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*Full Length Research Paper*

# Spatial variability in soil properties of a continuously cultivated land

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**Poor knowledge of soil suitability for agricultural production constitutes a major problem to land users. For proper assessment of the distribution soil properties, the use of geographic information system (GIS) has been considered a very effective tool to achieve this. A study on an Alfisol at the Institute of Agricultural Research and Training, Ibadan (7°23'N, 3° 51'E), Nigeria, was carried out to measure the spatial variation of soil properties of a continuously cultivated land under rain-fed and irrigation systems. The study involved a systematic grid mapping of about 3 ha of an experimental plot subjected to maize cultivation for more than 15 years. This study area was divided into 20 m by 20 m grids, and samples were collected at each grid point for laboratory analysis while the coordinates of each sampling point was taken for interpolation in ArcGIS. The results obtained from the analysis of various elements were imported into GIS environment and then presented in form of digital maps that shows the spatial distribution of the soil properties, which can be used for precision agriculture. The results obtained showed that the area had medium acid in majority of the area covered with a pH range of 5.5 to 5.9. The %N was majorly low at < 0.08%, the organic matter content ranges between 0.4 and 3.0%, the ECEC was found to be low at < 4 cmol/kg, potassium was medium at 0.2 to 0.5 while the phosphorus content was also low having < 7 ppm. The results showed that the fertility of the area is not so high with majority of the nutrients having low to medium amounts.**

**Key words:** Geographic information system (GIS), spatial variation, soil properties, precision agriculture.

## INTRODUCTION

Soil is an essential part of any terrestrial ecosystem. It is defined as the product of interactions between parent materials, biota, topography and climate through time. Because of human activities, the soil is also one of the most affected parts of the ecosystem (Flechsig et al., 1995; Rapaport et al., 1995; Schlesinger, 1991). Human activities have however resulted in soil degradation and reduction in soil functions. For sustainable crop production, reliable soil data are the most important prerequisite for the design of appropriate land-use systems and soil management practices as well as for a better understanding of the environment.

Though soil classification and mapping are necessary and very useful for general land use planning, what is of utmost importance to the farmer is knowing how profitable it is to grow a particular crop or series of crops on a given plot of land, and what amendments are necessary to optimize the productivity of the soil for specific crops. In the recent past, the ill effects of land use on the environment and environmental sustainability of agricultural production systems have become an issue of concern. The problems of declining soil fertility, low crop yield and accelerated soil erosion are associated

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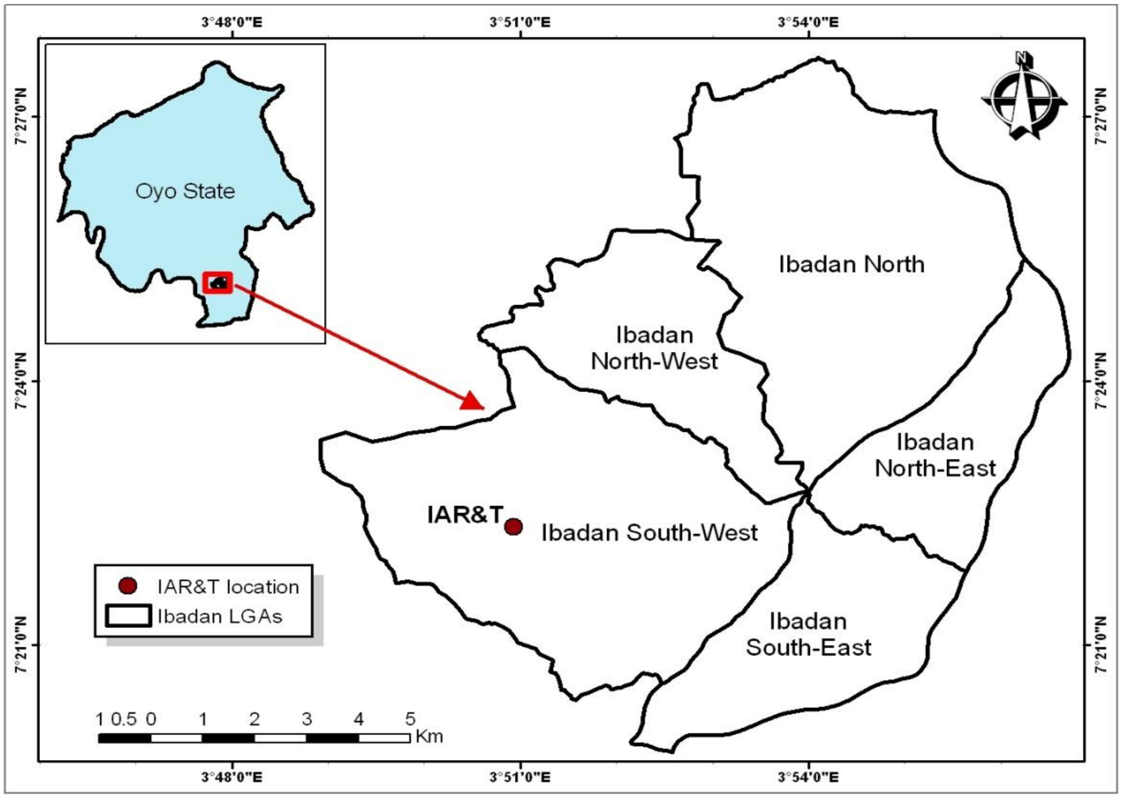


**Figure 1.** Oyo state showing core LGAs and location of study area.

with intensive and mechanized cultivation, while over-exploitation of natural resources and incessant use chemical fertilizers denote intensive agriculture in the developing areas. Soil survey evaluation is a tool to assess, manage and induce changes in the soil and to link existing resource concerns to environmentally sound land management practices and soil survey assessment, which can then be used to evaluate the effects of management on the soil (FAO, 1988). An intimate knowledge about the types of soils and their spatial distribution is a prerequisite in developing rational land use plan for agriculture, forestry, irrigation and drainage.

Technological advances in geographical information systems (GIS) have recently given land use planners as well as agriculturists a more efficient and effective way of handling large amounts of spatial data. The use of the global positioning system (GPS) and remote sensing in agriculture offers at least four advantages: (1) provision of data cheaply and quickly at a variety of resolutions; (2) use of repeatable methods; (3) provision of improved diagnostics for error detection and accuracy determinations; and (4) generation of information that can be used with the visualization tools in GIS to develop customized as well as tabular summaries.

A major problem of agricultural development in Nigeria is poor knowledge and appraisal of suitability of parcels of land for agricultural production. This has adverse implications for agricultural development since the bulk of agricultural production takes place under traditional systems where soil fertility is a key component. The result is poor farm management practices, low yield and an unnecessary high cost of production.

The objective of this study was to assess the spatial variation of soil properties of a continuously cultivated land under rain-fed and irrigation systems using the GIS approach to be able to determine agricultural suitability of the site and make suggestions for improvement in crop production.

## MATERIALS AND METHODS

This study was carried out at the experimental farm of the Institute of Agricultural Research and Training (IAR&T), Ibadan (7° 23' N; 3° 51'E and 160 m above mean sea level), Nigeria (Figure 1). The area is characterized by a tropical climate marked with wet and dry seasons. It is characterized by a bimodal rainfall pattern with rainfall peaks occur mostly in June and September. Annual temperature ranges from 21.3 to 31.2°C. There are two cropping seasons: Early (March/April to early August) and late (mid-August to October/November) seasons. The study area covered a 3 ha of land that has been under continuous cultivation for more than 10 years. During the dry season, the land is being cultivated under irrigation system. Several crops has been grown on the piece of land such as maize, upland rice, okra, kenaf, e.t.c without adequate knowledge as to which area of the land is most suitable for which crop.

**Table 1.** Critical limits of nutrients

| S/N | Criteria | High | Medium | Low |
|---|---|---|---|---|
| 1 | Nitrogen (%) | >0.15 | 0.08-0.15 | <0.08 |
| 2 | Phosphorus (ppm) | >22 | 7-22 | <7 |
| 3 | Potassium (Cmol/kg) | >0.5 | 0.2-0.5 | <0.2 |
| 4 | Organic matter (%) | >3 | 0.4-0.3 | <0.4 |
| 5 | ECEC (Cmol/kg) | >15 | 4-15 | <4 |

Source: Okalebo et al. (1993).

The surface soil is coarse gravelly soil ranges from sandy loam to loamy sand. It belongs to Alfisol, classified as Typic Kanhaplustalf according to USDA classification, and locally classified as Iwo association (Smyth and Montgomery, 1962).

#### Field work

Reconnaissance survey of the area was carried out to delineate the boundary and points taken with the use of global positioning system (GPS). The area was then gridded at an interval of 20 m. 9 transects and 40 points were identified. The GPS coordinates of the grid points were taken and imported into ArcGIS to generate the map of the area. Soil samples were taken at each grid point at the varying distances with the use of a Dutch auger. Depths of collection were at 0 to 25 cm and 25 to 50 cm so as to observe variation on surface soil and at depths. 80 samples were collected for onward transition to the laboratory for analysis.

#### Laboratory analysis

The samples were air-dried, crushed and allowed to pass through a 2 mm sieve. The gravel content (materials >2 mm) was determined and expressed as a percentage of the total weight of the soil. Soil samples were analysed for soil pH in both water and 0.01 M potassium chloride solution (1:1) using glass electrode pH meter (Mclean, 1965). Total nitrogen was determined by the macro-kjeldahl digestion method as described by Jackson (1962). Bray-1 P was determined by molybdenum blue colorimetry (Bray and Kurtz, 1945) while exchangeable cations were extracted with 1 M NH4OAC (pH 7.0) to determine K and Na using flame photometer and exchangeable Mg and Ca by atomic absorption spectrophotometer (Sparks, 1996). Exchangeable acidity was determined by the KCl extraction method (Mclean, 1965) and organic carbon was after dichromate wet oxidation method (Walkey and Black, 1934). Conversions between values of organic carbon and organic matter was made using Van Bemmelen factor of 1.724 on the assumption that, on average, SOM contains 58% of organic C. Cation Exchange Capacity (CEC) was calculated from the sum of all exchangeable cations. Particle size distribution was determined using hydrometer method (Day, 1965). All the data analysed were imported into GIS environment.

#### GIS datasets and analysis

The criteria's listed in Table 1 formed the basis for the GIS datasets that were analysed. The data were inputted into ArcGIS and interpolated using Inverse distance Weighted (IDW) technique, this is a technique used to interpolate a surface from points. The GPS coordinates of each grid point, the corresponding nutrient values were interpolated, and a raster image derived for each. After interpolation the raster data obtained was then reclassified using the reclassify module of a spatial analyst tool in ArcGIS to group into three classes that is, low, medium and high based on the values in the raster data set.

The nutrient status of the soil was assessed based on the concentration of the macronutrients (N, P, K), organic matter and the ECEC. These criteria's were used to classify the fertility of the area into three major classes low, medium and high (Okalebo et al., 1993)

## RESULTS AND DISCUSSION

### Particle size distribution

The spatial variability of particle size distribution plays an important role in crop production as they impact the soil texture, soil quality and soil erosion. The textural classifications of 0 to 25 cm depth of the study area are presented in Figure 2. The result showed that the surface soil texture ranges from sandy loam to loamy sand. Sandy loam dominated the study site with pockets of loamy sand, which accounted for about 8% of the whole area. This textural class is particularly noted for its high infiltration rate making it very good for cultivation.

### Chemical properties of the soil

The soil reaction in terms of soil pH as presented in Figure 3 was tested in water; this showed that the surface soil (0 to 25 cm depth) ranges from strongly acid, medium acid, slightly acid and very slightly acid. Most of the study area had medium acid with a range of 5.5 to 5.9. This could be attributed to the nature of the area as it is been intensively cultivated throughout the year with the use of chemical additives in form of fertilizer could also be a factor.

The soil nitrogen and phosphorus of the soil were low based on the classification scale for maize production as shown in Figures 4 and 5. This could be due to the continuous cropping of the area both in the raining and dry season. Only a small spot shows a high concentration of nitrogen and it is towards the tail end of the area, this could be as a result of rainfall eroding the soil and thus concentrating the nutrients there. Areas having a medium range of nitrogen are also not much and these are the places that are least cultivated and have been left to

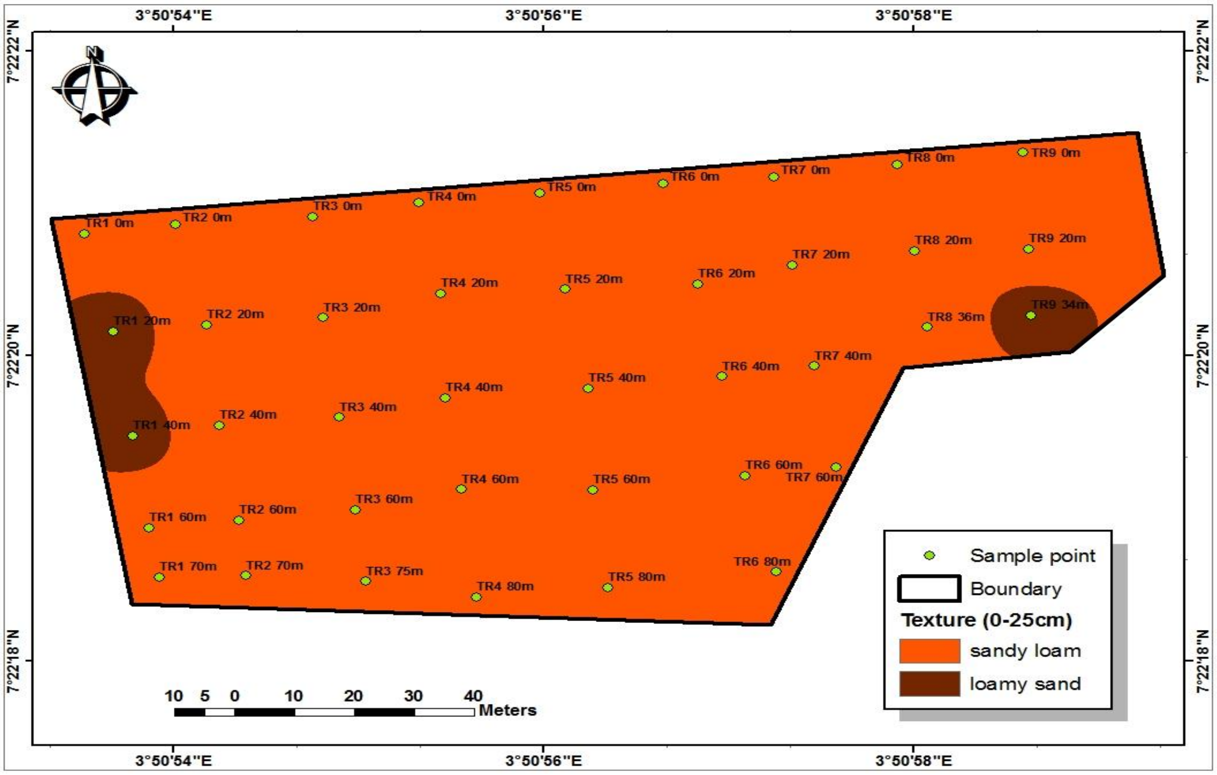


**Figure 2.** Map showing soil textural classification of the area at depth 0 to 25 cm.

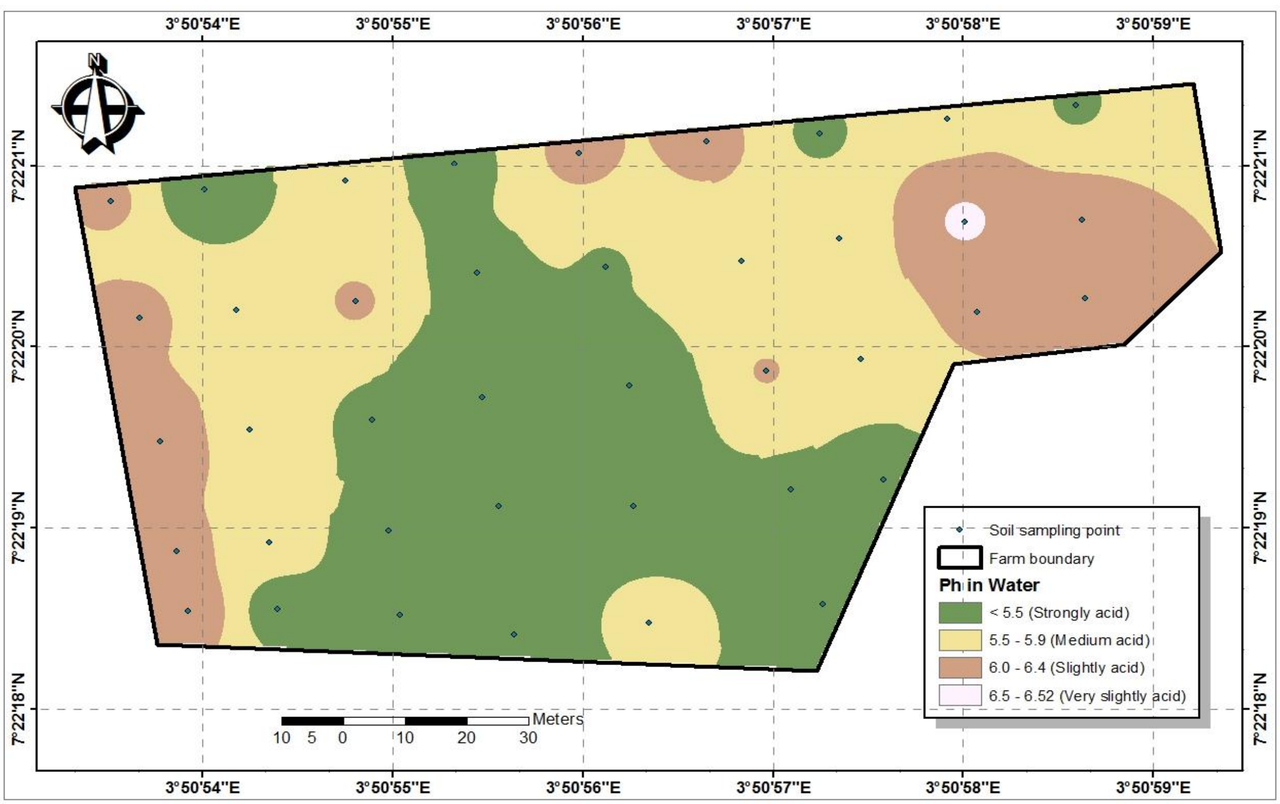


**Figure 3**. Soil pH rating.

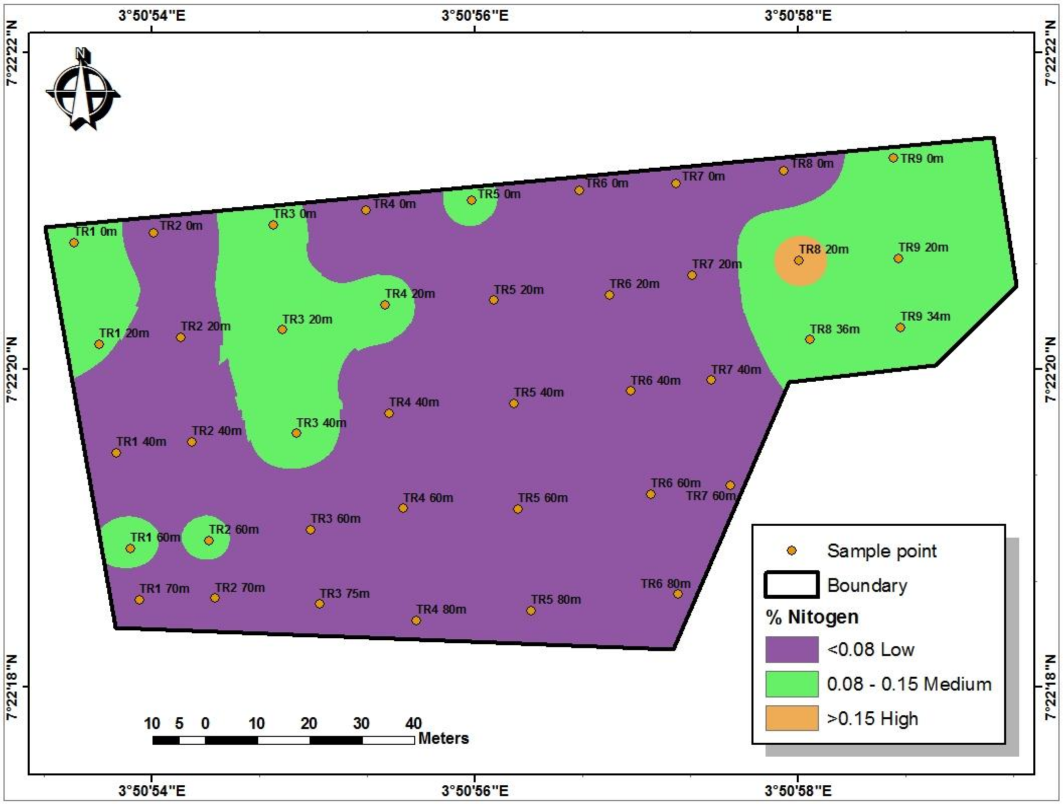


**Figure 4.** Spatial distribution of Nitrogen in this study area.

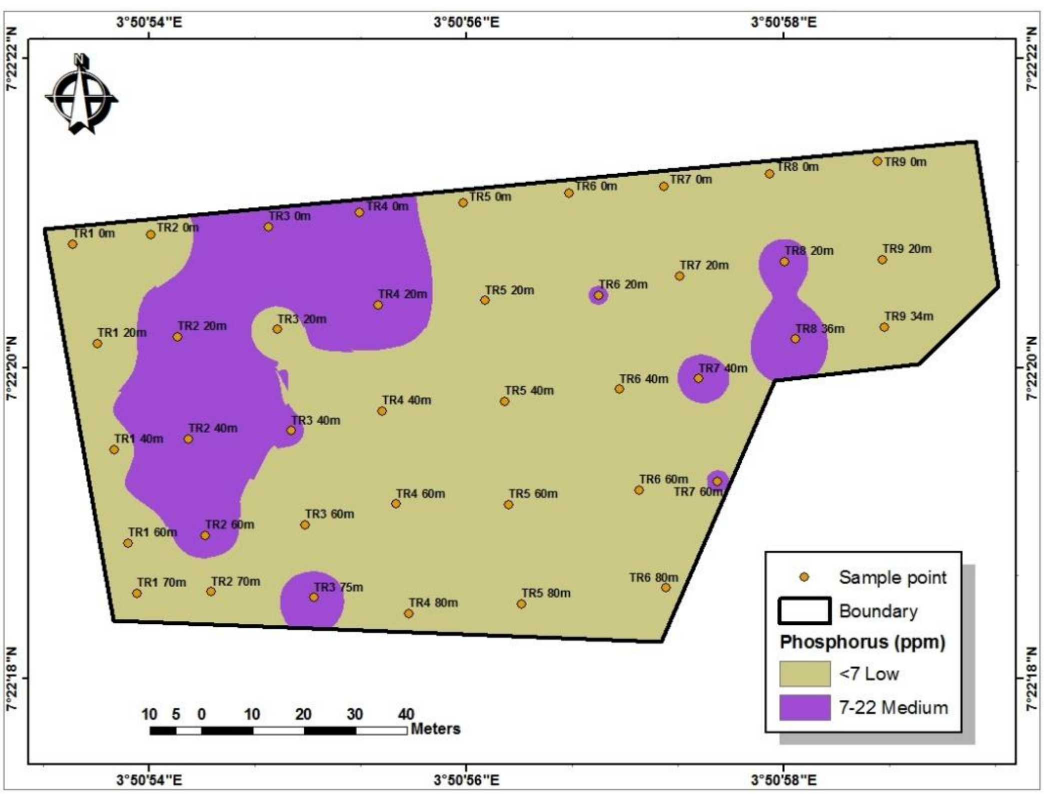


**Figure 5.** Spatial distribution of Phosphorus in this study area.

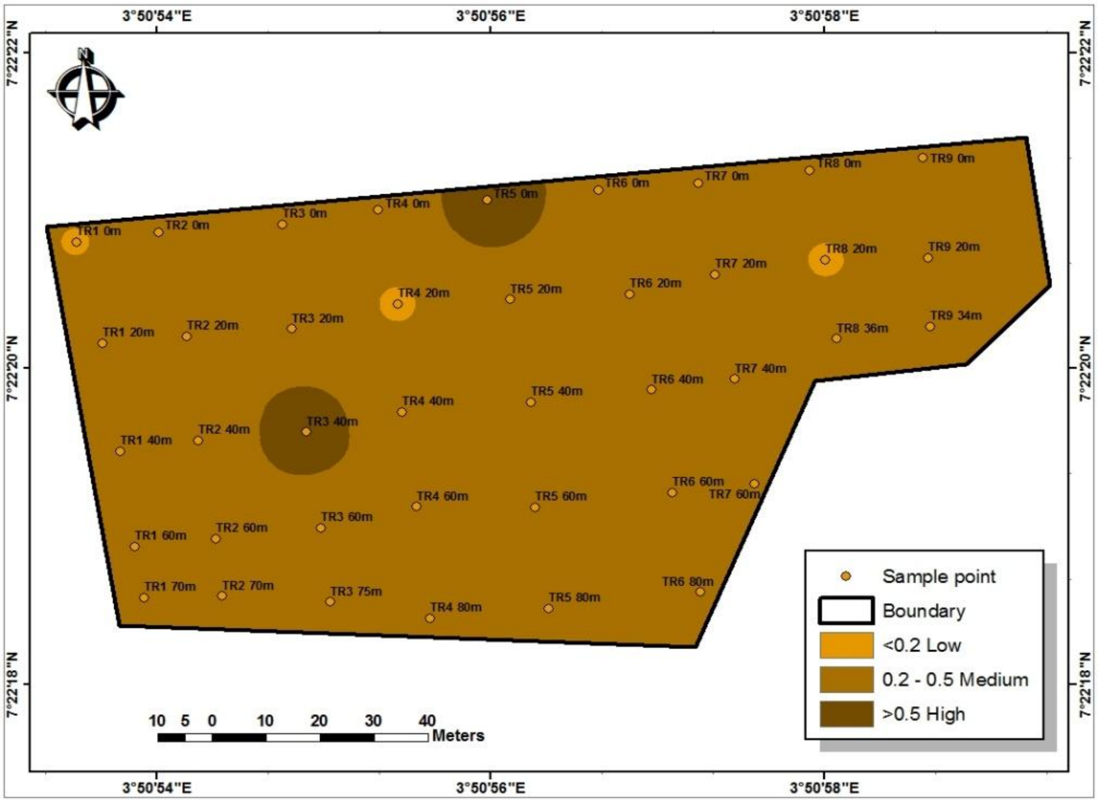


**Figure 6.** Spatial distribution of potassium in the study area.

fallow over time Figure 6 shows that the potassium content in the area is of the medium limit, it is evenly spread across the entire field with just a few spots having a high concentration. The ECEC which was calculated from the combination of the exchangeable bases (Ca, Mg and Na, K and EA) in Figure 8 is generally low in the study area. This has implication on the overall productivity of the soil because soils with CEC less than 5 meq/100 g generally have a low clay and organic matter content, have a low water holding capacity, requires more frequent lime and fertilizer additions, and is subject to leaching of $NO_3$, B, $NH_4$, K and perhaps Mg. Such soils will have lower yield potential than soils with higher CEC under the same level of management, but high productivity can be maintained by intensive management.

## Land suitability classification

This study area was evaluated based on the physical soil characteristics that is, the texture and gravel content and the fertility characteristics that is, effective CEC, base saturation and organic matter content. Suggested land characteristics and scores for suitability evaluation for maize that was used for the evaluation and suitability classification of the area are listed in Table 2. Land characteristics (LC) are simple attributes of the land that can be directly measured or estimated in routine surveys, including remote sensing as well as resource survey (Rossiter, 1996; FAO, 1976; Dent and Young, 1981).

The mean values of the two sampling depths for these land characteristics was obtained and used for the classification. Based on the data, two capability classes were identified as S1 and S2, this being highly suitable and marginally suitable respectively (Figure 7).

## Conclusion

The outcome of this research reveals the effectiveness and usefulness of GIS especially in the analysis and interpolation of soil data which is then used in the production of thematic maps. However GIS cannot stand alone in the absence of conventional soil survey if accurate results are to be obtained, they are meant to complement each other so as to yield better results in the shortest possible time thereby reducing cost. Other limitations of GIS include the lack of adequate and up to date maps and data; most of the legacy soil maps available are old and should have been updated. GIS might enable us to make better use of information but it cannot work without data. Though the combination of field inspection and GIS tools can be used in the production of soil maps, follow-up by agronomic

**Table 2**. Land suitability classes.

| Land characteristics | Land classes | | | | |
|---|---|---|---|---|---|
| | S1 | S2 | S3 | N1 | N2 |
| Physical soil characteristics | | | | | |
| Texture/structure | C+60s to SCL | C+60v to LS | C+60v to fS | C+60v to fS | Cm to cS |
| Gravel content (%) | <15 | <35 | <55 | <55 | any |
| Fertility characteristics | | | | | |
| Apparent CEC | >3 | 1-3 | <1 | - | - |
| Base saturation (%) | >35 | >20 | Any | | |
| Organic matter (%) | >1.2 | >0.8 | Any | | |

SCL, Sandy clay loam; LS, loamy sand; FS, fine sand.

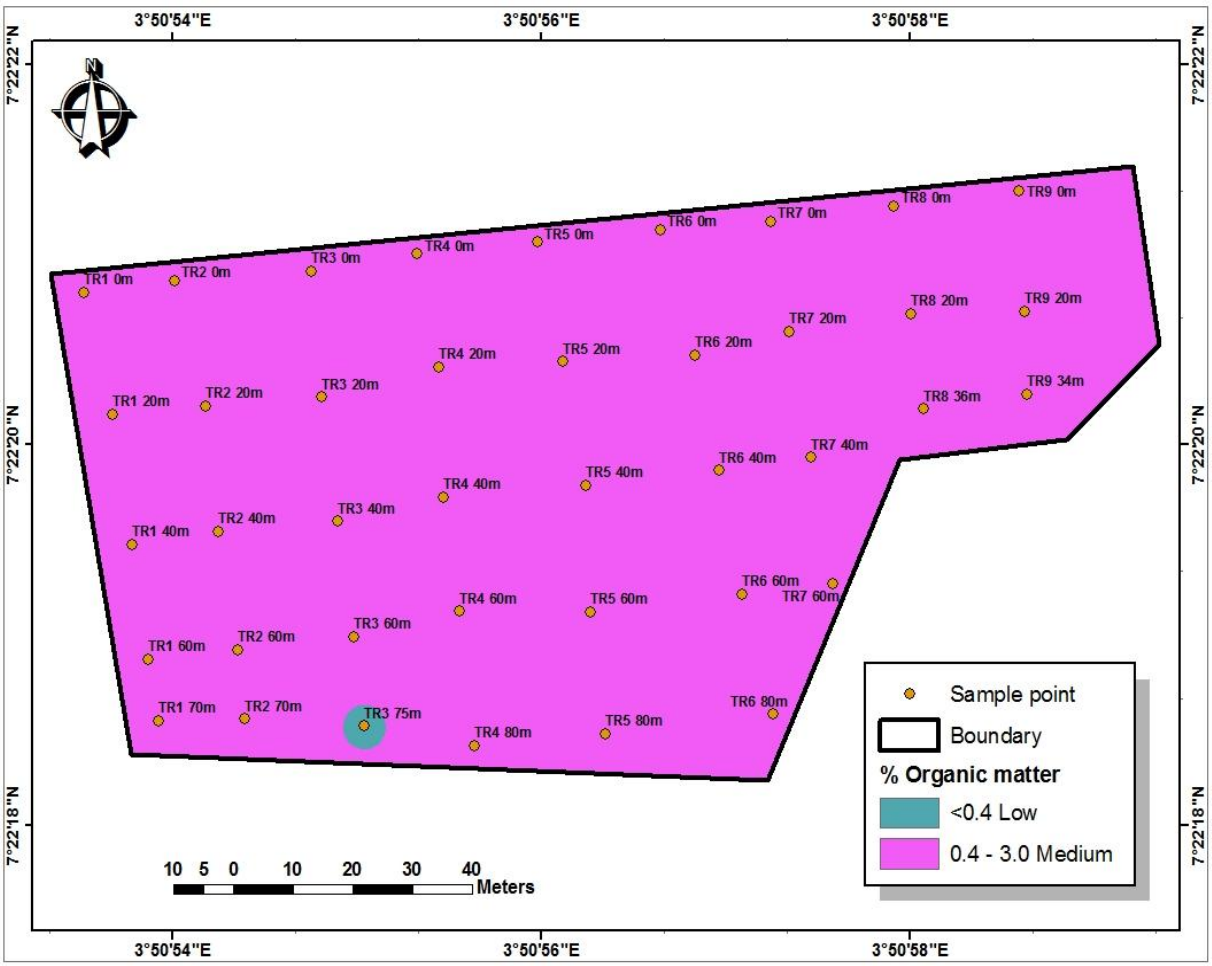


**Figure 7.** Spatial distribution of organic matter content in this study area.

experimentation are vital. The result reflect the soil properties of this study area, there is need to add appropriate fertilizer N, P, K to the soil in order to increase the fertility status. Also areas that have a high concentration of the nutrients needed for maize production should be cultivated more as this would save cost and

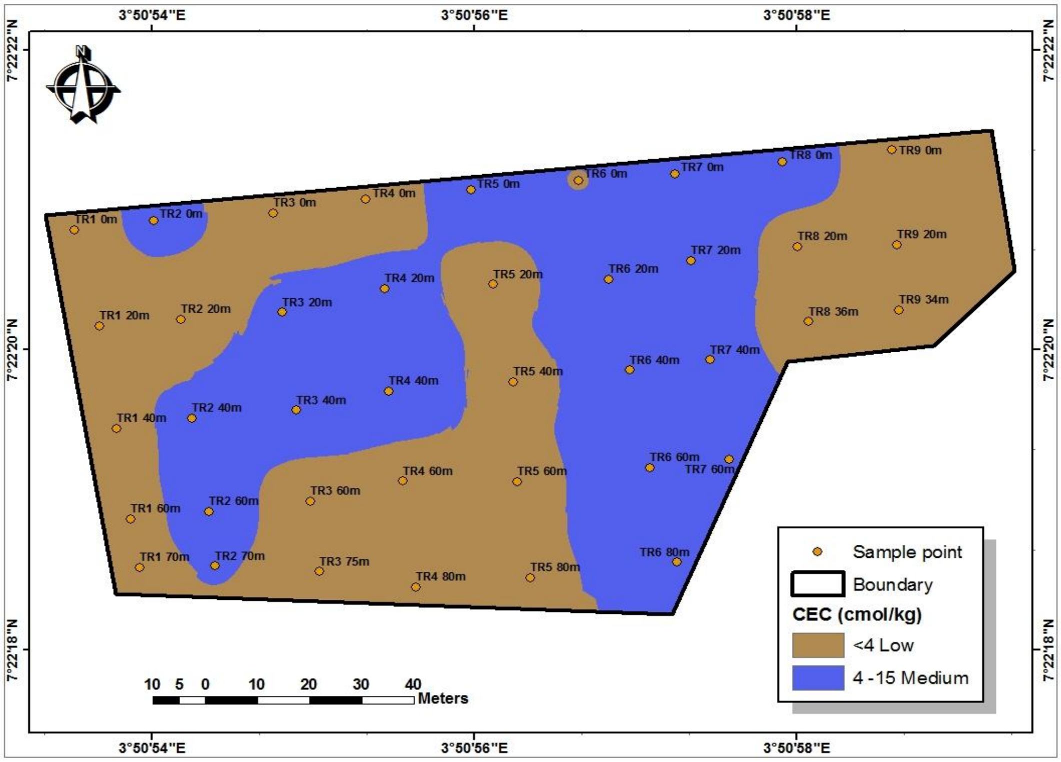


**Figure 8.** Spatial distribution of ECEC in the area.

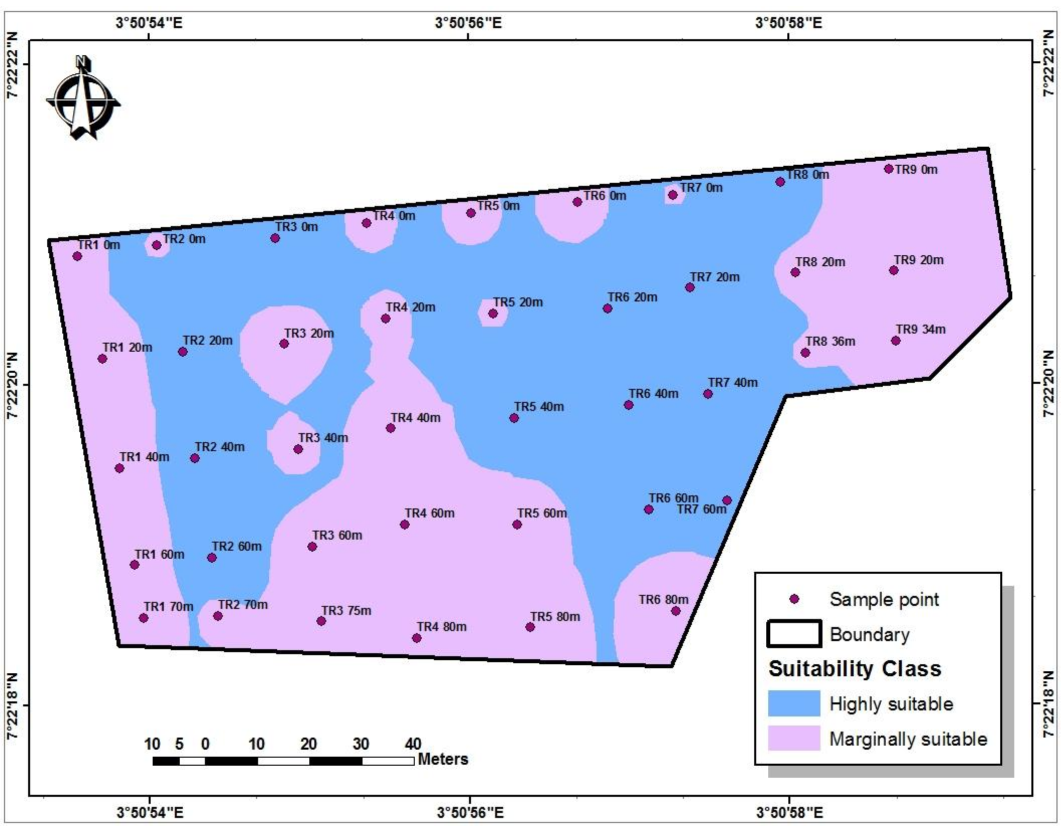


**Figure 9.** Spatial distribution of land suitability classes.

increase production.

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