss of valuable farmlands, the best management approaches, appropriate land use/cover changes, and land suitability analysis are necessary (Bagherzadeh and Gholizadeh, 2018). Among the finest management techniques used to enhance soil health and agricultural production are rehabilitative farming methods, improving soil biodiversity, and controlling soil erosion (Yageta et al., 2019).

Total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium, soil organic matter, cation exchange capacity, and pH were used as indicators for the generation of fertility indices in a study that used GIS and the fuzzy evaluation method to assess the soil fertility status (Li and Zhang, 2011). According to this fertility indicator, paddy fields have higher levels of soil organic matter and total nitrogen.

These fertility maps also provide information on the appropriate soil properties for various land use scenarios and climate scenarios. Available N, P, S, Zn, and Fe are the governing agents of soil fertility, according to sub-watershed level nutrient mapping (Patil et al., 2016). Fertility maps therefore function as an information system for precision agriculture, given their correlation with soil characteristics and crop yields.

## **2.6: Benefits of Using GIS in Soil fertility Management**

The following are some advantages of using GIS (Geographic Information System) in soil fertility management:

- i.** Real-time spatial information: Farmers can use GIS to obtain real-time spatial information on soil fertility, which they can then utilize to make well-informed decisions about managing their soil and applying fertilizer.
- ii.** Integration of heterogeneous data: To gain important insights, GIS enables the integration of many kinds of spatial information, including land use, soil management techniques, and agro-climatic zones.
- iii.** Enhanced yield and production: By better controlling soil fertility and making the most use of available land, GIS has helped farmers raise yields and production.
- iv.** Cost reduction: By giving farmers accurate information on soil fertility and enabling them to use fertilizers and other inputs more strategically, GIS helps farmers cut expenditures.

- v. **Sustainable agriculture:** By giving farmers information on ideal crop yields, environmental parameters, and stocking rates, GIS can assist farmers in preserving soil sustainability.
- vi. **Precision agriculture:** GPS and sensors installed on tractors and other agricultural equipment allow data to be continuously fed back to optimize soil management. GIS is a key component of precision agriculture.
- vii. **Soil fertility mapping:** Farmers and local governments can obtain the essential fertility information by using GIS to build soil fertility maps that display soil nutrients and spatial variance.
- viii. **Decision assistance for nutrient management:** By analyzing soil data and forecasting yields, GIS can assist farmers and policymakers in making well-informed decisions regarding nutrient management.
- ix. **Data sharing and collaboration:** GIS facilitates the exchange of maps and data across departments, organizations, and local communities, fostering informed decision-making and cooperation in the management of soil fertility.
- x. **Climate change adaptation:** By keeping an eye on water supplies, predicting droughts, and assessing the consequences of both natural and human-caused phenomena on the environment and the economy, GIS can assist farmers and policymakers in adapting to climate change.

In conclusion, GIS is critical to managing soil fertility because it offers up-to-date information, integrates a variety of data, boosts output and yield, lowers expenses, supports sustainable agriculture, and makes cooperation and data sharing easier.

## 2.7: Challenges

The use of GIS in soil fertility mapping is fraught with difficulties, such as the following:

- i. **Inaccuracy in soil mapping and sampling:** Mapping soil fertility incorrectly can result from surveying a single place and assuming homogeneity surrounding it. This difficulty can be lessened with the use of GIS and geostatistics, particularly in precision agriculture.

- ii. **Reproducibility:** To guarantee the precision and dependability of GIS-based soil fertility maps, a software model framework for reproducing outcomes in soil data processing must be developed.
- iii. **Data harmonization:** Because several data formats, scales, and units exist, it can be difficult to combine and integrate data from multiple sources, including soil surveys, remote sensing, and agricultural records.
- iv. **Spatial resolution:** It might be challenging to aggregate results at different scales because the spatial heterogeneity of soil fertility may need high-resolution data.
- v. **Uncertainty:** Evaluating the degree of uncertainty around soil fertility maps is essential to comprehending the accuracy of the data and enabling well-informed decision-making based on the maps.
- vi. **Integration with other technologies:** The precision and effectiveness of mapping and managing soil fertility can be enhanced by integrating GIS with other technologies, such as remote sensing and soil science.
- vii. **Practical application delays:** New developments in GIS and soil science technologies are frequently followed by a lag in their localized practical use.

In order to overcome these obstacles, scholars and professionals can make better use of GIS, geostatistics, and other tools for spatial analysis. By doing so, soil fertility maps will become more accurate and reliable, which will help farmers optimize their methods and increase output.

### 3.0 Conclusions

To sum up, the utilization of Geographic Information Systems (GIS) in managing soil fertility has brought about a significant transformation in contemporary farming methods. With the use of GIS technology, agricultural information may be integrated with geographical data, including soil types, topography, and climatic patterns, to facilitate resource allocation and decision-making that is well-informed and efficient. Precision agriculture, which primarily uses GIS for tasks like field mapping, soil testing, tractor guidance, crop scouting, and yield mapping, is based on the geographic referencing principle in GIS, which states that each data point in the system is linked to a specific location on Earth's surface. With the use of GIS, farmers may make data-driven decisions in precision agriculture that result in better crop yields, more efficient use of resources, and ecologically friendly farming methods. Creating soil management zones, applying

variable rate inputs, mapping and monitoring soil properties and variability, accessing and comparing data from various sources, and testing out various scenarios are some of the advantages and uses of GIS for precision farming. The productivity and sustainability of agricultural systems are enhanced by the use of GIS in soil fertility management, which encourages evidence-based decision-making to increase the sustainability of agriculture.

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