Chapter 9

GIS Applications in Agronomy

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Additional information is available at the end of the chapter

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Abstract

Agronomy is a branch of agriculture that deals with soil and crop. Soil varies in space and is responsible for variation in the growth and yield of crops on the field. This variation in the yields of crops planted and monitored on the same parcel of land under the same environmental conditions has been a great concern to farmers. Spatial variations of soil nutrients status, as caused by topography, soil texture and management practices, have been observed across the fields. Hence, the need to separate the field into site specific management units using geographical information systems (GIS) for effective soil and crop management in order to obtain optimum productivity. Over the years, field sizes, farming direction, locations of fences, rotations and fertility programmes have changed the nutritional status of the farms. Consequently, the productivity of the soil has equally been affected. In spite of these factors, conventional agriculture treats an entire field uniformly with respect to the application of fertiliser, pesticides, soil amendments and other chemical application. The use of GIS will help farmers to overcome over- or under-applications of fertiliser and other agrochemical applications. The potential of GIS application in agronomy is obviously large. However, the GIS user community in the field of agronomy is rather small compared to other business sectors. To advance the use of GIS in agronomic studies, this Chapter in book tends to explore the applications of GIS to some fields in agronomy.

Keywords: spatial variability, soil properties, site-specific management, crop yields, ArcGIS

1. Introduction

Agronomy, an aspect of agriculture, is a spatial activity that represents the backbone of the economy of many nations. This is the result of its noticeable contribution to the employment of labour and the gross domestic product of most developing countries. However, as land is a finite resource, the increase in food production in order to meet an affluent population becomes one of the major issues faced by many developing countries in the world. Hence, the improvement in agronomic practices is inevitable to ensure wise land-use planning and proper management of available resources for Crop cultivation.

With the growing interest in placing site-specific information in a spatial and long-term perspective [1], precision in agronomic practices would require a technology that can calculate spatial and temporal variations in crop growth with a time scale appropriate for management decisions [2]. Today, advances have been made towards extraordinary digital systems for utilization in soil fertility examination, soil survey and land-use planning, crop production and yield monitoring. Computer programmes, such as geographical information system (GIS), contribute to the speed and efficiency of overall agronomic planning processes [3].

According to [1], most process-based agronomic models examine temporal variations using point data from specific sites, while GIS facilitates storage, manipulations, analysis and visualization of data. They further stated that the interaction of both spatial and temporal issues can be best handled through interfacing agronomic models with geographical information system (GIS).

2. What is geographical information system (GIS)?

A geographical information system (GIS) is a thematic mapping system, which allows for the production of maps based on themes such as soils or hydrology [4]. Geographical information systems are a special class of information systems that keep track of events, activities and things and also of where these events, activities or things happen or exist [5].

GIS is a part of a suite of technologies that enhance precision in agronomic practices. The system requires preliminary basic information that is relevant to the particular project discipline. The importation of information into a GIS would require time and attention, mainly because this information will provide the basic knowledge of the territory and on the individual parameters, and it is difficult to modify in a second time [6]. According to [6], all the information in a GIS can be linked and processed simultaneously, obtaining a syntactical expression of the changes induced in the system by the variation of a parameter. The GIS allows the updating of geographical information and their relative attributes, producing a fast adaptation to the real conditions and obtaining answers in near real time [6]. In [7], the authors reported that GIS techniques have been used for farm-related assessments at national and regional scales for many years. Geographical information systems have been in existence for about three decades, but only in the last 10 years, these applications have widely been used for agronomic and natural resource management [8]. The GIS is a dynamic product rather than a static product, Making it easy to update, edit, and reproduce maps [4]. According to [9], geographical information systems allow for the visualization of information in new ways that reveal relationships, patterns and trends that are not visible with other popular systems. Geographical information systems provide valuable support to handle out voluminous data that are generated through conventional and spatial format and for the integration of these

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data sets [10, 11]. The GIS technique uses a digital map that allows the users to view, update, query, analyse and manipulate the spatial and tabular data either alone or together, within few minutes. Unlike paper maps, GIS can prepare and manage large collection of agronomic and land resource data necessary for crop production [12].

2.1. Importance of GIS to agronomy

Agronomic activities are spatial and the need to place site-specific information in a spatial and long-term perspective would require special models that can be used to calculate spatial variation in crop growth and monitor variations in trend with a time scale appropriate for guiding decisions. GIS could play a significant role in agronomy at several levels due to the fact that it can be used to study the nutrient status of individual fields to arrive at specific requirements for external application of nutrients [12]. According to [13], the use of GIS in precision agronomic practices helps to manage the information intensive environment in crop production by combining site-specific (within field) management with computer software modelling for analyses and interpretation of varying inputs and outputs. As opposed to farmers' typical manual adjustment, GIS helps farmers to manage with-in field variable rate application, which results from spatial variation in crop yields within a field [14]. Hence, GIS enhances the assessment and understanding of variations in a field crop. According to [14], GIS can be used to assemble many layers of information such as soil nutrients, elevation, moisture content and topography to produce a map to show which factors influence crop yield. In [14], it was Also reported that the yield can then be estimated or used for future reference and the economic inputs and outputs can be calculated based on anticipated yield. This will have a huge potential for saving costs spent on over applied fertilisers that otherwise could have been used on another field.

3. Applications of GIS in agronomy

According to [1], applications of GIS have grown from primarily hydrological applications in the mid-1980s to the current wide range of applications in agronomy and natural resource management research. Examples of GIS applications in agronomy and natural resource management research include: atmospheric modelling [15], climate change, sensitivity and/or variability studies [16–18], characterization and zonation [19, 20], hydrology, water quality, water pollution [21, 22], soil science [8, 23] and spatial yield calculation—regional, global [24, 25] and precision farming (spatial yield calculation) [26, 27]. Several studies have been reported on the application of GIS on cultivation practices of various crops [10, 28–31]. In [12], the authors reported The application of GIS to fertility management of Soils planted to tea where digitized Maps of the soil pH, potassium, phosphorus and organic matter were prepared using the Arc MAP software. According to [12], it would be beneficial for tea growers in those locations for calculating fertiliser requirements. In [12], it was reported that measures may be required to reduce to a desired level the pH of fields having pH > 5.5. In [32], a geodatabase was developed using GIS mapping. This was to provide soil quality monitoring based on data of agrochemical soil survey in order to monitor land cover/soil quality changes between periods of soil survey. In the work of [32], ArcGIS was employed for mapping soil quality and it was reported that soil data can easily be handled and analysed using ArcGIS because they are spatial in nature. It was also reported in [32] that there was no significant changes in humus and easily hydrolysable nitrogen content within the period between the last two soil agro-chemical surveys (**Figures 1** and **2**). In [33], a GIS-based decision support system was used to establish potentials and limitations of different soils for crop production, while [34] employed GIS in soil erosion control where the factors and elements affecting erosion were studied by analysing numerical maps of different parts of a basin.

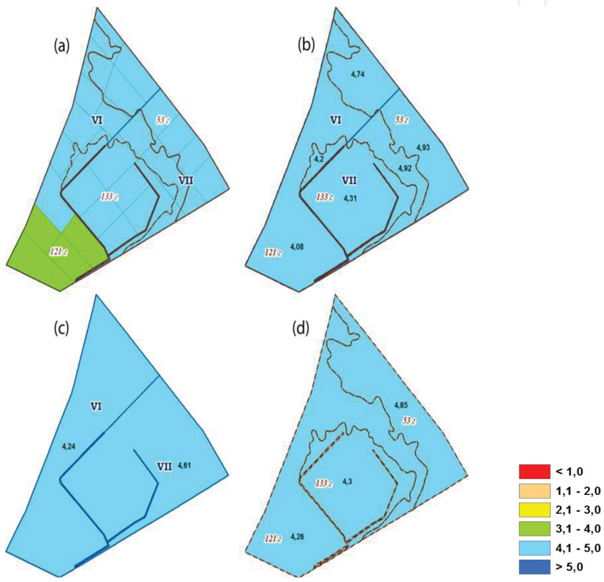

Figure 1. Humus content in the soil: (a) humus content per elementary plots; (b) humus average value per agricultural soil contour per field; (c) average value per field; (d) average value per agricultural soil contours per enterprise (Source: [32]).

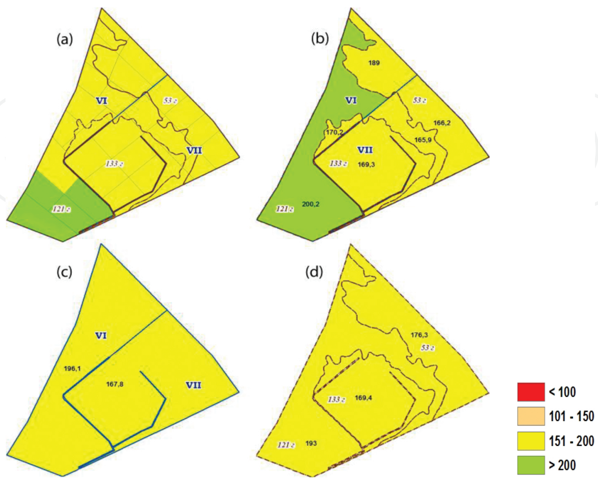

Figure 2. Nitrogen content in the soil: (a) nitrogen content per elementary plots; (b) nitrogen average value per agricultural soil contour per field; (c) average value per field; (d) average value per agricultural soil contours per enterprise (Source: [32]).

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3.1. Operational use of GIS in precision farming: regional and local levels

The GIS techniques have been used for farm-related assessments for many years at both national and regional scales, respectively [7]. The combination of these techniques and remotely sensed data have been used to aid the assessments of land capability [35], crop condition and yield [36–38], range condition [39], flood and drought [37, 38], soil erosion [40, 41], soil compaction [42] and climate change impacts [43, 44] on regional levels. Also, attempts have been made by [45, 46] to assess leaching behaviour for regional scale using a combination of the leaching and chemistry examination (LEACHM) models and GIS database.

At the local level, the number and variety of local agricultural GIS applications have dramatically increased during the past 5 years [45]. Most of the applications are targeted at individual farms [47]. For example, [48] utilized the spatial analysis tools in PC ARC/INFO to perform fully automated conservation program determinations, compliance monitoring and farm planning. In [47], it was stated that this particular application is noteworthy both for its substance and because it illustrates how rapidly the computing resources, user interfaces and database functions in desktop GIS have evolved during the past 5 years. Similarly, [49] determined possible pond sites and estimated rainwater-harvesting potential for a 172-ha farm using GIS.

Most of these field- and subfield-scale applications are connected with precision or site-specific farming, Which helps to direct the application of seed, fertiliser, Pesticide and water, within fields in ways that optimize farm returns and minimize chemical inputs and environmental hazards [7, 50]. In [51], the use of GIS in precision farming to generate production-based farming system that can be designed to increase long-term, site-specific and whole-farm production efficiency, productivity and profitability was discussed. In addition, [7, 52] reported that most site-specific farming systems utilize some combinations of Geographical positioning system (GPS) receivers, continuous yield sensors, remote sensing, geostatistics and variable rate treatment applications with GIS. According to [47], the reason for combining these advanced technologies is to collect spatially referenced data, perform spatial analysis, make decisions and apply variable rate treatment.

3.2. GIS applications in agrometeorological operations

Due to the increasing pressure on land and water resources for crop cultivation, land-use management and forecasting (crop, weather, fire, etc.) have become more essential every day. Hence, GIS is an important tool at the disposal of decision makers [6]. For instance, precipitation and solar radiation are meteorological conditions that can be mapped and monitored to directly assist in the agronomic process to provide advice on the occurrence of drought [53]. In [6], it was reported that developed countries use GIS to plan the times and types of agronomic practices, which requires certain information such as soil types, land cover, climatic data and geology, in describing a specific situation in any given location. Each informative layer provides to the operator the possibility to consider its influence on the final outcome [6].

3.3. Operational use of GIS in agroclimatological and agroecological studies

The GIS technology has been shown to synthesize and integrate more data than methods used in the pre-computer era and to shift the design of agroecological and agroclimatological studies towards user-specific classifications [35]. In a study carried out in Zimbabwe, effective rainfall and vegetation for variable interpolation between stations were calculated from rainfall and vegetation data using GIS maps [35]. In addition, seasonal rainfall surfaces were constructed for Zimbabwe using decadal rainfall data while adopting the procedures described by [54]. They also generated surfaces showing mean rainfall and annual rainfall anomalies to describe the main rainfall period for Zimbabwe in terms of rainfall variability. This showed the natural regions experiencing considerable spatial variability in terms of mean and inter-seasonal variability of rainfall (**Figure 3**).

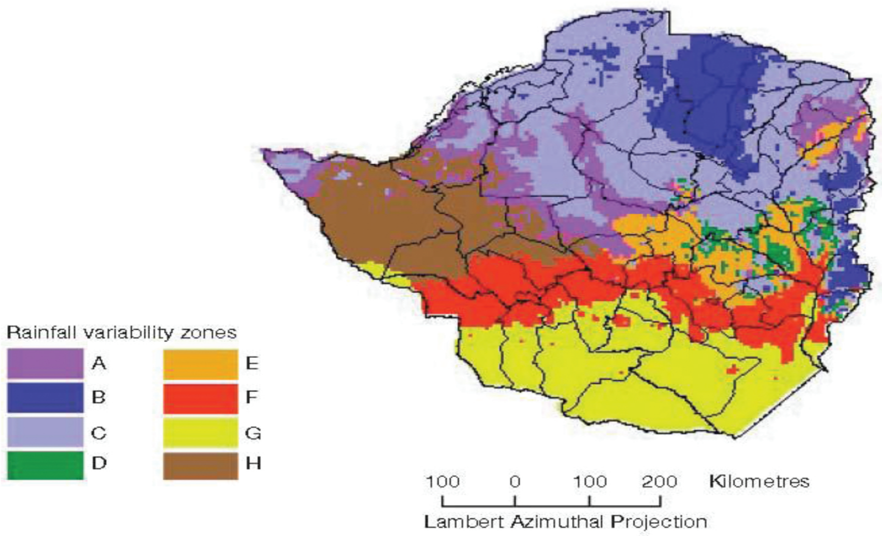

Figure 3. Rainfall variability zones in Zimbabwe (Source: [35]). See Table 4 in Corbett and Carter (1997) for zone descriptions.

3.4. Use of GIS for agronomic characterization and zonation

The GIS techniques have also been used to characterize agroclimatic diversity and to delineate maize-specific adaptation zones [55]. In the report of [55], it was concluded that the emergence of GIS has made it possible to delineate agroclimatic zones with greater precision, especially by allowing many 'layers' of spatially referenced data (including survey data) to be integrated into one digital database.

3.5. GIS application in soil survey studies

According to [47], three approaches have been implemented in an attempt to utilize GIS and/or GPS to improve soil attribute predictions at regional scales. The first approach evaluated the use of GIS and/or GPS to improve traditional soil surveys. For example, Long et al. [56] examined the potential of using GPS methods in soil surveys and found these methods to be

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more efficient than traditional methods of mapping and sufficiently accurate to support positioning/navigating in fields and field digitizing of soil boundaries.

The second approach combined geostatistical modelling with soil survey maps to generate improved soil descriptions. In [57], a map that preserved the map unit boundaries and incorporated the spatial variability of the attribute data within the map unit delineations were produced. This was done by combining spatially interpolated (krigged) distributions of measured values with soil map unit delineations within a GIS framework. It was reported by [47] that this approach appeared promising for countries and regions with well-developed soil survey programs.

The third approach neglects the use of traditional soil survey methods and explores the possibilities of integrating GIS, pedology and statistical modelling to improve soil resource inventory [58, 59]. In a study, [60] combined a GIS with an existing soil landscape model to create soil drainage maps. The soil landscape model used multivariate discriminant to predict soil drainage class from parent material, terrain and surface drainage feature variables [61].

3.6. GIS as an agronomic land-use planning tool

Figure 4 is a pictorial view of SPAREC GIS being used for land-use planning [4]. It was stated by Coleman AL and Galbraith JM that soil survey data and geographic information systems (GIS) are important tools in land-use planning. They reported that the map unit interpretive records (MUIR) were used to create interpretation maps, flooding frequency maps and runoff maps after soil data were added to other data layers and images. **Figure 5** shows a flooding frequency map converted from tabular estimates of values in an ArcView GIS. It was explained by [4] that the blue areas are frequently flooded, red areas are occasionally flooded, while the green areas are rarely flooded. They further reported that the soil based-GIS made the decision-making process more accurate, automated and efficient, hence promoting wise land-use planning. In [3] and [62], it was reported that the soil-based GIS is a dynamic product that serves to convert verbal communication into visual communication while preventing information overload. In the Report of [4], it was reported that with the GIS, tabular soil information

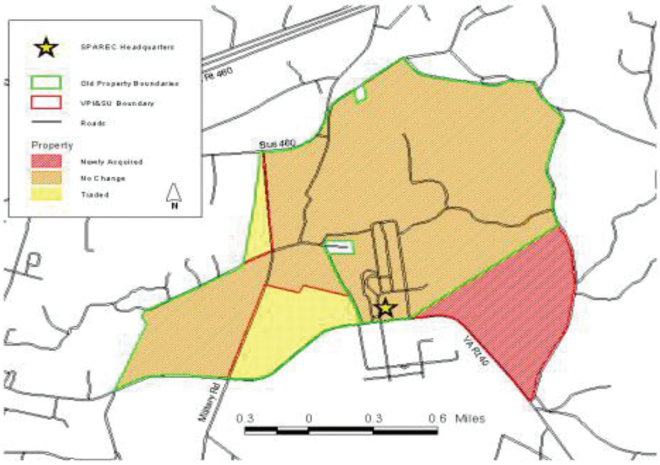

Figure 4. Pictorial view of SPAREC GIS (Source: [4]).

can be georeferenced and easily converted to geographic and interpretive maps, which provides the user with a visual representation of the tabular data. **Figure 6** is an example of an interpretive map showing the ratings for site suitability of local roads and streets, where [4] explained that the green areas represent a slight rating, meaning they are the most suitable, while the yellow areas are rated moderate and the red areas are severe areas having the most serious limitations.

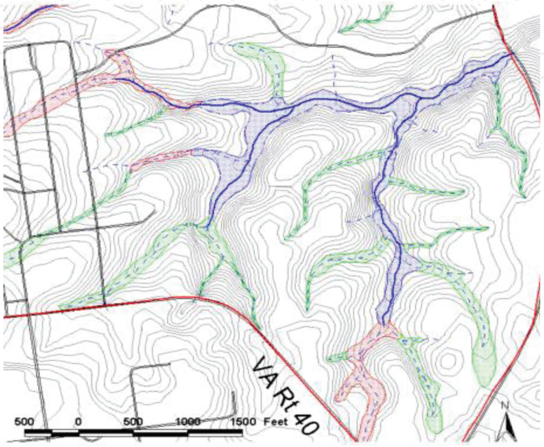

Figure 5. Flooding frequency map (Source: [4]).

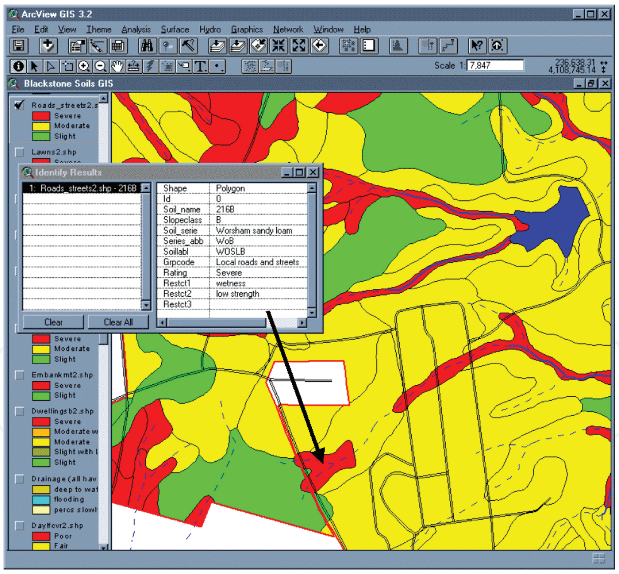

Figure 6. An example of an interpretive map showing ratings for local roads and streets (Source: [4]).

3.7. Operational use of GIS for soil fertility studies

Soil fertility investigations are necessary to confirm soil fertility status [63], which is also necessary as a guide for the fertility management practice to adopt [64, 65]. Several methods

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of soil fertility investigation have been employed in confirming the fertility status of soils [66, 67]. In [68], the authors reported that these methods did not ensure the completion of soil fertility investigation within the specified time frame and the required degree of accuracy, as change in soil fertility status over a period of 2 or 3 years makes these methods invalid, thus making it difficult for agronomists to manage soil fertility over large areas. They reported that the application of geospatial technology involving the use of global positioning system (GPS) and geographic information system (GIS) had greatly improved the old traverse techniques.

In the application of space-time evolution of soil fertility data mining based on visualization, a three-dimensional spatial variation of soil nutrient spatial map for soil available phosphorus (**Figure 7**) was produced by [69]. In a study, [70] evaluated the spatial variation of soil organic carbon, soil water content, NO_3–N, PO_4–P (phosphate-phosphorus) and K (potassium) in the 0–15 cm layer of a 3.3 ha field cropped with maize and soya beans. They calculated that as many as 400 randomly selected samples per hectare may be needed to develop an accurate soil NO_3–N map and that an application travelling at 8 km h^{-1} would need to modulate fertiliser rates every 2.25 s to match nitrogen fertiliser rates to soil NO_3–N requirements.

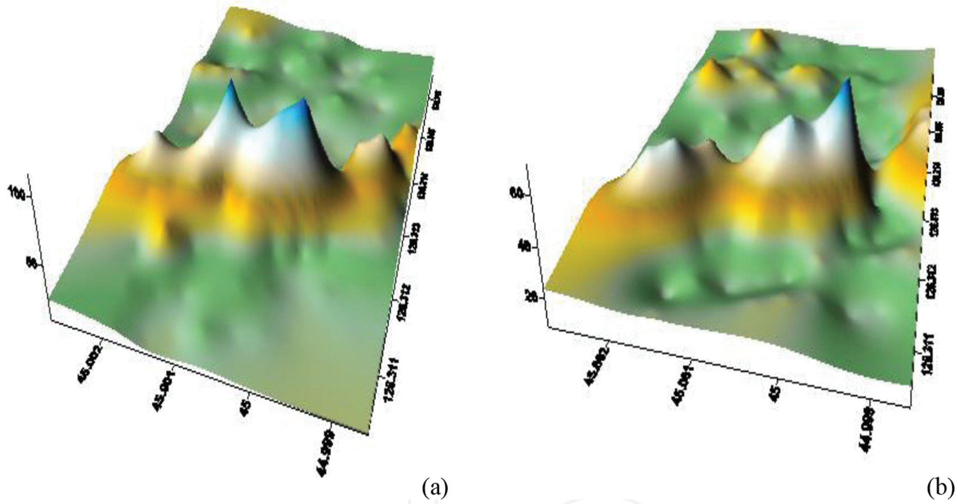

Figure 7. A three-dimensional spatial variability map of available phosphorus for 2003(a) and 2008(b) (Source: [69]).

In [71, 72], the authors reported the use of GIS techniques and remote sensing in forest soil fertility studies. According to [68], GIS could be used to map fertility levels across a farm to serve as basis for the application of farm inputs and also for establishing accurate location of yield data for the production of yield maps for monitoring yield [73, 74]. It was also reported by [68] that periodic review of soil fertility status can be done on digital maps generated with GIS technique (**Figure 8**). According to [12], this is due to the fact that the GIS technique uses a digital map which allows the user to view, update, query, analyse and manipulate spatial and tabular data either alone or together, within a few minutes. In assessing the relative efficiency of GIS map-based soil fertility evaluation in relation to traditional soil testing, [76] reported minor variations in available nitrogen content, no variation in available phosphorus and a large difference in available potassium under the two methods of evaluation (**Table 1**).

They concluded that fertiliser recommendations generated from GIS maps were agronomically as effective as those generated form soil testing (**Table 2**).

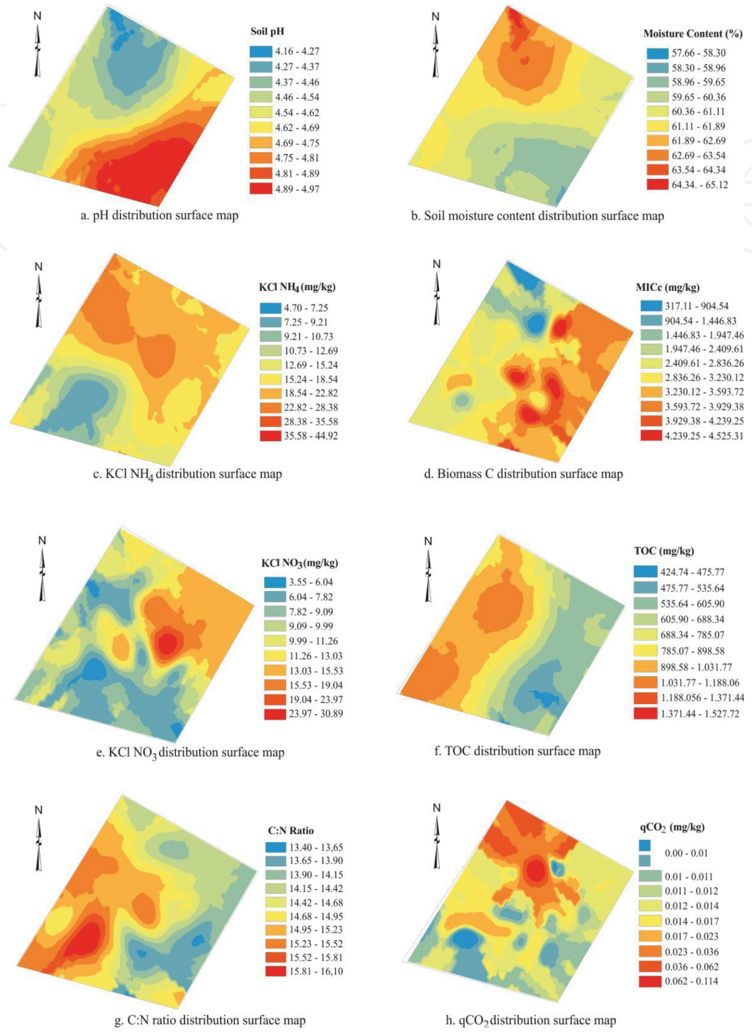

Figure 8. Surface maps showing the distribution of soil fertility indicators (Source: [75]).

Parameter	Low/Slightly Acidic		Medium/Acidic		High/Alkaline	
	Soil test	**GIS**	**Soil test**	**GIS**	**Soil test**	**GIS**
Available N (g/kg)	8.9	7.8	11	22	0	0
Available P (mg/kg)	100	100	0	0	0	0
Available K (cmol/kg)	44	33	33	67	22	0
pH	5.6	6.7	4.4	3.3	0	0

Source: [76].

Table 1. Comparison of traditional soil test and GIS method of assessing samples (%) that fall under low, medium and high nutrient availability and pH categories.

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Treatment	Rice	Potato	Sesame
Farm	60-30-30	300-200-200	Residual
State	80-40-40	200-150-150	80-40-40
Soil test	Variable	Variable	Variable
GIS	Variable	Variable	Variable

Source: [76].

Table 2. Nutrient rates generated from state, field-specific, soil test-based recommendations and GIS.

3.8. Spatial yield calculation

In [47], it was reported that new GIS data layers developed from models were used with some information in various GIS-based application of existing crop yield models. Several studies Showed that these applications can be used to store and process data for decision making with respect to the factors that influence Crop cultivation and crop yield in a crop production. For example, the climate surfaces can be used as inputs in genotype-sensitive crop models to assess the risks for specific crop varieties [35]. This was illustrated by [36] who used GIS and remote sensing technologies with the SOYGRO [77] physiological soya bean growth model to predict the spatial variability of soya bean yields. In the report of [78], continuous yield sensors with a combination of accurate location information obtained using a GPS with the results of a variable flow rate sensor can provide information about the crop performance for a year that can be used to guide the following year's crop management strategies. According to [36], the examination of spatial patterns of simulated yield improved production estimates and highlighted vulnerable areas during drought.

3.9. Agronomic impact assessment using GIS

The GIS and environmental models have been combined in many projects to evaluate the impacts of modern agriculture [47]. For instance [79], used the EPIC-PST crop growth/chemical movement model [80] interfaced with Earthone GIS to evaluate crop yield and nitrate (NO_3–N) movement to surface and ground waters for four soils and nine cropping systems. In [79], the authors digitized soil maps using GIS and described how the data can be used with model results to compare the predicted changes in crop yields and nitrogen losses on different soils under water quality protection policies that targets specific soils and/or cropping practices.

4. Conclusions

The GIS is an excellent informative tool that enhances visualization and ease of analysis and handling of spatial data. Its digital map allows for the periodic review of soil fertility status as it improves and updates information on crop, soil and the prevailing climatic conditions as they affect agronomic practices, thus greatly enhancing the management of finite resources and accurate land-use planning due to its accurate knowledge base.

The benefits of GIS applications could be better exploited with increase in the level of awareness and understanding of the potential use of GIS and related technologies in the assessment, storage, processing and production of data ranging from site-specific farming systems to global food production and food security issues. The GIS offers the advantage of generating and synthesizing new information cheaply and quickly Over a wide range of areas as well as temporal or historical changes resulting from management practices, thus, aiding the ease in decision-making process.

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