Nigerian
Journal of Soil and
Environmental Research

Nig. J. Soil & Env. Res. Vol. 17: 2018, 15 - 23
@ Department of Soil Science,
Faculty of Agriculture,
Ahmadu Bello University, Zaria, Nigeria

Relationship Between Bulk Density and Penetration Resistance of Alfisols in Northern Guinea Savanna of Nigeria

Abdulkadir, A.* and Christian, A. T.
Department of Soil Science, Faculty of Agriculture/Institute for Agricultural Research,
Ahmadu Bello University, Zaria, Nigeria.
****Corresponding author** (akadir762001@yahoo.com; aiabdulkadir@abu.edu.ng)

ABSTRACT

Bulk density and penetration resistence are two measures of soil compaction and root growth in agricultural land uses. Few studies exist to show the relationship between these two properties especially with respect to the effect of land use. This study attempts to establish a relationship between values of bulk density and penetration resistance (PR) of Alfisol under three different land uses (Jatropha plantation, cultivated land and bush fallow). The study was conducted at Institute for Agricultural Research farms in Samaru, Zaria. A field was used per land use and each of the field was divided into 3 sub-plots. Six (6) undisturbed soil cores (5cm x 5cm) samples were collected from 0-5 cm and 5-10 cm depth, i.e. from 3 points per sub-plot, giving a total of eighteen (18) soil core samples from each land use, and a total of 54 core samples from the three fields, for determination of bulk density. Six penetrometer readings were taken with a Cone Penetrometer close to the point (at approximately 4-5cm distance) where core samples were collected at the two soil depths per subplot per land use. Both sampling and measurements were conducted at two soil depths (0-5cm and 5-10 cm). Soil samples were collected and made into composite sample for each land use for routine analysis. Microsoft Excel (2010) was used to develop polynomial regression relationship between penetration resistance value (in MPa) and transformed bulk density (Mg m^{-3}) data. Gravimetric soil moisture at measurement ranged from 25 to 30%. Bulk density differed statistically ($p<0.0001$) between all the land uses and increased with increase in soil depth. Jatropha plantation had the highest bulk density of 1.72 Mg m^{-3}, followed by continuously cultivated land (1.63 Mg m^{-3}) and least was in fallow land (1.55 Mg m^{-3}). Similarly, penetration resistance was highest in Jatropha field (1.96 MPa) but which was statistically the same with fallow field (1.76 MPa), and both differ ($p<0.05$) from PR in cultivated field (1.06 MPa). Penetration resistance also increased with soil depth. Polynomial regression coefficient (r^2) values between bulk density and measured penetration resistance was between 0.8695 and 0.9919. Regression coefficients were higher in fallow and cultivated soils than from Jatropha soils, indicating better relationship. Linear regression between measured and calculated penetration resistance had r^2 between 0.8953 and 0.9793 for the three land uses, but relationship was found to be higher in cultivated soils. This study provides an insight to the existing relationship between bulk density and penetration resistance by polynomial regression model and suggests the use of the value of the bulk density to approximate that of PR. However, further improvement and validation of proposed models is required for soils under other land uses and other agro-ecological zones.

Key words: Land uses, Alfisol, penetration resistance, bulk density, Polynomial regression.

INTRODUCTION

Bulk density and penetration resistance are two indices used in describing soil compaction which has consequence on root growth and crop production in general. The two properties are dynamic and often management induced. Land uses such as continuous cultivation with conventional tillage will likely have an adverse on Alfisols of the northern guinea savanna of Nigeria as result of its weak structures liable to compact easily (Ogunwole *et al*., 2001). Practices such as overgrazing of pasture and the use of heavy machinery are known to increase the compaction of top soil (Lal, 1986). Knowledge of the relationship that exist between bulk density and penetration resistance will lead to a better understanding of these indices of soil compaction for the design of appropriate management options.

Soils of the Nigerian savanna are characterized with poor structure, poor infiltration capacity and liable to easily compact or form crusts (Ogunwole *et al*., 2001). Soils under different land uses affect soil physical properties especially the dynamic properties that are management induced. Determination of soil compaction is often focused on measuring bulk density due to the easy method and availability of measurement devices. Less focus is given to penetration resistance which has a direct implication of root growth and movement. Measurement of penetration resistance often requires the use of a penetrometer which gives a measure of the direct energy that a plant root must exert to move freely in the soil or resistance to grow due to high compaction energy. Current knowledge of the soil's resistance to penetration of penetrometers are 3 times a factor more of the force which the root must exert to penetrate the same soil (Benghough and Mullins, 1990), making the understanding of penetration resistance crucial in crop production.

Soil condition is affected by different land use systems. Systems under continuous cultivation may involve tillage practices which have a direct or indirect influence on the nature of the soil's porous system to water and root movement. Such studies showed a reduction of total pore volume and in total number of pores of soils after 11 years of no-tillage in the top 0 to 25cm (Vanden Bygaat *et al.,* 1999). The latter authors inferred that ease of root penetration and increase in biological activities in no-till fields may facilitate aeration and water movement due to formation of biopores (pores from increased organic matter induced by no till or minimum till conditions) that led to a long term decrease in bulk density. Meanwhile research has shown short term incidence of higher water movement and lower penetration resistance in conventionally tilled soils compared to no till soil condition (Lawal, 2015; Ogunsola, 2016).

Soil's penetration resistance remains a very important property in soil-plant water relations that renders its inclusion in soil physical quality assessment. This necessitates the need to develop a functional relationship between the two properties especially where soil penetration resistance is a required property and a penetrometer for its measurement is not available. Whalley *et al*. (2007) developed non-linear pedo-transfer function with water characteristics, bulk density and sand content to derive coefficients for penetration resistence that are insensitive to soil types, and demonstrated that pedo transfer functions(PTF) can be used to determine soil strength for independent soils. Costantini (1996) showed bulk density to be positively correlated with PR and negatively with moisture content. Attempt to develop empirical models showing the relationship between BD and PR indicated differences in model prediction based on different land uses. For example, the relationship between bulk density and PR was best predicted by additive model in cultivated soils, while it was a multiplicative model for uncultivated soils and shows that it is not possible to fit the model of BD and PR for cultivated soils to uncultivated and re-packed soils (Costantini, 1996). The same may be applicable to different land use types in the Nigerian Savanna. While some of these studies exist in some part of the world, few or none of such studies exist for Alfisols of the Northern Guinea Savanna (NGS) of Nigeria. The objective of this study is to compare bulk density and penetration resistance for soils under the different land uses (Jatropha Plantation, Continuously cultivated and Fallow) in Samaru, the NGS of Nigeria and attempt to develop a functional relationship between the two indicators of soil compaction and root growth for these soils.

MATERIALS AND METHODS

Site location and description

The study was conducted in the Experimental site of the Institute for Agricultural Research (I.A.R) Samaru, Zaria, from three different land use types which includesJatropha, fallowed, and cultivated fields. The Jatrophafield is a germplasm repository field and located in latitude N11°11.310' and longitude E007°37.110'with altitude of 676m above sea level. The field was established since 2005. The plantation is managed by seasonal pruning and NPK fertilization according to the crop requirement. The fallow field has a coordinate of N11°11.272' and E007°36.891' with altitude of 696m above sea level (S2), and has been under fallow for 10 years with history of cultivating annual cereal/leguminous crops The continuously cultivated field has a coordinate of N11°11.198' and E007°36.887' with altitude of 698m above sea level and engaged in annual cereal and legume cultivation. Land preparation is normally done with tractor-driven implement while subsequent tillage management is conducted with hoe or animal drawn implements. The I.A.R. field in general, is characterized by soils belonging to the order of Alfisol. The study site is also characterized by a mono-modal rainfall pattern which fall between May and September with long term mean annual mean rainfall from 1968 to 2017of 1016mm and mean annual temperature of 27.5°C (IAR Meteorological Unit, 2018).

Soil Sample collection and field measurements

Samples used for the study were obtained from the three different land use types. Each field measured 50m x 100m, and was divided into 3 sub-plots. Six (6) soil cores (measuring 5cm by 5cm) samples were collected from 0-5 cm and 5-10cm from 3 points in each sub-plot, giving a total of eighteen (18) soil core samples from each field (land use), and a total of 54 core samples from the three fields. Samples were collected using a systematic random sampling technique from an 'X-Shape' across the field.

These samples were used for the determination of bulk density using the core method described by Blake and Hartge (1986). A cone penetrometer (Farnell Military grade model) was used to measure the soil's penetration resistance at each sampling point where the 54 core samples were taken. Penetrometer readings were taken at a distance of 4-5cm from where the core was inserted, and this was done for every core sampling point and depth. Three replicate penetrometer reading was taken per point and depth so that PR data represents an average of the replicate readings. Soil cores of each sampling point and depth collected were also used for determination of moisture content. Disturbed soil samples were collected randomly from five points of each subplot using a 20cm soil auger, to give 3 composite replicates per land use types. These disturbed soil samples were air-dried, crushed and sieved with 2-mm sized sieve for routine physical and chemical properties using standard soil analytical methods.

Particle size distribution of the composite soil was determined using the hydrometer method described by Gee and Bauder (1986), while bulk density was determined by the core methods of Blake and Hartge (1986). Soil organic carbon (OC) was determined by dichromate oxidation method described by Nelson and Sommers (1982), while total nitrogen (TN) was determined using the micro Kjedahl distillation method (Bremner and Mulvaney, 1982). Available phosphorus was determined by Bray-1 acid fluoride method described by Bray and Kurtz (1945) and Exchangeable bases were determined by ammonium acetate extraction method (Anderson and Ingram, 1993). Functional relationship with PR and BD density data gave a poor fit in all forms of regressions (exponential, power, linear and polynomial, log-normal). However, a better fit was obtained with polynomial regression of PR (MPa) by transforming the BD values (Mg m^{-3}). This was achieved by raising BD with a matching factor. The matching factor was obtained as the ratio of measured BD and PR.

Statistical Analysis

Microsoft office Excel package (Microsoft Inc. 2010) was used to conduct a polynomial regression analysis between the transformed bulk density and penetration resistance (PR) values for each of the land use and soil depth. The PR data from the six measurements were split into two. The first set of data from two sub-plots was used to develop the relationship. Linear regression between measured and calculated penetration resistance was used to test models fit from the PR data collected from the third sub-plot of each land use. General linear model was used to analyze the variance of means of bulk density and penetration resistance from the three land uses and two soil depths, while least significant difference was used to separate means that were statistically different, all using Statistix version 9 software (*Statistix, Inc. 2010*).

RESULTS AND DISCUSSION

General soil properties

The physical and chemical properties of the three land uses are presented in Table 1. The result of particle size analysis indicated a textural class of sandy loam in all the three fields. The organic carbon (OC) content was low with values of 3.70 – 9.26 g kg^{-1} in all three fields, with the cultivated soil having the least OC content while the highest OC content was observed in soils of Jatropha field. Total nitrogen and available P were higher in soils of cultivated and Jatropha land use types than in fallow soils. Soils of the Nigerian savanna have been reported to have low OC contents (Jones and Wild, 1975) and continuous crop production may be responsible for the lower OC observed in the cultivated fields. This may be due to

Table 1: Characteristics of soils in the studied fields in IAR Research Farm, Samaru

Soil Property	Fallow	Jatropha	Cultivated
Particle sizes			
Sand (%)	68	71	64
Silt (%)	24	20	27
Clay (%)	8	9	9
Textural class	SL	SL	SL
Organic Carbon (g kg^{-1})	6.78	9.26	3.70
Total N (g kg^{-1})	7.98	8.68	9.45
Available P (mg kg^{-1})	6.30	14.00	11.20
Exchang. Bases ($cmol_{(+)}$ kg^{-1})			
K	1.06	1.38	1.30
Na	0.11	0.11	0.10
Ca	1.70	2.80	2.17
Mg	0.36	0.42	0.37

SL=sandy loam

conventional tillage and other non-sustainable management practices such as removal of crop residue and low addition of organic matter to the soils, which are commonly practiced by farmers (Odunze, 2017), while leaf litter from Jatropha plant may have added organic matter to the top soil. Higher total nitrogen (TN) and available phosphorus in soils of cultivated fields than fallow fields may be attributed to the residual fertilizers added to the soils from previous cropping season. Exchangeable bases were also low, but higher in soils of Jatropha field than the other land uses, which may be connected to the higher litter mass observed in the former than in the latter.

Effect of land use and soil depth on Bulk density and Penetration resistance

A summary of the ANOVA showing the significant differences of means of BD and PR from each land use, soil depth and their interaction is presented in Table 2. There was a highly significant difference ($p<0.0001$) in means of BD, PR and gravimetric moisture content for land uses, soil depth and their interactions. The variables were affected by land use while the difference was not significant at the two soil depths. The land use x soil depth interaction showed a greater effect of land use and soil depth on bulk density ($p<0.05$). From the interactions (Figure 1), BD of soils of Jatropha field at 5-10 cm was highest and differ statistically with all the land uses and soil depths. Meanwhile, BD of Jatropha field soils at 0-5 cm and cultivated soils at 5-10 cm were statistically the same, and both differ from BD of fallow fields at 5-10cm.

For all land uses, the PR values were within the lower critical limit for root growth (Taylor and Burnett (1964) and according to the classification in Boone *et al.* (1994). Gravimetric soil moisture at the time of measurements of PR vary in the different land uses with average of 25 and 27% for fallow and cultivated fields which were statistically similar ($p>0.05$) and both differ from Jatropha field with the least soil moisture (16%) (Table 2). Land use has an effect on both PR and BD at different soil depths. It has been shown that lower soil depths are often affected by soil management practices such as conventional tillage (Ogunsola, 2016). Pulverization in soils under the conventional soil disturbing processes with continuous cultivation breaks down soil aggregates which results in low BD and PR values, due to increase in the total pores spaces. However, BD values could increase as a growing season progresses with compaction by other biophysical factors (Franzen *et al.*, 1994). Meanwhile, BD and PR of fallow plots at the upper depth were moderate and implied fallow effects on rejuvenation of soils due to re-structuring of soil and its biological activities (Lampurlanes and Cantero, 2003) probably due to the formation of biopores (Junior *et al.*, 2014). In this study, the larger PR values in the Jatropha field may not restrict root growth as optimum values for root growth ranges from 1.7 to 2.0 MPa (Canarache, 1990; Raper *et al.*, 1998), while the critical PR values for root penetration ranges from 2.5 -3.0MPa(Taylor and Burnett, 1964). The Jatrophafield under study had a PR value of 1.96MPa. Taylor and Burnett (1964) showed normal root penetration at 1.9MPa. Root limiting values of 2.5MPa were reported for finer soils (clayey), while upto 6MPawas critical for coarser soils across moisture ranges of 3-20% and bulk densities of 1.5 – 1.7 Mg m^{-3} (Gerard *et al.*, 1982). Soils in all the studied fields were sandy loam and root growth may proceed even at higher PR values beyond 2.0 MPa.

Effect of soil moisture and organic carbon on bulk density and penetration resistance

Results from this study did not show a greater effect of soil moisture on BD in cultivated soils compared with the other land uses (Table 2). The effect of soil moisture was more pronounced in PR for both cultivated and Jatropha fields. Weber and Biskupski (2008) showed values of PR were more affected by soil moisture than BD. Moisture content is an important factor affecting soil PR, where drier soils have higher PR than soils that contain some moisture (Yasin*et al.*, 1993). Whalley*et al.* (2005) also found an inverse relationship between moisture content and PR, while Ohu*et al.* (1988) found an exponential relationship between moisture content and PR for a loam and clay soil.

Different land uses have different organic carbon contents in their soils possibly affected by differences in management practices as observed in this study. These may result in differences in soil physical properties such as bulk density, PR and aggregation (Unger, 2009). Several studies have shown a decreased PR and bulk density with additions of organic matter (Ohu*et al.*, 1994; Mamman*et al.*, 2007, Stock and Downes, 2008; Gülser and Candemir, 2012). These studies demonstrated that the higher the level of organic carbon in soils, the lower the values of BD and PR obtained. In this study, despite the higher organic carbon content of the Jatropha field, the effect of soil organic carbon on PR was masked by the greater effect of lower soil gravimetric moisture during measurement and probably with other factors(Weber and Biskupski , 2008). This is because PR is affected by an interplay of many factors such as bulk density, moisture content, texture, structure, voids, clay type as well as soil management practices, while bulk density is function of total porosity than moisture content and texture (Tokunaga, 2006; Singh *et al.*, 2015).

Relationship between soil bulk density and penetration resistance

The Soils of Jatropha plantation had the highest average bulk density value (1.72 Mg m^{-3}) and PR (1.96 MPa) among the three land uses (Table 2). Fallow field has an average bulk density value of 1.55 Mg m^{-3} and an

Table 2: Summary of analysis of variance of bulk density (BD), soil penetration resistance (PR) and gravimetric moisture content and their means under different land uses and soil depths in IAR fields, Samaru, Zaria

Source	DF	BD ($Mg\ m^{-3}$)	PR (MPa)	moisture content (g/g)
Land use (LU)	2	****	****	****
Soil depth (SD)	1	ns	****	ns
LU*SD	2	*	ns	ns
Error	48			
Land use				
Fallow		1.55c	1.76a	0.25
Cultivated		1.63b	1.06b	0.27
Jatropha		1.72a	1.96a	0.16
SE		0.033	0.081	0.012
Soil depth (cm)				
0-5		1.61b	1.34b	0.23
5-10		1.66a	1.85a	0.22
SE		0.027	0.093	9.9×10^{-3}

DF= degree of Freedom. *= significance at p<0.05; **** = significance at p<0.0001.
SE=standard error

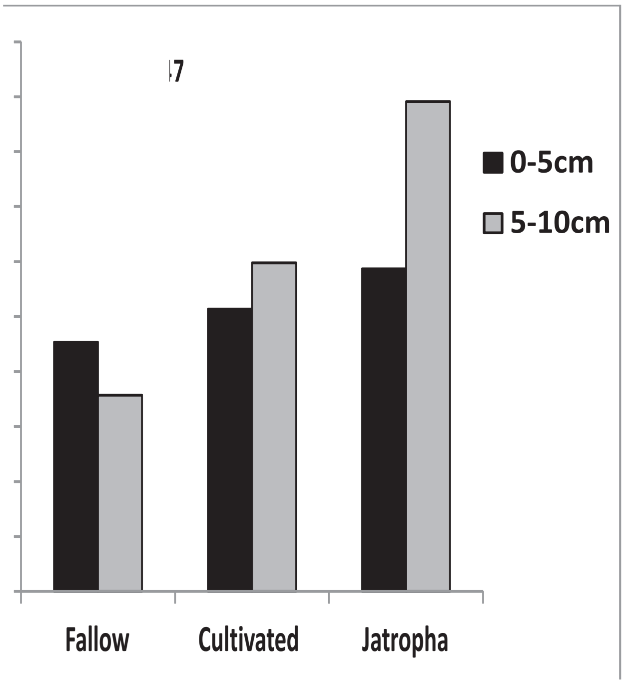

Figure 1: Interaction of land use and soil depth on soil bulk density

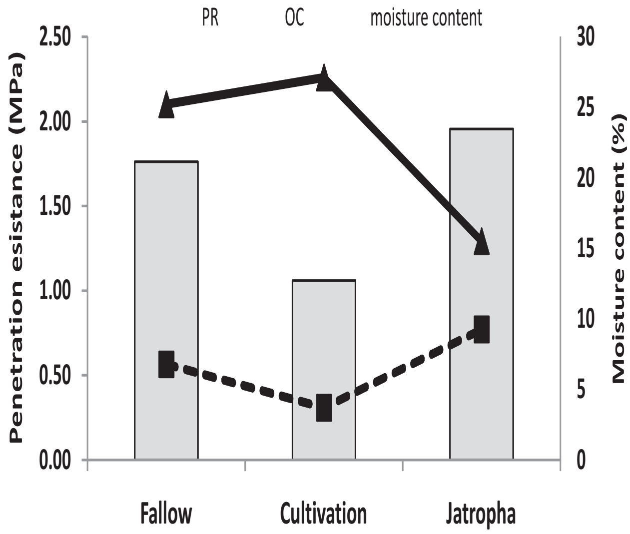

Figure 2: Penetration resistance (PR), organic carbon (OC; g kg^{-1}) and gravimetric moisture content (g/g) of the soils of the different land uses studied.

Note: Value of OC is read on the secondary y-axis of moisture content average penetration resistance value of 1.76 MPa. Average matching factors ranged from 0.645 to 1.14 across the land uses. Figure 3 (a and b) gives the polynomial graph of 0-10cm soil depths of fallow and cultivated fields, respectively. Polynomial regression relationship that was developed between soil bulk density and penetration resistance for each land use resulted in an average regression coefficients (r^2) of 0.9508across the two soil depths of the fallow soils. An r^2 of 0.9919 across both soil depths was obtained for the cultivated soils. Similar plots were obtained for all three fields and for each soil depths. A summary table of the regression coefficients and equations for each soil depth and field is presented in Table 3. These expressions show that the two soil properties can be related from a polynomial rather than a linear expression. The relationship was improved with penetration resistance when the value of bulk density was transformed by raising it to a matching factor for each soil depth and land use as presented on Table 3. Whalley*et al*. (2007) and developed PTF from non-linear regressions by log-transforming the dependent (PR) and independent variable as product of matric potential and degree of saturation for better prediction, and had to correct for bias when expressing PR in it's natural (non-logarithmic) state.

To validate the relationships, linear regression of the measured and calculated penetration resistance (MPa) from 0-10 cm of the cultivated land gave r^2 value of 0.9793 (Figure 4) and while the relationship was lower (r^2=0.8953) for Jatropha field. A summary of the r^2 obtained from linear regression of the measured and calculated penetration resistance for all the land uses and soil depths is given in Table 4. Regression coefficients across all the land uses were greater than 0.5 and indicate that fitting estimates from the polynomial regression equation could fit well in estimating penetration resistance of soils from measured bulk density values. Higher r^2 were obtained in cultivated and fallow land uses than for Jatropha fields, indicating that PR can easily be estimated for the former land uses using the polynomial function than the latter. All the functions were unique to each land use types at the measured moisture content, and could not fit to other land uses. The lesser relationship obtained from Jatropha field may be due to the lesser moisture content at measurement that resulted in higher PR. This was similar to findings by Costantini (1996) where the models of PR and BD of cultivated soils could not be fitted to uncultivated (fallow) soils.

The relationship by Whalley*et al*. (2007) for predicting PR was with the log-transformed product of the matric potential and degree of saturation and other soil properties such as bulk density and sand content. They showed that the PTF can be used to predict PR and had a more physical-basis when the product of the soils' matric potential and S are used than using either of the properties. This work had demonstrated that knowing the soil's bulk density alone, which is readily available soil information, knowledge of the soil's strength could be easily known especially as influenced by tillage from developed relationships. Although there may be other properties with physical basis such moisture content, that influences the

Table 3: Regression coefficients and regression equations from polynomial plots of bulk density and penetration resistance for 0-10 cm, and average matching factor used for the different land uses

Land Use	Soil depth (cm)	Maching factor (MF)	R^2 value	Regression equation
Fallow	0-10	1.133	0.9508	$y=-0.9312x^2+5.0248x-3.9639$
Cultivated	0-10	0.645	0.9919	$y=-1.1373x^2+5.515x-4.3574$
Jatropha	0-10	1.140	0.8695	$y=0.0461x^2+1.0666x-0.1827$

y= penetration resistance (MPa); x= bulk density ($Mg\ m^{-3}$) $^{\wedge MF}$

Table 4: Regression coefficients (R^2) obtained from linear regression between measured and calculated penetration resistance (PR; MPa) for 0-10cm soil depths in the different land uses

Land use	Soil Depth (cm)	R^2 value	Regression equation (1:1)
Fallow	0-10	0.9098	y=1.0129x
Cultivated	0-10	0.9793	y=0.9923x
Jatropha	0-10	0.8953	y=1.0208x

y=calculated PR, x=measured PR

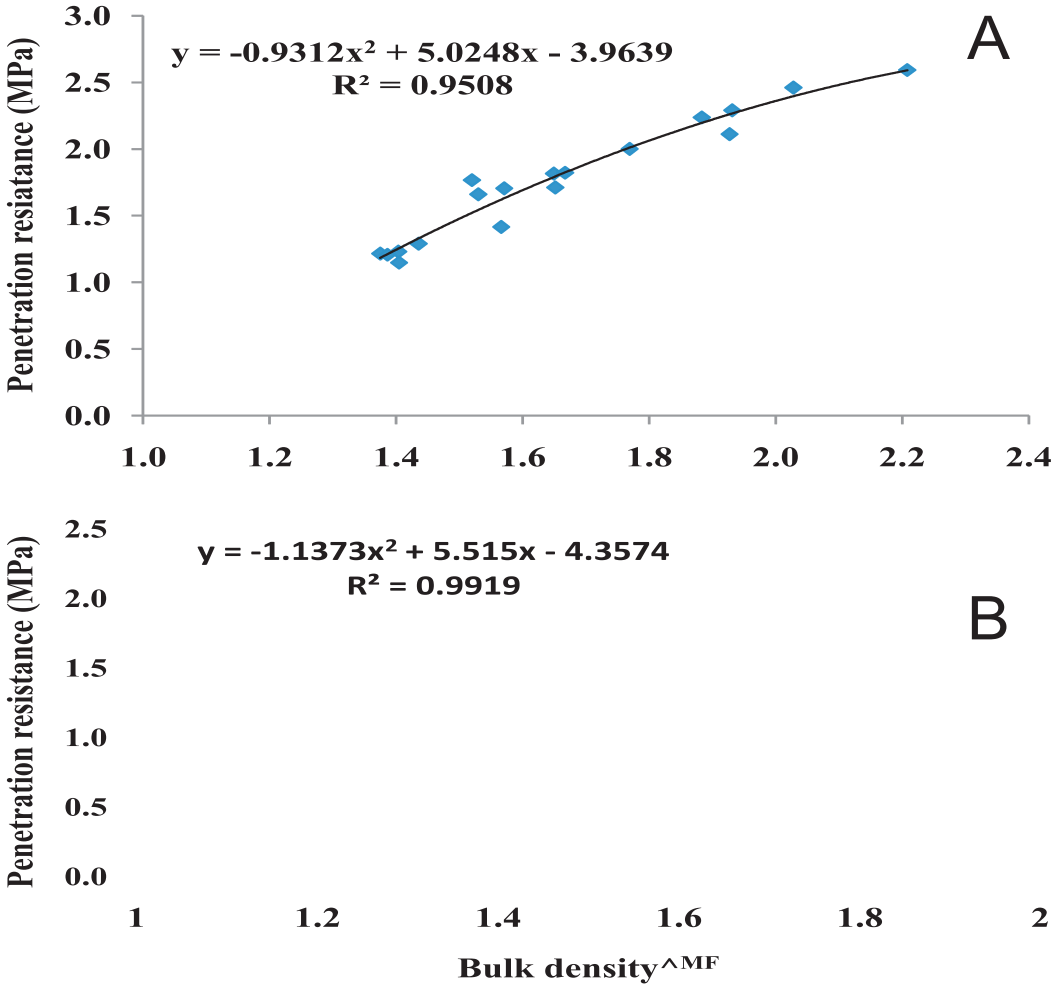

Figure 3: Polynomial regression of penetration resistance (MPa) and bulk density ($Mg\ m^{-3}$) at 0-10cm of (a) Fallow (b) Cultivated fields

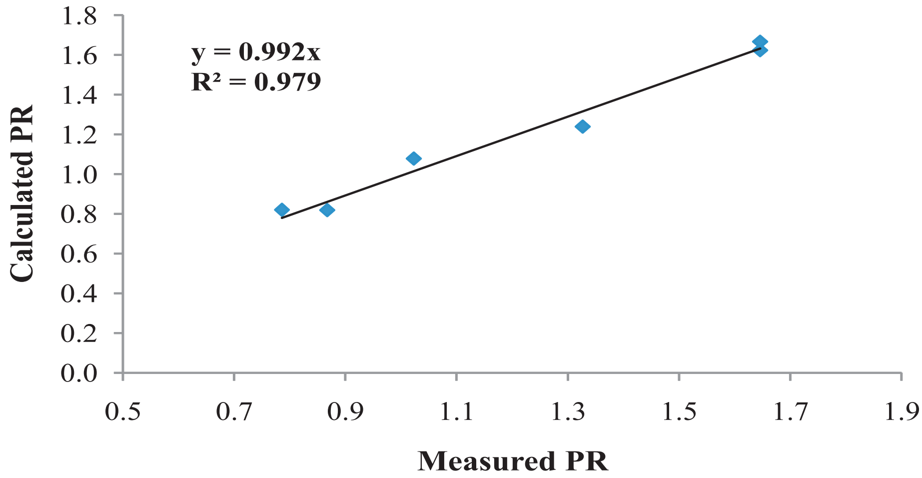

Figure 4: Linear regression (1:1) between measured and calculated penetration resistance (PR; MPa) at 0-10cm of the Cultivated field

soil's PR, polynomial functions developed could be utilized with only one soil property as a minimum data requirement.

CONCLUSION

Land uses affected the two soil physical properties as observed with the values obtained from the fallow field with lowest compaction levels compared to the other two land uses. Polynomial relationships developed can be used to determine soil penetration resistance from measured bulk density values. These functions were unique to each land use and had better prediction for soils in cultivated and Jatropha fields than fallow field. Further research can be explored to validate and improve the existing relationship especially with BD and PR data from independent soil measurements. Pedo-transfer functions using soil water characteristics and other physical properties could be explored to predict soil strength (PR).

REFERENCES

Anderson, J.M. and Ingram, J.S. (1993). *Tropical Soil Biology and Fertility*: A handbook of methods, 2nd Edition. C.A.B. International Wallingford, UK. Pp221.

Bengough, A.G. and Mullins, C.E. (1990). Mechanical impedance to root growth: a review of experimental techniques and root growth responses. Journal of Soil Science, 41: 341–358.

Blake, B. R. and Hartge, K. H. (1986). Bulk density. *In*: Klute (ed.). Method of soil analysis. Agronomy 9, Part 1, 2nd edition, ASA and SSA, Madison, WI: 377-382.

Boone, F.R. Vermeulen, G.D. and Kroesbergen, B. (1994). The effect of mechanical impedance and soil aeration as affected by surface loading on the growth of Peas. *Soil and Tillage Research*,32:237-251.

Bray, R.H. and Kurtz, L.F. (1945). Determination of total, organic and available forms of Phosphorus in Soil. *Soil Science*, 59:39-54.

Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen total. In: Page, A.L., Miller, R.H. and Keeney, D.R. (Ed.). *Method of Soil Analysis Part 2. Agronomy 9*. Madison WI. Pp 595-624.

Canarache, A. (1990). Penetr: a generalized semi-empirical model estimating soil resistance to penetration. *Soil and Tillage Research,* 16: 51–70.

Costantini, A. (1996). Relationship between cone penetration resistance, bulk density and moisture content in uncultivated, repacked and cultivated hard setting and non-hardsetting soils from the coastal lowlands of south-east Queensland. *New Zealand Journal of Forestry Science*, 26(3): 395-412.

Franzen, H., Lal, R. and Ehlers, W. (1994). Tillage and mulching effects on physical properties of a tropical Alfisol. *Soil Tillage Research*, 28:329–346

Unger, P.W. 2009. Soil total carbon content, aggregation, bulk density and penetration resistance of crop lands and nearby grasslands. *Soil Science Society of America Special Publication*. 57: 123.

Gee, G.W. and Bauder, J.W. (1986): Particle-Size analysis. Methods of soil analysis. Part Physical and mineralogical methods, 2nd ed.; *American Society of Agronomy: Madison*, WI, 383–411.

Gerard, C.J., Sexton, P. and Shaw, G. (1982). Physical factors influencing soil strength and root growth. *Agronomy Journal*, 74:875-879.

Gülser, C. and Candemir, F. (2012). Changes in penetration resistance of a clay field with organic waste applications. *Eurasian Journal of Soil Science.*1:16-21.

Tokunaga, A.A. (2006). Effect of bulk density and soil strength on the growth of blue wildrye (*Elymusglaucus*Buckl.). An MSc Thesis submitted to the Faculty of Humboldt State University, Germany. 59Pp.

IAR Meteorological Unit (2018). The Meteorological Unit of the Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.

Jones, M.J. and Wild, A. (1975). Soils of the West Africa Savanna. Tech. Comm. No. 55, Commonwealth Bureau of Soils, Harpenden, pp 246.

Junior, G.F.S., Cora, J.E. and Lal, R. (2014). The effect of land use and soil management on the physical properties of an Oxisol in Southeast Brazil. *R. Bras.C Solo*. 38: 1245-1255.

Lal, R. (1989). Conservation tillage for sustainable Agriculture; tropics vs temperature environments. *Advances in Agronomy*, 42: 85 – 197.

Lampurlanes, J. and Cantero, M. (2003). Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with Barley root growth. *Agronomy Journal,* 95:526-536.

Lawal, H.M.F. (2015). Tillage and cover crop effects on soil quality and maize growth at Samaru, northern Nigeria. A PhD Thesis submitted to the Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria. 315pp.

Mamman, E., Ohu, J.O. and Crowther, T. (2007). Effect of soil compaction and organic matter on the early growth of maize (Zea mays) in a vertisol. *International Agrophysics,21: 367-375.*

Microsoft Inc. (2010). Microsoft Office Version 2010. Microsoft Incorporation.

Nelson, D.W., Sommers, L.E. (1982): Total carbon, organic carbon and organic matter, in: A.L. Page et al. (Eds.), *Methods of Soil Analysis*, Part 2, 2nd ed. *Agronomy Monogram 9, ASA and SSA, Madison*, WI: pp. 539–577.

Odunze, A.C. (2017). Healthy Soil: The key to Agricultural Revolution in Nigeria. An Inaugural Lecture Delivered at Ahmadu Bello University Zaria on 15th November. Series No.04/17. P. 11.

Ogunsola, E.O. (2016). Contribution of conservation Agriculture to improvement of soil quality and maize (Zea mays L.) yield in Samaru, northern guinea savanna of Nigeria. An MSc Dissertation submitted to the Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria. 224pp

Ogunwole, J. O., Babalola, O. A., Oyinlola, E. Y. and Raji, B. A. (2001). A pedological characterization of soils in the Samaru area of Nigeria. *Samaru Journal of Agricultural Research*, 17:71-77.

Ohu, J.O., Ayotamuno, M.S. and Folorunsho, O.A. (1988). Characteristics of prominent agricultural soils in Borno State of Nigeria. *Agricultural International,* 40(11): 242-243.

Ohu, J.O., Ekwue, E.I. and Folorunso, O.A. (1994). The effect of addition of organic matter on the compaction of a Vertisol from Northern Nigeria. *Soil Technology*, 7(2): 155-162. doi.org/10.1016/0933-3630(94)90017-5.

Raper, R.L., Reeves, D. and Burt, E.C. (1998). Using in-row sub soiling to minimize soil compaction caused by traffic. *Journal of Cotton Science*, 2:130-135.

Statistix (2010). Statistix Inc. version 9 Statistical software.

Stock, O. and Downes, N.K. (2008). Effects of addition of organic matter on the penetration resistance of glacial till for the entire water tension range. *Soil and Tillage Research,* 99:191-201.

Singh, J., Salaria, A. and Kaul, A. (2015). Impact of soil compaction on soil physical properties and root growth: A Review. *International Journal of Food, Agriculture and Veterinary Sciences*, 5(1): 23-32.

Taylor, H.M. and Burnett, E. (1964). Influence of soil strength on the root-growth habits of plants. *Soil Science*, 98:174-180.

Vanden Bygaat, A.J., Protz, R. and Tomlin, A.D. (1999). Changes in pore structure in a no-till chronosequence of silt loam soils, Southern Ontario. *Canadian Journal of Soil Science*, 79: 149-160.

Whalley, W. R., Leeds-Harrison, P. B., Clark, I.J. and Gowing, D.J.G. (2005) Use of effective stress to predict the penetrometer resistance of unsaturated soils. *Soil Tillage Resources*, 84:18-27.

Whalley, W.R., Tob, J., Kay, B.D. and Whitmore, A.P. (2007). Prediction of the penetrometer resistance of soils with models with few parameters. *Geoderma*, 137: 370–377.

Weber, R. and Biskupsski, A. (2008). Effect of penetration resistence, bulk density and moisture content of soil on selected components of winter triticale in relation to method of cultivation. *International Agrophysics*, 22:171-177.

Yasin, M., Grisso, R.D. Bashford, L.L. Jones, A.J. and Mielke, L.N. (1993). Normalizing cone resistance values by covariance analysis. *Transactions of the ASAE*, 36: 1267-1270.