Asian Soil Research Journal

1(2): 1-15, 2018; Article no.ASRJ.41183

Soil Physico-chemical Properties Changes under Different Crops in Ado Ekiti, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors GOA, OON and SOO designed the study, performed the statistical analysis, wrote the protocol, and authors GOA and OON wrote the first draft of the manuscript. Authors GOA and OON managed the analyses of the study. Authors AAA, DO and TT managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ASRJ/2018/v1i2653
Editor(s):
(1) Tunira Bhadauria, Professor, Department of Zoology, Kanpur University, U. P, India.
Reviewers:
(1) R. K. Mathukia, Junagadh Agricultural University, India.
(2) Adonia K. K. Bintoora, Nkumba University, Uganda.
Complete Peer review History: http://www.sciencedomain.org/review-history/25110

Original Research Article

Received 31st March 2018
Accepted 2nd June 2018
Published 12th June 2018

ABSTRACT

The sustainable soil management necessary to maintain soil quality depends on the understanding of how the soil responds to agricultural practices over time. This paper reports the changes in physicochemical properties that resulted from different cropping systems on a soil in Ado Ekiti, Nigeria. Soil samples were collected from sole maize plot (1.0 ha), sole cowpea plot (1.0ha) and cassava/maize intercrop plot (0.6ha) on a land that was previously under fallow. The sand, silt and clay contents of the soil and some selected chemical parameters varied considerably within the study area (different cropping zones). The soil was generally sandy loam and was found to vary from slightly acidic to slightly alkaline and generally low in Soil Organic Matter (SOM) and Available P (Av. P) with no salinity problem. High magnitude of variability was observed for Electrical Conductivity (EC), Av. P and SOM while pH had the least magnitude. A geostatistical evaluation of the soil chemical properties showed moderate to strong spatial dependence. The geospatial maps clearly revealed the heterogeneity of the soil chemical properties across the field. Both classical statistics and geo-statistical analyses of the soil of the area provided a better understanding of the

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spatial variability of soil chemical properties and the influence that such could have on crop performance. The results indicated that the soil pH is slightly acidic and contained low amounts of both SOM and Av. P. It is suggested that planting of cover crops, minimum tillage and controlled application of phosphate fertilizer should be done so as to increase the SOM, improve Av. P and maintain the soil pH. Further studies should be conducted to include other soil chemical properties such that robust site specific management programme could be effected.

Keywords: Soil physicochemical properties; cropping systems; spatial variability.

1. INTRODUCTION

Sustainable agricultural production requires a good knowledge of the changes soils undergo under different land uses in relation to the management options that can be adopted. Land use and management practices influence soil quality and related soil processes such as erosion, oxidation, leaching and mineralization [1,2,3]. It has been reported that soil nutrients varied from one land use type to another with soil nutrients depletion in this order: Secondary forest < Oil palm <Arable cropping <Building sites [4]. Soil chemical properties deterioration indices obtained from studies conducted in (Southland and Highland) Ethiopia showed that pH, EC, CEC were higher in continuously cultivated fields than in other land uses. The reasons adduced for this observation included higher organic matter content, crop removal and tillage practice.

In Southwest Nigeria, various authors [2,3] have reported that once a land that was previously under forest fallow is converted for cultivation, serious degradation sets in. [2] reported higher sand and lower silt and clay contents in the top 15cm of a cultivated soil compared with similar soil under forest fallow. On a similar soil, [3] found a heavily depleted chemical fertility consequent upon conversion of a land previously under fallow to arable cropping. Such chemical changes reported by [2,3] included: reduction in pH, cation exchange capacity and organic matter. In addition, within-field variability was reported for the evaluated soil properties.

An understanding of the spatial variability of the soil properties is important in planning and development of site-specific management options by making use of geostatistical techniques. The use of variograms and kriging as geostatistical tools in the study of tropical soils has been reported [5,6]. Therefore, the objective of this study was to evaluate some soil physico-chemical properties under the different cropping systems, viz: sole maize, sole cowpea and cassava/maize intercrop in Ado Ekiti, Nigeria.

2. MATERIALS AND METHODS

2.1 Description of Study Location

The study was conducted at the SIWES (Students Industrial Work Experience Scheme) Training Farm, Irasa, Ekiti State University, Ado-Ekiti, Southwest Nigeria. The study site (Fig. 1) lies on latitude 7^{o} 41'N and longitude 5^{o} 15'E with an altitude of about 406 m above the mean sea level. The land in the time past had been used for the cultivation of yam and cowpea and was left fallow for about 3 years before the SIWES students started cultivating on it for cowpea, sole-maize and maize/cassava intercrop.

2.2 Field Procedure

The field was about 2.6 ha in size. 1.0 ha was planted to cowpea, 1.0 ha to sole-maize and 0.6 ha to maize/cassava intercrop. Grids of 10 m x 10 m were set up on the field within the three land uses with ninety-four (94) grids set up in cowpea plot, fifty (50) grids in sole maize and forty (40) grids in maize/cassava intercrop, giving a total of one hundred and eighty-four (184) grids (Fig. 1). The center of each grid was geo-referenced with the aid of GPS (Garmin model) and was used for collecting soil samples.

2.2 Soil Sampling and Sample Preparation

Disturbed soil samples were collected from 0-20 cm surface layer at the center of each grid. A total of one hundred and eighty-four (184) samples were collected altogether. The samples collected were neatly packed in polythene bags and transported to the laboratory for analysis. The disturbed soil samples were air-dried, crushed and sieved to remove materials larger than 2 mm with the aid of 2-mm sieve.

2.3 Laboratory Analysis

Particle size analysis was carried out by hydrometer method [7], soil pH was determined

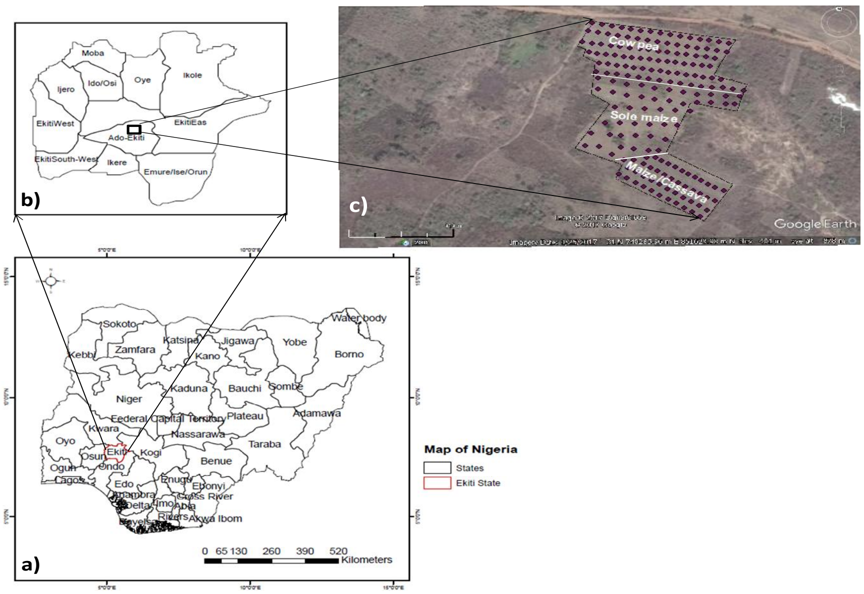

Fig. 1. (a) Map of Nigeria showing (b) Ekiti State and (c) the sampling points

in a 1:1 soil water suspension. Electrical conductivity (EC) was measured using Jenway conductivity meter with glass electrode in a 1:1 soil water suspension [8]. Organic carbon (OC) was determined by Walkley-Black dichromate wet oxidation method [9]. The content of available phosphorus was determined by [10].

2.4 Data Analysis

2.4.1 Descriptive statistics of soil chemical properties

Data were subjected to descriptive statistics of minimum, maximum, average, standard deviation (SD), skewness, kurtosis and coefficient of variation (CV) of data on soil pH, electrical conductivity, available phosphorus, organic carbon. According to the classification proposed by Warrick and Nielsen (1980), a parameter is considered to have low variability if the CV<12% as moderate variability when 12%<CV<60% and high variability when CV>60%. In addition, the frequency distribution graph was plotted for each variable. All classical analyses were carried out using SPSS (IBM Version 20.00).

2.4.2 Geo-statistical analysis

Geostatistical analysis was done using the GS+ (Gamma Design Software, Version 5.2, 2005) to determine the spatial dependency and estimation of the soil properties evaluated. Isotropic semivariograms of linear, power, spherical, exponential and Gaussian, were tested from omnidirectional semivariances, (h), of a set of spatial observations following the methodology in [11].

To characterize the spatial covariance structure of the variables, the best model was selected based on the coefficient of determination, R^2. From the models, basic spatial parameters such as nugget (Co), sill (C+Co) and range (Ao) were determined. The nugget to-sill ratio expressed as the structural variance was calculated for each soil physical property and used to evaluate the degree of spatial dependence associated with each soil property. Structural variance values were categorized into one of three classes of spatial dependence as proposed [12]. For structural variance less than 0.25, the variable is considered strongly spatially dependent; if the structural variance is greater than 0.25 and less than 0.75, the variable is considered moderately spatially dependent; and if the structural variance is greater than 0.75, the variable was considered weakly spatially dependent [12,13]. In addition, a structural variance value close to zero indicates continuity in the spatial dependence. After selecting the best fit semivariogram model for each variable, contour maps were created through ordinary kriging of the Geostatistical Analyst extension in ArcGIS v. 10.1® (Esri, Redland, CA, USA).

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistics

The summary of the descriptive statistics of the studied soil properties on the cowpea plot is provided in Table 1. The number of samples tested for all the parameters was 90 (i.e. for sand, silt and clay contents, pH, Soil organic matter (SOM) and Electrical conductivity (EC), except for the Available Phosphorus (Av. P) which had 45 samples (Table 1). The results of the particle size analysis showed that the soil under the cowpea cropping system was generally sandy with sand content ranging from 51 to 91% with an average value of 84% while both clay and silt contents were less than 10%. The soil could thus be classified, according to the textural triangle developed by [14], as sandy loam. The soil pH was slightly acidic with a mean value of 5.9 while organic matter was generally low, with most values being less than 1.0. Av P contents of the soil averaged 11.69ppm while electrical conductivity ranged from 2.30 to 301 and had a mean value of 60.83 dS/m. All the evaluated chemical properties showed different degrees of variation under cowpea cropping. For instance, electrical conductivity and Av. P showed high variability with a coefficient of variation of 76% and 71% respectively while organic carbon demonstrated medium variability with CV of 50% according to the guidelines proposed by [15].

The results of the changes in soil properties under sole maize are presented in Table 2. Sand content is high with values ranging from 81.60 to 89.60, averaging 86.60% while silt and clay contents were generally low with mean values of 6.26 and 7.10% respectively. According to [13], the soil could be classified as loamy sand. The pH of the soil ranged from 2 to 8 but averaged 6. Organic matter content of the soil was low and varied from less than 1 to 6 but averaged 1.82%. The mean values of the Av. P contents and the electrical conductivity were respectively 16.02 ppm and 161.33 dS/m. The coefficients of variation of the measured soil chemical properties indicated that while pH exhibited low degree of variability (14.4%) the other three properties (OM, Av. P and EC) had very high variability (61.4 to100.5).

Table 1. Descriptive statistics of soil physico-chemical properties of the cowpea section of the SIWES Farm

Property	N	Min.	Max.	Mean	SD	CV	Skewness	Kurtosis
Sand, %	90	51.29	91.40	83.60±1.08	10.26	0.123	-1.98±0.25	2.48±0.50
Silt, %	90	1.56	38.95	9.36±1.01	9.60	1.023	1.97±0.25	2.51±0.50
Clay, %	90	2.32	11.32	7.03±0.17	1.63	0.232	0.01±0.25	0.45±0.50
pH	90	4.01	7.12	5.89±0.07	0.64	0.108	-1.23±0.25	1.70±0.50
EC, dS/m	90	2.30	301.00	60.83±4.88	46.29	0.761	2.49±0.25	8.31±0.50
OM, %	90	0.07	1.07	0.48±0.03	0.24	0.503	0.71±0.25	-0.05±0.50
Av. P, ppm	45	0.52	27.17	11.69±1.24	8.31	0.711	0.37±0.35	01.09±0.69

EC: electrical conductivity, dS/m; SOM: soil organic matter, %; Av. P: available phosphorus, ppm; N: number of samples; Min.: minimum value; Max.: maximum value; SD: standard deviation; CV: coefficient of variation. Values after the ± sign are the standard errors of the statistical parameters in the respective column.

Table 2. Descriptive statistics of soil physico-chemical properties of the sole maize section of the SIWES Farm

Property	N	Min.	Max.	Mean	SD	CV	Skewness	Kurtosis
Sand, %	50	81.60	89.60	86.60±0.32	2.29	0.026	-0.92±0.34	0.02±0.66
Silt, %	50	2.08	10.08	6.26±0.36	2.55	0.408	0.12±0.34	-1.12±0.66
Clay, %	50	3.32	8.32	7.10±0.21	1.50	0.211	-0.93±0.34	-0.43±0.66
pH	50	2.32	7.88	6.24±0.13	0.89	0.144	-2.37±0.34	9.04±0.66
EC, dS/m	50	3.40	865.00	161.33±22.9	162.14	1.005	2.65±0.34	8.16±0.6
OM, %	50	0.13	6.38	1.82±0.20	1.42	0.776	1.32±0.34	1.39±0.6
Av. P, ppm	25	1.30	39.58	16.02±1.97	9.84	0.614	0.77±0.46	0.40±0.90

EC: electrical conductivity, dS/m; SOM: soil organic matter, %; Av. P: available phosphorus, ppm; N: number of samples; Min.: minimum value; Max.: maximum value; SD: standard deviation; CV: coefficient of variation. Values after the ± sign are the standard errors of the statistical parameters in the respective column.

Table 3. Descriptive statistics of soil physico-chemical properties of the maize/cassava intercrop section of the SIWES Farm

Property	N	Min.	Max.	Mean	SD	CV	Skewness	Kurtosis
Sand, %	44	81.40	91.60	88.65±0.33	2.18	0.025	-1.03±0.36	1.25±0.70
Silt, %	44	2.08	13.72	4.97±0.33	2.16	0.434	1.69±0.36	5.13±0.70
Clay, %	44	3.88	8.32	6.37±0.15	1.01	0.159	-0.32±0.36	0.03±0.70
pH	44	3.36	7.27	6.16±0.11	0.72	0.116	-2.47±0.36	7.45±0.70
EC, dS/m	44	44.80	395.00	180.59±14.9	98.83	0.547	0.51±0.36	-0.58±0.70
OM, %	44	0.13	1.34	0.54±0.05	0.31	0.569	0.57±0.36	0.53±0.70
Av. P, ppm	22	1.18	23.82	6.58±1.34	6.29	0.917	1.61±0.49	1.58±0.95

EC: electrical conductivity, dS/m; SOM: soil organic matter, %; Av. P: available phosphorus, ppm; N: number of samples; Min.: minimum value; Max.: maximum value; SD: standard deviation; CV: coefficient of variation. Values after the ± sign are the standard errors of the statistical parameters in the respective column.

The responses of various physicochemical properties of the soil under cassava/maize intercrop are presented in Table 3. Results showed that the soil had high sand content that ranged between 81 and 92% while both silt and clay contents averaged 4.97 and 6.37% respectively. The soil textural class according to [14] was loamy sand. Organic matter and Av P contents of the soil were very low with mean values of 0.54% and 6.58 ppm, respectively while electrical conductivity was high with 180.59 dS/m.

All measured chemical parameters varied considerably within the study area (different cropping zones) as indicated by the coefficient of variation (CV) which varied widely. EC, Av. P and SOM showed high variability (CV > 0.5) within the study area while pH, sand and clay had low variability (CV <0.12) according to the guideline provided by [14]. This corroborates with the findings of [15] and [16] who also reported varied soil parameters within their study area. High variability of a soil parameter may be attributed to a lack of homogenous fertilization for chemical parameters or tillage practices for parameter such micronutrients while microbial activity may also be reduced or changed. In addition, lower pH increases the solubility of Al, Mn, and Fe, which are toxic to plants in excess.

The EC of the soil under the three crops is classified as low (EC < 2.0) salinity soil, although small patches of the field are saline, however this soil does not pose a salinity problem. Usually, addition of fertilizer including amendments can result in high EC, due to a relative amount of the salts which are leached by irrigation water. Management history of this soil showed that irrigation has not been practiced and also, fertilization has not been consistent enough to raise salinity above normal. The SOM from the three cropping systems is also classified as being low in organic matter (SOM < 15%). Other studies suggest that low SOM may be due to tillage practices [17]. For available phosphorus, the values in the study area varied indicate that the soil of the study area can be classified as having moderate level of available phosphorus for the cultivated crops considering the critical level of 10-12mg/kg available P for soils of South Western Nigeria [18].

The standard deviation (SD) values for the tested parameters indicate that only the mean value obtained for the pH is representative of the studied parameter (SD value significantly lower than mean value), however, EC, SOM and available phosphorus mean values are not representative (SD values closer to the mean values).

The range of the values of coefficient of skewness indicates that some soil chemical properties such as pH and available phosphorus values are normally distributed (Figs 2, 3 and 4), while EC and SOM were not normally distributed because of some local distribution with some values far higher than the rest (Figs 2, 3 and 4). When a parameter has local distribution, it follows that high values were found for these elements at some points, but most values were low [19]. The main reason for some soil properties not having normal distribution may be due to soil management practices [20], where necessary, data were transformed to a normal distribution. The same tendency in skewness was observed for the coefficient of kurtosis (Tables 1, 2 and 3) and it can be concluded in this study that the data distribution for pH and available phosphorus tends to be normal but EC and SOM tends to log normal (Figs. 2, 3 and 4).

3.2 Geostatistical Analysis and Mapping

The mathematical models (theoretical semi-variograms) adjusted to the experimental semi-variograms, as well as the C_o parameter (nugget effect), $C_o + C$ (sill), A_o(range), $C_o/C_o + C$ (spatial dependence), and R^2 (coefficient of determination) related to the adjusted process are shown in Table 4. The nugget (C_o) which is an indication of micro-variability was low for pH (0.19) and SOM (0.89%), high for available phosphorus (58.7 ppm) and extremely high for EC (43.90dS/m) as shown in Table 4. The close to zero nuggets from pH and SOM is an indication of very smooth spatial continuity between neighbouring points. On the other hand, the highest nugget effect found in EC compared to other variables indicates high discontinuity among samples. [21] stated that the higher the nugget effect, the greater the discontinuity in samples. With increase in separation distance (*h*), the semivariance increases to a more or less constant value, which is known as the sill or total semivariance. In this study, the sill values ranged from 0.18 (pH) and 14650 $(dS/m)^2$ (EC). The range of spatial dependencies varied between 74 and 511 m, indicating that the optimum sampling interval varies greatly among the different soil properties [22]. The SOM that showed small range (74 m) of spatial dependence indicates that spatial continuity could diminish rapidly over a relative short distance. This result corroborates the findings of [16] who also reported variability in spatial distribution range of tested soil parameters.

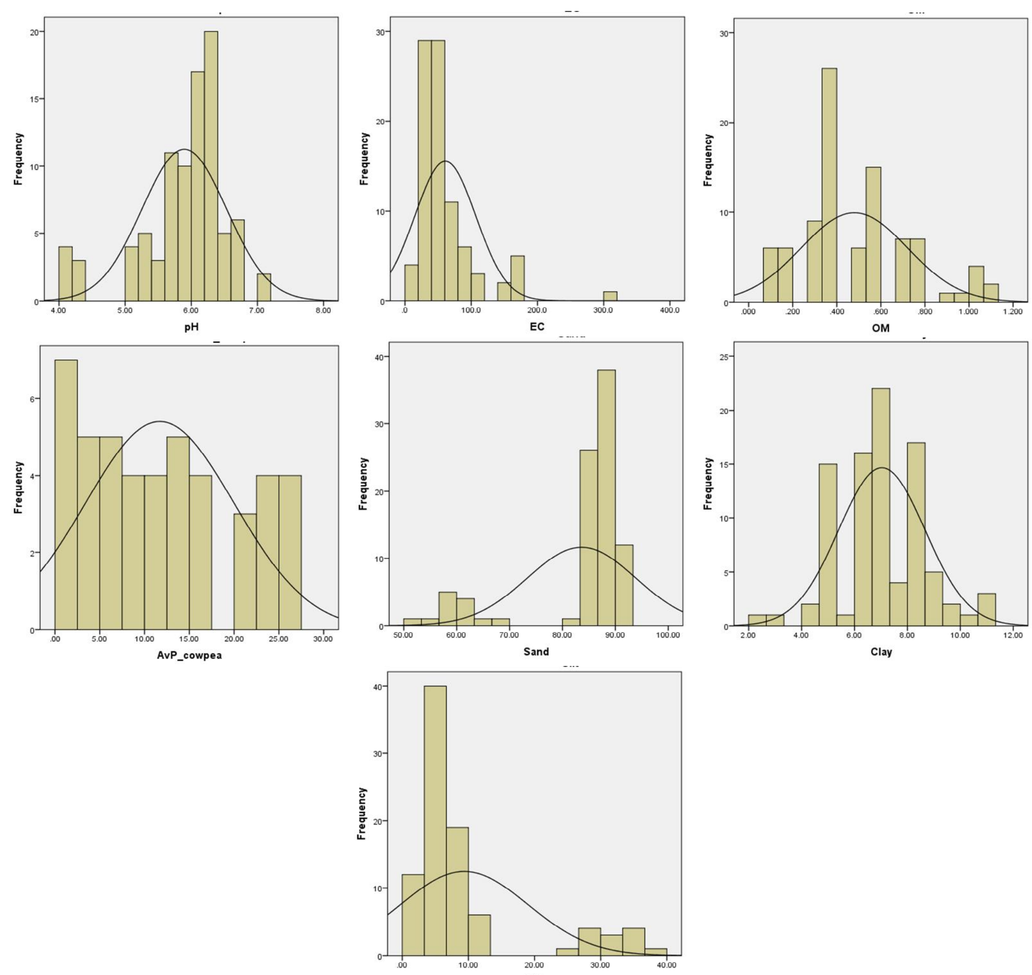

Fig. 2. Frequency and normal distribution curve of some soil physico-chemical properties of cowpea section of the SIWES Training Farm.

The nugget to sill ratio is used to define the degree of spatial dependence of soil properties. If the ratio is < 0.25, there is strong spatial dependence; if it is 0.25 to 0.75, there is moderate spatial dependence; and if the ratio is > 0.75, the spatial dependence is weak [12].

The ratio values (Table 4) indicate that pH, EC and Av. P showed moderate spatial dependence while SOM had strong spatial dependence. The moderate spatial dependence indicates that the chosen sampling distance of 10m × 10m of this study moderately characterized the spatial variation of each of the parameters. On the other hand, the strong spatial dependence observed for SOM that showed the influence of soil composition characteristics, such as original material, climate, organism or time [15]. [16] attributed possible cause of strong spatial distribution of a soil parameter to non-existence of extrinsic factors, such as management cultivation practices, that influences soil properties and when left undisturbed. Based on the range values and spatial dependence status of the tested soil parameters, it can be emphasized that choosing sampling distance of 10 m × 10 m characterized the spatial variation of soil parameter and the sampling distance adequately capture the variation.

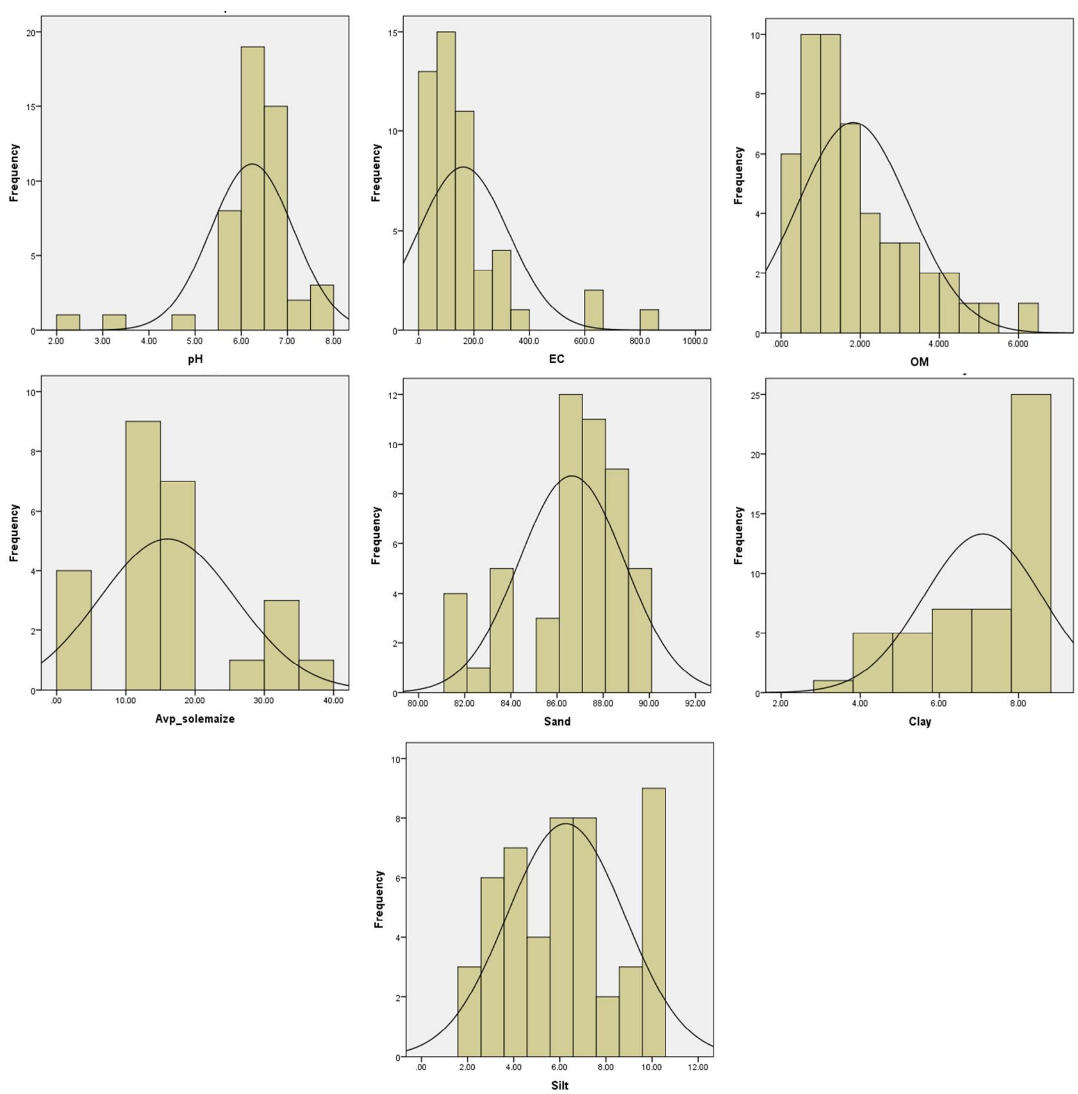

Fig. 3. Frequency and normal distribution curve of some soil physico-chemical properties of sole maize section of the SIWES Training Farm

Table 4. Fitted models and estimated parameters of the experimental semi-variograms of soil chemical properties of the SIWES Training Farm

Prop.	Model	Co	Co+C	Ao	Co/(Co+C	Spatial dependence	R2	MAE	MSE
pH	Exp.	0.195	0.394	510.9	0.495	MSD	0.100	0.026	0.013
EC	Exp.	4390	14650	36.6	0.300	MSD	0.444	0.043	0.018
SOM	Sph.	0.181	0.89	74.2	0.203	SSD	0.080	0.064	0.002
Av. P	Sph.	58.7	117.41	511.0	0.500	MSD	0.255	0.012	0.001

Prop.: soil property; EC: electrical conductivity, dS/m; SOM: soil organic matter, %; Av. P: available phosphorus, ppm. Co: nugget effect; Co+C: sill; Ao: spatial range, m; SSD: strong spatial dependence; MSD: moderate spatial dependence. R_2: coefficient of determination; MAE: mean absolute error; MSE: mean square error.

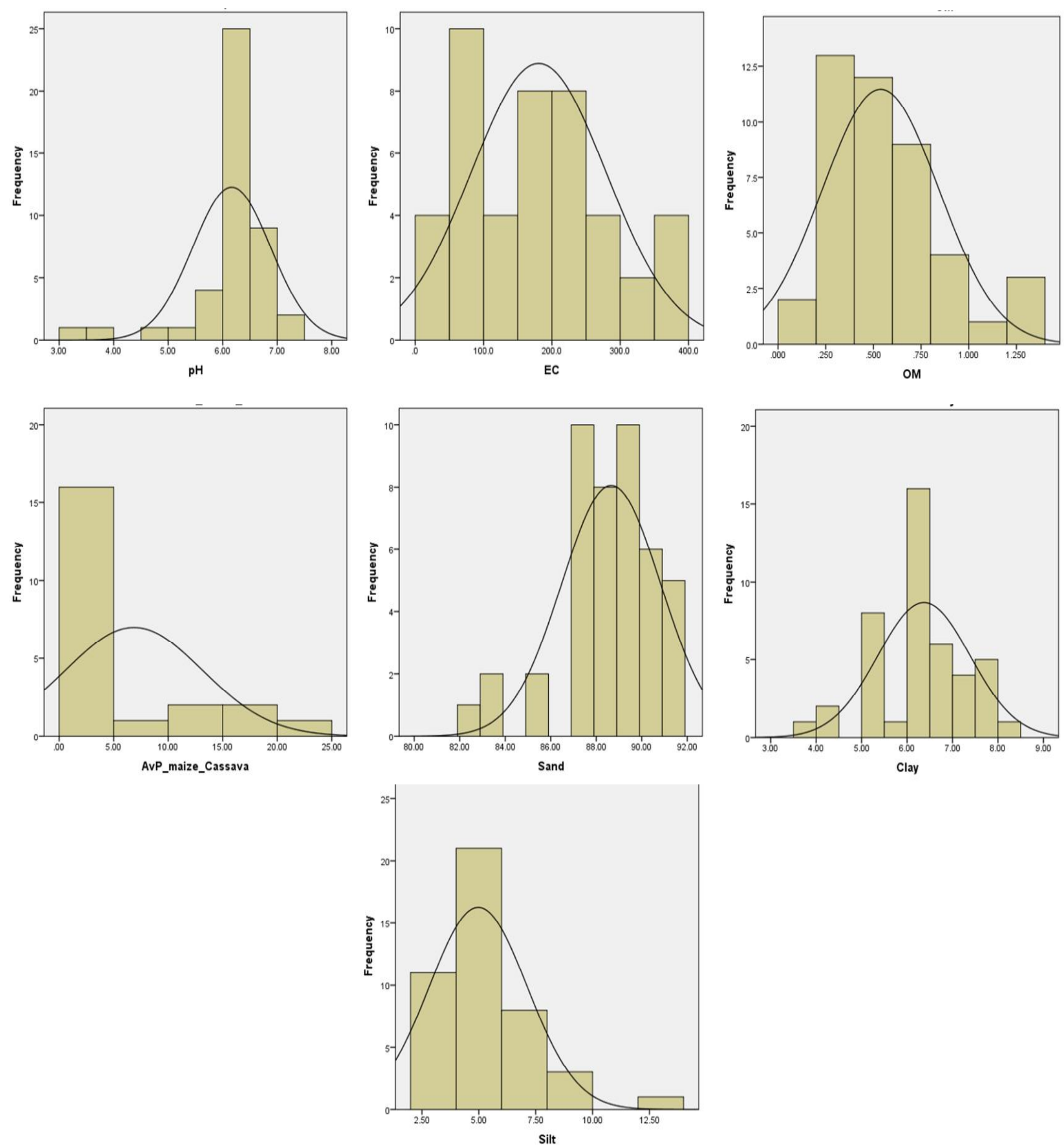

Fig. 4. Frequency and normal distribution curve of some soil physico-chemical properties of maize/cassava intercrop section of the SIWES Training Farm

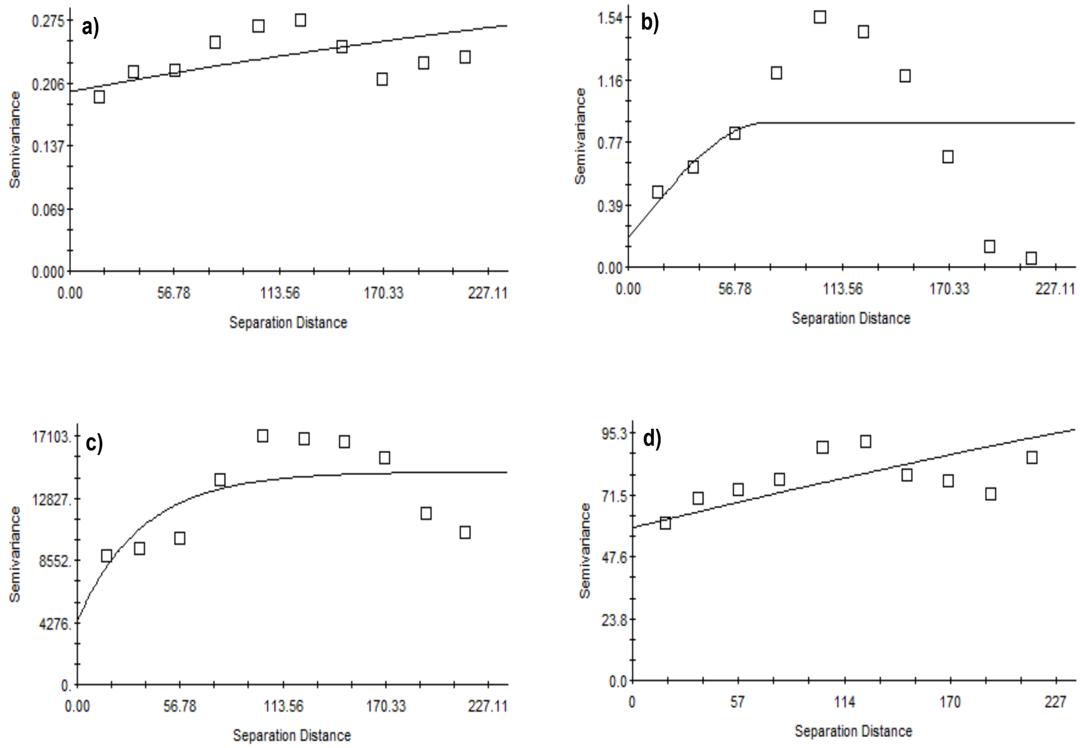

Fig. 5. The semivariogram of the a) pH, b) soil organic matter , c) electricalconductivity , and d) available phosphorus of the field

The experimental semi-variograms which describe the structure of spatial variability of the studied soil chemical properties were best fitted to exponential model for pH and EC, and the spherical model for SOM and available phosphorus. These models are depicted in Fig. 5. The coefficient of determination (R^2) for the adjusted theoretical semi-variogram as presented in Table 4 varied from 0.080 to 0.444 which is < 0.5. This is in agreement with the findings of [15] who also reported $R^2 < 0.5$ for the tested soil parameters. This result indicates average quality of theoretical model fitting to the empirical values of the semi-variogram. The test of validation was checked with the MAE and MSE (Table 4). Low values observed indicate that kriging predictions of the studied soil chemical properties are equally accurate.

Figs. 6-9 show the digital maps obtained by kriging techniques for soil properties. The comparison of these maps is useful in the interpretation of results. The map indicates a high variability in the distribution of pH across the different cropping zones (cowpea, sole maize, maize/cassava intercrop), indicating that the pH contents in this study area is highly heterogeneous. According to this map, the pH range of strongly acidic to slightly alkaline are present in the soil (Fig. 6). In all, this soil can be classified as slightly acidic. The SOM of the field is classified as low and has the highest homogeneity across the 3 cropping zones with a minor variable distribution (Fig. 7). According to Fig. 8, EC content is classified low with variable distribution around the study area and showed homogeneity around the cowpea and cassava/maize cropping zones. The Av. P content is moderate for the cultivated crops in the study area with variable distribution around the different cropping zones (Fig. 9). Visual inspection of distribution maps of soil parameters such as pH and Av. P with distribution map of SOM and EC shows that they are not very identical. High heterogeneity of properties occurred in the former while the latter is close to being totally homogeneous in the study area indicating that soil parameter distributions within the field may be influenced by erratic fertilization management and heterogeneous management practices on the soil.

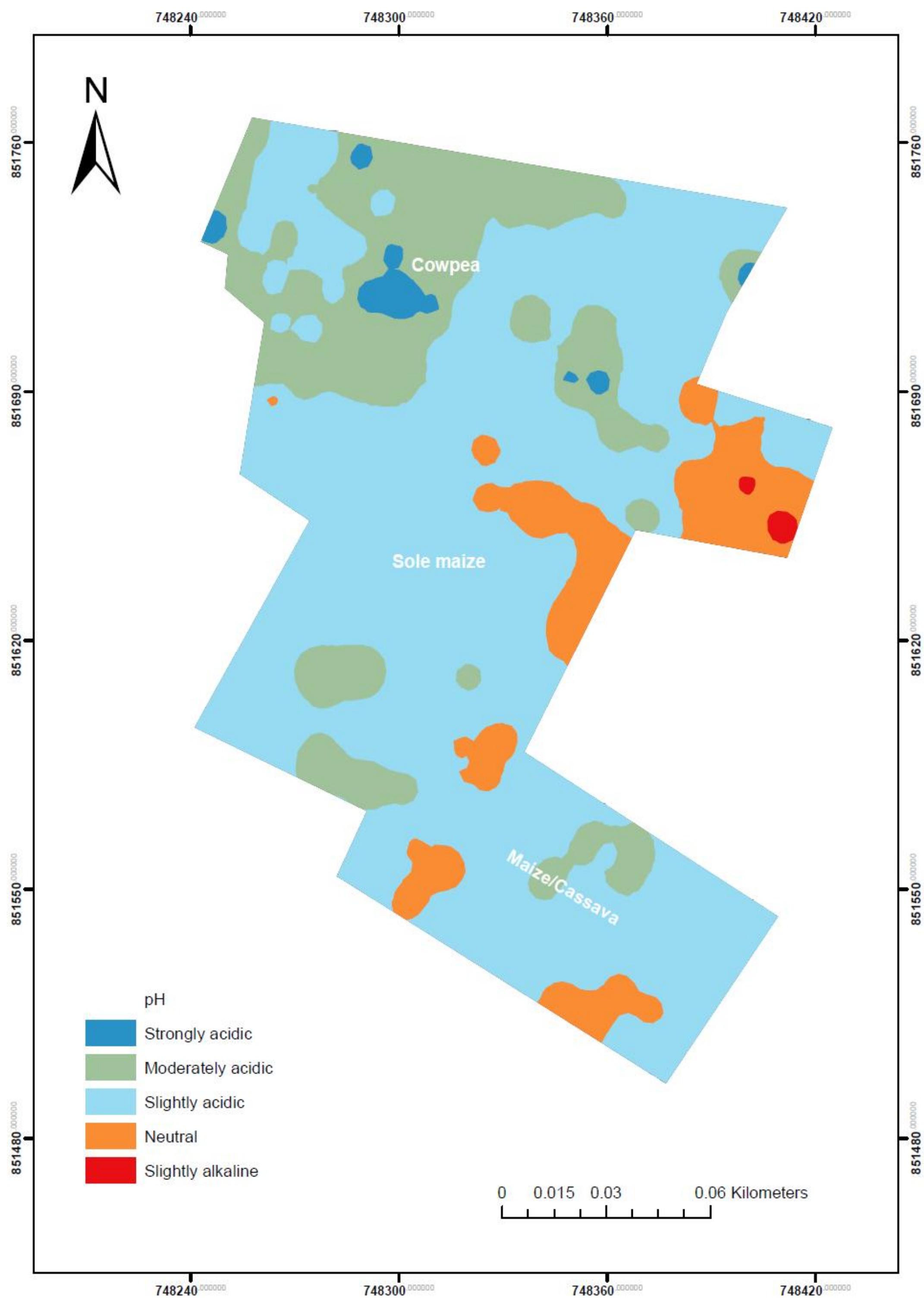

Fig. 6. Kriged contour map showing the spatial variability and classification of soil pH of the field

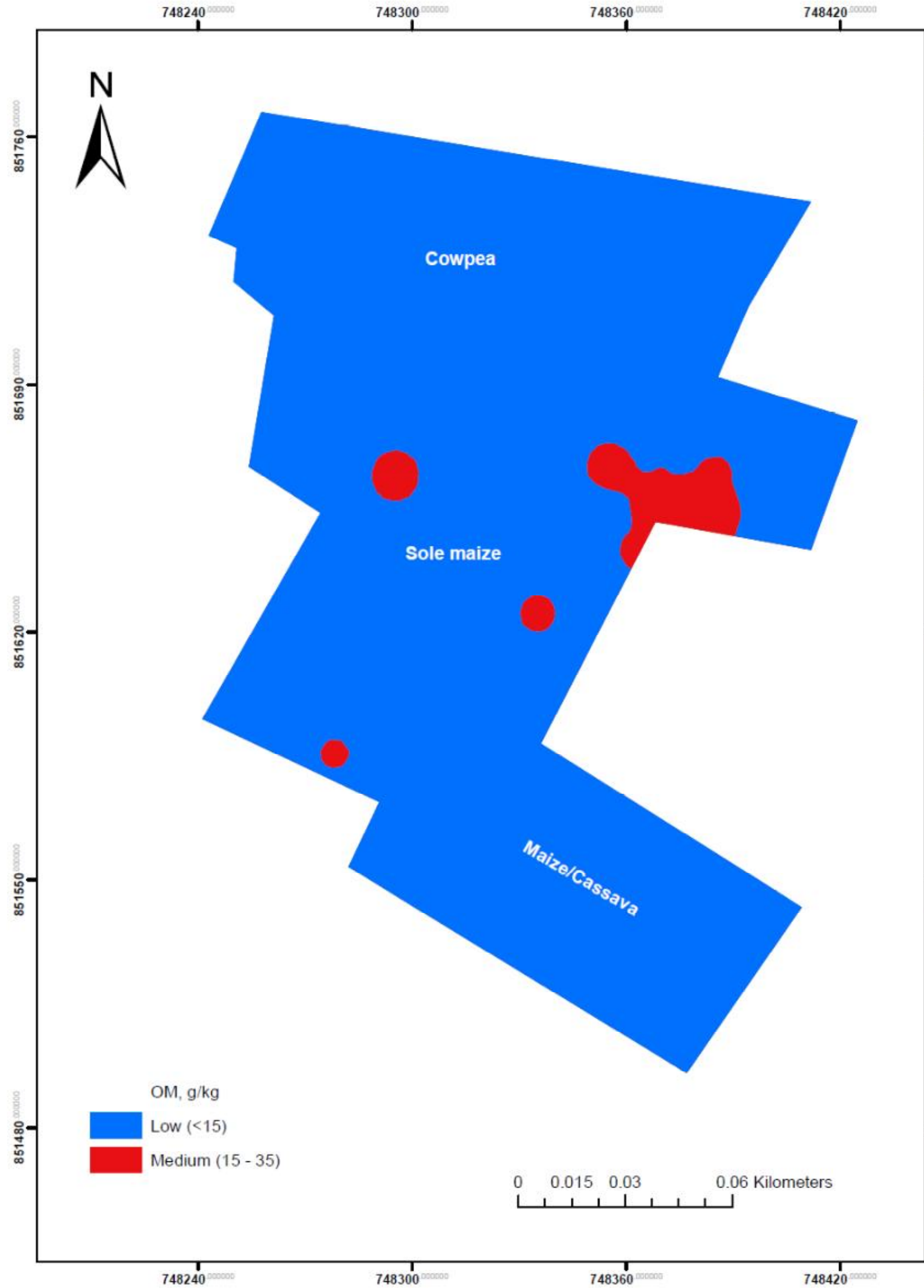

Fig. 7. Kriged contour map showing the spatial variability and classification of soil organic matter (SOM) of the field

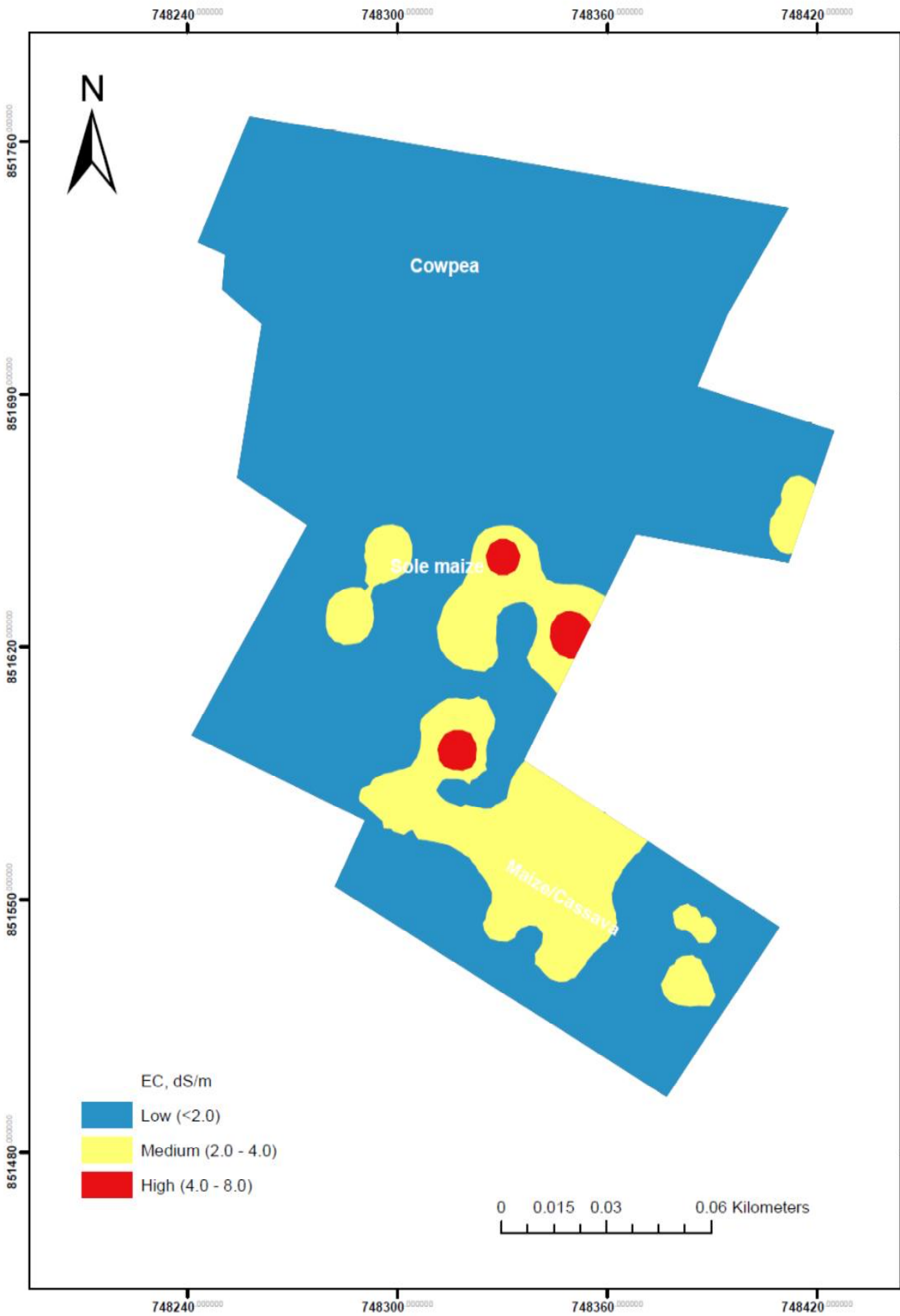

Fig. 8. Kriged contour map showing the spatial variability and classification of electrical conductivity (EC) of the field

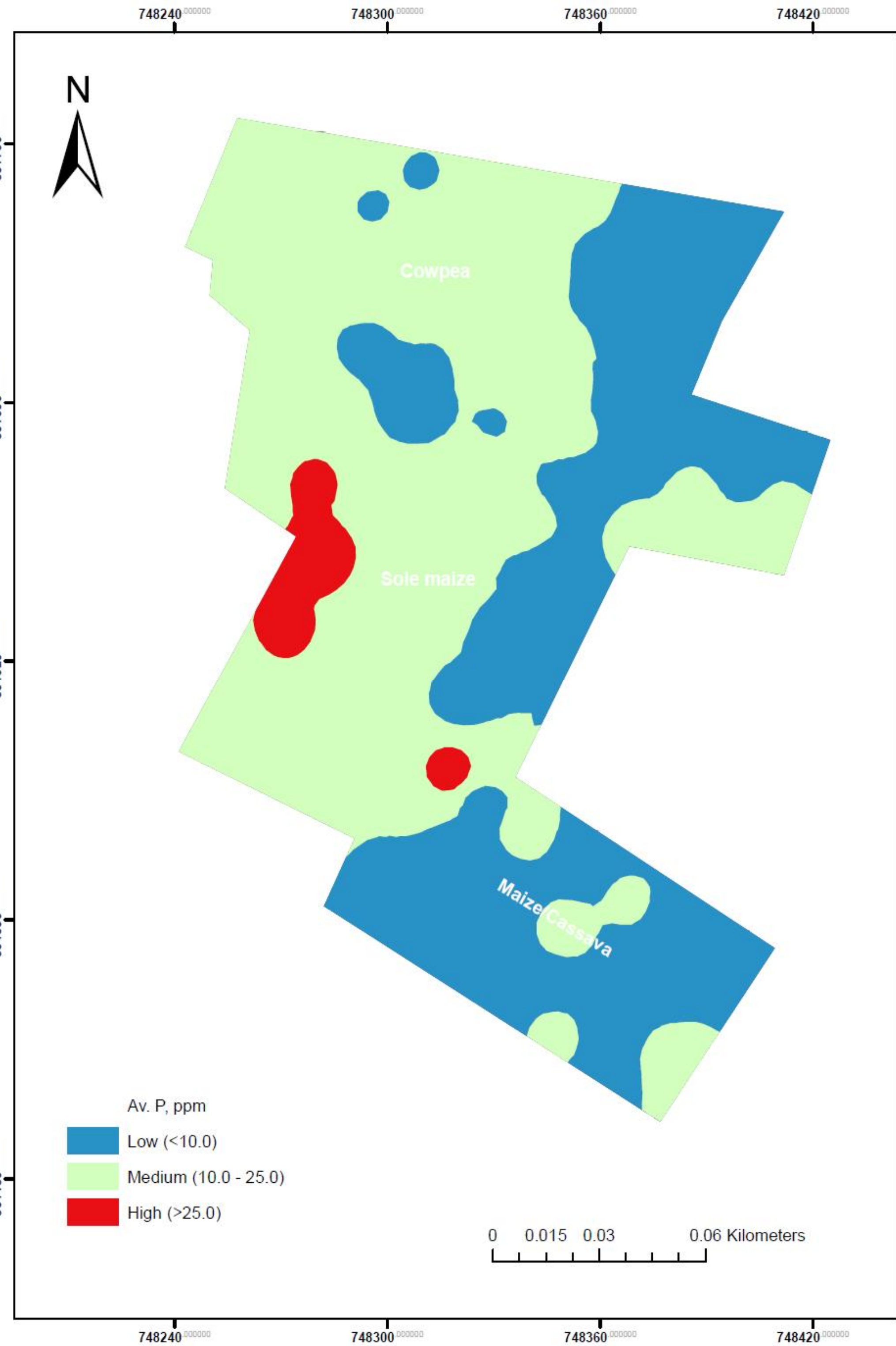

Fig. 9. Kriged contour map showing the spatial variability and classification available P (Av. P) of the field

The interpolation maps obtained with geo-statistical analysis are essential for better understanding of spatial variability and have influence on soil management and land use.

In addition, spatial variability in certain soil parameters can have influence on the spatial distribution of crop productivity potential as initially observed for crops grown in the study area. The spatial distribution maps are consistence with other studies [e.g. 22, 23, 24, 25] that had reported the spatial variability of soil chemical properties across cultivated field. Therefore, the quantitative and visual information obtained from these maps could be used to facilitate site specific management in the study area.

4. CONCLUSIONS

Some soil physico-chemical properties of SIWES Training Farm, Ekiti State University, Ado –Ekiti, Ekiti State were studied. The soils under the three cropping systems belonged to loamy sand textural class. All measured soil chemical parameters varied considerably within the study area (different cropping zones) and the field is slightly acidic to slightly alkaline and generally low in SOM and Av. P, with no salinity problem. High magnitude of variability was observed for EC, Av. P and SOM while pH had the least magnitude. The soil chemical properties showed moderate to strong spatial dependence. The geospatial maps clearly revealed that the heterogeneity of the soil chemical properties across the field. Both classical statistics and geostatistical analyses of the soil of the area gave a better understanding of the spatial variability of soil chemical properties of this field and these results could help in defining site-specific management zones aimed at reducing cost and protecting the environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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