VARIABILITY OF SOME SELECTED SOIL PARAMETERS IN A 50 YEARS INTENSIVELY CULTIVATED EXPERIMENTAL PLOT ON AN ALFISOL (IWO SERIES) †

[VARIABILIDAD DE ALGUNOS PARÁMETROS DE SUELO EN UNA PARCELA EXPERIMENTAL CULTIVADA INTENSIVAMENTE DE 50 AÑOS EN UN ALFISOL (SERIE IWO)]

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SUMMARY

Background. Soil has variability inherent to how its formation factors interact within the landscape. **Objective.** This study was carried out to describe the variability of some selected physical and chemical soil properties in a 50 years intensively cultivated field. **Methodology.** Eighty soil samples from a 100m × 180m plot were collected at 0 - 25 and 25 – 50cm depths and subjected to physical and chemical analysis. Semivariogram was calculated for each variable to ascertain the degree of spatial variability between neighboring observations. **Results.** Soil pH was moderately acidic with a mean of 5.64 and CV 6.91 % at 0- 25cm while at 25- 50cm it was strongly acidic with mean value of 5.54 and CV 7.04 %. Mean value of OC in the experimental field was higher at the top soil than sub soil with values 5.96 g/kg and 4.54 g/kg respectively with CV 38.26% and 50.44%. At 0 – 25cm, % silt had a significant negative correlation with % sand (-0.790) at 0.01%. % clay and % silt was negatively correlated (-0.428), however CEC was positively correlated with % clay (0.460) at 0.01% probability while OC concentration was positively correlated with TN (r = 0.833) at 0.01. Semivariograms indicated the existence of moderate to strong spatial dependence of soil variables at both depths. **Implications**. The study was used in determining the degradation status of the soils in the area, the findings of this study also showed that spatial structure exist in the soil properties at the field scale in the study site. **Conclusion.** These results support the importance of collecting information in experimental fields to know how a site –specific system should be undertaken.

Keywords: Soil variability; semi variograms; ordinary kriging; spatial dependence

RESUMEN

Antecedentes. El suelo tiene una variabilidad inherente a cómo interactúan sus factores de formación dentro del paisaje. **Objetivo.** Este estudio se llevó a cabo para describir la variabilidad de algunas propiedades físicas y químicas del suelo en un campo de 50 años de cultivo intensivo. **Metodología.** Se recolectaron ochenta muestras de suelo de una parcela de 100 m x 180 m a profundidades de 0-25 y 25-50 cm y se sometieron a análisis físicos y químicos. Se calculó el semivariograma para cada variable para determinar el grado de variabilidad espacial entre observaciones vecinas. **Resultados.** El pH del suelo fue moderadamente ácido con una media de 5.64 y CV 6.91% a 0-25 cm, mientras que a 25- 50 cm fue fuertemente ácido con un valor medio de 5.54 y CV 7.04%. El valor medio de OC en el campo experimental fue mayor en la capa superior del suelo que en el subsuelo con valores de 5.96 g / kg y 4.54 g / kg respectivamente con CV 38.26% y 50.44%. A 0-25 cm, el % de limo tuvo una correlación negativa significativa con el % de arena (-0.790) al 0.01%. El % de arcilla y el % de limo se correlacionaron negativamente (-0.428), sin embargo, la CIC se correlacionó positivamente con el % de arcilla (0,460) con una probabilidad de 0.01%, mientras que la concentración de OC se correlacionó positivamente con TN (r = 0.833) con 0.01. Los semivariogramas indicaron la existencia de una dependencia espacial de moderada a fuerte de las variables del suelo en ambas profundidades. **Implicaciones.** El estudio se utilizó para determinar el estado de degradación de los suelos en el área, los hallazgos de este estudio también mostraron que existe estructura espacial en las propiedades del suelo a escala de

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campo en el sitio de estudio. **Conclusión.** Estos resultados apoyan la importancia de recopilar información en campos experimentales para saber cómo se debe realizar un sistema específico para un sitio.
Keywords: variabilidad del suelo; semivariogramas; kriging ordinario; dependencia espacial

INTRODUCTION

Soil is a dynamic natural body which develops as a result of pedogenic natural processes during and after weathering of rocks; and consists of mineral and organic constituents, with definite chemical, physical, mineralogical and biological properties having a variable depth over the surface of the earth and providing a medium for plant growth (Biswas and Mukherjee, 1994). It is a heterogeneous and dynamic system with continuous changing properties in time and space (Rogerio *et al*., 2006). Heterogeneity may occur at a large (region) or at small (field) scales, even within the same type of soil or community (Du Feng *et al*., 2008). Soils also have variability inherent to its formation factors within the landscape. These variations are generally highly irregular especially on intensively cultivated land and are therefore not accurately described by deterministic equations. The value of soil properties on the landscape is location specific, with values at equidistant locations assumed to be similar. Variability can also occur due to cultivation, land use and erosion (Salviano, 1996). Spatial variability of soil properties has been reported and need to be taken into account during field sampling for investigation of its temporal and spatial changes (Salviano, 1996). The question often asked during soil sampling procedures is: whether samples should be taken randomly, uniformly or at intervals; how close should samples be taken to take care of variability and how far apart should it be to have their absolute differences in magnitude remaining constant.

The assessment of spatial variability is an important approach to understanding the distributions of soil properties at field scale, because soil properties vary spatially from a field to a larger regional scale and it is affected by both intrinsic (soil forming factors) and extrinsic factors such as soil management practices, fertilization, and agronomy practices (Aduramigba-Modupe *et al.,* 2003; Aduramigba-Modupe and Olanipekun, 2017). It is also important for carrying out site specific management practices which helps in saving cost of inputs as only specific nutrients needed in the field is added (Oluwatosin and Ogunkunle, 1991).

This variation is a gradual change in soil properties, and a function of landforms, geomorphic elements, soil forming factors, land use and management practices (Buol *et al.,* 1997). The physical, chemical and biological properties of soils are highly variable over time and space and this variation should be monitored and quantified to understand effects of land use management systems on soils. The knowledge of soil spatial variability and the relationships among soil properties is important for evaluating agricultural land management practices (Huang *et al.,* 1999). The importance of reliable and timely information on soils cannot be overlooked in other to acquire spatial information of the soil properties, such information is necessary in the implementation of effective management strategies for sustainable agricultural production.

Geostatistics (consisting of variography and kriging) can be used in studying and predicting the spatial structure of georeferenced variables, generating soil properties map and understanding their distribution (Krasilnikov *et al*., 2008). Variography uses semivariograms to characterize and model the spatial variance of data whereas kriging uses the modeled variance to estimate values between samples (Burgess and Webster, 1980; Yamagishi *et al*., 2003). The experimental plot used for this study had been intensively cultivated with different crops under different treatment combinations for 50 years. The area has also been cultivated during the dry season with drip irrigation facilities; thus making the study area under use all year round. This has resulted in the depletion of essential soil nutrients and a reduction in the organic matter layer. The main objective of this study therefore is to assess the level of soil fertility depletion in the area while determining the variability of some selected physical and chemical soil properties in a the study area.

MATERIALS AND METHODS

Study site

The study was carried out in the Institute of Agricultural Research and Training, located in the Ibadan South – West local government of Oyo state Nigeria at the listed coordinates (7.372735 N and 3.848168 E). The experimental field is located at the southern part of the institute at about 160m above sea level, in a rolling topography with a slope ranging from 4 – 8 % (Figure 1); and characterized by a tropical climate marked with wet and dry seasons. It has a bimodal rainfall pattern with peaks occurring mostly in June and September. Annual temperature ranges from 21.3 to 31.2°C (Denton and Gbadegeshin, 2013). There are two cropping seasons: early (March/April to early June/July) and late (mid-August to October/November).

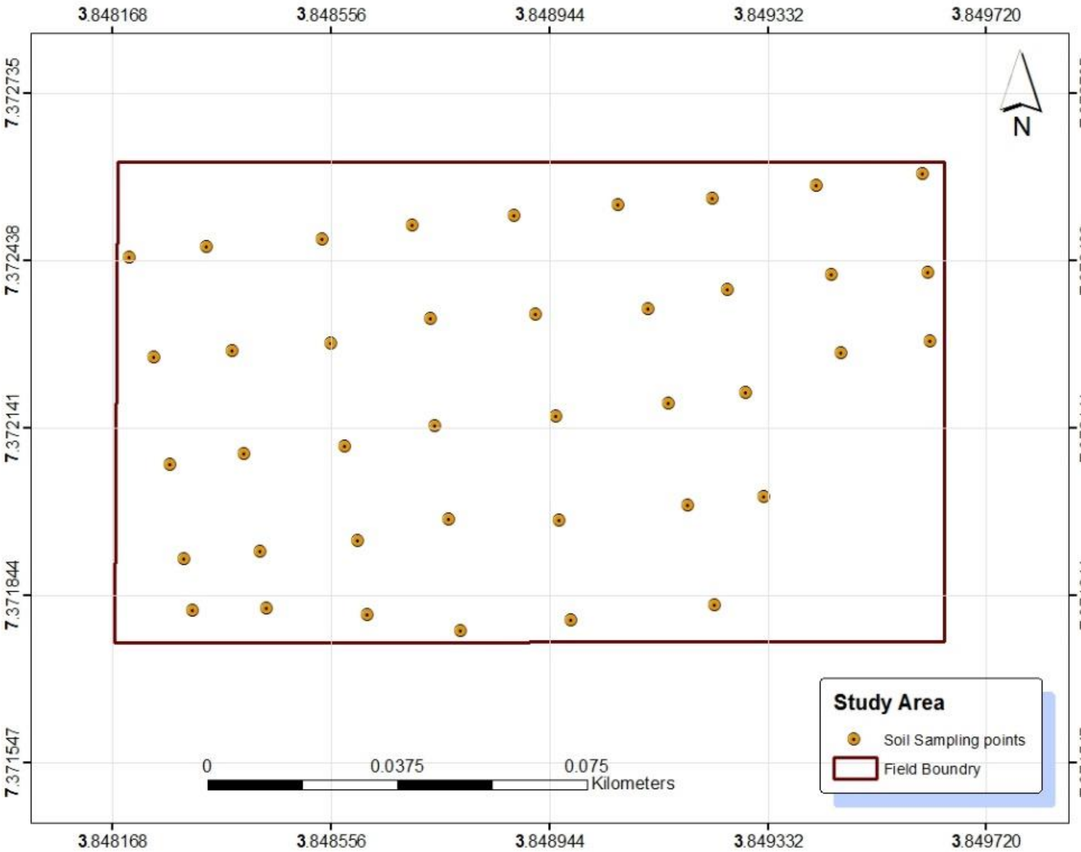

Figure 1. Study area and location of sampling points.

The study area covered a 3 ha of land (100 m × 180 m) that has been under continuous cultivation for more than 50 years. The area is cultivated all year round (rain-fed during the rainy season and under irrigation system during the dry season). Land preparation is done by plow and harrow at the beginning of every planting season; herbicides are used to prevent weeds while inorganic fertilizers such as NPK have been used constantly and extensively as the need arises. Crops were also being rotated in alternate plots over the years as a means of improving the soil structure and organic matter content of the soil. Stubbles from previous crops are usually plowed under during land preparation for subsequent field. Diverse crops (maize, upland rice, okra, kenaf, etc.) have been grown on the land without adequate knowledge of which area of the land is most suitable based on the variability of the soil nutrients (Denton and Gbadegeshin, 2013). The soils in the area were classified as an alfisol according to the USDA soil taxonomy which are soils that are moderately leached. They are typically formed under temperate humid and sub- humid regions. Alfisols are forest soils having moderate to high fertility and clay accumulation at the sub-surface (Soil survey staff, 2014). It is referred to as luvisols in WRB and are formed from basement complex parent material. The soil covers more than 70% of the study area and has a slope percentage of 2 – 4 which is gently undulating. In terms of management practices, no laid out practice was followed through the years, the plot was used as need arises.

Soil sampling and laboratory analysis

The field was sampled on a 20 m × 20 m grid resulting in 9 transects and 40 sample locations (field data points) spanning the whole experimental field. A garmin – etrex handheld GPS was used for recording the coordinates at each location for the collection of soil samples at 0 - 25 and 25 – 50cm depths with the aid of a Dutch auger; with a total of 80 samples collected from both depths.

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. The particle-size analysis was done by Bouyoucos hydrometer method (Ge and Bouder, 1986). The pH of the soil samples was analyzed 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). The Van Bemmeln factor of 1.724 was used for conversions between values of organic carbon and organic matter was on the assumption that, an average, SOM contains 58% of organic C (Walkey and Black, 1934). 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 analyzed were imported into GIS environment.

Statistical analysis

Descriptive statistical analysis was carried out on all the variables using the statistical packages for social sciences (SPSS v18.0) software.

Geostatistical analysis

Semivariogram was calculated for each variable to ascertain the degree of spatial variability between neighboring observations and the best fit model was applied to the semi-variogram. This also enabled the spatial correlation within the measured data points. The semivariogram function of Goovaerts (1997) was used in the calculation. Spatial inconsistency was estimated as a semi – variogram which portrays the mean square variability between two neighboring sample locations of distance h (Gouri Sankar Bhunia *et al*., 2018) as shown in the Eq (1) below:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(xi+h) - z(xi)]^2 \quad (1)$$

Where γ (h) = magnitude of the lag distance between the two samples location.
N (h) = number of observation pairs separated by distance h,
Z (xi) = random variable at location x_j

A semivariogram consists of three basic parameters which describe the spatial structure as: γ (h) = C_o + C. C_o represents the *nugget effect*, which is the local variation occurring at scales finer than the sampling interval, such as sampling error, fine-scale spatial variability, and measurement error; C_o + C is the *sill* (total variance); and the distance at which semivariogram levels off at the sill is called the *range* (beyond that distance the sampling variables are not correlated. Different classes of spatial dependence for the soil variables were evaluated by the ratio between the nugget semivariance and the total semivariance (Cambardella *et al*., 1994). Soil variables with ratios lower than 25% are considered to be strong spatially or strongly distributed in patches while ratios between 25 – 75 % are moderately spatially dependent and ratios above 75 % are considered weakly spatially dependent (Cambardella *et al*., 1994).

Ordinary kriging method (OK) was used to generate predictive maps of soil properties in the area using a semi-variogram model and critical limits of soil properties as stated by Agboola and Ayodele, 1985 Federal fertilizer department, 2012 (Table 1). The OK model is the most familiar type of kriging and provides an accurate estimate for an area around a measure sample (Pang et. al., 2011). This was used to interpolate soil samples in point location data into incessant fields of soil properties. Prediction maps of soil properties were produced using variograms from ArcGIS 10.5 software package. A cross-validation approach was then conducted to evaluate the efficiency and error of the prediction maps for soil properties. The root-mean-square- error (RMSE) and the mean error (ME) of the model were also calculated. A value of RMSE close to zero illustrates the accuracy of prediction of the model (Gouri Sankar Bhunia *et al*., 2018). The following formula were used to calculate the RMSE and ME values:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[z(xi) - Z*(xi)]^2} \quad (2)$$

$$ME = \frac{1}{n}\sum_{i=1}^{n}[z(xi) - Z*(xi)] \quad (3)$$

RESULTS

Descriptive statistical analysis of soil properties

The descriptive characteristics of some soil properties in the experimental field as presented in Table 2 suggested that they were all normally distributed (Kolmogrov-Smironov test). The skewness values also confirmed that all soil variables were normally distributed. Soil pH at 0 – 25 cm depth was higher than that obtained at the lower depth, this was also reflected in the values for SD and CV.

Table 1. Criteria for soil test interpretation and soil fertility classes in South – West Nigeria.

Soil properties	Criteria	Low	Medium	High
Acidity (pH)		6.0 – 6.90	5.00 – 5.90	< 5.00
O.M %	2.00	0 – 2.00	2.00 – 3.00	> 3.00
O.C g/kg		< 4.0	4.00 – 10.00	> 10.00
Total N %	0.15	0 – 0.15	0.15 – 0.20	> 0.20
Available P (mg kg^{-1})	8.50	0 – 8.50	8.50 – 12.50	> 12.50
K (Cmol kg^{-1})	0.16	0 – 0.16	0.16 – 0.31	> 0.31
Mg (Cmol kg^{-1})	0.28			
Ca (Cmol kg^{-1})	1.50	0 – 1.50	1.60 – 4.00	> 4.00
S (mg kg^{-1})	5.00	0 – 5.00	5.00 – 7.00	> 7.00
Zn (mg kg^{-1})	1.00	0 – 1.00	1.00 – 1.50	> 1.50
Cu (mg kg^{-1})	0.50	0 – 0.50	0.50 – 0.70	> 0.70
B (mg kg^{-1})	0.50	0 – 0.50	0.50 – 0.60	> 0.60
Fe (mg kg^{-1})	3.50			
Mn (mg kg^{-1})	3.00			

Based on recommendations by Federal fertilizer department 2012

The CVs of total nitrogen (TN), Available P (AV.P) and Potassium (K) at both depths exceeded 35%, which shows considerable geographical heterogenous in the N, P, K properties within the experimental field. The texture parameters in the field i. e sand, silt and clay fractions showed a minimum range of variation with the sand fraction having the lowest CV of 5.15 % and 5.66 % at both the top and sub soils respectively showing that texture parameters is less variable (CV < 15%). Also the sand fraction had the highest mean value of 69.10 % and 65.90% at depth indicating that the plot was mostly sandy in nature. The mean value of OC in the experimental field was higher at the top soil than sub soil with values 5.96 g/kg and 4.54 g/kg respectively with CV 38.26% and 50.44%. TN, Av. P, K, CEC and soil pH all have higher mean values at

Table 2. Descriptive statistics of an Alfisol (Luvisol) properties in an experimental field (n = 80) at 0-25cm and 25 -50 cm in Ibadan Nigeria.

Variable	Depth (cm)	Min	Max	Mean	Median	SD	CV (%)	CV Grp	Skew ness	Kurtosis
Sand (%)	0 – 25	63.52	78.98	69.10	68.98	3.56	5.15	I	0.68	2.95
	25 – 50	58.98	71.52	65.90	66.98	3.73	5.66	I	-0.53	2.12
Silt (%)	0 – 25	5.84	23.38	17.38	17.84	3.88	22.32	II	-0.09	4.75
	25 – 50	8.38	24.38	17.65	17.84	3.25	18.41	II	-0.04	3.74
Clay (%)	0 – 25	8.12	17.18	13.62	14.12	2.37	17.40	II	-0.67	3.25
	25 – 50	11.14	32.64	16.45	16.11	3.89	23.65	II	2.16	9.06
TN (g kg^{-1})	0 – 25	0.10	1.90	0.67	0.60	0.36	53.73	III	1.06	4.53
	25 – 50	0.20	1.20	0.52	0.50	0.24	46.15	III	0.73	3.01
P (mg kg^{-1})	0 – 25	2.33	11.15	6.01	5.58	2.11	35.11	III	0.38	2.66
	25 – 50	0.14	1.05	0.45	0.39	0.23	51.11	III	0.87	3.05
K (cmol kg^{-1})	0 – 25	0.16	0.78	0.34	0.32	0.13	38.24	III	1.59	6.18
	25 – 50	0.13	0.41	0.26	0.25	0.08	30.77	II	0.19	1.86
Soil pH	0 – 25	4.99	6.53	5.64	5.61	0.39	6.91	I	0.29	2.20
	25 – 50	5.05	6.59	5.54	5.47	0.39	7.04	I	0.78	2.86
CEC (cmol kg^{-1})	0 – 25	2.81	5.69	4.01	3.89	0.63	15.71	II	0.75	3.45
	25 – 50	0.09	0.19	0.14	0.14	0.02	14.29	I	-0.06	3.63
OC (g kg^{-1})	0 – 25	1.70	12.40	5.96	5.15	2.28	38.26	III	0.78	3.37
	25 – 50	1.40	10.50	4.54	3.90	2.29	50.44	III	0.87	3.05
Base Saturation (%)	0 – 25	89.17	97.66	96.39	96.85	1.42	1.47	I	-3.38	17.65
	25 – 50	94.93	98.09	96.57	96.63	0.74	0.77	I	-0.15	2.51

%CV Group: I = 0 – 15%, II= 16 – 30%, III = 31 - < 50%

Table 3. Correlation matrix between the soil variables at 0 -25 cm depth.

	Soil pH	% Sand	% Silt	% Clay	K Cmol kg^{-1}	CEC $Cmolkg^{-1}$	Base Saturation (%)	O.C ($g\ kg^{-1}$)	P (ppm)	N ($g\ kg^{-1}$)
Soil pH	1									
% Sand	0.173	1								
% Silt	0.070	-0.790**	1							
% Clay	-0.385*	-0.204	-0.428**	1						
K Cmol kg^{-1}	-0.015	0.061	-0.178	0.203	1					
CEC Cmol kg^{-1}	-0.059	-0.199	-0.110	0.460**	0.263	1				
%Base Sat	0.515**	-0.066	0.152	-0.167	0.201	0.032	1			
O.C ($g\ kg^{-1}$)	0.457**	0.112	0.017	-0.182	0.098	0.057	0.053	1		
P (ppm)	0.045	-0.027	0.103	-0.105	0.043	-0.166	0.152	0.166	1	
N ($g\ kg^{-1}$)	0.528**	0.169	0.029	-0.272	-0.072	-0.108	0.023	0.833**	0.170	1

***. Correlation is significant at the 0.01 level (2-tailed).*
**Correlation is significant at the 0.05 level (2-tailed).*

depth of 0 – 25cm than at 25 – 50cm depth. The descriptive characteristics of soil properties imply that distribution of the soil properties varies from slightly negatively skewed (skewness ≤ 0.04) to moderately positive skewed (skewness > 2.16). The coefficient of variation (CV) shows that the overall variation of soil characteristics varied from low to high values according to Warrick guidelines (Warrick and Hillel, 1998). The highest CV however was recorded for TN (53.73 %) while the lowest was recorded for base saturation (0.77%). This variation could be attributed to the constant use of inorganic fertilizers over the 50 years of intensive cultivation of the field, resulting in noticeable variations in the surface soils within small distances (i. e sampling lag of 10m).

Table 4. Correlation matrix between the soil variables at 25 - 50 cm depth.

	Soil pH	% Sand	% silt	% Clay	K (cmol kg^{-1})	CEC (cmol kg^{-1})	Base Saturation (%)	O.C ($g\ kg^{-1}$)	P (ppm)	N ($g\ kg^{-1}$)
Soil pH	1									
% Sand	0.120	1								
% Silt	0.120	-0.383*	1							
% Clay	-0.215	-0.639**	-0.466**	1						
K (cmol kg^{-1})	0.115	0.178	0.056	-0.217	1					
CEC	-0.029	-0.657**	0.415**	0.283	0.051	1				
Base Saturation(%)	0.284	-0.472**	0.408**	0.113	0.012	0.786**	1			
O.C ($g\ kg^{-1}$)	0.252	-0.254	0.348*	-0.047	0.257	0.199	0.353*	1		
P (ppm)	0.185	0.098	-0.002	-0.091	-0.036	0.121	0.146	-0.160	1	
N ($g\ kg^{-1}$)	0.444**	-0.080	0.251	-0.132	0.265	0.038	0.189	0.874**	-0.110	1

**Correlation is significant at the 0.05 level (2-tailed).*
*** Correlation is significant at the 0.01 level (2-tailed).*

Correlation analysis

The correlation matrix for the soil properties at the two levels sampled were calculated to understand the relationship between soil nutrients (table 3 and 4). At the top soil % silt had a significant negative correlation with % sand (-0.790) at 0.01 % which implies that as the one increases the other decreases.

There was also a negative significant correlation between % clay and % silt (-0.428). CEC was positively correlated with % clay (0.460) at 0.01% probability, this implies that the clay is more active at the exchange site. This is as a result of the high clay content at the top soil as against the organic carbon content which was lower, which therefore made the clay to take over the exchange site therefore influencing the CEC. Organic carbon concentration was significantly and positively correlated with total nitrogen ($r = 0.833$) at 0.01 level of significance but its coefficient of correlation with clay, K and CEC was negative and weak. Correlation of Av. P with N was weak and negatively correlated while that between OC and Av. P was also weak. Av. P, K, OC and CEC had significant positive correlation with each other. The different concentration of P and K are influenced by the organic matter and mineral composition of the soil.

At depth however, % sand content was significant but negatively correlated to % silt, % clay, CEC and % base sat with r values of -0.380, -0.639, -0.657 and -0.472 at p = 0.01. % clay and CEC both had strong correlations to % sand. There was no significant relationship between OC and clay fractions, indicating that these two soil properties acted independently though responsible for soil fertility. There was a significant positive correlation between N and OC ($r = 0.874$, $p < 0.01$), N and soil pH ($r = 0.444$, $p < 0.01$). Also there was a strong significant positive correlation between base sat and CEC ($r = 0.786$, $p < 0.01$) which indicates the presence of high amount of exchangeable bases at the exchange site. Organic carbon content was positively correlated with base saturation and silt at $r = 0.353$ and $r = 0.348$ both at $p<0.05$. Relationships existed between the observed soil physical and chemical properties which may positively or negatively interfere with nutrient availability.

Geostatistical analysis

The best-fitted isotropic semivariogram model parameters and some spatial structural indices of soil properties in the experimental fields at 0 -25 cm and 25- 50cm depths are shown in table 4. Omni-directional semivariograms were modeled to determine the spatial dependence within the research area. For the top soil, sand and total nitrogen modeled very well with the spherical model; silt, soil pH and CEC were modeled with the exponential model while the Gaussian model was used to model % clay, Av. P, K, OC and base saturation. For the subsoil however, most of the soil properties were best fitted to the exponential and gaussian model. The resulting semivariograms indicated the existence of moderate to strong spatial dependence of the top soil. Sand, silt, K and base saturation had strong spatial dependence with nugget/sill values ranging between 0.100 and 19.37 % while clay, TN, Av. P, soil pH, CEC, and Organic carbon had moderate spatial dependence with values between 31.89 – 68.55 %. At 25 – 50 cm depth silt, K and soil pH had strong spatial dependence with values 15.21, 19.03and 21.15% respectively. Other soil properties with moderate spatial dependence were sand, clay and organic carbon except for total nitrogen, Available P and CEC with weak spatial dependence had values above 75% which tallies with the report of Eltaib *et al*., 2002; Jung *et al*., 2006 for TN and Brouder *et al*., 2001; Han *et al*., 2005 for Av. P.

The nugget which is the value at which the semi variogram intercepts the y–value was low for all the parameters at both depths. The highest recorded nugget was 11.17 for sand at the top soil which is a little above the lag distance of the soil sampled (10m) table 5. All other nugget values were lower than 10m indicating high variability within the soils sampled. Sill values was highest at depth with a value of 12.348 and this was recorded for % clay while the lowest recorded sill value was 0.0002 for CEC at the lower depth.

Another important spatial analysis measured is the range, this is the approximate distance from one point to another within the field which is usually assumed to be correlated. Therefore, a small value would indicate a large amount of variability within a field while large values indicate greater distances that the samples could be obtained and the data still correlated. In the study area range values in the top soil and sub soils were low (0.002 – 0.0008) indicating that there is a great variability of measured parameters within the field. The lower range values could be as a result of smaller sampling intervals (Tsegaye and Hill, 1998).

Spatial interpolation of soil properties

The distribution maps of measured soil properties at two depths are shown in Figures 3 -12 as obtained by ordinary kriging. The sand, silt and clay fractions differed at both depth with the sand content being higher at the top soil than the sub soil thereby making the soils in the area more sandy and variable as shown in fig 3a & 3b. The silt and clay fractions also showed

Table 5. Geostatistical parameters for soil properties at 0 -25 cm and 25 – 50cm depths.

Parameter	Sand (%)	Silt (%)	Clay (%)	TN (g kg^{-1})	Av. P (mg kg^{-1})	K (cmol/kg)	Soil pH	CEC	OC (g kg^{-1})	Base Sat. (%)
					Top Soil 0-25cm					
Model	Sph	Exp	Gau	Sph	Gau	Gau	Exp	Exp	Gau	Gau
Nugget(Co)	11.17	9.76	2.87	0.0004	2.14	0.003	0.038	0.159	0.033	0.003
Sill (Co+C)	0.58	8.23	7.29	0.0010	3.13	0.019	0.120	0.266	0.053	3.115
Range (m)	0.0005	0.002	0.002	0.0008	0.0004	0.0003	0.0003	0.0003	0.0016	0.0003
Nugget/Sill	19.37	11.86	39.38	40.00	68.55	17.17	31.89	60.02	61.63	0.100
Spatial class	S	S	M	M	M	S	M	M	M	S
ME	0.0085	-0.018	-0.015	-9.943	0.009	-0.003	-0.013	0.001	0.002	-0.038
RMSE	3.77	3.99	1.85	0.034	1.803	0.144	0.389	0.667	0.200	2.248
					Sub Soil 25 – 50 cm					
Model	Gau	Exp	Gau	Exp	Gau	Exp	Sta	Exp	Exp	Shp
Nugget (Co)	7.055	7.417	7.398	0.035	2.410	0.006	0.175	0.0002	1.416	0.173
Sill (Co + C)	9.480	4.877	12.348	0.029	2.242	0.0003	0.828	0.0002	5.272	0.222
Range (m)	0.0003	0.0008	0.0005	0.0005	0.0003	0.0006	0.0004	0.0003	0.0006	0.0003
Nugget/Sill	74.42	15.21	59.91	119.38	107.49	19.03	21.15	100	27.06	77.93
Spatial class	M	S	M	W	W	S	S	W	M	W
ME	0.0042	-0.0094	-0.0046	0.0059	0.0260	0.0014	0.0019	0.0003	0.0450	-0.0016
RMSE	3.8764	3.3074	4.1006	0.2399	1.9544	0.0809	0.3073	0.0193	2.1008	0.6658

Spatial class: S = Strong spatial dependency Nugget < 25, M = Moderate spatial dependency Nugget 25 - 75, W = Weak spatial dependency Nugget > 75. ME: Mean Error, RMSE: Root Mean Square Error. Models: Spherical (Sph), Exponential (Exp), Gaussian (Gau), Stable (Sta).

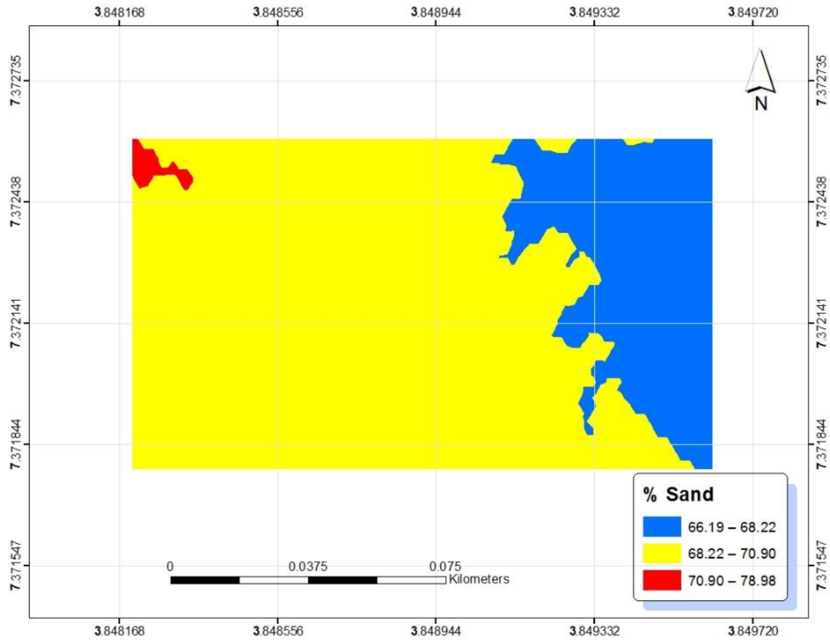

Figure 3 (a). Spatial distribution of sand at 0 - 25cm.

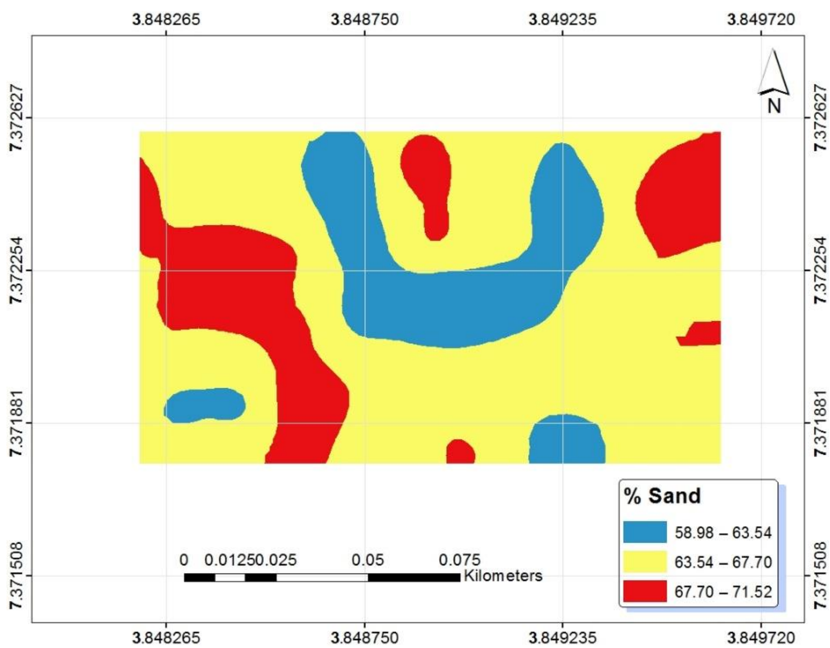

Figure 3 (b). Spatial distribution of sand at 25 – 50 cm.

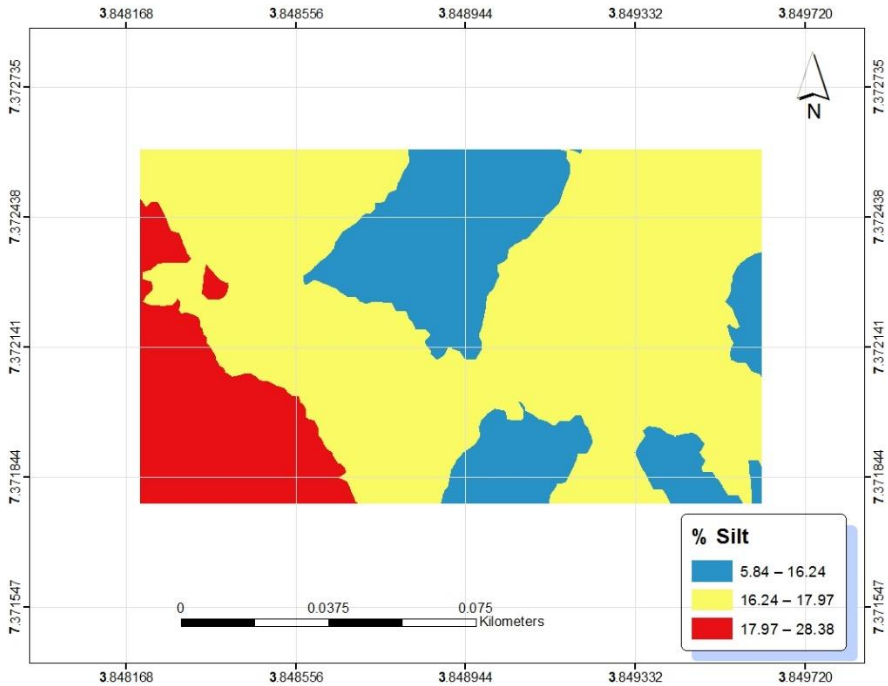

Figure 4 (a). Spatial distribution of silt at 0 – 25 cm.

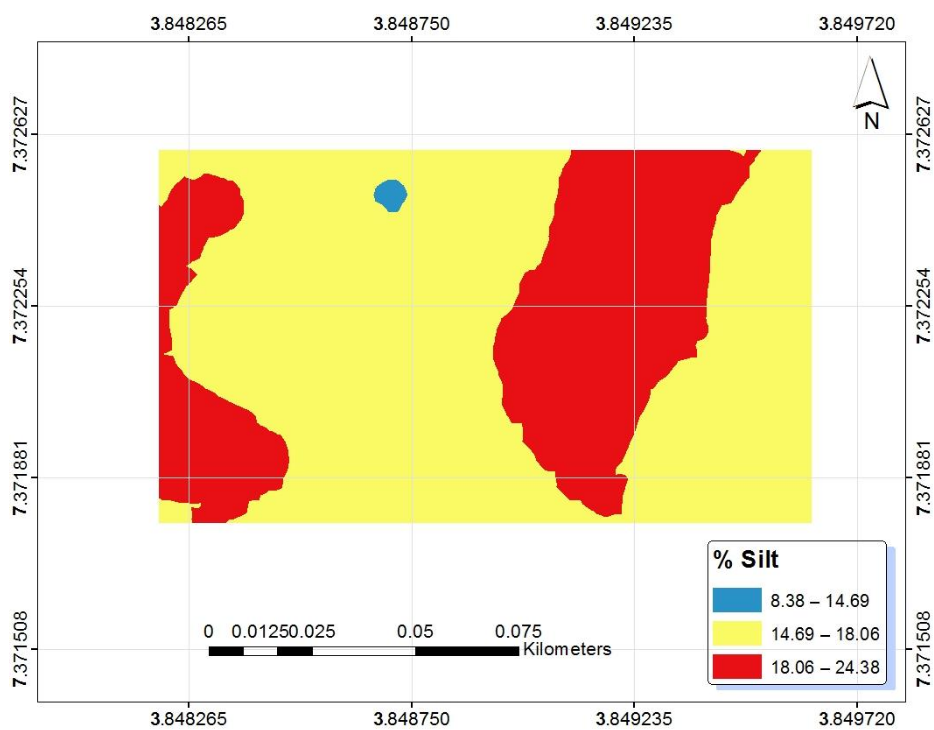

Figure 4 (b). Spatial distribution of silt at 25 – 50 cm.

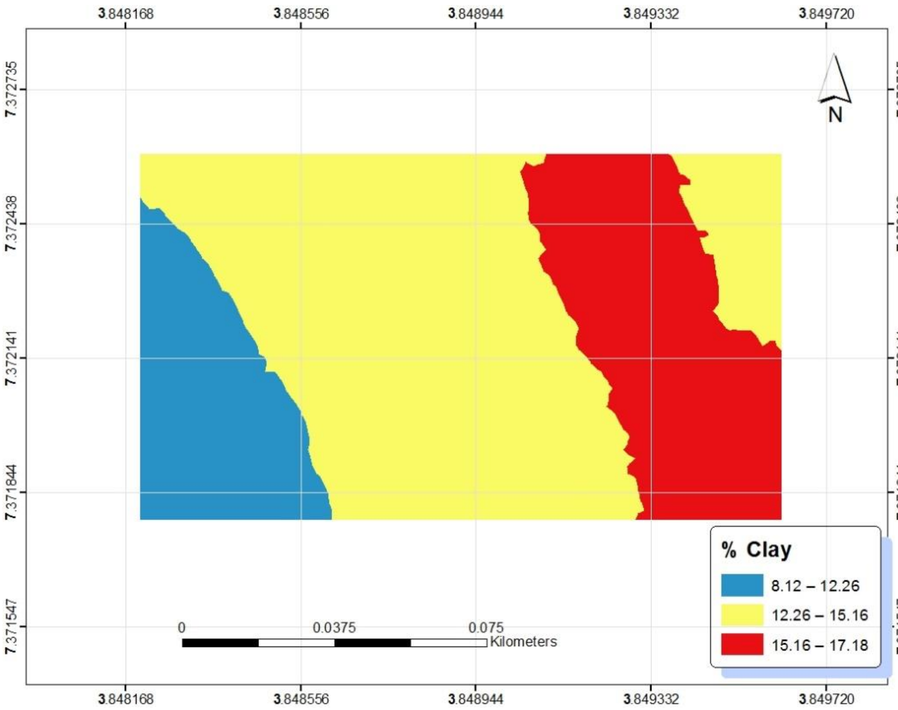

Figure 5 (a). Spatial distribution of clay at 0 – 25 cm.

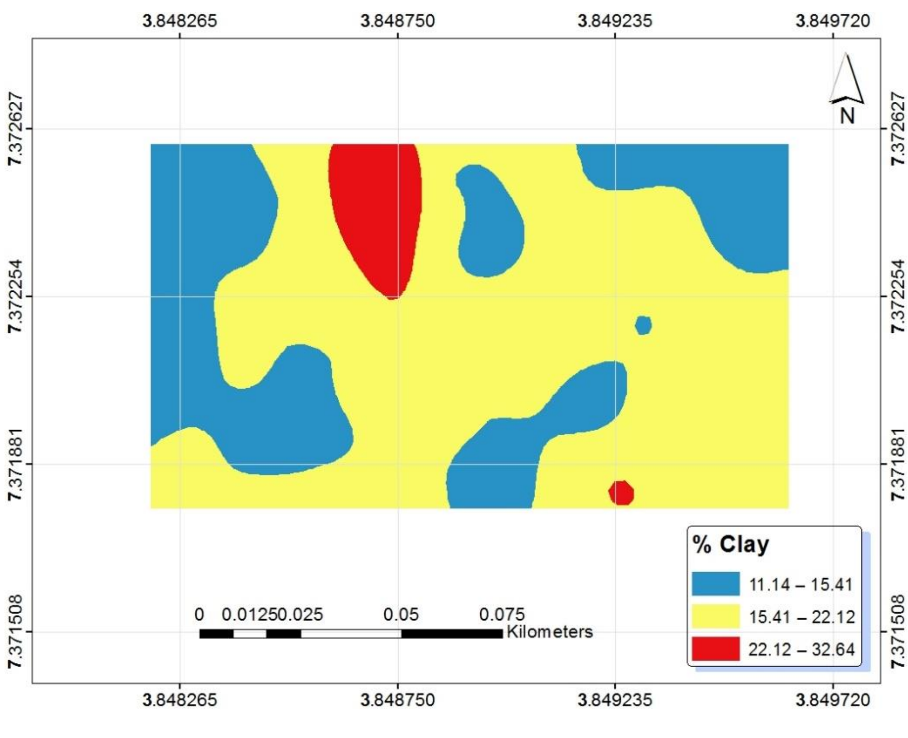

Figure 5 (b). Spatial distribution of clay at 25 – 50 cm.

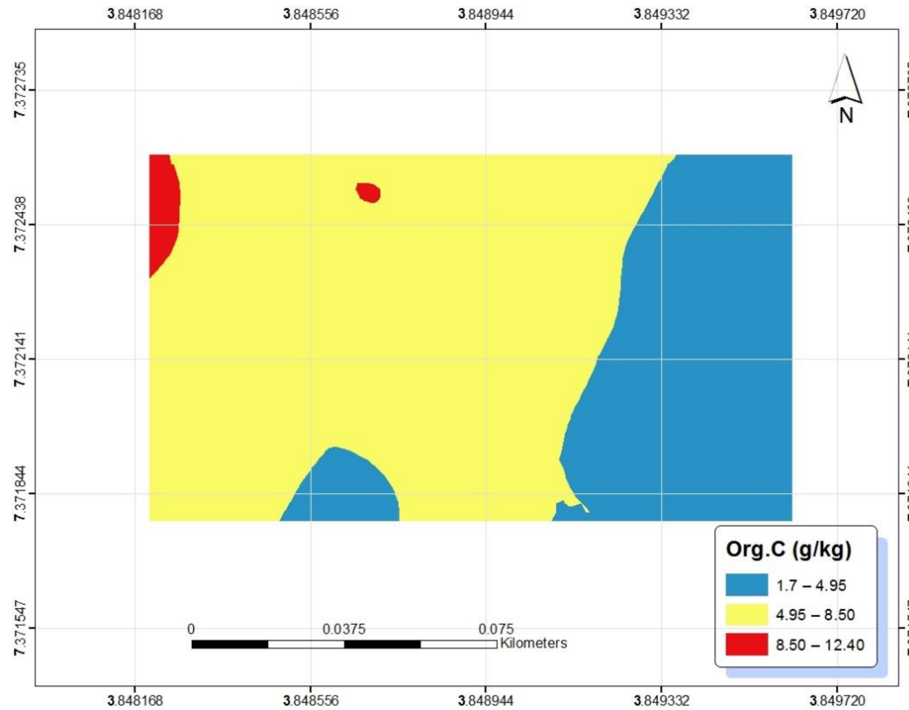

Figure 6 (a). Spatial distribution of Organic carbon at 0 - 25cm.

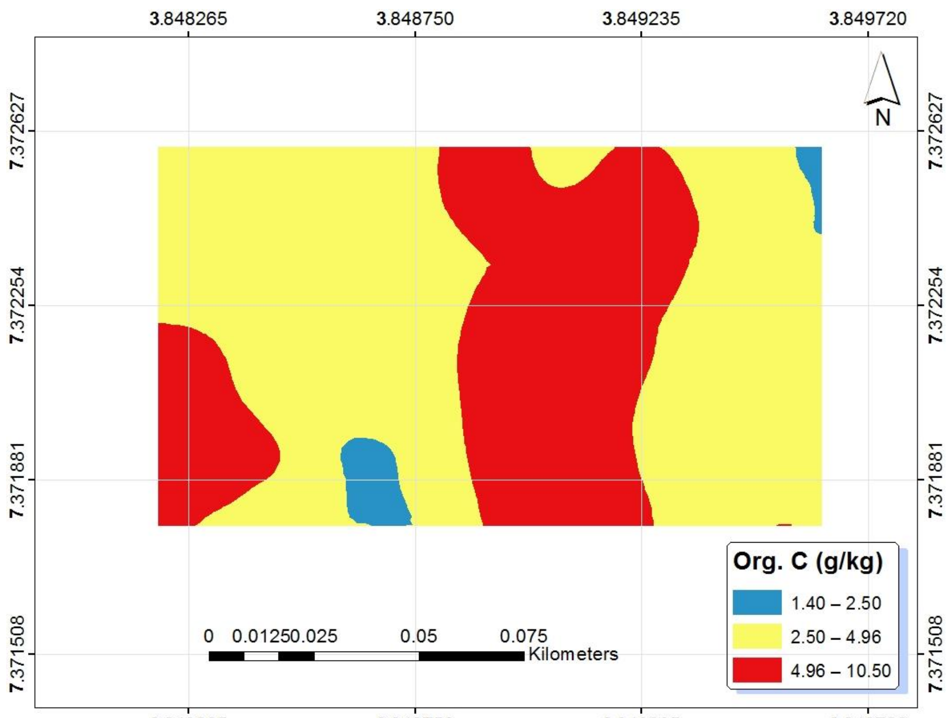

Figure 6 (b). Spatial distribution of Organic carbon at 25-50cm.

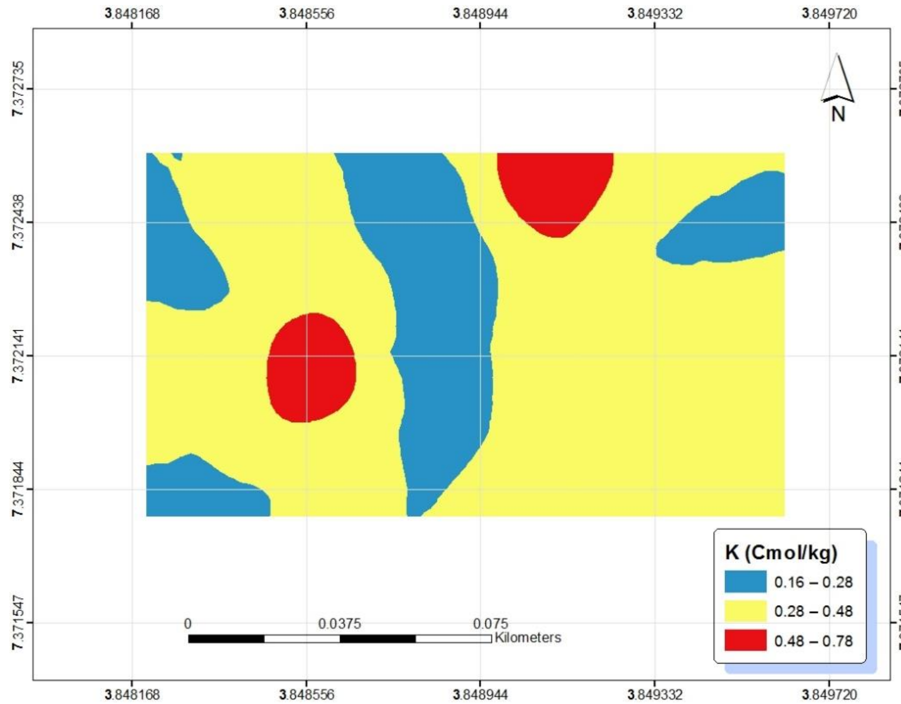

Figure 7 (a). Spatial distribution of potassium at 0 - 25cm.

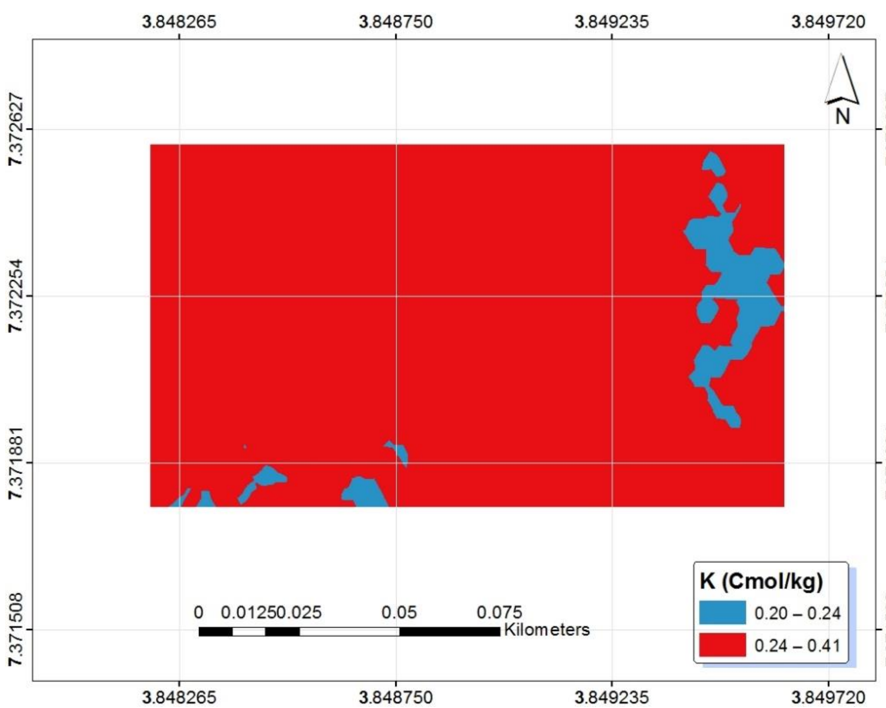

Figure 7 (b). Spatial distribution of potassium at 25 – 50 cm.

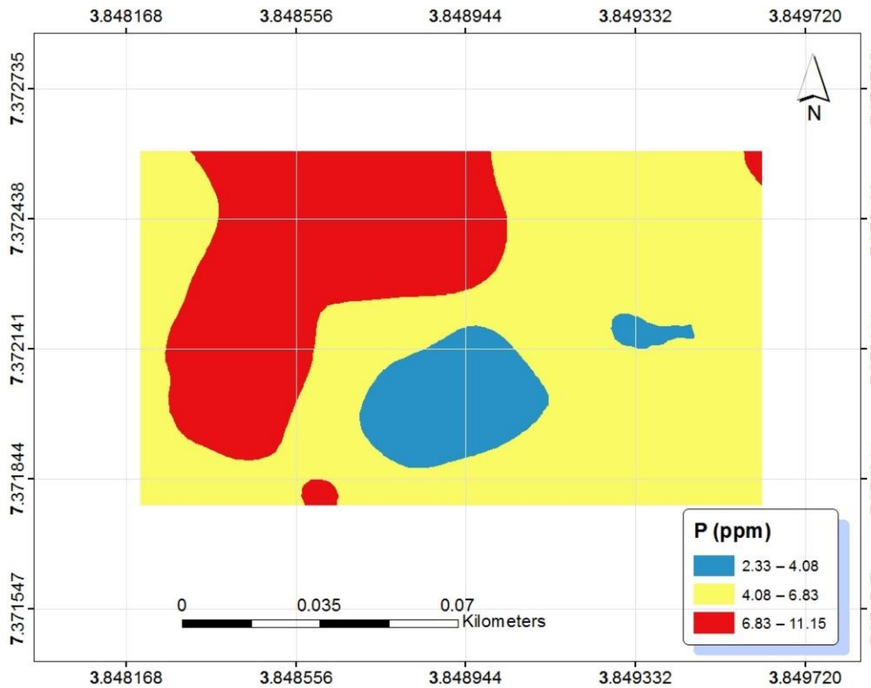

Figure 8 (a). Spatial distribution of phosphorus at 0 – 25 cm.

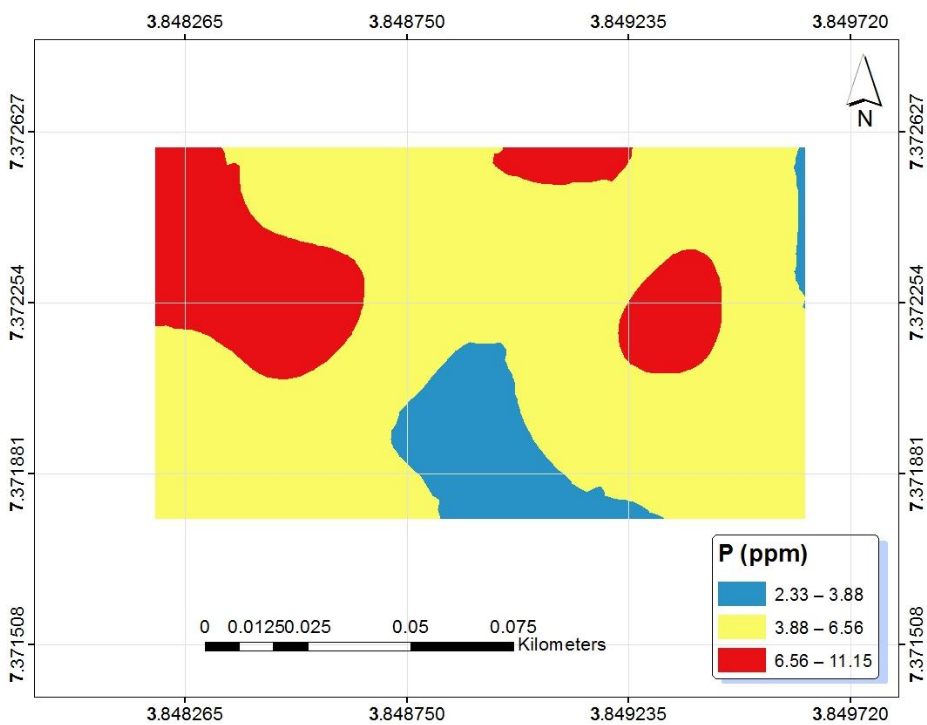

Figure 8 (b). Spatial distribution of phosphorus at 25 – 50 cm.

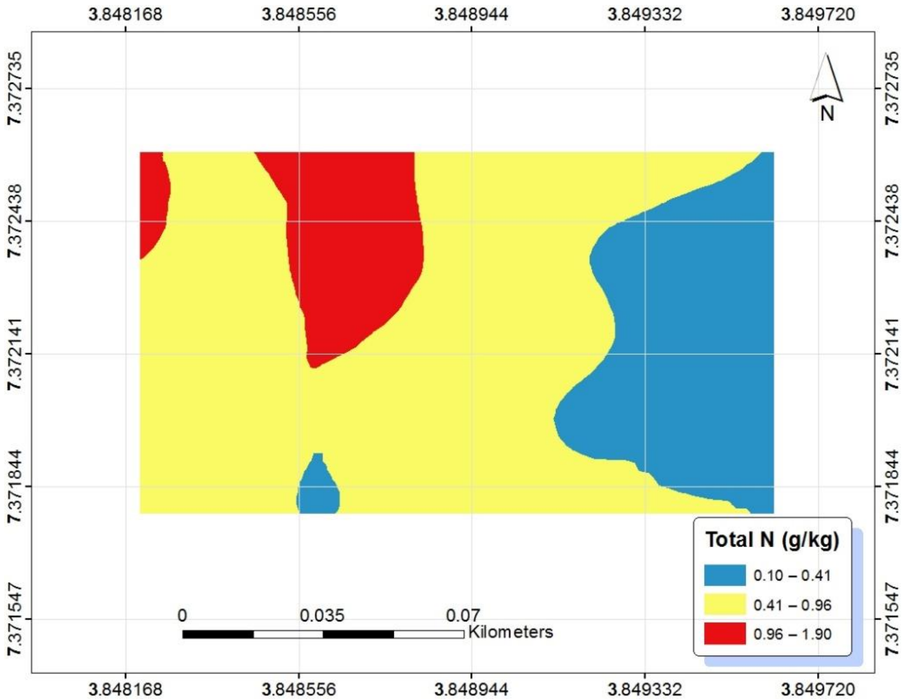

Figure 9 (a). Spatial distribution of Total Nitrogen at 0 – 25 cm .

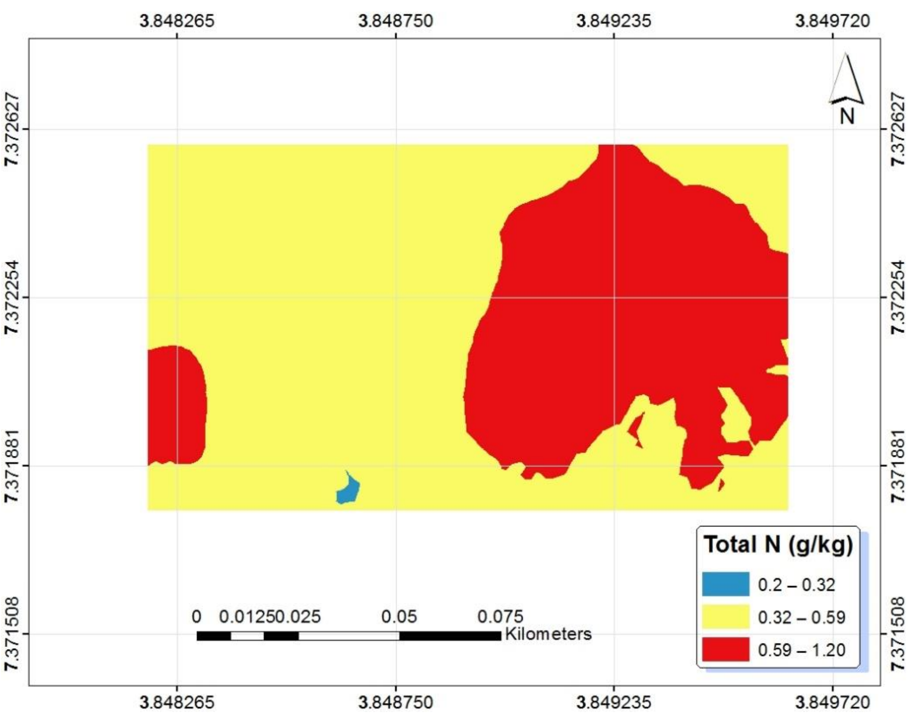

Figure 9 (b). Spatial distribution of Total Nitrogen at 25 – 50.

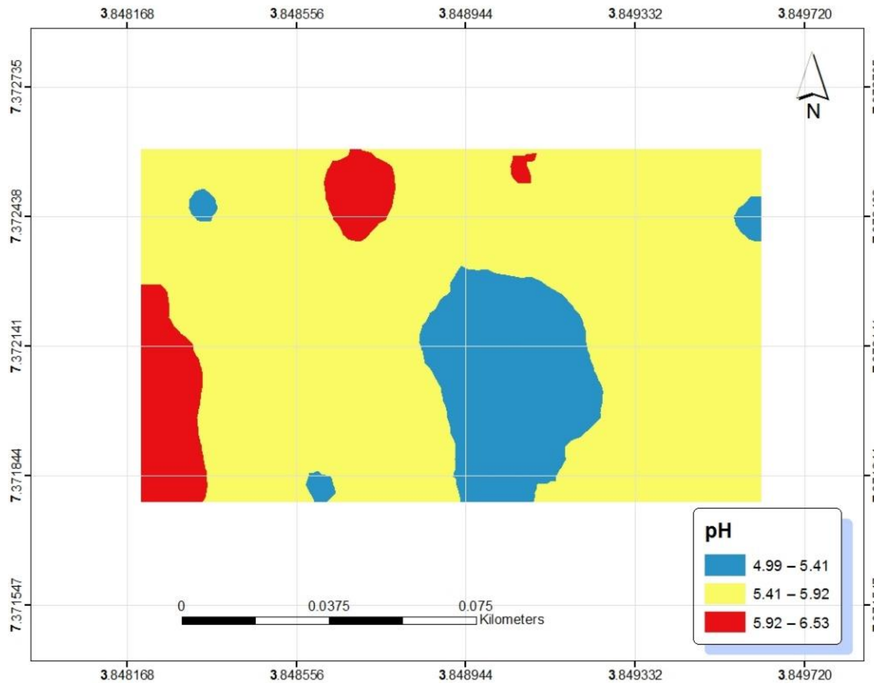

Figure 10 (a). Spatial distribution of pH at 0 – 25 cm.

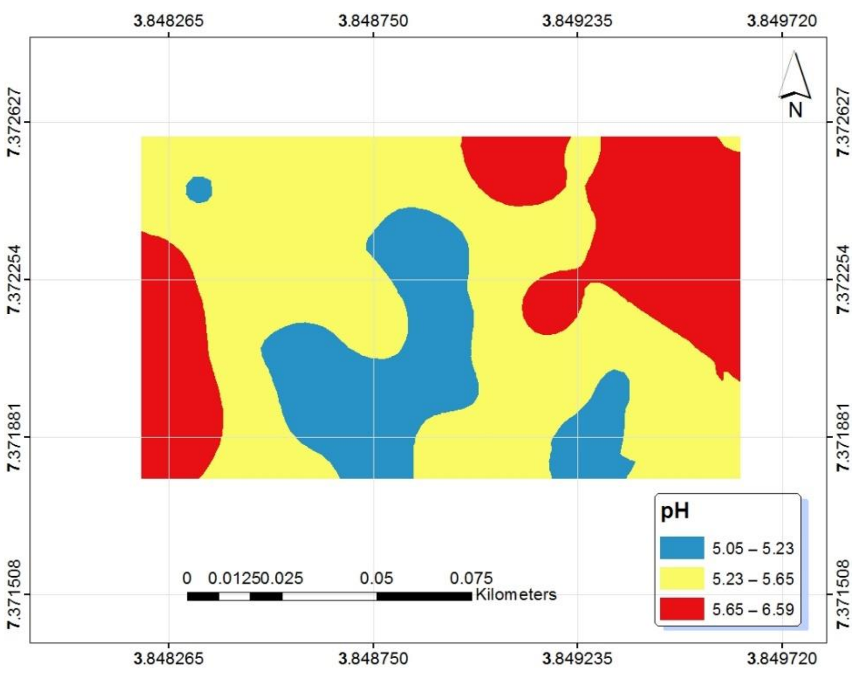

Figure 10 (b). Spatial distribution of pH at 25 – 50 cm.

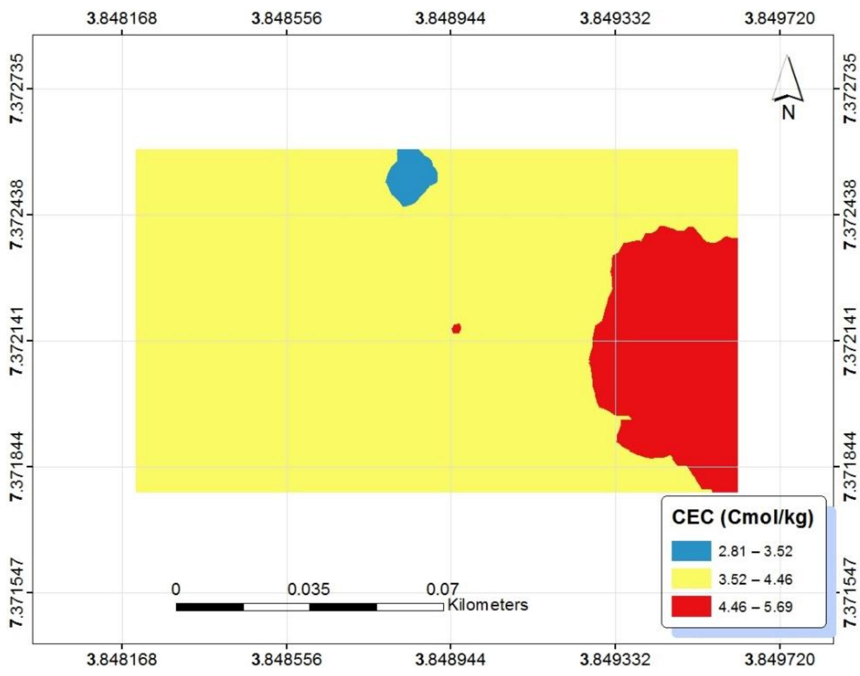

Figure 11 (a). Spatial distribution of CEC at 0 – 25 cm.

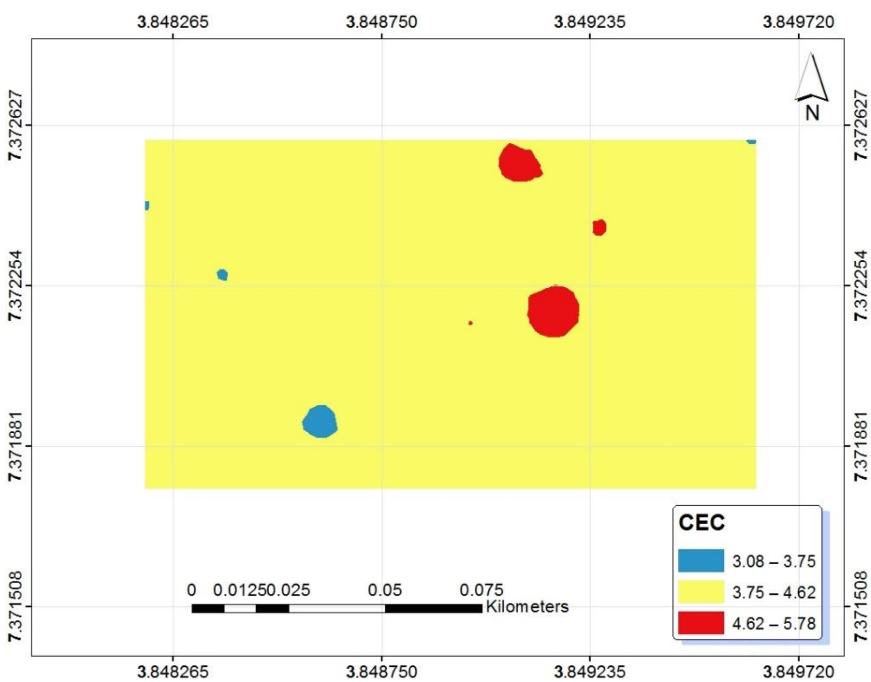

Figure 11 (b). Spatial distribution of CEC at 25 - 50 cm.

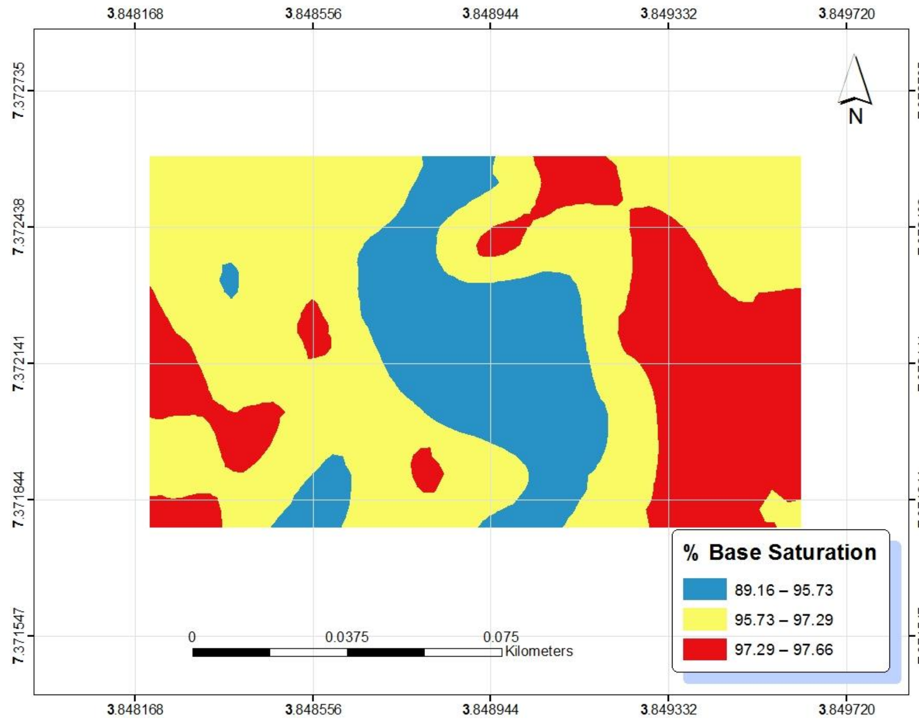

Figure 12 (a). Spatial distribution of base saturation at 0 – 25 cm.

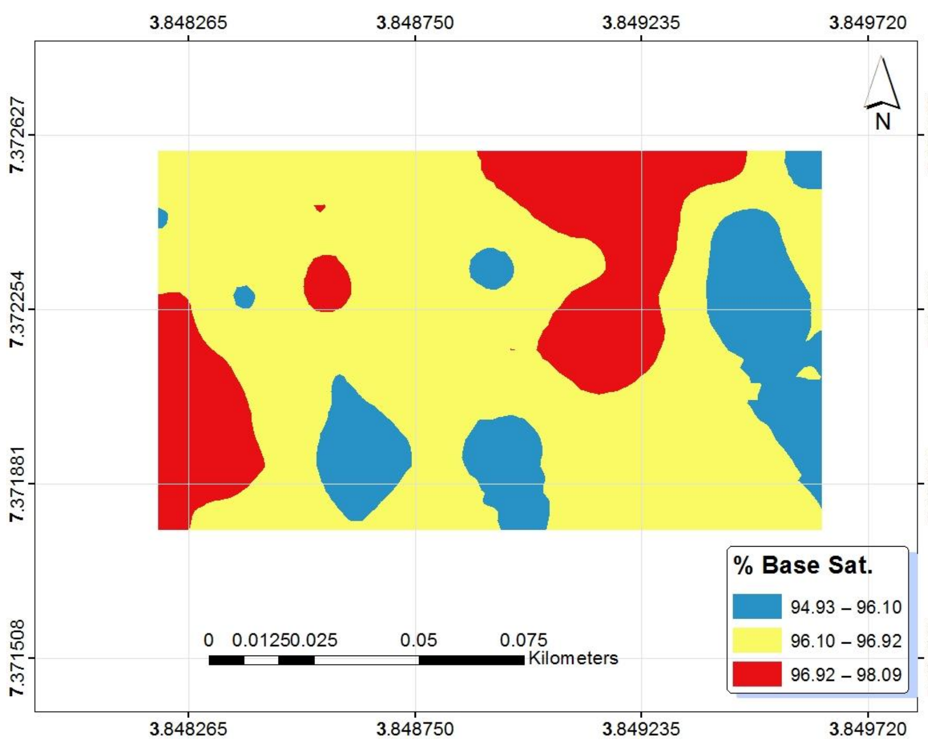

Figure 12 (b). Spatial distribution of base saturation at 25 - 50 cm.

the variability in the two depth, the silt content was lower at the top soil compared to the subsoil (fig 4a & 4b) while for the clay content it was lower at the top compared to the sub soil (fig 5a & 5b). This could be as a result of the exposure of the top soil during land preparation activities to agents of soil erosion washing away the finer sand particles at the surface of the soil. Total nitrogen content varied at both depths with the top soil having higher values and variability (Fig 9a &9b). This is mainly caused by the mode of land preparation adopted in the site which involves the plowing back of stubbles and plant residues into the soil. Organic carbon was higher at the top soil than the sub soil (fig 6a & 6b), this could be as a result of high litter deposit at the surface of the soil, microbial activities and crop residues incorporated back into the soil during plowing (Holeplass *et al*., 2004, Kukal *et al*., 2008). This result suggest that certain management practices such as leguminous cover crops and crop rotations being practiced over the years has helped increase the organic matter content of the soil through the ploughing back method. The spatial distribution of the soil pH (in water) as shown in fig (10a & 10b) shows that the soils in the area are strongly acid to slightly acidic with values ranging from 4.99 - 6.53 at the top soil while at the lower depth it ranged from 5.05 – 6.59. Phosphorus, potassium, CEC and base saturation all had higher values at the top soil than at lower depth and that also reflected in their variability. The different amounts of heterogeneity of field management factors such as fertilizer (types and amount) application, irrigation, or intrinsic factors such as micro relief, drainage, soil texture and erosion is evident in the spatial relation of the soil properties.

For validation, the analysis also shows that most of the soil properties had low mean error value (ME) table 5, indicating a lack of reasonable bias for predicting spatial distribution using ordinary kringing and a good fit of the semivariogram. The root mean square error (RMSE) was calculated from the validation dataset and values obtained were relatively low. This is an indication of better fit of the models and also a good extent of how precisely the model predicts (Table 5).

DISCUSSION

The experimental field which has been continuously cultivated for over 50 years in season and out of season shows very low nutrient status at both depths. Results of the descriptive statistics in table 2 indicates substantial variation in the minimum and maximum values of the parameters measured. Based on the pH values recorded the soils in the field can be said to be moderately acidic at 0 -25 cm while it is strongly acidic at depth (Agboola and Ayodele, 1985). The strongly acidic state of the soil could be as a result of the constant use of inorganic fertilizers on the soils. According to Chen, 2006 the use of excess fertilizer can cause a number of problems such as nutrient loss, surface and ground water contamination, soil acidification, reduction in useful microbial communities and increased sensitivity to harmful insects. The low levels of OC recorded in the area is attributed to the constant cultivation of the area for experimental purposes thereby leading to a depletion of the organic matter layer of the soil. As stated by Gregory *et. al.*, 2015 a reduction in the soil organic matter predominantly affects soil biological and microbiological properties while also impacting on soil physical properties due to the link with soil structure. Total nitrogen, Available phosphorus and potassium contents in the soils were all generally rated as low, this is as compared to the established levels for Southwestern soils in Nigeria (Federal fertilizer department 2012).

The spatial variability of soil properties is sometimes affected by intrinsic factors (parent material and climate i. e soil formation factors) and extrinsic factors such as land use management, human interference, fertilization (Vasu et. al., 2017). Cambardella *et al*., 1994 stated that strong spatial dependency of soil properties can be caused by intrinsic factors while weak spatial dependency can be attributed to extrinsic factors. Textural components (sand and silt) and potassium and base saturation at both depths showed strong spatial dependency at the top soil which may indicate that the variability in these properties is being affected by erosion. When soil parameters show strong spatial dependency it most likely indicates that the variability of such parameters is controlled by extrinsic variation which could be as a result of long use of fertilizers and other management practices. The nugget variance (Co) which represents variance due to measurement error or short range variability of the parameter which cannot be detected with the current scale of sampling was low for all the parameters measured except for % sand which had a slightly higher nugget than the lag distance at the top soil. The semivariance increases as the separation distance between sample locations increases, resulting to an approximately constant value called sill (Co + C). Sill values in the study site was also generally low depicting high variability within the parameters sampled. Spherical, exponential, Gaussian and stable semivariograms were used for the different soil parameters measured at both the topsoil and sub soil based on the model of best fit

CONCLUSION

Knowledge of spatial analysis and precise mapping of soil properties are very important for sustainable land management and precision agriculture. These results support the importance of collecting information in experimental fields to know how a site –specific system should be undertaken. Geostatistical techniques offer alternative methods to conventional statistics for the estimation of parameters and their associated variability. The findings of this study showed that spatial structure exist in the soil properties at the field scale in the study site.

The comparison of these maps may be useful in the interpretation of the results by visual inspection of distribution maps of soil nutrients indicating that nutrient distributions within the field are influenced by land use management systems. In addition, the quantitative information obtained from these maps could be used to facilitate site-specific management in the study site.

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Conflict of interest statement. There are no conflict of interest before, during or after the execution of the project.

Compliance with ethical standards. All procedures and methodologies involved in the execution of the work was carried out with compliance with ethical standards.

Data availability. All data used in the study were generated and can be produced upon enquiry to the corresponding author.

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