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Development of empirical models for analysis of subsoil agricultural parameters from resistivity measurement in a basement complex terrain

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ABSTRACT

Soil electrical resistivity measurements and soil properties determination were carried out at an arable plot located within the Federal University of Technology, Akure, Ondo State. This was with a view to establishing relationship between in-situ soil resistivity and selected topsoil properties in a typical basement complex environment. Electrical Resistivity was measured from the soil surface at 0 to 50 cm soil depths using Wenner Array. Electrode spacing of 130 cm (1.3 m) was utilized. Soil samples were collected to a depth of 50 cm at the mid points of 2 m by 2 m cell. These were analyzed for properties that include: moisture content, particle size analysis, Organic Matter (OM), pH and electrical conductivity. The regression analysis plots show that ER correlate significantly to soil properties, with coefficient of correlation of 0.90 for MC, 0.63 for SC, 0.74 for CC, 0.57 for OM, 0.94 for EC. Except for SC and PH that shows a non-significant correlation of 0.52 and 0.30 respectively. Validation of the derived empirical model gives a coefficient of correlation between the observed and predicted result as 0.94 for MC, 0.74 for OM, 0.93 for EC, 0.79 for SC, 0.94 for silt content, 0.52 for clay content and 0.48 for PH. The study concluded that electrical resistivity measurements could be used as a rapid tool for obtaining the selected topsoil properties.

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Electrical resistivity; soil properties; regression analysis; validation of results; Wenner Array

1. Introduction

Agricultural geophysics is a sub-discipline of geophysics that is focused only on agricultural applications (Allred et al. 2008). Agriculture is the science or practice of faming, including cultivation of soil for the growing of crop and the rearing of animals to provide food, wool and other products. Soil is the medium for crop growth, anchorage for plants. It contains nutrients, water and air on which plants depend (Ibitoye 2008). Therefore, the impact of soil properties on plant growth and yield cannot be over emphasised. Soil properties such as texture, moisture content, total organic matter, pH, electrical conductivity (EC), etc., influence plant growth and yield, and so must be treated with utmost importance (Joshua and Mokuolu 2016). Therefore, it is of great importance to conduct pre-planting soil investigation in order to ascertain the suitability of the arable soil properties for cultivation. These soil properties, which are grouped into physical, chemical and biological factors, have the potential to effectively affect crop production and some ecological activities but cannot be measured directly.

The pre-planting soil investigation may involve the conventional method of disturbing the soil, removing soil samples, and analysing them in the laboratory. It may also involve non-invasive geophysical investigation such as electrical resistivity survey, which allow rapid measurement of soil electrical properties directly from soil surface to any depth without soil disturbance (Omar 2012).

Electrical resistivity prospecting is one of the most attractive geophysical methods in agricultural field's application (Joshua and Mokuolu 2016). The soil resistivity measured by geophysical methods provide information about the volume density of mobile electric charges in soil (Pozdnyakova 2015) and is subjected to great variation due to many soil properties such as soil water content, organic matter, salt, cation exchange capacity, soil texture (sand, silt and clay) and temperature (Omar 2012). Soil electrical resistivity is increasingly used in near surface soil application because it is related to several soil properties; it therefore represents a rapid and flexible tool to predict spatial soil variability at the field or local scale (Rossi et al. 2013). Electrical resistivity technique is inexpensive in terms of cost and time compared to direct pitting method. It supplies reliable subsurface information over depth ranges that are much greater than the depth ranges of direct pitting techniques (Mohammed and Ajayi 2014). Variations in electrical resistivity of the earth materials when combined with other measurements can reveal information about the composition, extent of soil texture, structure, water content, soil organic matter and salinity of the

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subsurface material (Nwankwo et al. 2013). Soil electrical resistivity is widely used in agricultural applications because of its calibration ease, its linear relationship with depth and relatively large volume of soil measurement compared to other methods.

Increase in the demand for food and other agricultural products has demanded for a quick and, when possible, non-disturbing estimations of numerous soil properties, faster means to investigating the topsoil properties that may influence agricultural production. In agriculture, the suitability of topsoil is evaluated through series of laboratory soil analysis for texture/soil characterisation, pH, moisture content, electrical conductivity (EC), total organic matter, and salinity. These soil properties are found to be physicochemical properties. Electrical resistivity responds to the physical and chemical variation of a soil (Gebbers et al. 2009). It is therefore possible to use electrical resistivity measurements as indices to determine the topsoil properties. Therefore, the need to establishing possible relationship(s) between apparent electrical resistivity and selected topsoil properties cannot be over emphasised. This study aims at establishing the relationship between electrical resistivity measurements and selected subsoil agricultural parameters in a typical Basement Complex environment of Federal University of Technology, Akure, Southwestern Nigeria.

2. Geomorphology, climate, vegetation and geology

The study area falls within the teaching and research farm of the Federal University of Technology, Akure, Nigeria. The University Campus (Figure 1) is situated on the northwestern flank of Akure, which is the capital city of Ondo State, Nigeria. The University, which occupies an area of about 5 km2,lies between Latitudes 7° 17′ 0″ N – 7° 19′ 0″ N and Longitudes 5° 7′

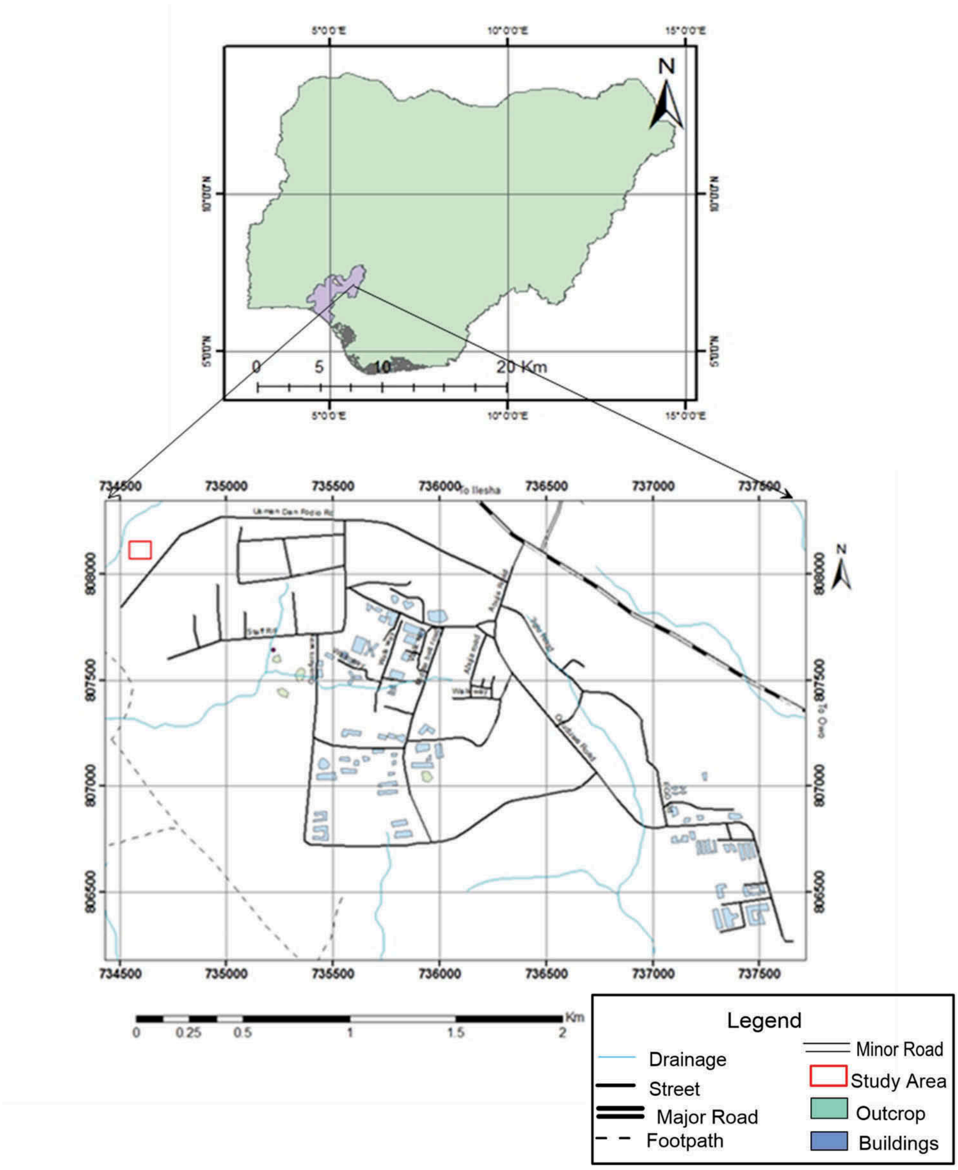

Figure 1. Map of the Federal University of Technology, Akure (FUTA) showing road network and the study area (Modified after Akinlalu et al. 2015).

0″ E – 5° 9′ 0″ E. It is easily accessible through Akure – Ilesha expressway. There are network of roads and foot paths within the campus.

The topography of the study area indicates a general gentle slope. The study area has elevation ranging between 375 and 381 m above mean sea level. The area is characterised by dry (November to March) and wet (April to October) seasons and mean annual rainfall ranging between 1000 and 1500 mm. The annual mean temperature ranges from 21.9 to 30.40 C. Humidity is relatively high during the wet season and low during the dry season with values ranging annually from 39.1 to 98.2 % (Akinbode et al. 2008). The vegetation is of tropical rain forest which is characterised by thick forest.

The study area is underlain by rocks of the Precambrian Basement Complex of Southwestern Nigeria (Rahaman 1988). The dominant rock types within the study area are Granite, which weathered slowly to form sand. Other observable rock types within the campus are; Charnockite, Quartzite, and Migmatite-gneiss (Figure 2). A quartzite ridge that extends over 100 m is located towards the northern part of the campus. However, Charnockites occur as discrete bodies mainly in the eastern part. Outcrops of Migmatite-Gneiss occur around the centre and towards the southwestern part of the campus. Granites occur as intrusives or lowlying outcrop within the Migmatite-Gneiss. Field observation however shows that the granite rocks constitute slightly extensive outcrops in the Northwestern and Northeastern part of the campus. The geology and boundaries of lithological units were inferred in places

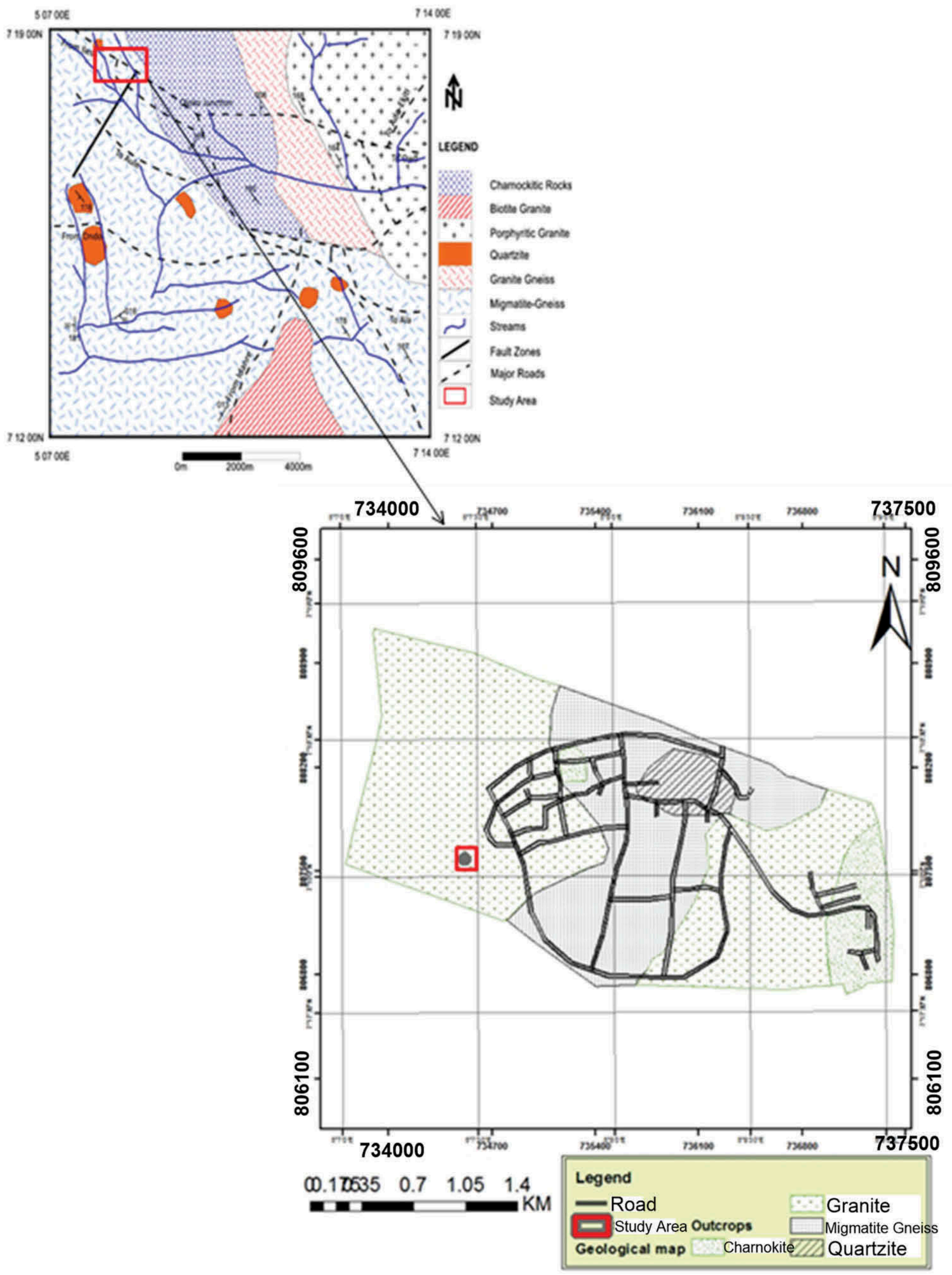

Figure 2. Geological map of (a) Akure (b) FUTA showing the study area (modified after Kareem 1997).

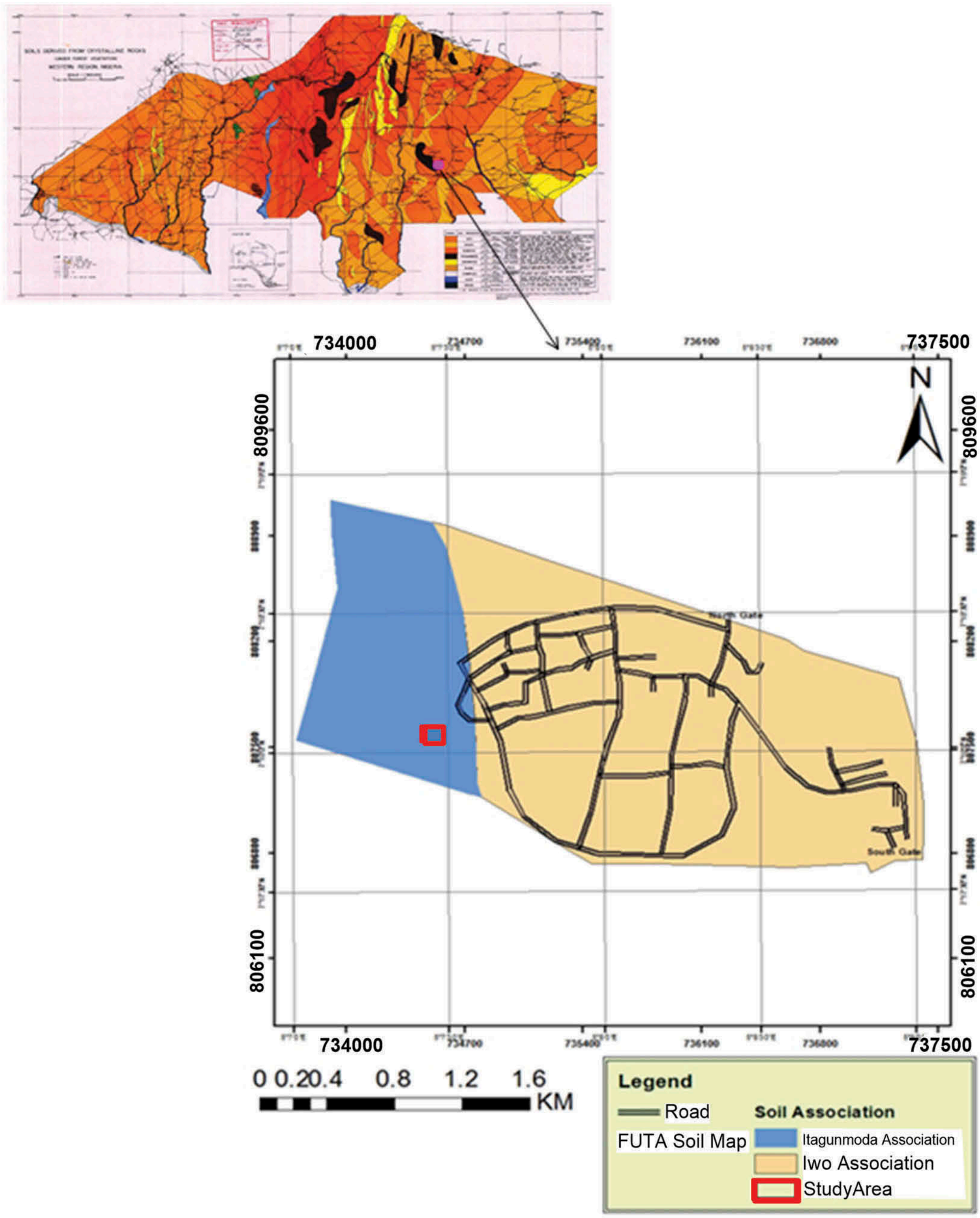

Figure 3. Soil association map of Southwestern Nigeria showing the study area (extracted from Smith and Montgomery, 1962).

where they are concealed by superficial residual soil (Kareem 1997).

3. Soil association of the study site

The Federal University of Technology Akure (FUTA) falls within two different soil association which are Iwo association and Itagunmodi association. The study site of this research work falls within the Itagunmodi association of the campus (Figure 3).

The Itagunmodi association is situated at the western flank of the campus. Soil of this association

has a very fine textured soil of uniform brownish red or dark chocolate brown colour to depth. The soil is derived from parent rock of amphibolites and related basic rocks. The soils derived from these rocks are exceptionally clayey to within a few inches of the surface and their sand fraction is extremely fine. Quartz gravel and stones are very rare in the profile and all are classified as drift soils although it is not impossible that some are sedentary (i.e. developed in-situ from rocks almost devoid of quartz).

4. Material and methodology

4.1. Electrical resistivity measurement

Electrical resistivity measurements were conducted using Ohmega resistivity metre. Ohmega is a high quality earth resistance metre capable of accurate measurements covering a wide range of applications.

Traditionally, high power was thought to be necessary for successful surveys. However, it is now accepted that the superior precision of the Allied Ohmega enables accurate electrical measurements to be made in all but the most extreme environments, normally down to depth of 700 metres. A choice of current setting from 0.5 mA to 200 mA, with automatic gain steps, enables measurements to be made between 0.001 ohm and 400 kohm. The Ohmega 52 will deliver up to 200 mA making this a most powerful yet lightweight tool for sounding applications.

Electrical resistivity measurements were carried out on a 14 m by 14 m arable plot of land utilising horizontal profiling techniques adopting Wenner array configuration (Figure 4). In this configuration, four electrodes are utilised. The outer electrode A and B are used to send current into the ground and the inner electrode M and N are used to measure the potential difference. The current and potential electrodes pair have a common midpoint such that the distance between adjacent electrode are equal i.e AM = MN = NB = a

The apparent resistivity measured with Wenner array is given by;

$$\rho a = 2\pi a(\frac{V}{I})$$

Since $R = \frac{V}{I}$

$$\rho a = 2\pi aR$$

But the geometric factor $(G) = 2\pi a$

Therefore, $\rho a = GR$

Where,

ρ = Apparent Resistivity (Ohm-cm)

a = Electrode spacing (cm)

V = Potential difference voltage measured in joule/coulomb

I = current (Ampere)

R = Resistance (Ohms)

$\pi = constant(3.142)$

Fourteen traverses, with inter-traverse separation of 1 m were established on the plot of land. The inter-station separation on each traverse was 1 m (Figure 5). The plot was partitioned into cells with each cell having 2 m by 2 m dimension. The electrode spacing of 1.3 m was adopted; this was found appropriate to take resistivity measurements within the upper 50 cm of the topsoil (Eluwole 2016).

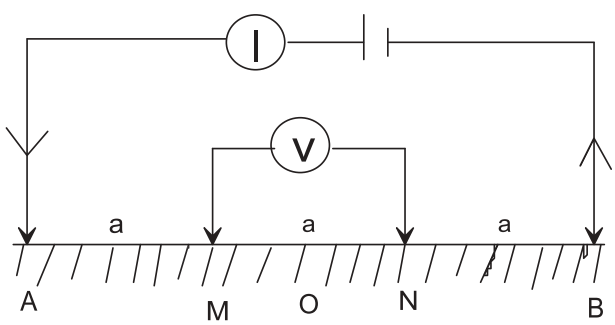

Figure 4. Wenner electrode configuration.

5. Soil sampling and soil analysis

Soil samples were collected at the midpoint of 2 m by 2 m cells amounting to a total of twenty five (25) sample points on the experimental site (Figure 5). The samples were analysed for moisture content, texture/soil characterisation, pH, organic matter and electrical conductivity.

6. Statistical analysis

The statistical method adopted in this research work involved the regression analysis. This enables the establishment of the empirical model between Apparent Electrical Resistivity measurement and the selected topsoil properties. The regression techniques adopted are:

(i) Linear regression analysis
(ii) Nonlinear regression analysis

Simple Linear and Non-Linear Regression Analysis: Simple linear and non-linear regression analysis were carried out to estimate the relationship between an independent variable X (Apparent Resistivity) and a Single explanatory dependent variable Y (Moisture Content, or Electrical Conductivity, or Organic Carbon, or Organic Matter, or pH) given a set of data that includes observation for both of these variables. These techniques were adopted in this research work to establish the empirical equation that will relate the Y with a single variable X.

7. Results and discussions

7.1. Spatial distribution of apparent electrical resistivity

The apparent resistivity values obtained from the two hundred and twenty five (225) profiling stations ranges from 101 to 439 ohm-m. Table 1 was used to classify the results, and subsequently used to generate a map. The map (Figure 6) shows that the area consist of clayey sand soil at the western and southern part accounting for 71.1% of the study area, and sandy clay soil at the extreme eastern part accounting for 28.9% of the study area.

8. Spatial distribution of soil properties

The laboratory analysis result of soil sampling and there classification are presented in Table 2. The moisture content of the soil ranges from 12.28% to 15.26 %. The

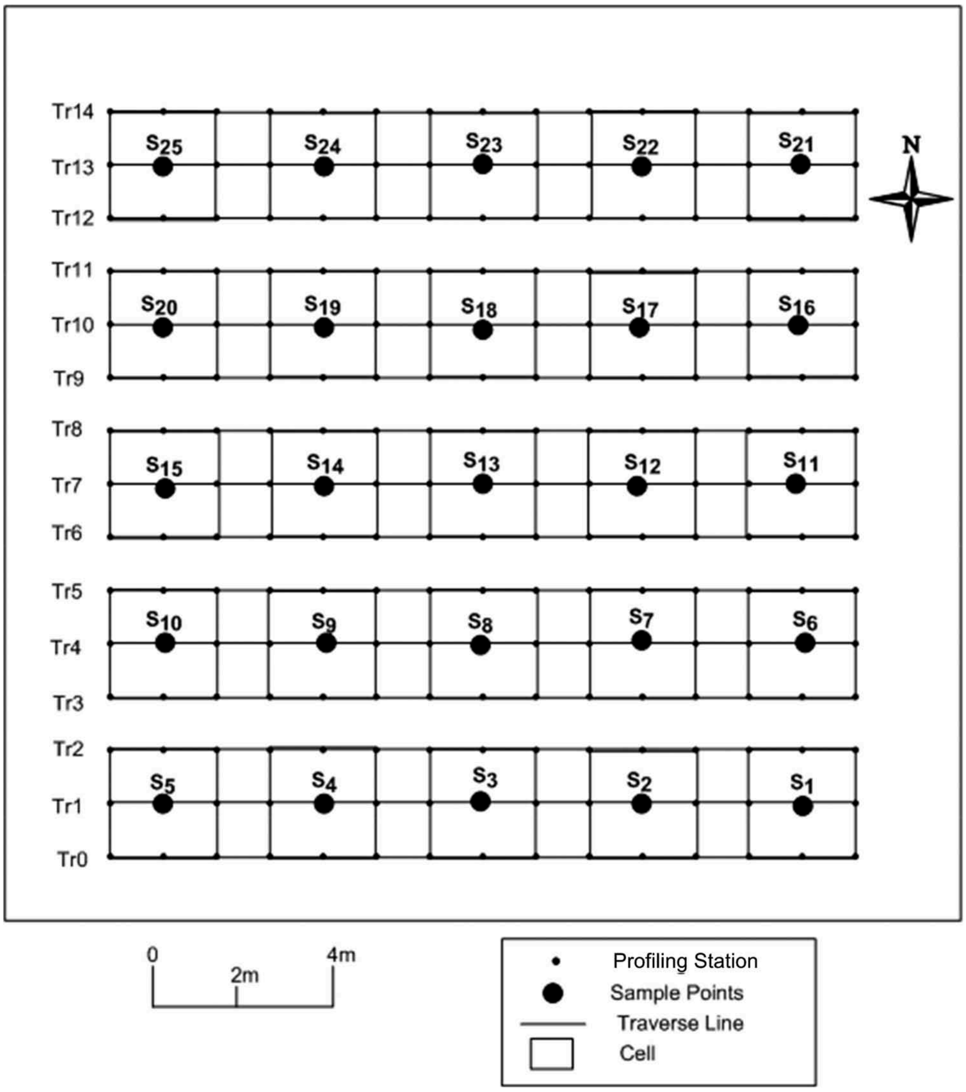

Figure 5. Site layout showing cells and sample points.

Table 1. Resistivity-derived soil classification (adapted from Bayowa, 2013).

Resistivity range (ohm-m)	Soil type
1–20	Plastic clay
1–100	Clay
100–210	Sandy clay
210–750	Clayey sand
>750	Sand

moisture content of soil within the study area was classified based on Figure 7 as unavailable water (permanent wilting points). This is a stage where the capillary water that is available to plant for proper growth and yield has been used up, and the remaining water is held too tightly by the soil for plant to extract (McCauley et al. 2005). At permanent wilting point, the leaves of plants wilt and cannot recover their turgidity in a saturated atmosphere (Ibitoye 2008). This may be as a result that the study was conducted during the dry season.

The electrical conductivity value ranges from 0.01 to 0.1 mS/cm and were classified based on Table 3 as very low EC. This is an indication that there is decrease in the amount of moisture and salinity in the soil. The very low electrical conductivity is also an indication that cation exchange capacity of the soil is low, and organic matter is also low. (Robert et al. 2009) shows that area of field having low electrical conductivity has low yield, and area having high electrical conductivity have high yield. Therefore, since the study site have a low electrical conductivity, crops planted on the site will have a low yield.

The results of the laboratory analysis for soil organic matter (SOM) range from 0.86% to 2.61 %.

Classifications of the results based on Table 4 were presented as map (Figure 8).

The soil map generated from the results of textural characterisation of soil samples is shown in (Figure 9). The textural triangle (Figure 10) classified the soil within the area to consist of sandy clay loam at the western, southern, central and part of the northern section thus accounting for about 76% of the study area. Sandy clay at the extreme eastern part accounts for about 24% of the study area. The texture of the soil influences the amount

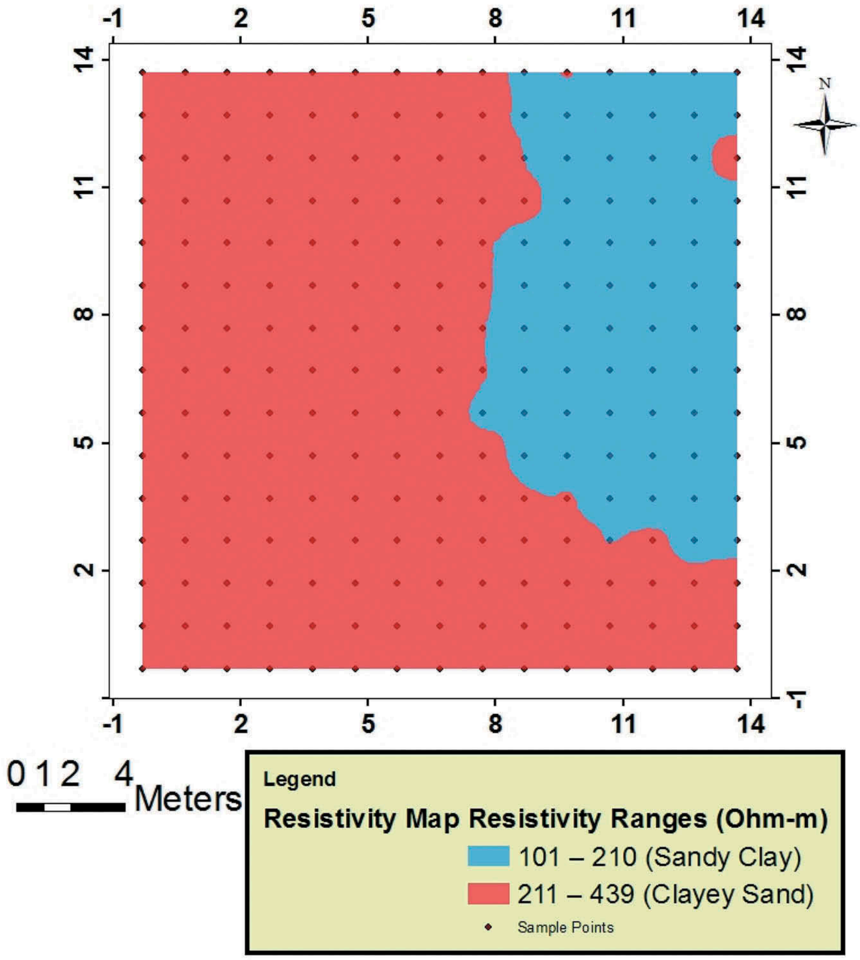

Figure 6. Resistivity map of the study area.

Table 2. Basic statistical description of the soil properties in the study area.

Soil Properties	Min	Max	Mean	Classification
MC	12.28	15.26	13.94	Plant unavailable water
EC	0.01	0.1	0.05	Very low
OM	0.86	2.61	1.51	Low, moderate and satisfactory
% SAND	50.80	62.80	57.04	Sandy clay loam and sandy clay soil
% SILT	6.00	20.00	13.92	
% CLAY	23.20	39.20	29.91	
pH	5.30	6.06	5.70	Moderately acidic

of air, water and nutrients held in the soil. The soil texture within the study site will allow the penetration of air, root, water and has good soil fertility.

The soil pH value ranges from 5.06 to 6.06. The pH values were classified based on Table 5 as moderately acidic. Since this soil are acidic, it implies that the activities of many micro-organisms are inhibited, nitrifying organisms and growth of some crops becomes inhibited when soil pH is less than 6.0, The result of these soils also indicated that earthworm cannot grow and proliferate, this invariable will hamper the production of macro-pores resulting from earthworm burrowing which will greatly enhance water infiltration and air circulation (Lee 1985; Tomlin et al. 1995). And as it were, neither earthworm nor its cast was identified in the studied soils. Edward et al. (1990) observed that some species of earthworm facilitate the breakdown and mineralisation of surface litter while others incorporate soil organic matter deeper into the soil profile and enhance aeration and water infiltration through burrow formation. Manganese is soluble at pH value lower than 6.0 and since pH of the soils tested ranged from 5.06 to 6.06 that means manganese will be readily soluble and this will greatly affect the productivity of crops in these soils, as it might become toxic to plant roots. Nitrogen fixation activities will be low, which means that the activities of Azotobacter as well as Rhizobium activities will be reduced. This affects the provision of nitrogen/nitrates nutrition for good crop growth and root development as well as plant/organism association in soil. Majority of crops such as maize, pepper, pumpkin, okra, etc., cannot do well in these soils following their pH levels. Therefore

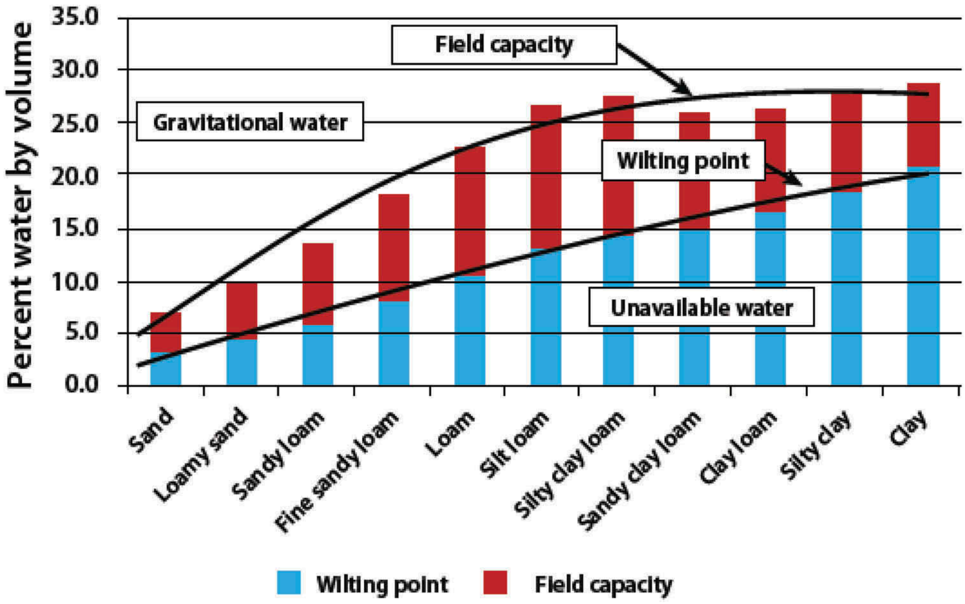

Figure 7. Relationship of soil texture with percentage of water by volume (adapted from Rogers et al. 2015).

Table 3. Electrical conductivity ratings (mS/cm) (adapted from Ibitoye 2008).

Rating	1:5 Soil: Water ratio
Very low	<0.15
Low	0.15–0.4
Medium	0.4–0.8
High	0.8–2.0
Very high	>2.0

Table 4. Soil organic matter rating/status (Ibitoye 2008).

Soil organic matter rating	Soil organic matter rating (%)
Very low	<0.75
Low	0.76–1.35
Moderate	1.36–1.85
Satisfactory	1.86–2.55
High	2.56–4.00
Very high	>4.00

lime application is needed to neutralise excess acidity of the soil in the studied area for optimum crop yield.

9. Exploratory statistical analysis

Exploratory statistical analysis was conducted to determine the relationship between the selected topsoil properties and apparent electrical resistivity measurements. The exploratory statistical analysis involves the regression analysis of scattered plots relating both parameters (Figures 11(a) and 11(b)). The regression analysis plots of the apparent resistivity (ρa) values against each of the determined topsoil properties show an empirical equation of the form;

$$Y = MX + C \quad (1)$$

$$Y = AX^2 + BX + C \quad (2)$$

$$Y = AX^n \quad (3)$$

Equations (1)–(3) show the general equation for linear, polynomial (quadratic) and power (exponential) relationships respectively. Where, "Y" represents the topsoil property, "X" represent the apparent resistivity, "A, B, M" represent the gradient of the trend line, "n" represent the exponent, and "C" is the intercept on the soil property axis. From the plot, the relationship between the topsoil properties and the apparent resistivity measurements is best described by a linear and non-linear (quadratic and power) relationship, where the topsoil properties are taken as dependent (predicted) variables and the apparent resistivity measurements is taken as independent variable (predictor), that is the determined topsoil properties vary with the electrical conductivity of the topsoil.

Coefficient of correlation (r) was utilised to check the strength of the regression analysis between

the selected topsoil parameters and the apparent resistivity measurements. The interpretation range and classification of coefficient of correlation (r) is between −1 and 1 (Colton, 1974). $r = -1$ means there is a perfect negative correlation and $r = 1$ means there is a perfect positive correlation. The closer r is to 1 or −1, the stronger the correlation.

The regression analysis indicated that the following soil properties were most significantly related to apparent electrical resistivity: MC, EC, OM, % sand, and % clay. Table 6 reveals that the correlation coefficients between Apparent Electrical Resistivity and MC, EC, % clay were significant at the 0.01 level. The correlation coefficients between Apparent Electrical Resistivity and OM, % sand were significant at the 0.05 level. While that of % silt and PH were not significant. The non-

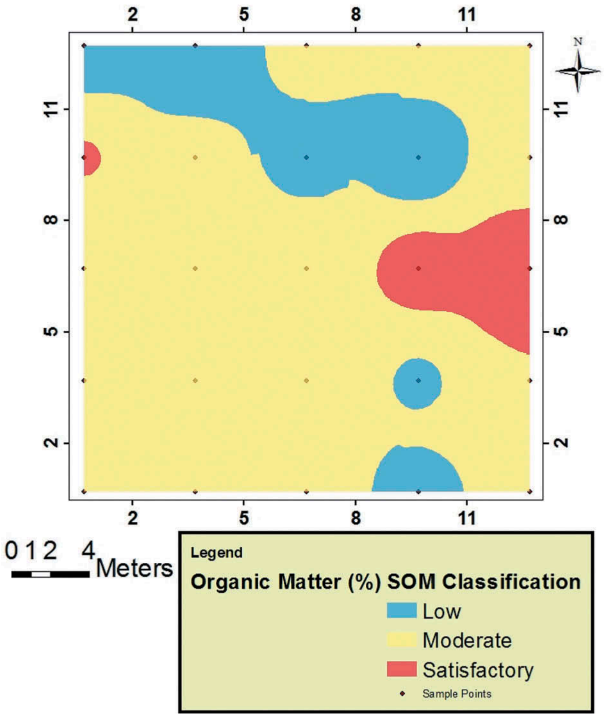

Figure 8. Soil organic matter map of the study area.

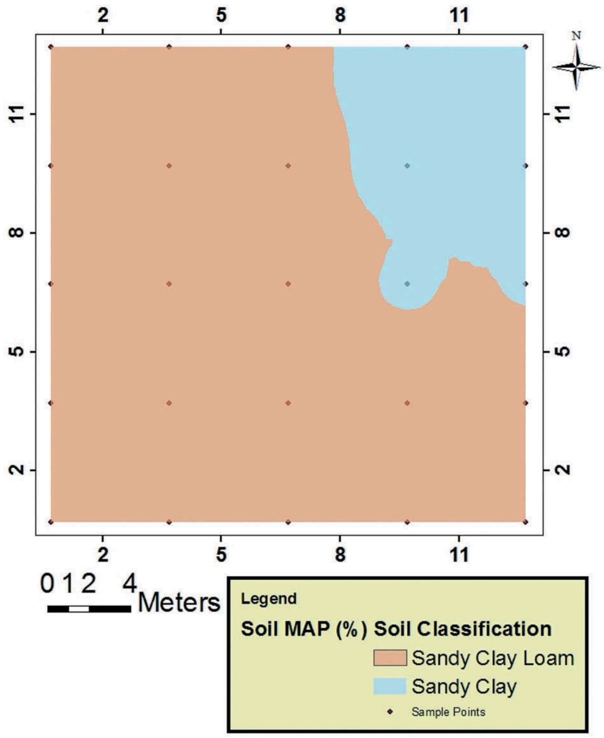

Figure 9. Soil map of the study area.

significance of silt to apparent electrical resistivity may be due to the fact that the field is largely dominated by higher content of Sand and Clay. The correlation coefficient for MC, EC, OM, % sand, % silt, % clay and PH are −0.90, −0.94, 0.57, 0.63, 0.52, 0.74, and 0.30 respectively, indicating a high correlation between apparent electrical resistivity and MC, EC and a moderately strong correlation between apparent electrical resistivity and OM, % sand, % silt, % clay, and a fair correlation for PH. The established models are presented in Equations (4)–(10).

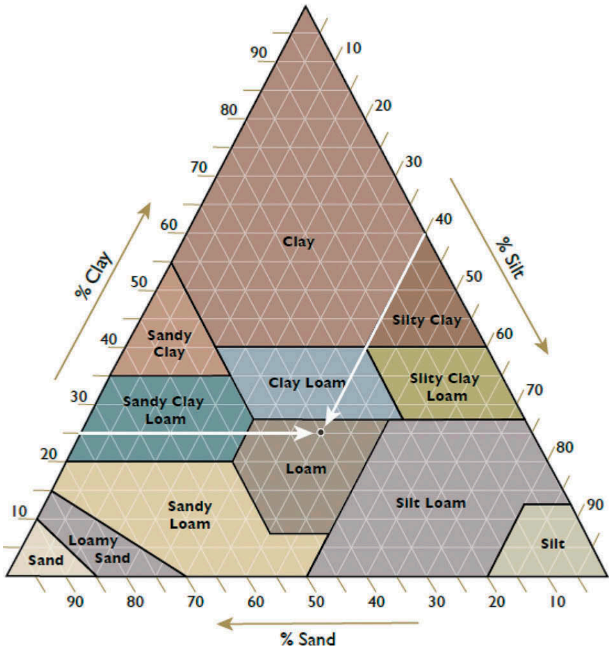

Figure 10. Textural triangle, showing soil textural group according to percentage sand, silt and clay contents. (Adapted from McCauley et al. 2005).

Table 5. Soil pH classification (adapted from Horneck et al. 2011).

Soil pH	Category
<5.1	Strongly acidic
5.2–6.0	Moderately acidic
6.1–6.5	Slightly acidic
6.6–7.3	Neutral
7.4–8.4	Moderately alkaline
> 8.5	Strongly alkaline

10. The established models

$$MC = -0.0092\rho a + 16.327 \quad (4)$$

$$EC = -0.0003\rho a + 0.1278 \quad (5)$$

$$OM = 4E - 05\rho a^2 - 0.0217\rho a + 4.2259 \quad (6)$$

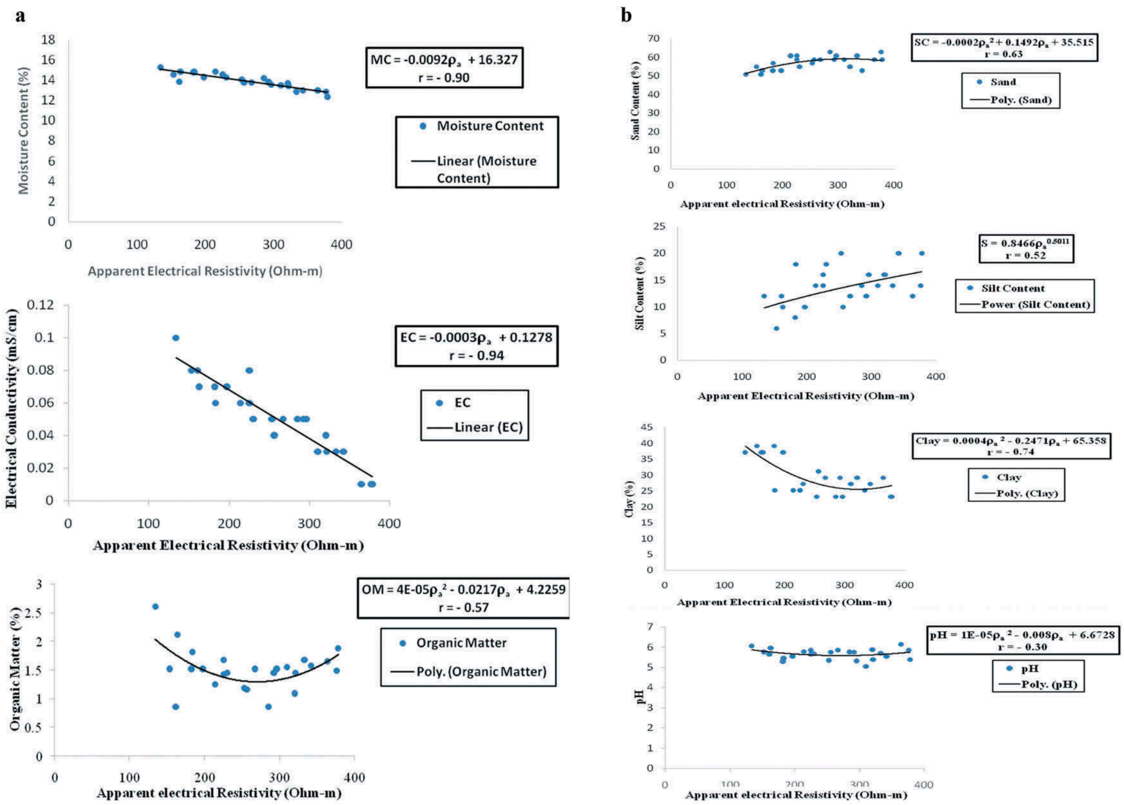

Figure 11. Cross plots between soil properties and apparent electrical resistivity measurement.

Table 6. Simple correlation coefficient between ER and soil properties.

Soil properties	Apparent electrical resistivity (r)
MC	−0.90[a]
EC	−0.94[a]
OM	0.57[b]
% Sand	0.63[b]
% Silt	n.s
% Clay	0.74[a]
pH	n.s

[a]Correlation is significant at $P < 0.01$ level
[b]Correlation is significant at $P < 0.05$ level
n.s: non-significant.

$$\% \text{ Sand} = -0.0002\rho a^2 + 0.1492\rho a + 35.515 \quad (7)$$

$$\% \text{ Silt} = 0.8466\rho a^{0.5011} \quad (8)$$

$$\% \text{ Clay} = 0.0004\rho a^2 - 0.2471\rho a + 65.358 \quad (9)$$

$$\text{pH} = 1\text{E} - 05\rho a^2 - 0.008\rho a + 6.6728 \quad (10)$$

11. Validation of models

A 5 m by 14 m arable plot of land was chosen within the same environment. The arable land was partition into cells of 2 m by 2 m. Resistivity measurement and soil sampling were conducted at the midpoint of corresponding cells. The apparent resistivity values obtained were computed into the empirical models generated from the regression analysis (Equations (4)–(10)). Corwin *et al*, 2013 relates the observed and predicted cotton yield using a linear regression analysis. This informed the use of a linear regression for the validation of the results. The predicted results were compared to the observed results obtained from the laboratory analysis of the soil samples using linear regression. This will inform us about the reliability of the derived empirical models.

Figures 12(a) and 12(b) suggests that the estimated regression relationship has been reasonably successful at reproducing the predicted yield estimates with coefficient of correlation *r* value of

0.94, 0.93, 0.78, 0.79, 0.94, 0.54, and 0.48 for MC, EC, OM, % Sand, % Silt, % Clay and PH respectively.

12. Conclusion

The study have successfully showed that apparent electrical resistivity measurements could be used as a rapid means of obtaining the selected topsoil properties. The cross plots gave a trend line coefficient of correlation (r) of 0.90, 0.94, 0.57, 0.63, 0.52 and 0.74 for MC, EC, OM, % Sand, % silt and % clay content, respectively, and a fair correlation between pH and apparent resistivity (ρa) with coefficient of correlation (r) of 0.30. Validation of the results for MC, OC, OM,

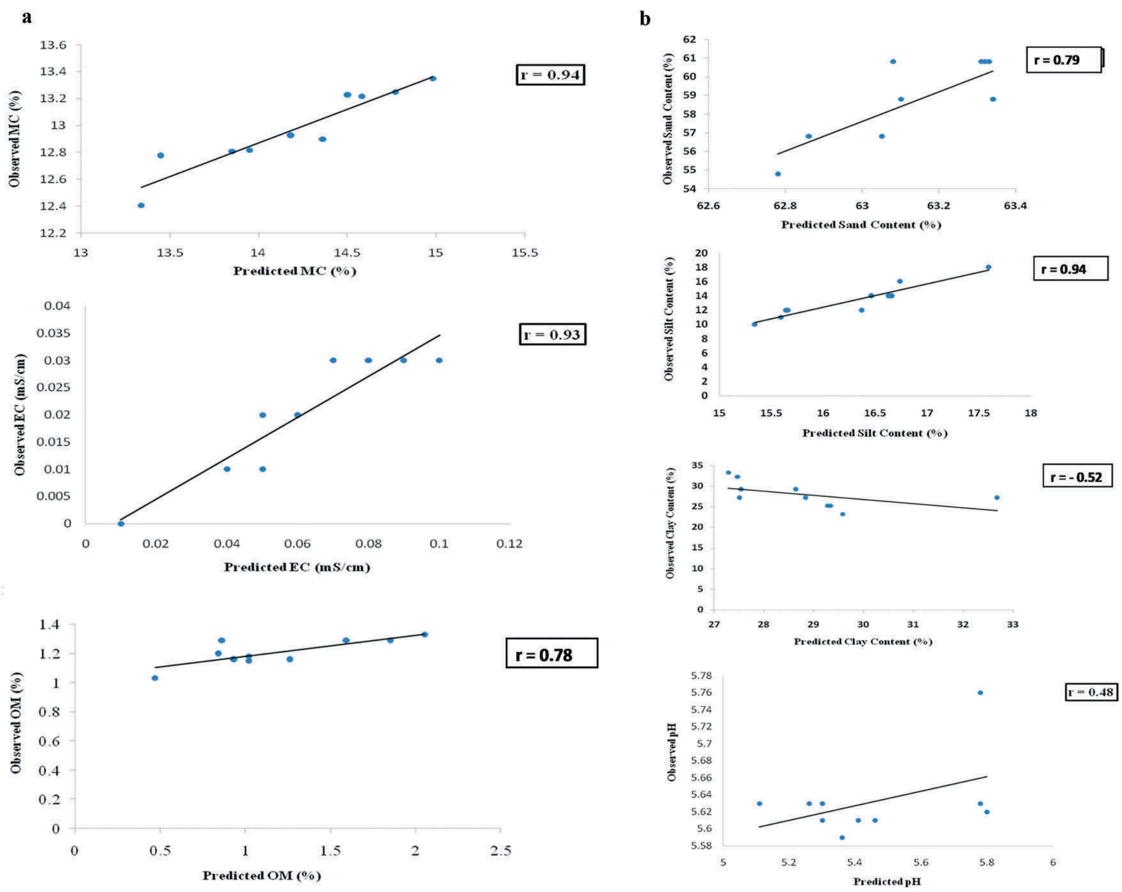

Figure 12. Cross plots between observed and predicted soil properties.

% Sand, % Silt, % Clay and PH, shows that the estimated regression relationship has been reasonably successful at reproducing the predicted yield estimate with an "r" value of 0.94, 0.72, 0.78, 0.79, 0.52, 0.93, 0.94 and 0.48 respectively.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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