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Geostatistical Mapping Of Soil Fertility Indicators In Sorghum-Based Cropping System In Sudano-Sahelian Zone Of Nigeria

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ABSTRACT: Crop productivity in smallholder farms as a pre-requisite for sustainable agriculture is largely dependent on mapping of soil fertility parameters. This research was aimed at quantifying the degree of spatial variability of selected soil fertility indicators under sorghum-based cropping system along a rainfall gradient to develop appropriate fertilizer recommendation. Sorghum-based farms were selected through multistage sampling techniques based on isohytes of 50 mm interval across three States in the study area. Twelve communities were selected where sorghum is predominantly grown from Kofa (950 mm) to Zango (400 mm) of Sudano-Sahelian zone of Nigeria. Within each community, ten sorghum farms were randomly selected using 10 km x 10 km sampling grids. Soil samples were collected from the communities and analyzed. Descriptive Statistics, Kolmogorov- Smirnov test and geostatistical analyses were used to analyze the data generated. Results indicated high variability in most soil properties, with potassium having the highest CV value of 555.3% while low variability was obtained in soil pH with a value of 7.42%. The results also showed that the best fit semivariogram model for nutrients i.e. organic carbon, total nitrogen, available P and K was stable, and the range of spatial dependency varied from 0.1 km to 1.68 km. The results also indicated that Nugget to sill ratio of the OC, TN, AVP, was 0% respectively and 14% for K. Moreover, the trend map indicated that the sand and pH were increased with decrease in rainfall while OC, TN, AVP and exchangeable bases, increased with increase in rainfall. However, the soil was poor in most major nutrients. The high spatial dependency observed for N, P, K, and organic carbon recommends for developing a strategy for site-specific fertilizer management taking into account the structural and random factors dominant in the study areas. Improvement in CEC is required due to its weak spatial dependency. Integrated soil fertility management should be adopted to improve soil fertility for increased and sustainable sorghum production in the study area.

I.INTRODUCTION

Food insecurity is one of the major problems affecting humanity in Sub-Saharan African (SSA) countries where the human population is about 646 million. This increased pressure on agricultural land which necessitated continuous cropping, thus bring about nutrients deficiency (Woperies *et al.*, 2005 and William Dar, 2013) and resulted in low yield crop production. Therefore, poor soil fertility is the main biophysical constraints affecting crop production in SSA. Sorghum is one of the most important staple food crops in SSA including Nigeria. Apart from food, the grains and biomass are used as livestock feed, fencing, thatching, alcoholic and non-alcoholic drinks, as well as baking and confectionary uses (FAOSTAT, 2012).

Food insecurity and malnutrition are the greatest challenges in SSA where the people living in the region are poor, and their population in the dry land is about 646 million (William Dar, 2013). This leads to pressure on agricultural land hence necessitated continuous cropping, and has exposed the soils to nutrient deficiencies especially N, P, K and other nutrients (Bationo *et al.*, 2003). However, several literatures reviewed that sorghum yield in SSA is generally low with less than a tone per hectare compared with developed country where their obtainable yield was up to 4.8 tons per hectare (FAOSTAT, 2015). This low yield was as a result of poor soil fertility, unpredicted weather pattern, poor management practices, and other biotic factors (Adamu *et al.*, 2010). Nevertheless, soil properties varied spatially and temporally due to inherent variability of the soil and other management strategies. Hence not all areas of a field may require the same level of nutrients inputs. Small-scale farmers who produce two-thirds of the total food produced in Nigeria have inadequate knowledge of this spatial variability that may exist in their agricultural lands (Moshia, 2009).

Thus, applying soil amendments and other management strategies uniformly which may lead to waste of resources as a result of excessive or under application of fertilizer to the soil where crops like sorghum are grown.
The overall outcome of this research may give useful justification on site-specific fertilizer application in sorghum-based farms in order to minimize blanket fertilizer recommendations which could be useful for decision making on land use planning, soil fertility management and ensure optimum sorghum production on one hand, and to avoid environmental degradation by excess fertilizer wastage via leaching, and saving the farmers from economic cost of fertilizer procurement on the other hand.
Monitoring of soil fertility in sorghum-based farming is highly imperative for smallholder farmers to survive and improve their livelihood because soils can easily lose their quality within a short period of time, and variability may occur due to various factors. Therefore, development of site-specific management gives smallholder farmers the potential to apply the exact nutrients requirement at each given location. This may assist to knock out blanket fertilizer recommendation. In addition, to understanding the significance of sustainable agriculture and environmental protection, there is need for innovative, dynamic, and improved farming method that assures optimum productivity, nutrients management across soils.
Accurate and reliable information on geo-statistical mapping may assist the smallholder farmers and other research institutes for proper land use management which could be useful for decision making on land use planning and soil fertility management strategies. Therefore, a research that aimed to bridge the gap by assessing the soil fertility constraints in relation to sorghum yield is highly imperative for smallholder farmers to survive and improve their livelihood.

II.MATERIALS AND METHODS

The study area is within Sudano-Sahelian zone of Nigeria located between the latitude 11^{o}0`0``N and 13$^o$0`0``N and Longitude of 8^o 0`0``and 9$^0$0`0``E (Figure 1) with an altitude of 481-500 m above sea level.

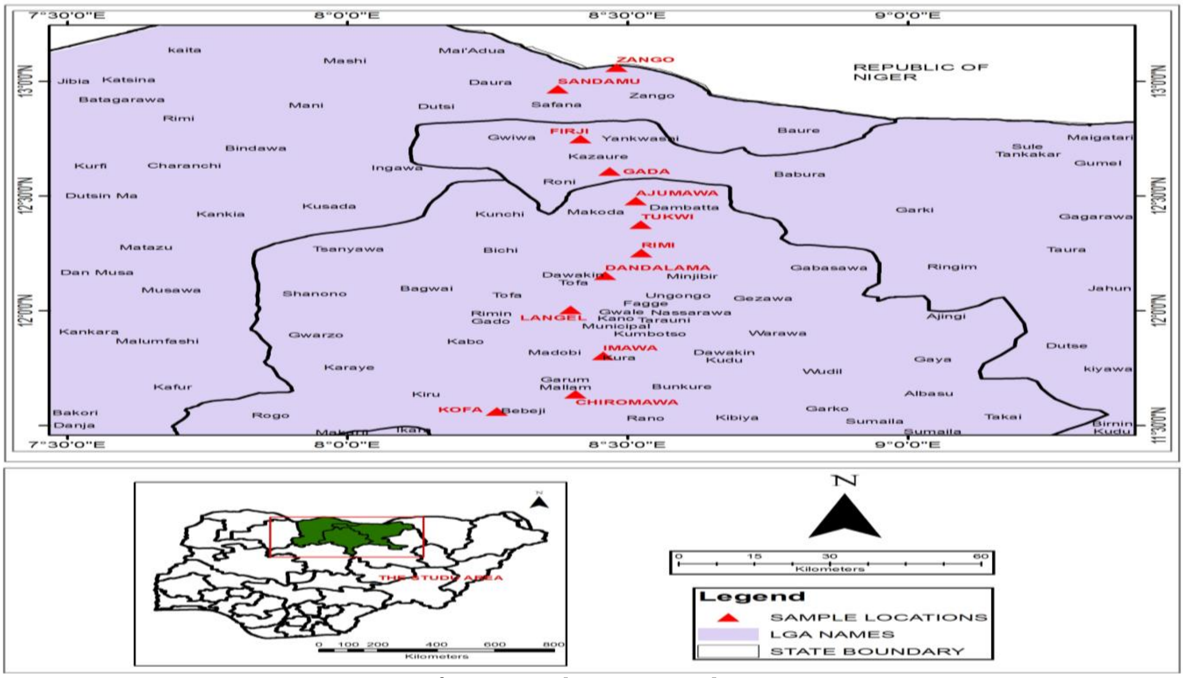

Figure1: Map of Transect Showing Sampling Communities

A. Soil sampling, preparation and analytical procedures

Twelve (12) communities were selected along Kofa- Zangon Daura transect (Figure 1) of Sudano-Sahelian zone of Nigeria. The selection was based on 50 mm difference of rainfall (Figure 2). The farms were selected using multistage sampling technique. In each community, ten (10) farms of which sorghum grown ware selected using 10 km by 10 km sampling grid. In each farm, two meter quadrats were laid diagonally in order to capture variability (i.e. at four cardinal

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points and center). From each quadrat one soil sample was collected at depth of 0-20 cm using soil auger. The soil samples were mixed thoroughly and resampled using quartering process to obtain a composite soil sample representing each of five (5) quadrats.
Therefore, one (1) composite soil sample was collected from each farm giving a total of ten (10) composite soil samples from ten identified farms in each community. Thus, one hundred and twenty (120) composite soil samples were collected from twelve communities and used for the research. The coordinates were recorded using global positioning system (GPS) receiver for the purpose of plotting spatial map on soil fertility of the study area.

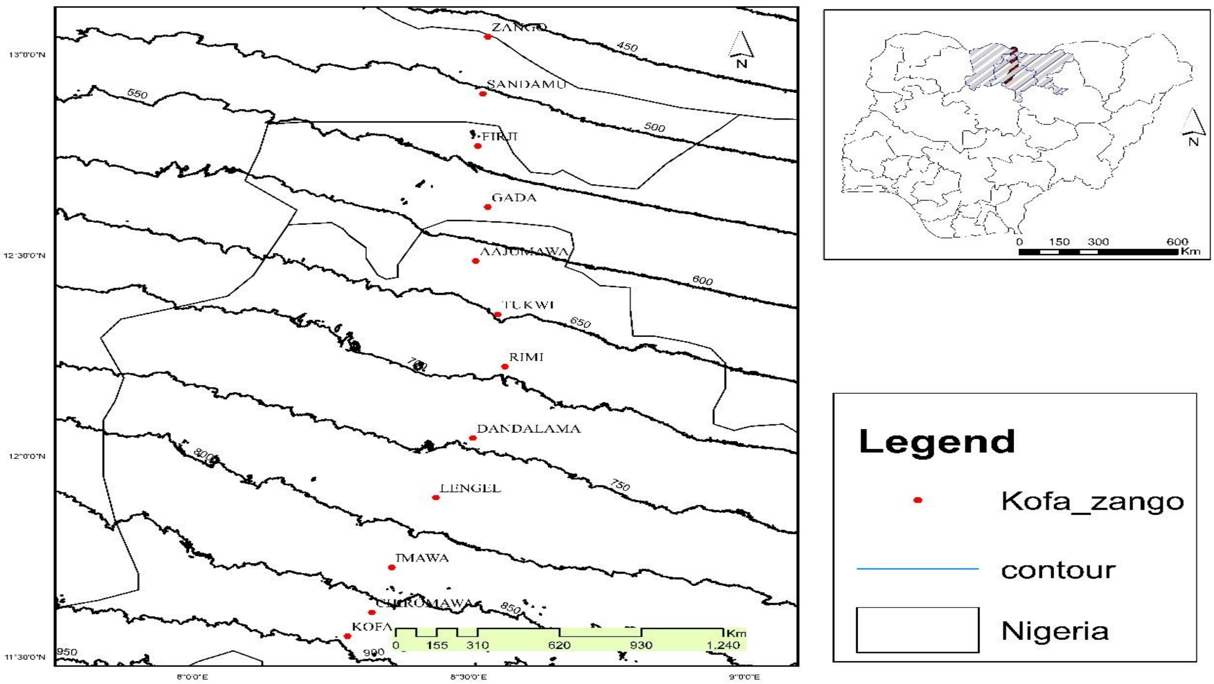

Figure 2: Map of Rainfall Gradient Showing the Isohyets

The soil samples were air-dried, crushed gently with porcelain pestle and mortar and then passed through 2 mm size sieve. The fine earth separated was stored in plastic bottles for laboratory analysis.
The soils samples were analyzed in the laboratory using standard laboratory procedures.
Soil particle size distribution, pH and electrical conductivity were determined using methods described by Boyoucos (1962), Thomas (1996) and Bower and Wilcox (1965), while organic carbon, available phosphorus, exchangeable bases were estimated using procedures described by Walkley and Black (1934), Olsen (1965), Anderson and Ingram (1993), respectively. Total nitrogen was determined using Micro-Kjeldahl digestion method (Bremma, 1996). Effective cation exchange capacity was determined using summation method.

B. Spatial Distribution Maps and Semivariogram

The spatial distribution maps and status of some soil fertility indicators was designed using kriging interpolation through semivariogram package. The package was used to compute and determine the spatially dependent variance of the soil properties.
The experimental data were fitted to various semivariogram models ranging from exponential, Stable and Gaussian, and the best model was selected based on the fit. Using the model semivariogram, basic spatial parameters such as nugget (Co), partial sill (C), range (A) and sill (C + C0) was calculated. Nugget is the variance at zero distance, the sill is the lag distance between measurements at which one value for a variable does not influence neighboring values and range is the distance at which values of one variable become spatially independent of another (Lapez- Granados *et al.*, 2002).
Different classes of spatial dependence for the soil variables were evaluated by the ratio between the nugget and the sill. For the ratio lower than 25%, the variable was considered to be strongly spatial dependent, or strongly distributed in patches; For the ratio greater than 25%, the soil variable was considered moderately spatial dependent; and for the

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ratio higher than 75%, variable was considered as weak spatially dependent variable, or if the slope of the semivariogram was close to zero, the soil variable was considered non-spatially correlated (pure nugget) (Cambardella *et al.*, 1994).
ArcGIS was used to delineate filled contour maps for some soil fertility parameters. Several interpolations techniques and models were fitted into semivariogram to select the best model that will bring positive nugget to minimize estimation error.

C. Statistical Analysis

The data obtained was subjected to a series of statistical analysis ranging from descriptive statistics such as mean, maximum, minimum, standard deviation, CV, skewness, and Kurtosis to determine the degree of variability and normality of the data sets. Then, a geo-statistical analysis was performed using kriging interpolation to predict the spatial variability of soil fertility parameters along transect. Correlation analysis was used to determine the relationship between soil properties and rainfall distribution.
The soil properties data obtained were subjected to descriptive statistics including mean, median, maximum, minimum, coefficient of variation, standard deviation skewness and kurtosis to estimate the variation between sampling locations and normality of dataset using version 15 GENSTAT and Kolmogorov- Smirnov test at 5% level of significance respectively.
The geostatistical analysis was performed using the kriging interpolation technique within the spatial analyst extension module in ArcGIS 10.3 software package to determine the spatial dependency and spatial variability of soil properties. An interpolation technique called ordinary, simple and universal kriging was used to produce the spatial distribution of the soil parameters for the study area. The models of semivariograms such as stable, exponential and Gaussian were used on the basis of a goodness of model fit criterion. The data were checked for normality and transformed as appropriate. Spatial analyses and mapping of the classified, pH, ECe, OC, total N, available P, exchangeable K, Ca, Mg, Na, ECEC, micronutrients and PSD, were performed in a GIS environment and experimental semivariogram were calculated using Equation(1):

$$Y(h) = \frac{1}{2\mathrm{N(h)}} \sum_{i=1}^{N(h)} ([Z(xi+h) - Z\,(xi)]^2)$$

Where (h) is the semivariance for interval class, N (h) is the number of pairs separation by lag distance (separation distance between sample portions), Z (Xi) is measured variable at spatial location at spatial location i, and Z (Xi + h) is the measured variable at spatial location i+h.

D. Results and Discussion

Descriptive Statistics
Table 1 shows the descriptive statistics of the soil fertility indicators. The variability of the indicators was interpreted using coefficient of variation (CV) as described by Wilding (1985). The criterion classifies the indicators in to high (CV > 35), moderate (15-35) and Low (< 15). Accordingly, all the indicators did not follow normal distribution except soil pH.

Table 1: Descriptive Analysis of Soil Physico-chemical Properties of the Study Area

Soil properties	No.	Min.	Max.	Mean	CV	Sk.	Kurt.	Norm.
Sand (%)	120	46.8	98.8	84.26	13.64	-1.09	0.89	No
Silt (%)	120	0.40	35.2	12.0	67.8	0.61	-0.40	No
Clay (%)	120	0.80	29.6	3.65	133.4	3.42	13.24	No
pH (H_2O)	120	4.98	7.19	76.06	7.42	0.25	-0.01	Yes
ECe (dS/m)	120	0.04	0.19	0. 04	72.92	2.65	7.65	No
OC (%)	120	0.14	1.58	0.72	37.50	6.35	0.23	No
TN (%)	120	0.04	0.46	0.14	64.4	1.20	0.80	No
AVP (ppm)	120	0.15	10.23	5.26	15.4	7.09	63.24	No
K (cmol)	120	0.005	1.65	1.65	555.3	10.78	114.4	No
Ca (cmol/kg)	120	1.23	6.33	2.75	39.52	1.07	0.48	No
Mg (cmol/kg)	120	0.02	0.35	0.11	60.43	1.43	2.3	No

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Na (cmol/kg)	120	0.07	0.27	0.17	52.84	3.22	12.97	No
ECEC(cmol/kg)	120	1.50	7.06	4.28	36.38	1.04	0.57	No

ECe (Electrical Conductivity of saturated paste extract), OC (Organic Carbon), TN (total nitrogen), AVP (Available phosphorous), ECEC (Effective Cation Exchange Capacity), No. (Number of sample), Min (Minimum), Max (Maximum), CV (Coefficient of variability), Skew (Skewness), Kurt (Kurtosis), Norm (Normality).

B.Particle Size Distribution

The sand content showed low variability along the locations (CV = 13.64%). Minimum of 46.8% and maximum of 98.8% were obtained with a mean value of 84.26%. Negative skewness with value of -1.09 and positive kurtosis with value of 0.89 were also observed, thus indicating that the data was not normally distributed (Table 1).
The minimum values of silt and clay were 0.40% and 0.80% while the maximum values were 35.2% and 29.6% with CV of 67.8% and 133.4% respectively. This indicated the silt and clay content in the study area have strong variability across the locations. The skewness of the silt was positive with value of 0.61 while the kurtosis was found to be negative with value of -0.40. The skewness and kurtosis of clay were positive with values of 3.42 and 13.24 respectively. Considering the rule of normality, the particle size distribution data failed to pass the normality test, (i.e. -0.8 to 0.8 for skewness and -0.3 to 0.3 for kurtosis), therefore the data were transformed into normal analysis using geostatistical software package.
The trend map of sand content observed in the study area indicated increase in sand content with increase in rainfall as shown in Figure 3. This implies high sand content was found in Zango, Sandamu, and Firji while the least content was obtained in Kofa, Chiromawa, and Imawa. Unlike the sand content, the percent silt and clay content were decreased with increase in rainfall along transect (Figure 3). The positive correlation of sand and negative correlation of silt and clay with rainfall obtained might be as a result of northeast trade wind that contributed to wind erosion. This was similar to the findings of Shehu *et al.*, (2015).
The low variability observed for sand may be due to the sandstone nature of parent material and aeolian deposit that dominated the area as reported by Vocir (2008), Malgwi (2000) and Shehu *et al.*, (2015). The variation of clay and silt content was probably due to the high content of sand particle that dominates the study area.

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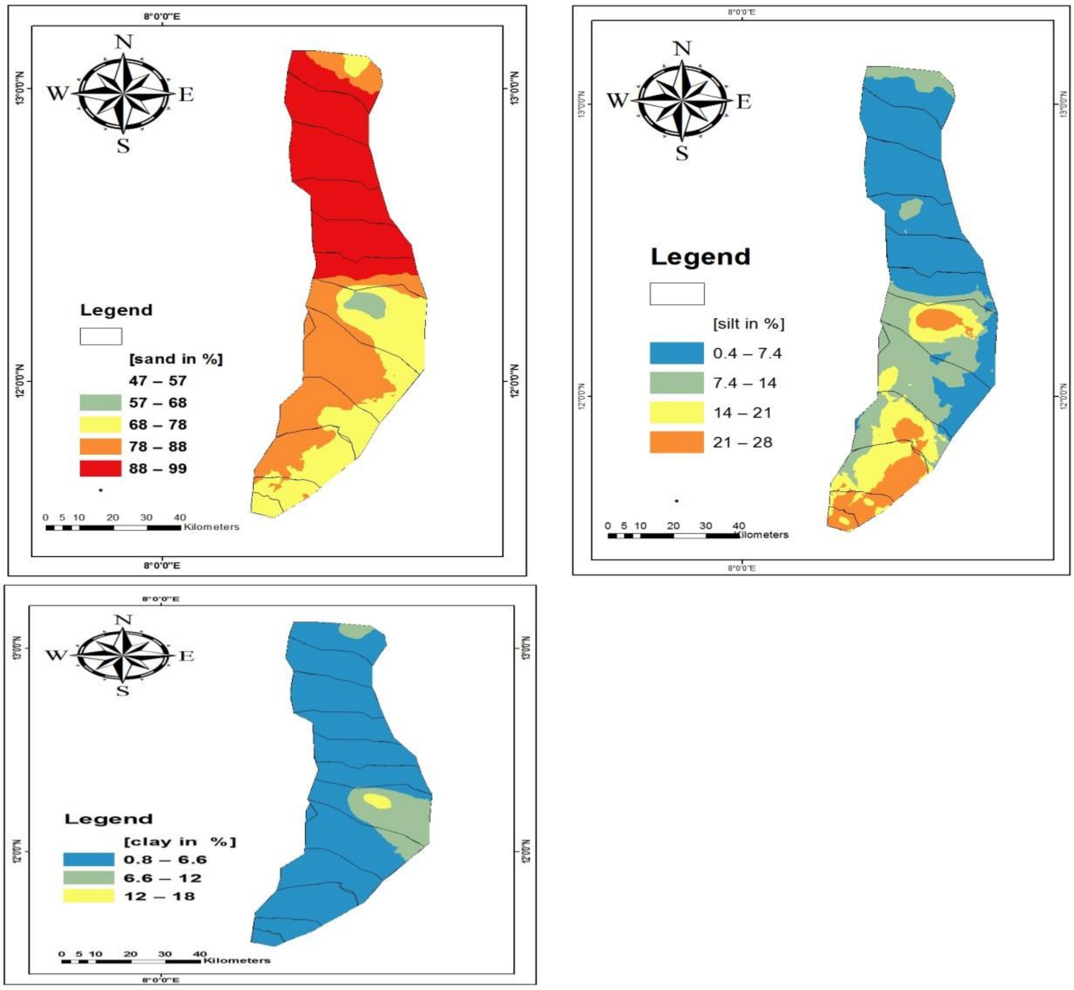

Figure 3: Map of the Study area Showing the Distribution of Sand, Silt and Clay

Soil Reaction (pH)

There is less variability (CV= 7.42) of soil pH along the transect (Table 1). The maximum value of soil pH was 7.19 and minimum value of 4.98 with an average of 76.06. The result of soil pH passed normality test as a result of negative value of kurtosis (-0.01) and positive value of skewness (0.25) respectively (Warick and Nelson 1980).
The soil pH showed strong acidity to a neutral reaction in which neutral soil reaction was observed from Kofa to Ajumawa and moderately to slightly acidic reactions were obtained in Gada, Firji, Sandamu, and Zango. Hence the pH increased with increase in rainfall (Figure 4). In addition, some patches of neutral soil reaction were obtained in Firji and Zango which may as a result of decomposition of organic manure, texture and alluvial deposits. However, the pH has strong dependency variable, thus indicating that the constraints are attributed to intrinsic factors. The slight acid to neutral pH reaction is considered ideal for most crops as reported by Brady and Weil (2002); Shehu *et al.*, (2015). The moderate to strong acidic found at Gada and some parts of Zango may be due to low organic matter content, low activities of clay and leaching of bases. This is in agreement with the findings of Giller (2001) who reported that soil acidity may be due to ancient parent rock that is poor in bases, leaching of bases and low activity of clay and low organic matter content.

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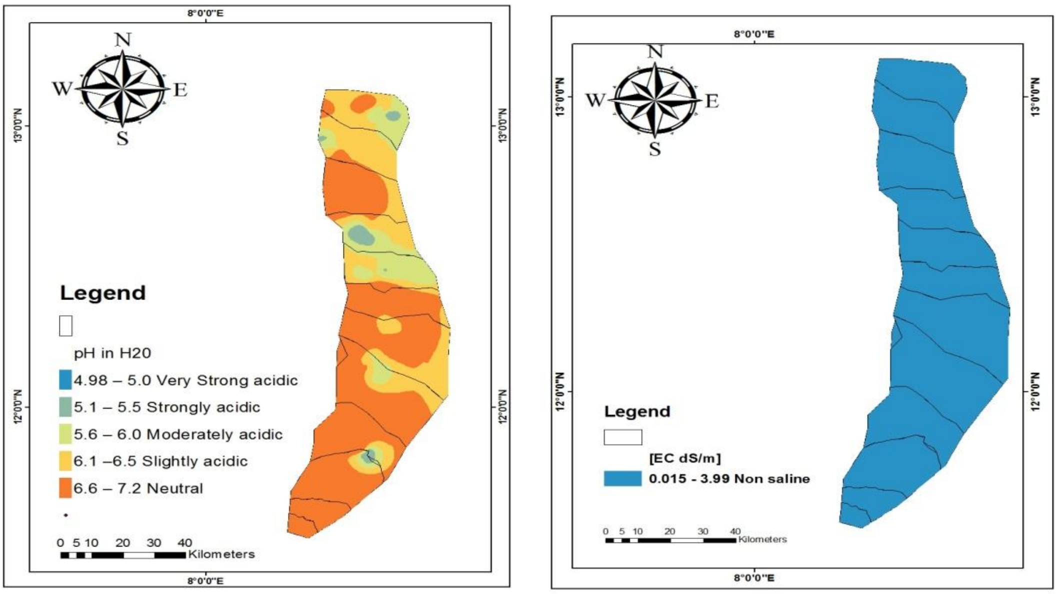

Figure 4: Map of pH and ECe in the Study Area

Electrical Conductivity of Paste Extract (ECe)

The ECe ranged from 0.02 dS/m to 0.19 dS/m with a mean value of 0.04 dS/m and CV of 72.92% thus indicating high variability between locations as shown in Table 1. The skewness and kurtosis values of ECe were 2.65 and 7.65 also indicating positive skewness and kurtosis respectively which implies the data failed to pass normal distribution; hence, the data was transformed in geostatistical software package (Webster and Oliver, 2001).

The trend map of ECe (Figure 4) showed that the ECe decreases with increasing rainfall. The non-saline nature of the soil was confirmed by the findings of Adamu and Dawaki (2008).

Soil Organic Carbon (SOC)

High variability of Soil Organic Carbon content was observed (CV = 37.50%) across the locations. It ranged from 0.14% to 1.58% with a mean value of 0.72% (Table 1) indicating low soil organic carbon. Surprisingly, the soil organic carbon failed to pass normal distribution plot as both the Skewness and kurtosis were above the standard value -0.8 to 0.8 and -0.3 to 0.3 respectively.

Strong spatial dependency ratio of soil organic carbon (SOC) was obtained along the transect ranging from low to medium (Figure 5). Low organic carbon was observed in Kofa, Chiromawa, Dandalam, Rimi, Tukwi, Gada and some part of Zango, while medium organic carbon was obtained in Imawa, Langel, Fiji, and Sandamu. In addition, some small portion of medium SOC was found in Imawa and Langel. The medium level content of organic carbon might be due to the addition of organic matter and its subsequent decomposition, while the low SOC could be as a result of low organic matter content in the soil. A negative correlation (r = -.059) of soil organic carbon was observed, thus indicating decrease with increase in rainfall as indicated in Figure 5. Similar results were reported by Singh *et al.*, (2004), (Mandavgade *et al.*, 2015) and Shehu *et al.*, (2015).

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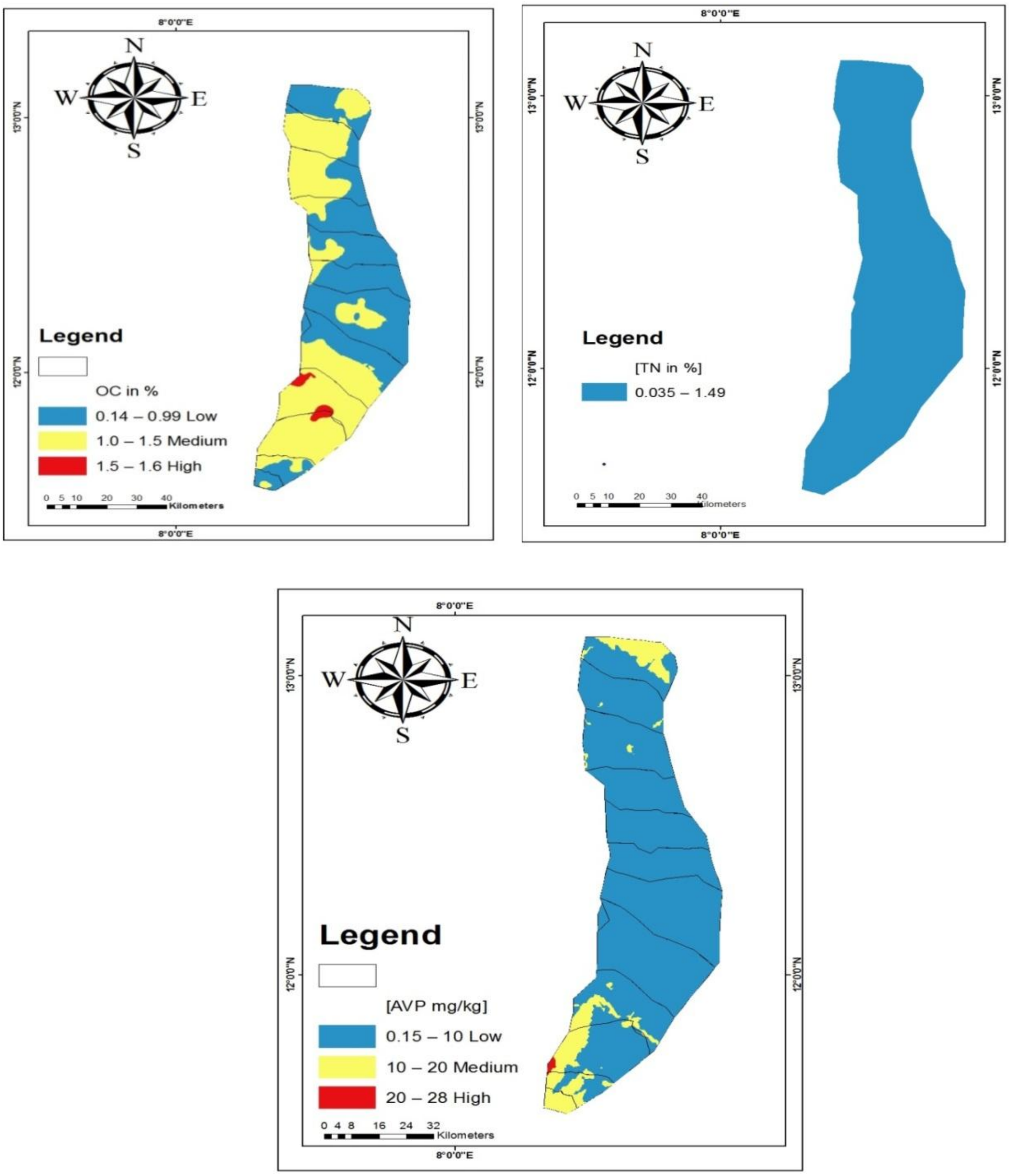

Figure 5: Map of OC, TN and AVP in the Study Area

Total Nitrogen (TN)

The total nitrogen content in the study area ranged from minimum value of 0.04% to maximum value of 0.46% with an average of 0.14%, thus nitrogen content was strongly varied between locations (CV = 64.4%). The skewness and kurtosis of the TN were positive with a value of 1.20 and 0.80 respectively. The result of TN failed to pass normality test (Table 1). Hence the data was transformed to a normal distribution.

The TN was low across the locations. A strongly spatial dependence was observed. The TN content was increased with the decrease in rainfall (Figure 5). The low content of TN might be as a result of low organic matter, nature of parent material, low weatherable mineral reserve, a reserve necessary for nutrient recharge. This was similar to the findings of Singh *et al.*, (2007) and Wade (2017) who reported that low soil TN content may be due to high temperature resulting in rapid organic matter decomposition, leaching and in combination with low inputs of organic material, microbial activities, moisture content and inherent nature of parent material.

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Available Phosphorous (AVP)

The result of available phosphorous in Table 1 shows moderate variation with a CV of 15.4%. The minimum value of 0.15 mg/kg and maximum value of 10.23 mg/kg with an average of 5.26 mg/kg was observed. The data set of AVP was not normally distributed in which both skewness and kurtosis were positively varied with values of 7.09 and 63.24 respectively. As a result, the data set failed to pass normal distribution because it did not fall within the range of -0.8 to 0.8 and -0.3 to 0.3 for skewness and kurtosis respectively.
The spatial dependent ratio of AVP content was strong as presented in Table 3 in which medium AVP content was obtained in Kofa, Chiromawa, Imawa and Langel, while the low AVP content was observed in Dandalama, Rimi, Tukwi, Ajumawa, Gada, Firji, and Sandamu. This implies that the AVP content in the study area increases with decrease in rainfall. The trend map (Figure 5) shows that the AVP concentration in Zango was medium. This low AVP concentration may be attributed to widespread deficiency of P in tropical soils as a result of low organic matter content, Zinc, pH, (Ismail *et al.*, 2010) and this is in agreement with findings of Shehu *et al.*, (2015) who reported low AVP concentration in soils of Sudan Savanna of Nigeria. However, the strong dependency variable observed in AVP implies that the variation is most likely due to pedogenic processes.

Exchangeable Bases

The result presented in Table1 indicated that there was strong variation of exchangeable K across the locations with a CV of 555.3%. The maximum value of 1.65 cmol/kg and minimum value of 0.005 cmol/kg with an average value of 0.82 cmol/kg indicated high variation across the locations. Exchangeable Ca has strong variation (CV = value of 39.52%) with minimum value of 1.23 cmol/kg, maximum value of 6.33 cmol/kg and average of 2.75 cmol/kg.
Exchangeable Mg content across the study area was strong with minimum and maximum values of 0.02 cmol/kg and 0.35 cmol/kg respectively with a mean value 0.11 and CV of 60.43% while exchangeable sodium ranged from 0.07cmol/kg to 0.27cmol/kg with CV of 60.52%. The result shows that, all the exchangeable bases failed to pass normal distribution plot because all the skewness and kurtosis values deviated from normal range (i.e. -0.8 to 0.8 and -3.0 to 3.0) respectively.
The exchangeable K and Na have a strong spatial dependent ratio which is attributed to pedogenic factors. The trend map of exchangeable K content (Figure 6) in the indicated high concentration K in most sites of Kofa, Chiromawa, Imawa, Lengel, Rimi, Tukwi, Ajumawa, Gada, and Firji, with some patches of low to medium concentrations around Dandalama and some parts of Zango (Figure 6). This indicates that, the high K content increased with decrease in rainfall as presented in Table 4 may be due to weathering of K bearing minerals and release of K from organic residues while the low to medium content might be due to leaching of bases particularly K (Sharma and Anil Kumar 2003; Rao *et al.*, 2008).
However, the high content of exchangeable K contradicted the findings of Shehu *et al.*, (2015) who reported low content of K in Nigerian Sudan Savanna soils which may be due to weathering of K bearing minerals and release of K from organic residues in the area. With regards to other exchangeable bases (Figure 6), moderate spatial dependency ratio of calcium and magnesium contents (Figure 6) were obtained along the transect ranging from high to low concentration, with high amount of magnesium recorded at Kofa and some parts of Imawa, medium in chiromawa, Imawa, Lengel, Dandalama, Rimi, Tukwi, and some parts of Ajumawa Gada, Sandamu and Zango. Low content of Ca was observed in Zango, Sandamu, Firji Gada and some parts of Ajumawa. Correlation between Ca, and Mg with rainfall indicated negative relationship (Table 4). This suggested that Ca and Mg concentrations increase with decrease in rainfall (Figure 7). However, the trend map of Ca content in the study area unpredictably showed some patches of high to medium concentrations of Ca in Rimi, Gada, Firji and Zango respectively. Negative correlation was also observed in ECEC content in which the concentration increased with decrease in rainfall while the trend map of exchangeable sodium indicated increase with increase in rainfall, as a result, negative correlation was obtained.
The low to high recorded concentrations of exchangeable bases may be attributed to low activities of clay and organic matter content, nature of parent material of soil. This has been confirmed by Giller (2001). Contrastingly, weak spatial dependent ratio was obtained in ECEC (Table 2), thus the variable was derived from anthropogenic or management activities such as tillage, fertilization etc. The low to medium concentrations of ECEC might be due to low organic matter content and low clay activities combined with highly weathered soil left with only single layer clay (Kaolinited) with small surface area for charge Singh *et al.*, (2007).

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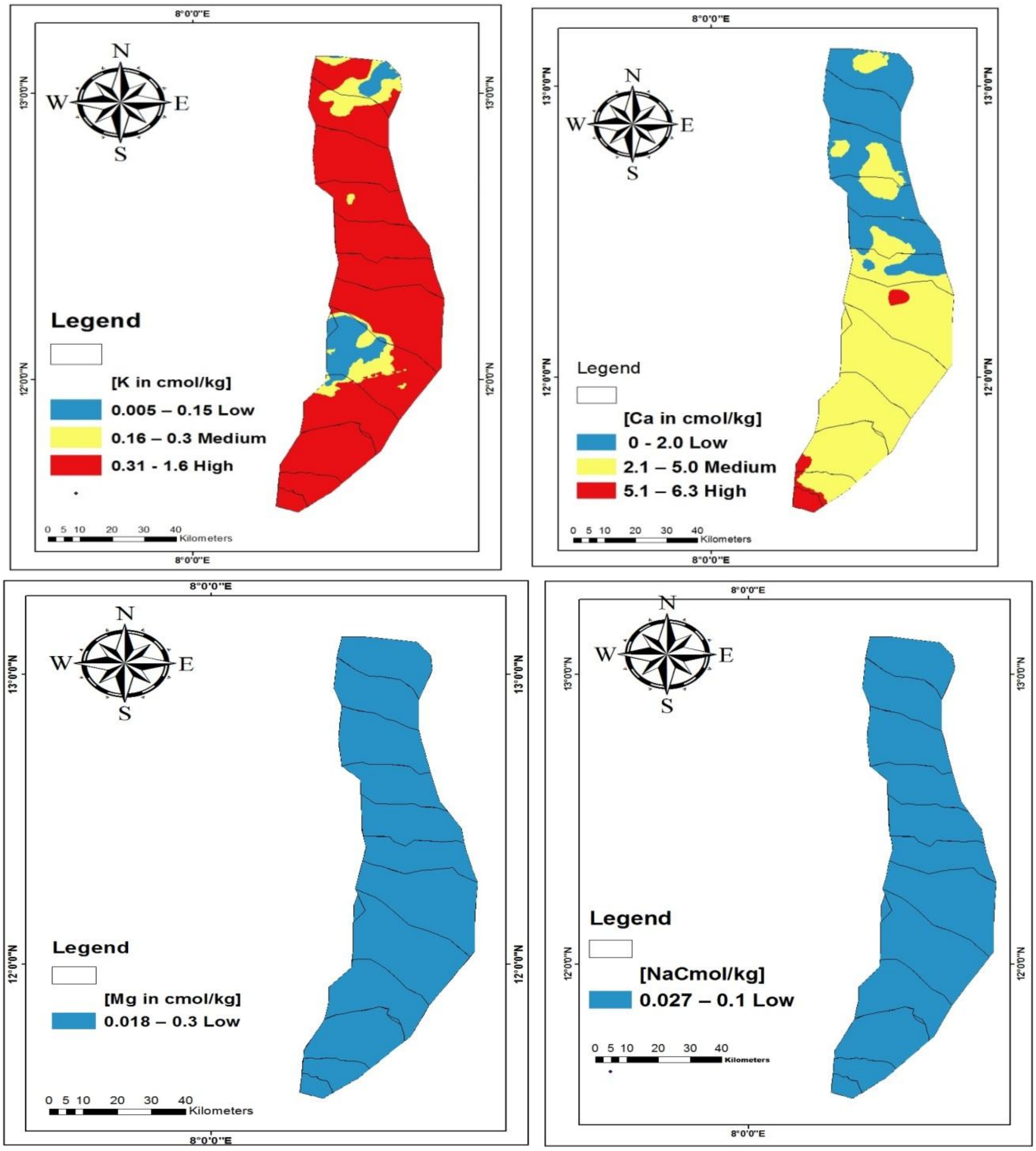

Figure 6: Map of Exchangeable K, Ca, Mg and Na in the Study Area.

Effective Cation Exchange Capacity (ECEC)

The ECEC of the study area ranged from 1.50 cmol/kg to7.06 cmol/kg with an average value of 4.28 cmol/kg and CV of 36.38% thus indicating high variation between locations. The normality (skewness and kurtosis) test of ECEC was positive with values of 1.04 and 0.57 respectively, hence the data set failed to pass normal distribution test, subsequently, the data were transformed into normal in order to carry out spatial analysis.

A weak spatial dependent ratio was obtained in ECEC (Table 2), thus the variable was derived from anthropogenic or management activities such as tillage, fertilization etc. The low to medium concentrations of ECEC (Figure 7) might be due to low organic matter content and low clay activities combined with highly weathered soil left with only single layer clay (Kaolinited) with small surface area for charge Singh *et al.,* (2007).

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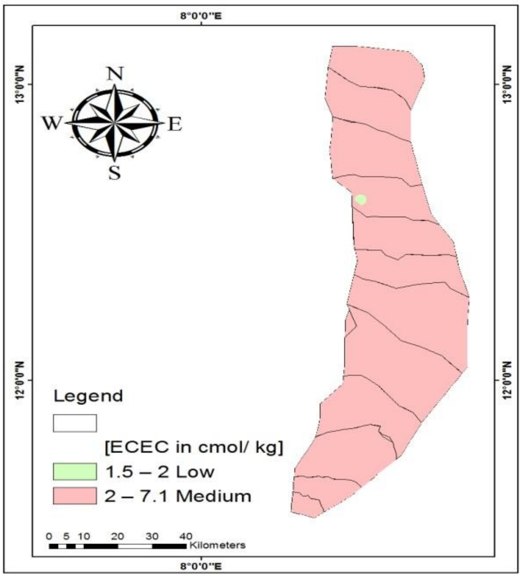

Figure 7: Map showing ECEC

D. Geo-statistical Analysis

Based on the models selected, the percentage sand, silt and clay have low nugget-sill ratio (spatial dependency ratio) as shown in Table 2. This implies strong dependency variables thus variation was derived from the pedogenic factors (intrinsic factors such as climate, geology, topography etc). Moreover, the pH was found to be strongly dependent, thus, this was as a result of pedogenic factors such as geology, and topography etc. On the other hand, ECe was found to show moderate spatial with dependency value of 73% (Table 2), hence the variation was from interplay between intrinsic and extrinsic or anthropogenic activities. The map of ECe indicated non-salinity.This could be attributed to good drainage and low Na content.

The soil organic carbon (SOC), total nitrogen (TN) and available phosphorus (AVP) in the study area showed a value of zero respectively (Table 2). This implies strongly spatial dependency, thus, the variation was from pedogenic factors. The exchangeable potassium and sodium showed Spatial Dependent Ratio (SDR) values of 14% and 0% respectively. This indicate strong dependency variable, hence the variation may be attributed to pedogenic factors. On the other hand, the exchangeable calcium and magnesium were found to be moderate spatial dependency with values of 36% and 34% respectively. This indicated that the variation was as a result of interaction between pedogenic and management factors. In contrast, the effective cation exchange capacity (ECEC) indicated weak spatial dependency ratio with a value of 80% as shown in Table 2. Therefore, the variation may be due to anthropogenic or management activities.

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Table 2: Semivariogram of Soil Fertility Indicators of the Study Area
ECe (Electrical Conductivity of saturated paste extract), OC(Organic Carbon),TN(Total Nitrogen), K(Potassium),

Soil Properties	Statistical Model	Nugget (Co)	Partial Sill (C)	Sill Co + C	Range (A/km)	SDR (N:S Ratio %)	SDC	R^2	Interpolation Techniques
Sand (%)	Stable	0	0.22	0.22	0.5	0	Strong	0.99	Ordinary
Silt (%)	Exponential	0.07	0.51	0.58	0.19	12	Strong	0.96	Universal
Clay (%)	Exponential	0.19	0.82	1.01	0.58	18	Strong	0.78	Ordinary
pH H_2O	Exponential	0.03	0.15	0.18	0.1	16	Strong	0.95	Simple
ECe (dS/m)	Exponential	0.22	0.08	0.3	1.68	73	Moderate	0.23	Ordinary
OC (%)	Stable	0	1.02	1.02	0.21	0	Strong	1.00	Simple
TN (%)	Stable	0	1.2	1.2	0. 18	0	Strong	0.99	Simple
AVP (mg/kg)	Stable	0	0.79	0.79	0.1	0	Strong	0.99	Ordinary
K (cmol/kg)	Exponential	0.07	0.47	0.55	0.19	14	Strong	0.99	Ordinary
Ca (cmol/kg)	Exponential	0.04	0.07	0.11	0.17	36	Moderate	0.81	Ordinary
Mg (cmol/kg)	Exponential	0.34	0.66	1.0	0.95	34	Moderate	0.92	Simple
Na (cmol/kg)	Stable	0	0.11	0.11	0.5	0	Strong	0.99	Ordinary
ECEC (cmol/kg)	Exponential	0.29	0.07	0.36	0.14	80	Weak	0.88	Ordinary

AVP(Available phosphorous),Ca(Calcium)Mg(Magnesium) Na(Sodium), ECEC (Effective Cation Exchange Capacity), C_0(Nugett effect),C_1(Structural variance),r^2(Coefficient of determination), SDR(Spatial Dependency Ratio), SDC(Spatial Dependency Class)

E. Correlation Analysis between Soil Properties and Rainfall Gradients

The result of correlation analysis between soil properties and rainfall gradients in the study area is presented in Table 3. The results indicated that sand content was positively correlated with rainfall (correlation coefficient (r) value of 0.633**). This implies that sand content increased with increase in rainfall gradients. However negative correlation was observed in silt and clay (r = -0.700** and -0.414** respectively) when correlated with northerly latitude, thus indicating that the silt and clay content were increased with decreasing rainfall.
With regards to the other nutrients, the OC, TN, and AVP contents were negatively correlated with rainfall (r = -.059, -0.684**, and -.138 respectively). This implies that the variables were increased with decrease in rainfall. A similar trend (negative correlation) for pH and ECe were observed (Table 3) with r values of -0.235** and -0.193* respectively. The correlation of exchangeable K, Ca, Mg, and ECEC with rainfall were strongly negative (r = -0.136, -0.593**, -0.388**, and -0.576** respectively). This indicated that the K, Ca, Mg, and ECEC were increased with decrease in northerly latitude while positive correlation (r = .048) was observed between exchangeable Na and rainfall, implying that the Na content increased with increase in rainfall.

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Table 3: Pearson Correlation (r) Between Soil Properties and Rainfall Gradients

Soil Properties	Correlation Coefficient(r) values
Sand	0 .633**
Silt	-0.700**
Clay	-0.414**
pH	-0.235**
ECe	-0.193*
SOC	-0.059
TN	-0.684**
AVP	-0.138
K	-0.136
Ca	-0.593**
Mg	-0.388**
Na	0 .048
ECEC	-0.576**

*Significant at 5% Level of Probability, ** Significance at 1% Level of Probability

F. Conclusion

Mapping of soil fertility constraints is one of pre-requisite for sustainable agriculture to address the issues of low crop productivity in smallholder farms and also beneficial in detecting soil fertility problems since these maps will quantify the degree of spatial variability and provide the basis for monitoring it. Consequently, this may assist in site-specific management useful for smallholder farmers to improve soil fertility as well as providing a base line for research institutes and policy makers for proper land use management and decision making tool on land use planning and soil fertility management strategies.
With regards to spatial analysis of the data, findings showed that the best fit semivariogram model for nutrients i.e. organic carbon (OC), total nitrogen (TN), potassium (K) and available phosphorous (AP) was stable and the range of spatial dependency varied from 0.1 km to 1.68 km. Nugget to sill ratio of the organic carbon, total nitrogen and available phosphorous was 0% and 14% for potassium respectively. Furthermore, the high spatial dependency observed for N, P, K and OC recommends for developing a strategy for site specific fertilizer management taking into account the structural and random factors dominant in the study areas. Improvement of cation exchange capacity is needed due to weak spatial dependency observed for this variable to improve sorghum production.

G. Recommendations

The result obtained indicated that, high spatial dependent ratio was observed for N, P, K, O.C, and Zn, and recommended for developing a strategy for site specific fertilizer management taking into account due to the structural and random factors dominant in the study areas. Improvement of cation exchange capacity is also needed due to weak spatial dependency observed for this variable to improve sorghum production. However, due to poor concentration in major soil nutrients, integrated soil fertility management through application of both organic and inorganic fertilizers should be adopted in the area.

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