Relationship between *in-situ* spatial soil resistivity and selected soil physical properties

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**ABSTRACT**

Statistical and spatial approaches have been used to determine the relationship between *in-situ* resistivity, soil moisture content and pH. These are done to establish the extent to which resistivity measurements can be used in mapping selected soil properties. Soil resistivity measurements were taken via a Wenner array platform having an electrode spacing of 8 cm. Soil samples were taken at 0–3 cm depth. The samples were analysed for moisture content and pH. Clayey sand and sand textural classes were deduced from resistivity values (210–750 ohm-m and >750 ohm-m respectively). Moisture content values were classified in conjunction with texture as unavailable water (UW) and available water (AW). pH values were classified as moderately acidic (5.2 – 6.0), slightly acidic (6.1 – 6.5) and neutral (6.6 – 6.9). A moderate inverse relationship was observed between resistivity and moisture content. The spatial correlation between resistivity-derived textural classes and moisture content classes was 62%. Resistivity was also found to be inversely correlated with pH. Spatially, higher resistivity zones were abundantly associated with moderately acidic pH zones, while lower resistivities correlated with slightly acidic to neutral pH zones – thereby bringing the spatial association between resistivity and pH to 60%. The pilot/plot-scale study concluded that to a satisfactory extent, *in-situ* soil resistivity measurements can be adopted as a complimentary tool for selected soil properties mapping.

**Keywords:** *in-situ* resistivity, moisture content, pH, spatial association, mapping.

**INTRODUCTION**

The soil is inherently variable in its physical, chemical and biological properties that determine crop yield potential. To achieve sustainable agriculture, precision farming which ensures efficient use of resources is needed. Precision farming involves accurate measurement of within field variations in soil physico-chemical properties through efficient methods.

Geophysical methods have been adopted as valuable tools in precision farming. They have assisted farmers in making informed decisions on “what to plant where, and when to plant what” on their farmlands. The electromagnetic induction (EMI) method has been used in mapping pesticide penetration coefficients ($K_d$) (Jaynes et al. 1994). Soils have been characterised from electrical...
conductivity mapping and in-situ resistivity measurements (Johnson et al. 2001; Pozdnyakova et al. 2004; Eluwole et al. 2018). Corwin et al. (2003) delineated site-specific management units from electrical conductivity (EC)-directed soil sampling approach. Continuous measurement of near-surface water dynamics are also possible (Serbin and Or 2004; Gish et al. 2005). The advantages of geophysical methods in precision farming cannot be overemphasised. They have been found to be efficient in delineating soil variability in less laborious, non-invasive and relatively inexpensive manner compared to traditional sampling methods.

The soils of Ekiti State, Nigeria (the study area) have been evaluated, characterised and classified using the traditional pedological methods of taking disturbed samples and analysing the same (Ogunkunle 1988; Shittu and Fasina 2004; Fasina and Adeyanju 2007; Fasina et al. 2009; Fasina 2013; Ogunkunle 2009). The complimentary potential of in-situ, non-invasive, relatively fast and cost effective geophysical measurements in soil mapping, land quality assessment and management have not been adequately embraced in the study area. This study was conducted to determine the relationship between in-situ soil electrical resistivity, moisture content and pH. Moisture content and pH are considered to be extremely important indices for establishing the relationship between the way a soil behaves and the availability of nutrients (Jones and Jacobsen 2001; Reddy 2002; and McCauley et al. 2005). This was with a view to establishing the extent to which in-situ resistivity can be adopted as an index for the determination of selected soil properties so as to serve as a fast guide in farmers’ decision making.

MATERIALS AND METHODS

Location
This study was conducted on a 676-m² arable plot of land in the Teaching and Research farm of the Ekiti State University, Ado-Ekiti, South-western Nigeria (7° 42′ 40″ N and 5° 14′ 53″ E). Soils at this site, according to the Soils Science Division Staff (2017) textural triangle, are sandy loam and loamy sand (Eluwole et al. 2018). Both soils are members of the Iwo Association (Smyth and Montgomery 1962) (Figure 1). Under the FAO-UNESCO (1988) classification, the Iwo Association is equivalent to the Plinthic Luvisol classification (Fagbami and Shogunle 1995).

Measurements
In-situ soil resistivity measurements were taken on a 1 – by – 1 m grid at 729 stations (Figure 2) with the aid of a calibrated four-electrode Wenner array platform (Plate 1). The platform is made up of two outer electrodes (C1 and C2) through which current is sent into the soil; and two inner electrodes (P1 and P2) from which potential difference arising from the transmitted current is measured via the Ohmega resistivity meter. A similar arrangement has been reported by Pozdnyakova et al. (2004). The depth of probe of the array is a
Figure 1. Location and soil association map of the area around the study area (adapted from Smyth and Montgomery (1962)).

Plate 1. The Wenner Array platform
function of the soil type and the distances between the electrodes (known as geometry). The depth of interest of this study was the topmost (0–3 cm thickness) of the topsoil described by Eluwole et al. (2018) as the surface layer – the so-called O-horizon in agricultural parlance. A constant electrode spacing of 8 cm was adopted. Eighty-one (81) sampling locations were distributed with a spacing of 3 m (Figure 2). Soil samples were also taken at 0–3 cm depth on the same day of resistivity measurements and under the same climatic conditions – more importantly 24 h after rainfall in order to establish Field Capacity (FC). Soil samples were analysed for moisture content and pH using the gravimetric method (Black, 1965) and glass electrode pH meter respectively.

Data Analysis
Electrical resistivity values obtained from stations parametric to soil sample stations were compared with measured soil properties through cross plots, cross-tabulations and spatial pattern inspection. The resistivity, moisture content and pH data were classified using relevant tables and charts from Eluwole et al. (2018) (Figure 4), Gurevitch et al. (2002) (Figure 5) and Horneck et al. (2011) (Table 1).

RESULTS AND DISCUSSION

Resistivity Classification
Eluwole et al. (2018) have classified the soils of the topmost layer (O-horizon) of the site in terms of resistivity as clayey sand (210–750 ohm-m) and sand (>750 ohm-m) (Figure 3). The figure shows that about 60% of the study area is underlain by sandy soils, while the remaining 40% is underlain by clayey sand.
Moisture Content Classification
The chart presented in Figure 4 formed the basis for the classification of the moisture content of the O-horizon. Field capacity is the amount of water remaining in the soil after all gravitation water has drained. The amount of capillary water that is available to plants is the soil’s available water (AW) and the point at which there is no water for plant uptake is referred to as the unavailable water (UW).
The moisture content obtained from the 81 soil samples collected from the surface layer of the pilot plot varied between 4.11% and 12.6% (Figure 5). Zones characterised by relatively low moisture content (ranging between 4.1% and 7.3%) belong to the unavailable water (UW) class and they are present around the north-eastern, southern and the north-western/western parts of the pilot plot. The other class which covers about 62% of the pilot plot represents areas with moisture contents greater than 7.3%, and is classified as available water (AW) areas.

\[ \text{Figure 5. Soil moisture content map} \]

**pH Classification**
Soil pH expresses soil acidity and most crops grow best when the soil pH is between 6.0 and 8.2 (Horneck et al. 2011).

The pH obtained from the soil samples ranged between 5.1 and 6.9. Based on the pH classification in Table 1, the pH characteristics of the soils of the pilot plot falls within the moderately to slightly acidic and neutral pH categories (Figure 6). The moderately acidic category dominates the layer, having 61% coverage, while the slightly acidic category has 36.6% coverage. On the other hand, the neutral pH category which covers the remaining 2.4% manifests itself around the south-western region of the pilot plot.
Resistivity Versus Moisture Content

Regression Analysis: The cross-plot graph of resistivity and moisture content (Figure 7) shows that an inverse relationship exists between soil resistivity and moisture content. The coefficient of correlation (r) of 0.33 is an indication of

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5.1</td>
<td>Strongly acidic</td>
</tr>
<tr>
<td>5.2 – 6.0</td>
<td>Moderately acidic</td>
</tr>
<tr>
<td>6.1 – 6.5</td>
<td>Slightly acidic</td>
</tr>
<tr>
<td>6.6 – 7.3</td>
<td>Neutral</td>
</tr>
<tr>
<td>7.4 – 8.4</td>
<td>Moderately alkaline</td>
</tr>
<tr>
<td>&gt; 8.5</td>
<td>Strongly alkaline</td>
</tr>
</tbody>
</table>

Figure 6. Soil pH map Comparative Analyses

Horneck et al. 2011
a moderate relationship between the two variables. The regression curve which shows that soil resistivity increases with a decrease in moisture satisfies the empirical equation of Archie (1942) which indicates that resistivity of rocks decreases with increasing water saturation.

![Figure 7. Linear regression analysis on soil resistivity and moisture content](image)

**Cross-tabulation and Chi-square Tests:** The cross-tabulation report (Tables 2a and b) describes the relationship between soil moisture content and resistivity in terms of resistivity-derived soil classification. The percentage occurrence of the available water-moisture content regime within the clayey sand and sand resistivity-derived soil classes is 33.3% and 29.6% respectively. It can therefore be inferred that a greater percentage of the zones within the available water-moisture content regime falls within the clayey sand which is characterised by lower resistivity values.

On the other hand, comparing the percentage occurrence ratio (12.3:24.7%) of the unavailable water-moisture class within the clayey sand and sand soil classes, it is evident that the unavailable water has greater association with the sand soil class. In Table 2b, the significance probability of 0.087, which is not too distant from the 0.05 standard significance level portrays the possibility of a moderately statistically significant relationship between soil moisture content and resistivity.

**Spatial Pattern Analysis:** The relationship between the spatial distribution of soil moisture content classes and resistivity-derived soil classes was assessed from the spatial association map of soil moisture content and resistivity (Figure 8). The black colored portion on the spatial association map represents areas where moisture content classes are inversely related to resistivity-derived soil classes. The areas account for 62% of the entire plot, while the remaining 38% with no color are areas where there are no spatial relationships between soil moisture content and resistivity.

The spatial association map was used to evolve a composite map (Figure 9) that was partitioned based on the relationships between moisture content
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<table>
<thead>
<tr>
<th>Moisture content classification</th>
<th>AW</th>
<th>UW</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>27</td>
<td>10</td>
<td>37</td>
</tr>
<tr>
<td>% of total</td>
<td>33.3%</td>
<td>12.3%</td>
<td>45.7%</td>
</tr>
<tr>
<td>Total</td>
<td>Clayey sand</td>
<td>Sand</td>
<td>51</td>
</tr>
<tr>
<td>% of total</td>
<td>63.0%</td>
<td>37.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

* AW = Available water, UW = Unavailable water

TABLE 2b
Chi-square and symmetric measures

<table>
<thead>
<tr>
<th>Value</th>
<th>Significance probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-square</td>
<td>2.927</td>
</tr>
<tr>
<td>Phi</td>
<td>0.20</td>
</tr>
<tr>
<td>No. of samples</td>
<td>81</td>
</tr>
</tbody>
</table>

Figure 8. Spatial pattern association map of moisture content and resistivity-derived soil classes.
classes and soil resistivity. The areas identified by stars on the composite map depicts areas within the unavailable water class that are characterised by the resistivity-derived sand soil class which is associated with higher resistivities. The black colored areas describe the zones having available water; these zones are also associated with lower resistivities, in the range of the clayey sand soil category. Areas covered by the white colour are areas where the relationship between moisture content and resistivity is overlapping. In such areas, high moisture content does not necessarily translate to lower resistivity, and neither does low moisture content translate to higher resistivity.

**Resistivity Versus pH**

Regression Analysis: The weak coefficient of correlation of 0.22 depicts a poor relationship between resistivity and soil pH (Figure 10). The regression trend shows that both parameters are inversely correlated, i.e. soil acidity increases with increasing resistivity but tends towards neutrality when the resistivity reduces. Murad (2012) reported that soils within the acidic pH range have coarse sand particles as their main constituents and are characterised by high resistivity.
Cross-tabulation and Chi-square Tests: The cross-tabulation results of the comparison of surface layer pH and resistivity presented in Table 3a show that 53.1% of the resistivity data are characterised by the moderately acidic pH category. The percentage ratio of this pH category within the clayey sand and sand resistivity-derived soil types is 19.8:33.3%. The neutral pH category is only present within the clayey sand, while the slightly acidic pH category, which represents 42% of the sample data, is present within the clayey sand and sand resistivity-derived soil types in equal proportions. The high occurrence of the moderately acidic pH category (characterised by pH values of between 5.2 and 6.0) within sand, and the association of the neutral pH category with clayey sand only, further explains the inverse relationship between pH and resistivity. The equal distribution of the slightly acidic pH within the clayey sand and sand soil types may have been a result of the overlapping resistivity phenomenon. The chi-square value of 6.26 and a significance probability of 0.044 (4.4%) which is significant at the conventional cut-off of 5% can be regarded as evidence that there is an association between soil pH and resistivity (Table 3b).

![Linear regression analysis on resistivity and pH](image)

Figure 10. Linear regression analysis on resistivity and pH

Spatial Pattern Analysis: The spatial association map of soil pH and resistivity (Figure 11) shows that soil pH is related to resistivity to an extent of about 60%, owing to the coverage of the spatial association indicated by the shaded portions. Areas where there are no distinct relationships between soil pH and resistivity constitute the white colour band. Areas under identified by square patterns on the composite map (Figure 12) fall within the neutral pH category and are characterised by clayey sand. The shaded portions having star patterns are
characteristic of the slightly acidic/clayey sand category, while the moderately acidic/sand category is the shaded portion without patterns.

**TABLE 3a**
Cross-tabulation of surface layer pH and resistivity-derived soil classification

<table>
<thead>
<tr>
<th>pH category</th>
<th>Resistivity-derived soil classification</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clayey sand</td>
<td>Sand</td>
</tr>
<tr>
<td>MA</td>
<td>Count</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>% of total</td>
<td>19.8%</td>
</tr>
<tr>
<td>SA</td>
<td>Count</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>% of total</td>
<td>21.0%</td>
</tr>
<tr>
<td>N</td>
<td>Count</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>% of total</td>
<td>4.9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>Count</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>% of total</td>
<td>45.7%</td>
</tr>
</tbody>
</table>

MA = Moderately acidic  
SA = Slightly acidic,  N = Neutral

**Figure 11. Spatial pattern association map of pH and resistivity-derived soil classes**
CONCLUSIONS

The soils were classified in terms of resistivity as clayey sand and sand with a resistivity range of 210 – 750 ohm-m and > 750 ohm-m respectively. Moisture content varied between 4.11 and 12.6%. Using an appropriate chart, moisture content values were classified in terms of their relationships with soil texture as AW and UW. The pH ranged between 5.1 and 6.9 and the values were classified as moderately acidic, slightly acidic and neutral. The regression analysis of moisture content and resistivity indicated that there was a moderate inverse relationship between resistivity and moisture content owing to a coefficient of correlation \( r \) of 0.33.

The significance probability of 0.087 obtained from the chi-square tests showed that a moderately statistically significant relationship existed between resistivity and moisture content. The extent of spatial association of resistivity and moisture content was estimated to be about 62%.

Resistivity was also compared with pH. The regression analysis carried out on resistivity and pH showed that resistivity varied inversely with pH. The relationship was, however, weak, based on the low (0.22) coefficient of correlation. The chi-square tests however portrayed a statistically significant relationship between resistivity and pH, because of the significance of probability of 0.044. Also a spatial pattern association of about 60% was estimated for resistivity and pH classes. This pilot/plot scale study has demonstrated that to a satisfactory extent, in-situ soil resistivity can be considered as a relevant index in
estimating soil properties such as moisture content and pH. The study showed that in its present scale, it can only serve as a complimentary tool to conventional soil measurements.

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