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# Relationship between Forest Structure and Soil Properties in Bagale Forest Reserve in North Eastern Nigeria

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## ABSTRACT

*An extensive soil survey with assessment of growth and yield of trees in Bagale forest Reserve in North East Nigeria is conducted. Five fragments within five altitudes are selected using LANDSAT ETM+ satellite imagery from Google earth. Composite soil samples are collected from 0-20cm and 20-40cm depths in the fragments and their physico-chemical analysis is done in the laboratory. Height, DBH, Volume, Basal area and crown area of trees are assessed in the quadrats, and laid in the fragments. Using Pearson's correlation coefficient, correlation matrix are derived from the relationship between soil properties and forest structure. At both, surface and sub-surface depths, negative relationships are recorded between forest structure and soil physical and chemical properties. Based on the in-depth analysis of the study, it is therefore, concluded that salinization is not a significant pedogenic process in the soil and the soil does not contain a concentration of soluble salt that may hamper the growth of plant.*

**Keywords:** *Forest structure, soil properties, fragments, forest reserve, soil properties*

## INTRODUCTION

Vegetation can affect soil properties as well as show preferences for specific edaphic site characteristics, hence establishing causal relationships is difficult (Sollins, 1998). Some authors (Salo *et al.*, 1986, Duivenvoorden 1996, Laurance *et al.*, 1999, Clark, D. B., Plamer and Clark D. A, 1999, Harms, Condit, Hubbel and Foster 2014; Pyke, Condit, Aguilar and Lao, 2001, Daque, Sanchez, Cavelier and Duivenvoorden 2002, Svenning, Kinner, Stallard, Engelbrecht and Wright 2004, and Valencia *et al.*, 2004) have opined that soil class, soil texture, flooding regime, slope angle, precipitation gradients and topography have all been found to covary with patterns in vegetation distribution. Forest structure is a driving factor behind forests growth processes (Dobbertin, 2005, Pommerening 2006; Ruprecht *et al.*, 2009). A quantitative description of forest structure could be useful for a wide range of applications in modern

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forest management and biodiversity research (Ruprecht *et al.*, 2009). The structural attributes of forest stands are increasingly of theoretical and practical importance in the understanding and management of forest ecosystems. This is because structure is the attribute most often manipulated to achieve management objectives following the establishment of a forest stand (Franklin, Spies, Pelt, Carey, Thornburgh *et al.*, 2002). Therefore, a study of the relationship between forest structure and soil status of a forest reserve is very crucial for the purpose of forest management, planning and policy formulation.

## METHOD

***Study Location and Site Selection:*** Bagale Forest Reserve is an old reserve constituted in 1954, located within latitude $9^0$11'N and longitude $12^0$20'E in North East Nigeria (Fig 1) with a total area of about 18,000 hectares.

Figure 1: the Study Area
*Produce @ GIS Laboratory, Geography Department MAUTECH Yola 2018*

***Fig. 1: Study Area***

The geology of the area is dominated by Bima sandstone and consists of fine sand, clayish sand, silt, ironstone and alluvium deposit. The flood plain along the river Benue is subject to erosion during high flooding in the rainy or wet season. The most dominant colour of soil is reddish dark brown with variation of brown to reddish brown, according to Department of Soil Science (MAUTECH, 2018). The area experiences two distinct seasons, the rainy which starts from April and ends in October, and a long dry season which extends from November to March. It records minimum and maximum rainfalls of 0.4 and 47.55mm respectively and a total rainfall of about 1030mm per annum (MAUTECH, 2018). The physiography of the reserve is typically undulating, generally of flat plan and steep to gentle slope surface. The most important landforms are small mountains and flood plains along the River Benue. The lowland is about 100m and the highland rises to an altitude of about 700 meters above sea level (Adebayo, 1999). A contour map (Fig. 2) and the cross section of the study area (Fig. 3) running from the South-West to the North East were produced as adopted by Cayuela *et al.*, (2006b). Elevation above sea level and the distance between plots were measured using a Garmain GPS.

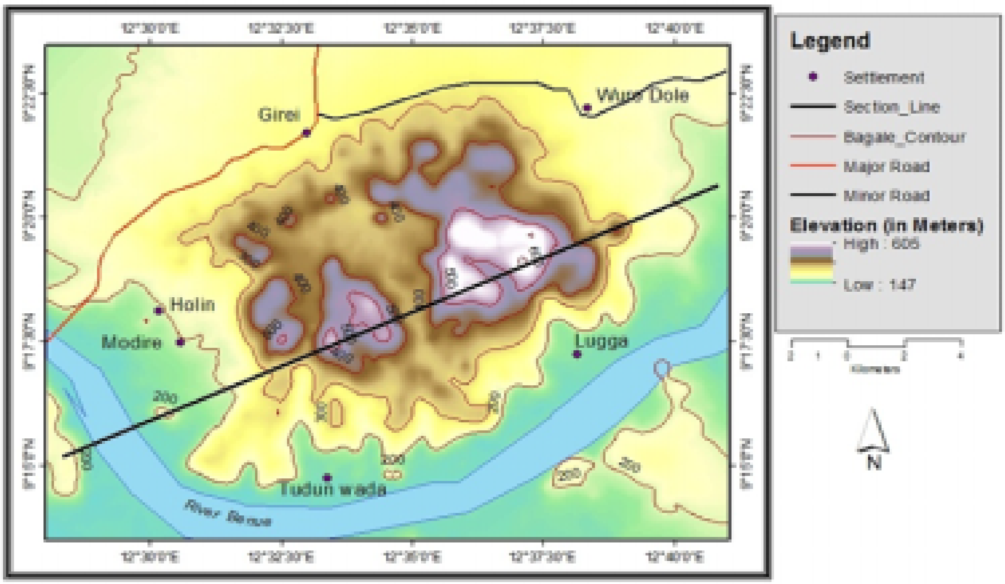


***Fig. 2: Contour of the Study Area***

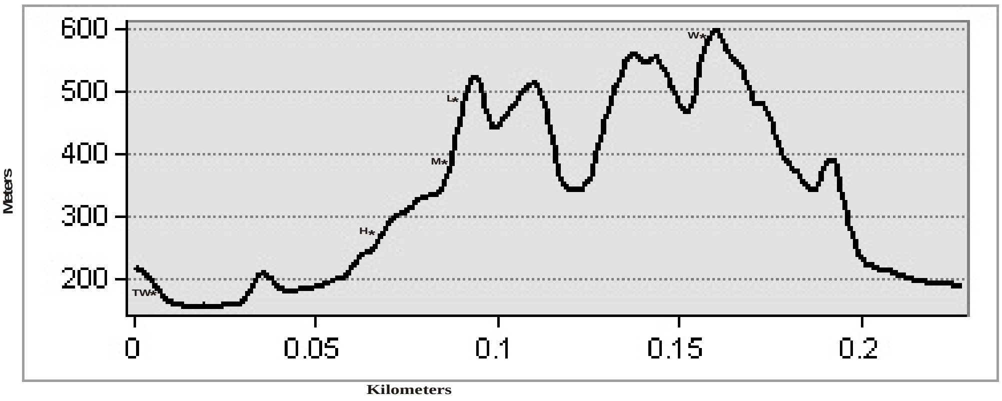


Fig. 3: The Cross Section of Bagale Forest Reserve along a section line from SW to NE
T/W = Tudan Wada, H=Holin, M=Modire, L=Lugga, W=Wurodole

***Source:*** Department of Geography, MAUTECH, Yola (2018).

## Procedure for Data Collection

In this study, the quantitative indicators of major forest parameters are correlated with various soil factors to establish a relationship between variables. However, the relationship between soil properties in the forest fragments of this reserve and forest structure has not been assessed. Five fragments were selected and sampled within the altitudes, and this included Tudun Wada (<200masl), Holin (200-300masl), Modire (300-400masl), Lugga (400-500) and Wurodole (>500masl). One profile pit each of 120cm depth was dug in each fragment to reveal and describe the three horizons in each pit. Composite soil samples were collected from four points each in each fragment at 0-29cn and 20-40cm, put in air tight containers and taken to the laboratory for physio-chemical analysis. Physical properties analysed in soils from the two depths included, sand (%), clay (%), silt (%), texture (%), partied density (%), bulk density (%), porosity (%). Chemical properties analysed in both surfaces included, pH (1:1), $H_2O$, Electrical conductivity ($M_3m^{-1}$), organic carborn (gm/kg$^{-1}$), organic matter (gm/kg$^{-1}$), sodium (cmol,kg$^{-1}$), Total Exchangeable Base (gm/kg$^{-1}$), Total Exchangeable Acid (gmkg$^{-1}$), Effective Cation Exchange Capacity (cmol, kg$^{-1}$) and Percentage Base Saturation.

## Measurement of growth parameters of trees

**Tree height:** Clihometer was used to measure tree heights using the formular;
X = Y tan A+Z
Where X = tree height
Y = distance from tree to the observer
A = angle of elevation
Z = height of the observer at eye level (Gareth, 1991).

**Tree girth:** Individual tree circumference at 1.35 metres breadst height (in metres) using a measuring tape (Eyre and Neldner, 2006).

Crown area was calculated using $\frac{(D1+D2)^2}{4\pi}$ x $\frac{100}{1}$ (Eyre, 2006).

**Basal area:** This was determined after Wratten and Fry (1980) using

Basal area = $\frac{c^2}{4\pi r}$

Where C = girth six (diameter at breadth height)

$$\pi = \frac{22}{7} = 3.14$$

**Volume:** Mean tree volume was estimated using the Newton's formula (Husch, Miller, and Beers, 1982).

$$V = \frac{H(A_b+4A_m}{6}$$

Where: V = Actual tree volume (over bark in $M^3$)
H = Tree height (metres)
$A_b$ = Cross-sectional area at the base of the tree ($m^2$)
$A_m$ = Cross-sectional area at the middle of the tree ($m^2$)
$A_n$ = Cross-sectional area at the top of the three ($m^2$)

**Crown Ratio:** This was estimated by dividing crown diameter of each tree by height (Written and Fry, 1980).

**Data Analysis:** Pearson's correlation coefficient and rating of the relationship between tree growth parameters and soils for each fragment were carried out. Microsoft Excel was used to run the analysis. The formula, according to Legendre and Blanchet (2008) used was:

$$\rho_{xy} = \frac{E(XY) - E(X)E(Y)}{\sqrt{E(X^2) - E(X)^2}\sqrt{E(Y^2) - E(Y)^2}}$$

Where ñ = expectation
X and Y = variables to be correlated

## RESULTS AND DISCUSSION

Tables 1, 2, and 3 show the result of correlations between forest structure and soil chemical properties at 0-20cm horizon. Height had no significant (pe”0.05) relationship between organic carbon (.73), Ca (.0.2), Mg (.87), total exchangeable base (.15), total exchangeable acidity (.32), effective cation exchange capacity (.42), but had negative relationship with pH (.39), electrical conductivity (.05), available phosphorus (.37), potassium (.04), sodium (.18), and phosphorus (.13). DBH had negative correlations with pH (-.38), electrical conductivity (.05), potassium (.05), sodium (.17) and phosphorus (.11), other elements, organic carbon (.73), organic matter (.73), total nitrogen (.73), Ca (.03), Mg (.87), total exchangeable base (.16), total exchangeable acidity and effective cation exchange capacity (.41) had no significant (pe”0.05) relationship.

Volume had negative relationship with pH (.36), electrical conductivity (.05), potassium (.06), sodium (.17), phosphorus (.07), and had no significant (pd”0.05) relationship with organic carbon (.72), organic matter (.72), total nitrogen (.72), available phosphorus (.39), calcium (.05), magnesium (.84), total exchangeable base (.17), total exchangeable acidity (.26) and effective cation exchangeable capacity (.38).

HH Basal area had negative relationships with pH (.37), electrical conductivity (.05), available phosphorus (.39), potassium (.06), sodium (.17) and phosphorus (.08) and had no significant (pd"0.05) relationship with organic carbon (.73), organic matter (.73), total nitrogen (.73), calcium (.05), magnesium (.85), total exchangeable base (.17), total exchangeable acidity (.27), effective cation exchange capacity (.39). Crown area had negative relationships with pH (.40)n, electrical conductivity (.05), potassium (.04), sodium (.18), and phosphorus (.14), while it had no significant (pe"0.05) relationship with organic carbon (.72), organic matter (.72), total nitrogen (.72), calcium (.02), total exchangeable base (.15), total exchangeable acid (.33) and effective cation exchange capacity (.43). It had a significant (pe"0.05) correlation with magnesium (.88). pH had negative correlations with height (.39), DBH (.38), volume (.37), basal area (.37), crown area (.40). Electrical conductivity had negative relationship with height (.05), DBH (.05), volume (.05), basal area (.05), crown area (.05). Organic carbon had no significant (pe"0.05) relationship with pH (.73), DBH (.73), volume (.72), basal area (.73), crown area (.72). Organic matter had no significant (pe"0.05) relationship with pH (.73), DBH (.73), volume (.74), basal area (.73) and crown area (.73). Total nitrogen had no significant (pe"0.05) relationship with height (.73), DBH (.73), volume (.72), basal area (.72), crown area (.72). Available phosphorus had negative relationship with height (.37), DBH (.37), volume (.39), basal area (.39), crown area (.36). Calcium had no significant (pe"0.05) relationship with height (.02), DBH (.03), volume (.05), basal area (.05), crown area (.02)

Magnesium had no significant (pe"0.05) relationship with height (.87), DBH (.87), volume (.84), basal area (.85) but is highly significant ($p<0.01$) with crown area (.88). Potassium had negative relationships with height (.04), DBH (.05), volume (.06), basal area (.06), crown area (.04). Sodium had negative relationship to height (.18), DBH (.17), volume (.17), basal area (.17), crown area (.18). Total exchangeable base was not significantly (pe"0.05) correlated with height (.15), DBH (.16), volume (.17), basal area (.17), crown area (.15). Total exchangeable acid was not significantly (pe"0.05) correlated with height (.32), DBH (.30), volume (.26), basal area (.27), crown area (.33). Effective cation exchange capacity was not significantly (pe"0.05) correlated with height (.42), DBH (.41), volume (.38), basal area (.39), crown area (.43). Phosphorus had a negative relationship with height (.13), DBH (.11), volume (.07), basal area (.08) and crown area (.14).

Two major relationships in the study area are revealed – negative and positive associations between Forest Structure and the soil elements. Sand, texture and bulk density had negative relationships with forest structure, while clay, porosity, had relatively strong positive relationship with height, DBH, volume and basal area. Height, DBH volume, basal area and crown area had negative relationship with pH, electrical conductivity, phosphorus, Na, available phosphorus and K but positive correlations with organic carbon, organic matter, total nitrogen, Calcium, Magnessium, total exchangable base, total exchangable acidity. The positive relationship observed between organic carbon, height, DBH, volume, basal area and crown area in both horizons agree with the findings of Eche *et al.* (2013), who record similar results in GIS research in a similar ecological zone. However, negative correlation observed between phosphorus and height, DBH, volume basal area and crown area does not agree with the findings of Eche *et al.,* (2013). The negative association between pH and height, DBH, volume, basal area and crown area; EC and height, DBH, volume, basal area, crown area; K and height, DBH, volume, basal area and crown area; phosphorus and height, DBH, Volume, basal area and crown area does not agree with the findings of Olujobi (2016) who records positive associations between these elements and three selected multipurpose tree species – *Senna siamea Gliricida sepum* and *Leucenea leucocephala* at the 0 – 15cm and 15 – 30cm horizons. The observed improvement in texture from loamy sand to sandy loam could be attributed to the increase in silt level, which probably resulted from the formation and addition of humus from the decomposed high quality litter from agroforestry species, Olujobi (2016). The findings of Jimoh *et al.* (2016) who used the USDA soil taxonomy classification and World Reference Base (2014) in soil mapping of the soils of Gabari district, Zaria Northern Guinea Savanna zone which is in a similar agro ecological zone as the study area, agree to a greater extent with results from the study area.

Base saturation in the study area ranged between 37.33 – 80% which according to FAO (1999), soils with base saturation >50% are regarded as fertile, while soils <50% are regarded as not fertile. Hence, the soils in the study area could not really be described as fertile. The electrical conductivity (EC) of the soils was rated very low. The EC value of the soil was rated very low (<4dsm$^{-1}$), agreeing with the very low EC of the study which ranged between 0.06 – 0.10dsm$^{-1}$). This indicates none saline electrical conductivity class. Similar result was also reported by Maniyunda and Gwari (2014) in Northern Guinea Savanna. These imply that salinization is not a significant pedogenic process in the soil and the soil does not contain a concentration of soluble salt that may hamper the growth of plant, Maniyunda and Gwani (2014). Based on this, therefore, the soils are generally not fertile. Cation exchange capacity of the soils is generally low according to Esu (1991) rating of < 6 low, 6-12 medium and > 12 high. The low CEC of the soils could be attributed to the nature of the clay minerals (kaolinite). (opuwaribo and Odu 1978); Juo and Moorman, 1981; Hassan *et al.,* 2011; Yakubu, (2006) opined that organic matter content of soils which normally influences the CEC is generally low and therefore the CEC values may not be attributed to the amount of organic matter.

## CONCLUSION AND RECOMMENDATIONS

This study was conducted to find out the relationship between forest structure and soil properties. Trees in sampled quadrats were assessed for volume, basal area, height, DBH and crown ratio, while the physico-chemical properties of the soil in these quadrats were analysed in the laboratory using Pearson's correlation coefficient, Microsoft Excel and SPSS. Results showed a preponderance of negative correlations between forest structure on one hand and soil properties on the other. The soil of this forest reserve is acidic and structurally weak.

The reserve will require adjustments and interventions to enhance its sustainability and development. There is need to educate the people especially those proximal to the reserve through extension programmes and capacity building to avoid illegal felling of trees and practice of harmful anthropogenic activities such as wrong farming techniques, bush burning which are detrimental to the soil and trees. This study could be used as a template to evaluate current edaphic status and performance of trees in other forest reserves in the sub-region.

**Table 1:** Correlation matrix of relationship between forest structure and soil properties at 20-40cm depth

| | **%Sand** | **%Clay** | **%Silt** | **%Tex** | **%PDg/cm$^3$** | **%BDg/cm$^3$** | **%POR** |
|---|---|---|---|---|---|---|---|
| Ht(m) | -.683 | .766 | .235 | -.596 | .425 | -.661 | .803 |
| DBH(m) | -.672 | .758 | .224 | -.590 | .435 | -.651 | .800 |
| VOL.(m$^3$) | -.651 | .743 | .201 | -.589 | .451 | -.628 | .791 |
| BA(m$^2$) | -.656 | .746 | .207 | -.587 | .448 | -.633 | .793 |
| CR | -.689 | .772 | .239 | -.597 | .422 | -.671 | .808 |

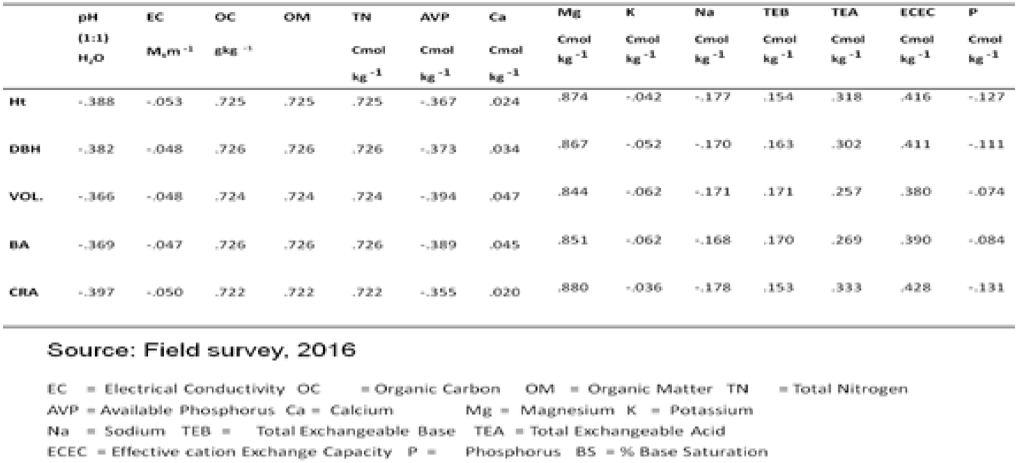
TEX=Texture Class, PD=Particle Density, BD=Bulk Density, POR=Porosity
***Source:*** Field Survey, 2016

**Table 2:** Correlation matrix of relationship between forest structure and soil physical properties at 0-20cm depth in the study area

| | **%Sand** | **%Clay** | **%Silt** | **%Tex** | **%PDg/cm$^3$** | **%BDg/cm$^3$** | **%POR** |
|---|---|---|---|---|---|---|---|
| Ht(m) | -.496 | .594 | .188 | -.390 | .274 | -.579 | .700 |
| DBH(m) | -.488 | .587 | .182 | -.380 | .274 | -.572 | .694 |
| VOL.(m$^3$) | -.471 | .559 | .182 | -.360 | .272 | -.541 | .668 |
| BA(m$^2$) | -.475 | .568 | .181 | -.365 | .272 | -.551 | .676 |
| CR | -.498 | .599 | .186 | -.394 | .279 | -.586 | .709 |

TEX=Texture Class, PD=Particle Density, BD=Bulk Density, POR=Porosity
***Source:*** Field Survey, 2016

**Table 3:** Correlation matrix of relationship between forest structure and soil chemical properties at 0-20cm depth

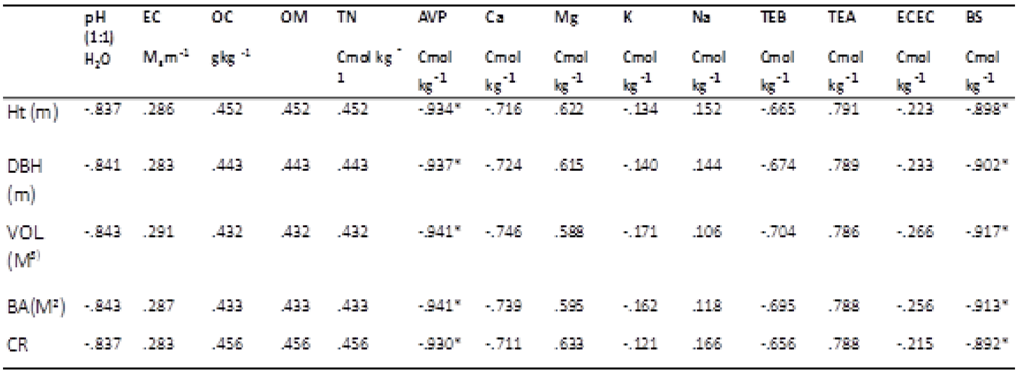


| | pH (1:1) $H_2O$ | EC $M_sm^{-1}$ | OC $gkg^{-1}$ | OM | TN Cmol $kg^{-1}$ | AVP Cmol $kg^{-1}$ | Ca Cmol $kg^{-1}$ | Mg Cmol $kg^{-1}$ | K Cmol $kg^{-1}$ | Na Cmol $kg^{-1}$ | TEB Cmol $kg^{-1}$ | TEA Cmol $kg^{-1}$ | ECEC Cmol $kg^{-1}$ | P Cmol $kg^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ht | -.388 | -.053 | .725 | .725 | .725 | -.367 | .024 | .874 | -.042 | -.177 | .154 | .318 | .416 | -.127 |
| DBH | -.382 | -.048 | .726 | .726 | .726 | -.373 | .034 | .867 | -.052 | -.170 | .163 | .302 | .411 | -.111 |
| VOL. | -.366 | -.048 | .724 | .724 | .724 | -.394 | .047 | .844 | -.062 | -.171 | .171 | .257 | .380 | -.074 |
| BA | -.369 | -.047 | .726 | .726 | .726 | -.389 | .045 | .851 | -.062 | -.168 | .170 | .269 | .390 | -.084 |
| CRA | -.397 | -.050 | .722 | .722 | .722 | -.355 | .020 | .880 | -.036 | -.178 | .153 | .333 | .428 | -.131 |

Source: Field survey, 2016

EC = Electrical Conductivity OC = Organic Carbon OM = Organic Matter TN = Total Nitrogen
AVP = Available Phosphorus Ca = Calcium Mg = Magnesium K = Potassium
Na = Sodium TEB = Total Exchangeable Base TEA = Total Exchangeable Acid
ECEC = Effective cation Exchange Capacity P = Phosphorus BS = % Base Saturation

**Table 4:** Correlation matrix of relationship between forest structure and soil chemical properties at 20-40cm depth



| | pH (1:1) $H_2O$ | EC $M_sm^{-1}$ | OC $gkg^{-1}$ | OM | TN Cmol $kg^{-1}$ | AVP Cmol $kg^{-1}$ | Ca Cmol $kg^{-1}$ | Mg Cmol $kg^{-1}$ | K Cmol $kg^{-1}$ | Na Cmol $kg^{-1}$ | TEB Cmol $kg^{-1}$ | TEA Cmol $kg^{-1}$ | ECEC Cmol $kg^{-1}$ | BS Cmol $kg^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ht (m) | -.837 | .286 | .452 | .452 | .452 | -.934* | -.716 | .622 | -.134 | .152 | -.665 | .791 | -.223 | -.898* |
| DBH (m) | -.841 | .283 | .443 | .443 | .443 | -.937* | -.724 | .615 | -.140 | .144 | -.674 | .789 | -.233 | -.902* |
| VOL ($M^3$) | -.843 | .291 | .432 | .432 | .432 | -.941* | -.746 | .588 | -.171 | .106 | -.704 | .786 | -.266 | -.917* |
| BA($M^2$) | -.843 | .287 | .433 | .433 | .433 | -.941* | -.739 | .595 | -.162 | .118 | -.695 | .788 | -.256 | -.913* |
| CR | -.837 | .283 | .456 | .456 | .456 | -.930* | -.711 | .633 | -.121 | .166 | -.656 | .788 | -.215 | -.892* |

***Source:*** Field Survey, 2016

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