PAT December, 2025; 21(2):73-81, ISSN: 0794-521
Online copy available at https://www.patnsukjournal.org/
Publication of Nasarawa State University, Keffi

ORIGINAL ARTICLE

EFFECT OF COMPACTION ON SOIL PROPERTIES AND HYDRAULIC FUNCTIONS UNDER DIFFERENT LAND USE TYPES IN CHOBA, PORT HARCOURT, NIGERIA

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ABSTRACT
This study evaluated the effect of soil compaction on soil properties and hydraulic functions across grassland, cassava, and tree land use types at the University of Port Harcourt Teaching and Research Farm. The objectives were to assess the influence of compaction on soil properties, determine critical threshold that can affect the use of the soil, and understand its effect on hydraulic functions. Soil samples from various depths were analysed under two compaction levels (561.40 kJ/m³ and 935.67 kJ/m³). Results revealed that maximum bulk density increased significantly with the level of compaction averaging 2.03 g/cm³ at 561.40 kJ/m³ and 2.13 g/cm³ at 935.67 kJ/m³. Total porosity decreased from 44.48 % in uncompacted soils to 23.59 % and 19.90 % respectively, for 561.4 and 935.67 kJ/m³ compaction levels, while moisture retention at field capacity declined from 31.00 % in uncompacted soils to 17.35 % and 15.97 % for the two compaction levels, respectively The results further indicated that compaction decreased total porosity and moisture retention while increasing the soil bulk density, with grassland and cassava areas exhibiting compaction at depth that limits water movement and root growth, while tree areas showed higher resilience at the surface due to higher organic matter content but experienced deeper compaction. The results of this study confirmed that compaction negatively affect soil properties and hydraulic function, therefore practices that encourages compaction should be avoided while addition of organic materials to improve the organic matter content of the soil, improve soil structure and maintain soil health for crop productivity should be encouraged.
KEYWORDS: *Bulk density, Compaction, Hydraulic properties, Moisture content, Porosity,*

INTRODUCTION

The capacity of land to enhance and maintain agricultural productivity is closely linked to effective soil management practices. Achieving sustainable agriculture requires soils with optimal structure, characterized by adequate aeration, efficient water infiltration, and favourable water retention (Seifu *et al.*, 2018). These factors are essential for reducing soil degradation through runoff and erosion. Additionally, well-structured soils offer essential mechanical support to crops, minimize root penetration resistance, and reduce the energy needed for tillage as they are key attributes for farmers to maximize crop yields and efficiency in agricultural operations.

Soil compaction affects soil fertility through increasing bulk density and soil strength. It also decreases infiltration rate, total porosity and amount of water stored in the root zone for crop use (Udom and Ehilegbu, 2018). Compacted soils tend to have reduced water infiltration and root penetration, leading to poor crop yields. Soil compaction, if not properly managed, could undermine efforts to achieve food security in line with the United Nations Sustainable Development Goal 2, which aims to end hunger and ensure access to nutritious and sufficient food for all (Gonzalez, 2022). Soil bulk density is a critical measure of soil compaction, influencing key properties such as porosity and hydraulic conductivity. These soil characteristics directly affect soil's ability to transport air and water, essential for plant growth and overall soil health. The relationships between bulk density, porosity, and hydraulic conductivity are dynamic and influenced by moisture content, with tropical soils, such as those in Nigeria, being particularly sensitive due to their unique structure, land use, and environmental conditions

MATERIALS AND METHODS

Study Site

The study was carried at the University of Port Harcourt, Teaching and Research Farm, a rainforest zone of Southern Nigeria. The area is located within latitude 4°54’31” N and longitude 6°55’22”E, covering a total perimeter of 901.14 m and area of 48,243.35 m^2 with an elevation of 12.76 m height above sea level,

Field Methods and Data Collection

The study site was categorized based on three different land uses viz: Teaching and Research Farm Unit (TRFU 1) Grassland Area, Teaching and Research Farm Unit (TRFU 2) Cassava Cultivated Area and Teaching and Research Farm Unit, (TRFU 3) Tree Crop Area. A soil profile pit was sunk on each of the identified mapping units, and was analysed for some pedological features. Disturbed and undisturbed bulk soil samples were collected from the different soil horizons at a depth of 0-15 cm apart and 15 kg. Disturbed samples were collected using soil auger. The horizons were sampled from bottom to top to avoid contamination. The soil samples collected for some physicochemical analysis were air-dried and passed through a 2 mm sieve for laboratory analysis. Particle size distribution was carried out by Gee and Bauder, (1986) method, bulk density by Grossman and Reinsch (2002), total porosity by Flint and Flint (2002), and moisture content by the Blake (1965) method

Laboratory Compaction Procedure

The soil samples collected were air dried and passed through a 19 mm sieve and pulverized. 5 kg of the samples were weighed into the compaction pan for the compaction test. A minimum of five different moisture contents was used in developing the laboratory soil compaction curves. The initial moisture content which vary from 2-3 % of the oven dried samples were increased by five units at each level of compaction. Thorough mixing of the soil and minimum moisture losses by evaporation was ensured during the test. A manual hand soil compactor was used for the test. The soil samples collected from the field were moistened in the compaction pan and compacted in a metal rings of 10 cm diameter and 12.73 cm height in three layer each receiving 25 blows of a 2.5 kg rammer drop from a height of 30.5 cm.; The number of blows was reduced by 10 to a give a second compaction level of 15 blows. After application of the blows, a specimen sample was removed to determine soil moisture, dry bulk density, wet density and the compaction efforts under which the soil were compacted and calculated as described by Head (1992).

Data Analysis

Data was presented as means and analysed using one way ANOVA. Least significant differences (LSD) was determine at ($p<0.05$)

RESULTS AND DISCUSSION

Presentation of Results According to land Use/Mapping Units

The soils in Mapping Unit One (Grassland) are classified under light brown to yellowish-brown hues (10YR 5/6) at the surface, transitioning to slightly darker shades with depth. The soil texture in this unit is sandy loam at the surface, comprising 57.2% sand, 24.6% silt, and 18.2% clay, indicative of a well-drained, loose soil structure. The subsurface layers are more compact with a sandy clay loam texture, reflecting the influence of compaction and rainfall patterns typical of the region. Bulk density in this unit increases with depth, from 1.55gcm^{-3} in the surface layer (0-15 cm) to 1.63gcm^{-3} in the 15-30 cm layer. This increase in density could be attributed to raindrop-induced compaction, as well as the mechanical impact from cultivation practices. Soil compaction affects water infiltration and root penetration, influencing plant growth. The mean particle density of the soils, 2.61gcm^{-3}, aligns with typical values for mineral soils, which suggests that organic matter content is relatively low in this unit.

Porosity, an important indicator of the soil's ability to store water and air, is relatively high at the surface (40.44%), but it decreases with depth, reaching 36.40% in the lower horizons (15-30 cm). This reduction in porosity at lower depths limits water and air movement, which can impact root growth and nutrient uptake. Despite this, the moisture retention capacity at field capacity (FC) remains steady, with values ranging from 24.64% to 26.63%, suggesting that the soil has a good water-holding capacity despite compaction at deeper levels. The available water content (AWC), an indicator of the soil's ability to supply water to plants, varies between 5.54% and 7.84%, reflecting the influence of texture and compaction on water availability in the root zone.

In Mapping Unit Two, which is predominantly used for cassava cultivation, the soil shows a light brown colour at the surface (10YR 5/6), gradually shifting to lighter shades in the subsurface. The soil texture in this unit is sandy loam at the surface, containing 53.2% sand, 16% silt, and 30.8% clay. Beneath the surface, the soil transitions into a sandy clay loam, reflecting a more compacted subsurface likely due to the dense, fibrous root systems of cassava plants.

The bulk density of the surface soils is relatively low at 1.51gcm^{-3}, increasing to 1.60gcm^{-3} in the deeper layers (45-60 cm). The gradual increase in bulk density with depth may be due to the mechanical impact of cultivation practices, combined with the natural compaction from the cassava root system. The particle density, averaging 2.71gcm^{-3}, is slightly higher than the other mapping units, which could suggest a higher mineral content or reduced organic matter in these soils. The porosity of the surface soil is relatively high (44.48%), which is beneficial for cassava growth as it allows for better air and water movement. However, porosity decreases with depth, and the deeper layers (15-60 cm) have porosity values of around 37.91%, restricting root expansion and water infiltration. The moisture content at field capacity also increases with depth, reaching values as high as 30.13%, indicating that deeper layers retain more water, which could be useful during dry spells.

However, available water content (AWC) ranges from 3.60% to 5.42%, indicating that only a moderate amount of water is accessible to cassava roots at any given time. Mapping Unit Three, primarily used for tree crops, shows a sandy loam texture at the surface with 43.8% sand, 17.4% silt, and 38.8% clay. The surface colour is dark brown (10YR 3/3), which deepens to a slightly darker brown (10YR 3/4) in the subsurface layers. The presence of tree crops influences the soil's structure, particularly through the accumulation of organic matter in the upper layers, improving the soil's water retention and porosity. The bulk density in this unit starts at 1.36gcm^{-3} in the surface layer (0-15 cm) and increases to 1.62gcm^{-3} in the 30-45 cm layer. The relatively lower bulk density in the topsoil can be attributed to organic matter accumulation and less soil compaction due to tree roots acting as natural stabilizers. However, the increase in bulk density in the subsurface indicates compaction from repeated agricultural practices. The particle density ranges from 2.39gcm^{-3} to 2.58gcm^{-3}, suggesting relatively higher mineral content in the deeper layers.

Table 1: **Morphological and physical properties of the various land used/units with corresponding horizon depths**

Land Use	Depth (cm)	Colour	Particle size			Textural class	Permeability code
			% Sand	% Silt	% Clay		
TRFU 3	0 – 15	Dark Brown (10YR 3/3)	43.8	17.4	38.8	Clay loam	4
	15 – 30	Dark Brown (10YR 3/4)	42.0	18.0	40.0	Clay	5
	30 – 45	Dark Brown (10YR 3/4)	41.0	18.5	40.5	Clay	5
	45 – 60	Dark Brown (10YR 3/4)	40.0	19.0	41.0	Clay	5
TRFU 2	0 – 15	Light Brown (10YR 5/6)	53.2	16.0	30.8	Sandy Clay loam	3
	15 – 30	Light Brown (10YR 5/5)	52.0	16.5	31.5	Sandy clay loam	3
	30 – 45	Light Brown (10YR 5/4)	51.0	17.0	32.0	Sandy clay loam	3
	45 – 60	Light Brown (10YR 5/3)	50.0	17.5	32.5	Sandy clay loam	3
TRFU 1	0 – 15	Yellowish-Brown (10YR 5/6)	57.2	24.6	18.2	Sandy loam	2
	15 – 30	Yellowish-Brown (10YR 5/5)	56.0	25.0	19.0	Sandy loam	2
	30 – 45	Yellowish-Brown (10YR 6/5)	55.0	25.5	19.5	Sandy loam	2
	45 – 60	Yellowish-Brown (10YR 6/4)	54.0	26.0	20.0	Sandy loam	2

TRFU: Teaching and research farm unit

Table 2: Physical properties and soil moisture characteristics of the experimental soil samples

Land Use	Depth (cm)	BD (g/cm^3)	PD (g/cm^3)	Porosity	Moisture content (Dry basis)	Percentage Moisture Content at FC	PWP	AWC	Ksat (cm/h)	Conductivity class
TRFU 3	0 – 15	1.36	2.39	42.97	0.31	35.44	28.31	7.12	2.5	Moderate
	15 – 30	1.48	2.38	37.91	0.26	34.48	29.38	5.09	2.2	Moderate
	30 – 45	1.62	2.58	37.41	0.23	32.86	30.10	2.76	1.8	Slow
	45 – 60	1.54	2.55	39.43	0.26	34.39	30.22	4.17	1.5	Slow
TRFU 2	0 – 15	1.51	2.71	44.48	0.30	28.98	23.97	5.00	1.6	Slow
	15 – 30	1.54	2.48	37.91	0.25	29.03	24.51	4.52	1.5	Slow
	30 – 45	1.49	2.46	39.43	0.26	30.13	24.71	5.42	1.2	Slow
	45 – 60	1.6	2.74	41.45	0.26	28.95	25.35	3.60	1.1	Slow
TRFU1	0 – 15	1.55	2.61	40.44	0.26	24.64	17.74	6.90	3.0	Moderate
	15 – 30	1.63	2.57	36.40	0.22	24.00	18.46	5.54	2.6	Moderate
	30 – 45	1.53	2.73	43.98	0.29	25.82	18.53	7.29	2.3	Moderate
	45 – 60	1.50	2.53	40.95	0.27	26.63	18.79	7.84	2.0	moderate

TRFU: Teaching and research farm unit, FC: Field capacity, PWP: Permanent wilting point, AWC: Available water contents, Ksat: Saturated hydraulic conductivity

Table 3: Bulk Densities (gcm^{-3}) of uncompacted samples and the maximum bulk densities (gcm^3) of soils compacted at a compactive efforts of 561.40 KJm^{-3} and 935.67 KJm^{-3}

Compaction parameters	TRFU3 a	b	c	d	TRFU2 a	b	c	d	TRFU1 a	b	c	d
Bulk Densities of laboratorically uncompacted soil samples (B_o)	1.36	1.48	1.62	1.54	1.51	1.54	1.49	1.60	1.55	1.63	1.53	1.50
Maximum Bulk Density at a compactive effort of 561.40Kjm^{-3}(B_1)	1.91	1.93	1.95	1.98	1.89	1.92	1.93	1.96	1.87	1.89	1.90	1.93
Maximum Bulk Density at a compactive effort of 935.67Kjm^{-3}(B_2)	1.98	1.98	2.00	2.02	1.94	1.95	1.98	2.00	1.91	1.94	1.97	1.98

TRFU3a = soils of mapping unit three at a horizon of 0-15cm, TRFU3b = soils of mapping unit three at a horizon of 15-30cm, TRFU3c = soils of mapping unit three at a horizon of 30-45cm, TRFU3d = soils of mapping unit three at a horizon of 45-60cm, TRFU2a = soils of mapping unit two at a horizon of 0-15cm, TRFU2b = soils of mapping unit two at a horizon of 15-30cm, TRFU2c = soils of mapping unit two at a horizon of 30-45cm, TRFU2d = soils of mapping unit two at a horizon of 45-60cm, TRFU1a = soils of mapping unit one at a horizon of 0-15cm, TRFU1b = soils of mapping unit one at a horizon of 15-30cm, TRFU1c = soils of mapping unit one at a horizon of 30-45cm, TRFU1d = soils of mapping unit one at a horizon of 45-60cm.

Table 4: Percentage porosity values of laboratory uncompacted samples and the maximum percentage porosity values of soils compacted at a compactive efforts of 561.40 KJm^{-3} and 935.67 KJm^{-3}

Compaction parameter	TRFU3				TRFU2				TRFU1			
	a	b	c	d	a	b	c	d	a	b	c	d
Percentage Porosity of uncompacted soil samples (P_o)	42.97	37.91	37.41	39.43	44.48	37.91	39.43	41.45	40.44	36.40	43.98	40.95
Minimum Percentage Porosity of soil at a compactive effort of 561.40Kjm^{-3}(B_1)	33.30	32.50	31.70	30.90	34.10	33.30	32.55	31.70	34.90	34.10	33.30	32.50
Minimum Percentage Porosity of soil at a compactive effort of 935.67Kjm^{-3}(B_2)	26.15	25.35	24.00	23.65	26.90	26.15	25.30	4.55	27.70	26.90	26.10	25.35

Table 5: Percentage moisture contents at F.C of laboratory uncompacted samples and the maximum percentage porosity values of soils compacted at a compactive efforts of 561.40 KJm^{-3} and 935.67 KJm^{-3}

	TRFU3				TRFU2				TRFU1			
	a	b	c	d	a	b	c	d	a	b	c	d
Percentage Moisture contents at F.C of uncompacted soil samples ($F.C_o$)	31.00	26.00	23.00	26.00	30.00	25.00	26.00	26.00	26.00	22.00	29.00	27.00
Percentage Moisture contents at F.C of soil at a compactive effort of 561.40Kjm^{-3}($F.C_1$)	18.50	20.50	21.70	24.90	14.10	18.30	18.55	20.10	14.90	16.10	17.30	20.20
Percentage Moisture contents at F.C of soil at a compactive effort of 935.67Kjm^{-3}($F.C_2$)	16.15	17.35	19.70	22.65	12.90	14.15	17.30	16..55	10.70	15.90	13.60	18.70

Table 6: Means of compacted Soil parameters in relation to levels of soil compaction

Compaction level	Means of compacted soil parameters		
	Maximum bulk Density	Percentage porosity	Percentage moisture at field capacity
Uncompacted, No laboratory compaction	1.63^{c}	44.48^{a}	31.00^{a}
compacted at a compactive effort of 561.40Kjm^{-3}(B_1)	2.03^{b}	23.59^{b}	17.35^{b}
compacted at a compactive effort of 935.67Kjm^{-3}(B_2)	2.13^{a}	19.90^{c}	15.97^{c}

Means with a common letter along the columns are not significantly different (p=0.05)

Table 7: means of compacted soil parameters in relation to the sources of compacted soil samples (The mapping units and corresponding Horizon depth)

	TRFU3				**TRFU2**				**TRFU1**			
	a	**b**	**c**	**d**	**a**	**b**	**c**	**d**	**a**	**b**	**c**	**d**
Maximum bulk density(gcm-3)	1.85^{bc}	1.85^{bc}	1.80^{c}	1.80^{c}	1.82^{bc}	1.81^{bc}	2.04^{a}	2.03^{a}	1.90^{b}	1.85^{bc}	1.78^{c}	1.78^{c}
Percentage Porosity at Maximum Bulk Density	30.05^{ab}	30.3^{ab}	32.0^{ab}	32.0^{ab}	31.7^{ab}	31.9^{ab}	23.1^{c}	23.4^{c}	28.8^{b}	30.3^{ab}	33.1^{a}	33.0^{a}
Moisture at FC determined at Maximum Bulk Density	14.31^{de}	20.55^{b}	23.80^{c}	23.7^{c}	18.32^{c}	24.30^{a}	24.3^{a}	28.95	14.3^{de}	15.75^{d}	24.8^{c}	24.7^{c}

Porosity values decrease with depth, starting at 42.97% in the surface layer, and dropping to 37.41% in the 30-45 cm layer. High porosity at the surface improves water infiltration and air circulation, which are beneficial for tree roots. However, lower porosity at deeper depths could limit deep root development. The moisture content at field capacity increases with depth, indicating that the deeper layers can store more water, which is crucial for tree crops that rely on a steady water supply. The available water content (AWC) varies between 5.09% and 7.12%, meaning that the surface layers can provide adequate water to tree crops during dry periods, but deeper layers may retain water for longer durations. Each mapping unit's physical and morphological properties reveal that compaction and root structure influence water retention and soil structure differently. The grassland and cassava areas show increased compaction at depth, affecting porosity and water movement. The tree crop area, with high surface organic matter, retains good porosity and moisture but experiences compaction below the surface, potentially affecting deeper roots.

Means of compacted Soil parameters in relation to levels of soil compaction

The results of mean separation in Table 6, shows that means of maximum bulk density, percentage porosity, and percentage moisture content at field capacity of uncompacted soils and those compacted at the two compaction efforts (B1 and B2) are all statistically different. The bulk density of the uncompacted samples has the lowest value (1.63 g/cm^3) while it increases as the compactive effort increases (2.03 g/cm^3 for B1 and 2.13 g/cm^3 for B2). Conversely, the percentage porosity of the uncompacted samples has the highest value (44.48%) while it decreases as the compactive effort increases (23.50% for B1 and 19.00% for B2).

Similarly, the percentage moisture content at field capacity of the uncompacted samples has the highest value (31.38%) while it decreases as the compactive effort increases (17.35% for B1 and 15.97% for B2). These results indicate that as soil compaction increases, the bulk density increases, porosity decreases, and moisture content at field capacity decreases. This is due to the reduction in pore space between soil particles as they are pressed together during compaction.

Means of compacted soil parameters in relation to the sources of compacted soil samples

The means compaction parameters in relation to the sources of the soil samples, were separated and compared at 0.05 level of significant using Duncan multiple range. Results shows that means of maximum bulk density, percentage porosity at maximum bulk density, and moisture content at field capacity of different mapping units and depths are not all statistically different. However, there are some notable trends. Generally, the bulk density increases with depth within each mapping unit. For example, in mapping unit 1, the bulk density increases from 1.78 g/cm³ at 0-15cm to 1.80 g/cm³ at 45-60cm. Similarly, in mapping unit 2, the bulk density increases from 1.81 g/cm³ at 0-15cm to 2.04 g/cm³ at 30-45cm.

Conversely, the percentage porosity at maximum bulk density generally decreases with depth within each mapping unit. For example, in mapping unit 1, the porosity decreases from 33.1% at 0-15cm to 32.0% at 45-60cm. Similarly, in mapping unit 2, the porosity decreases from 31.9% at 0-15cm to 23.1% at 30-45cm. The moisture content at field capacity also shows some variation across mapping units and depths. However, the trend is not as clear as for bulk density and porosity. Some mapping units and depths have higher moisture content, while others have lower moisture content. These results indicate that soil properties can vary significantly across different mapping units and depths.

These variations likely reflect differences in soil texture, structure, and organic matter content across the different mapping units and depths. The observed increase in bulk density with compaction is consistent with findings by Pagliai (1988), who demonstrated that compaction reduces total soil porosity and modifies the pore system. Similarly, the decrease in porosity with compaction is in agreement with research by Skidmore et al. (2019), who found that compaction reduces pore size and connectivity, leading to decreased infiltration and increased runoff across different soil types.

CONCLUSION AND RECOMMENDATIONS

The findings of this research highlight the significant impact of soil compaction on various soil properties across different land-use types. Increased bulk density and decreased porosity, resulting from compaction, hinder air and water movement within the soil, negatively affecting root growth and plant access to essential resources. The reduced water retention capacity of compacted soils can lead to increased runoff and diminished water availability for plants, particularly during dry periods.

The tree area, characterized by higher organic matter content, exhibited better resilience to surface compaction but experienced compaction at deeper depths. In contrast, the grassland and cassava areas showed increased compaction throughout the soil profile, impacting water movement more severely.

These findings emphasize the need to tailored land management practices to address the specific challenges posed by compaction in different land-use scenarios. To mitigate the negative effects of compaction, it is crucial to implement practices that minimize soil disturbance, such as reduced tillage and controlled traffic farming. Enhancing organic matter content through cover cropping and compost application can improve soil structure, increase pore space, and enhance water retention capacity. Furthermore, tailoring land management practices to specific land-use types is essential. For example, promoting deeper root systems in tree crops can help mitigate the effects of subsurface compaction.

While this research provides valuable insights into the physical properties of compacted soils, further research is needed to explore the long-term consequences of compaction on soil biological and chemical properties, such as microbial activity, nutrient cycling, and organic matter decomposition. Additionally, investigating the impact of compaction on soil properties across a wider range of soil types and depths would help to refine our understanding of the mechanisms underlying compaction-induced changes. By considering these implications and limitations, land managers and researchers can work collaboratively to develop sustainable land management practices that minimize compaction and ensure long-term soil health and productivity for various land-use types.

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