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Bulk Density Values As Affected By Core Size Sampling Depth and Moisture on a Humid Tropical Soil

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Abstract
Since a number of physical properties and mechanical behaviour is dependent on bulk density; the need for greater precision in its determination is key for good soil management and productivity. This study assessed the effect of 4 core sizes (5cmx5cm, 5cmx10cm, 10cmx5cm and 10cmx10cm), moisture content at different seasons (dry season- MC1, early rains- MC2 and peak rains MC3) and 3depths (0-10, 10-20 and 20-30cm) on bulk density values. The results show that core size dimension and not volume affected bulk density values. The 5cmx5cm (C1) and the 10cmx10cm (C4) gave similar values, while the 5cmx10cm gave values that were quite significantly higher than the other sizes (P<0.05). Bulk density values, generally increased with depth, except for samples taken at the high moisture content (MC3). The moisture content at the time of determination significantly affected bulk density values. The were no differences in bulk density values, when samples were taken at the high moisture content (MC3), across all depths and core sizes used. Results also showed that bulk density values were of samples collected at the medium moisture content (MC2) were significantly higher than the other moisture contents. Except for C2, all the other core sizes gave relatively similar bulk density values at the low moisture content (MC1). The MC1 with core sizes that have relatively proportional height and diameter proportions are therefore recommended for sampling for bulk density.
Key words: *Bulk density; core size; moisture content*

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I. Introduction

Bulk density is defined as the mass of solids per unit volume of the soil (Dexter, 2004). It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in gcm^{-3}. Bulk density reflects the soil's ability to function for structural support, water and nutrient and microbial life movement, and soil aeration. It is an indicator of soil compaction and soil health. It affects infiltration, root growth and penetration, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity, which influence key soil processes and productivity. (Eftene *et. al* 2020, Twum and Nii-Annang 2015). Generally, the greater the soil bulk density, the less pore space for water movement, root growth and penetration, and seedling germination. Total volume of a typical mineral surface soil is about 50% solids and about 50% pore space which are filled with air or water. The bulk density of soil is a function not only of the soil composition but also of management factors such as compaction by heavy and consistent tillage, large machinery use, use of limited crop rotation without variability in root structure or rooting depth, burning or removing crop residues, overgrazing forage plants and overstocking land [Dexter *et. al* 2008].

Bulk density is also used to convert between weight and volume of soil. The values of both bulk and particle density are necessary to calculate soil porosity (Blake and Hartage 1986). Porosity can then be derived from, knowing, or approximating the particle density value (Rabot et. al 2018). It is used to express soil physical, chemical and biological measurements on a volumetric basis for soil quality assessment and comparisons between management systems. High bulk density is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth, and poor movement of air and water through the soil (Lal, 1996, Ishaq *et. al*., 2001, Mbonu and Babalola 2003, Mbonu and Opara-Nadi, (2008)., Orji and Oko-Jaja, 2016. Orji and Ikechi, 2018. Gameda *et. al* 1994,). Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect soil from erosion. Mbonu and Opara-Nadi, (2008), Mbonu, *et. al*. 2008. It was previously thought that the use of a pushed soil sampler would increase the bulk density of a soil sample due to an increased amount of compaction, but this hypothesis was proved to be incorrect (Raper and Erbach 1987).

Several methods have been used to determine bulk density. They include the core method, mercury displacement method, kerosene saturation method, kerosene displacement using water as impregnating liquid, coating the soil clods with molten wax of 65 and 100°C, coating the soil clods with collodion, coating the soil clods with rubber solution of varying dilutions and excavation method (Arshad et al 1996, Gebre, 2018,). However, the most used method is the core method. Using core method, soil samples are collected using metal cylindrical core samplers of varying heights and internal diameters pressed into the soil. The cutting edge is sharpened without disturbing the height of core. The cylinder is removed, extracting a sample of known volume estimated by the dimensions of the core sampler. The sample is then dried in an oven and weighed.

The importance of accurate consistent bulk density values for soils has informed this study. The factors commonly known to affect soil bulk density includes porosity, texture and organic matter contents. Information on the size of cores, moisture content at time of determination are few. This study therefore, is aimed at assessing the effect of varying sizes of cores, moisture content of soil and depth of determination on bulk density data.

II. Material and Method

Site Area

This study was conducted at the Teaching and Research Farm of the Rivers State university, Port Harcourt Nigeria. it is located on longitude 4.8^oN and 7.0^OE, on an elevation of 18m above sea level. The study area has average mean annual rainfall of 3,000 to 4500mm in monomodal distribution, lasting from March to November, with August break lasting for the period of 7 days in the month of August. Temperatures are moderate with monthly mean temperatures of the coolest (July and August) and hottest months (February to April) are 2 and 29^0C, respectively. Relative humidity in the area remains high throughout the year, with mean values ranging from 78% in February to 89% in July and September (Uko and Tamunobereton-Ari, 2013). The soil of the site is typically sandy loam and formed over sedimentary rocks (Ojanuga, et. Al., 1981). It belongs to the ultisol order in the United States Soil Taxonomy (Soil Survey Staff, 1975)

Soil Sampling

Samples were collected from an over a five year, 2 hectares bush fallow plot within the Teaching and Research Farm. Undisturbed core soil samples were collected at 3 different times within the year to represent the wet soil, dry soil and moist soil conditions; using the method described by Blake and Hartage (1986),

Cylindrical metal cores of different sizes: 5cm core height x 5cm core diameter (C1), 5cm core height x 10cm core diameter (C2), 10cm core height x 5cm core diameter (C3) and 10cm core height x 10cm core diameter(C4) were driven into desired depths with the use of hard wood placed over the core and a mallet. The 4 soil volumes used were therefore, were 98.21, 392.86, 196.43 and $785.71cm^3$ respectively.

The depths of collection were 0-10, 10-20 and 20-30cm. Samples were collected at various times in the year: dry season, early rains and peak of rainy season. The moisture contents at these times were used to represent the moisture factor in the experiment: namely low (MC1), medium (MC2) and high (MC3) moisture contents. The 4 x 3 x 3 factorial experiment had core size as factor 1, depth of collection as factor 2 and moisture content as factor 3. This gave a total of 36 treatment combinations, replicated 3 times to give a total of 108 core samples. The site was parted into 3 blocks following slope and vegetation variations.

Soil samples were collected from all sampling points for moisture content determination. Bulk samples were also collected at various depths, air-dried, passed through a 2mm sieve and used for the determination of some physico-chemical properties of the soil.

Data collection

Bulk density was determined using the procedure described by Blake and Hartage (1986).
The bulk density will be derived from the equation below:

$\ell b = Ms/Vb\ (gcm^{-3})$ ……………………………….. (1)

Where:
ℓb = Bulk density
Ms = Mass of oven dried soil (g)
Vb = Bulk volume of the soil (cm^3)

Particle size distribution was determined by Bouyoucos hydrometer method as described by Gee and Bauder (1986). The percentage of sand, silt and clay were used to assign the sample to a textural class based on the soil textural triangle.

The moisture retention capacity was determined by taking the ratio of the mass of the water in soil sample as a function of mass of the oven dried soil (at 105^0C) using the following equation.

$\theta m = Mw/Ms \times 100\%$ ……………………………(3)

Where;
θm = Gravimetric moisture content (%)
Mw = Mass of water (g)

Ms = Mass of oven-dried soil (g)

Soil pH was determined in water using the electronic glass electrode pH meter method; in 1:2.5 soil-water ratio. Organic Carbon content was determined by Walkley and black wet-oxidation method as described by Nelson and Sommer (1982) and converted to organic matter by a factor 1.724.

Data collected were subjected to analysis of variance, fitted into a randomized complete block design. means were separated using the turkey method of the Minitab statistical analysis software.

III. Results and Discussion

Some Physico-Chemical Properties of The Experimental Site Soil

The soil pH is generally acid to near neutral, ranging from 5.25 to 6.20 with the top 0-10cm depth being more acid than down the profile (Table 1). The soil organic matter decreased with depth and was in the order 2.02> 1.41 > 0.98 % for 20 -30cm, 10 -20cm and 0- 10cm depths respectively. The study site being under bush fallow for five years may have contributed to the high organic matter content at the 0-10cm depth.

The percentage of sand ranged between 83.2 to 89.2% and decreasing with depth, while percentage of clay ranged from 5.4 to 10.8% and increasing with depth. However, the results showed that the soil texture from 0 -30cm depth is loamy sand. This suggests that the particle size distribution gives a better information than just the textural class of soils; from the point of view of the colloidal and therefore chemical behaviour of the soil.

The mean moisture content of the soil at the various times of determination are as shown on Table 1. The moisture contents across depths were not significantly different. The moisture content at the 0-10cm depth at the various times of sampling are 0.080gg^{-1}(‘dry’), 0.141gg^{-1} (‘moist’) and 0.168gg^{-1} (‘wet’). These formed the basis of classifying the times of collection for ‘dry’, ‘moist’ and ‘wet’ soil.

Table 1. Some properties of the soil of the experimental site

Depth	pH	% OM	Particle Size Distribution			Texture	Moisture Content of Treatments (%)		
(cm)	(H_2O)		% Sand	% Silt	% Clay		Low	Medium (gg^{-1})	High
0-10	5.25	2.02	89.2	5.4	5.4	Loamy sand	0.080	0.141	0.168
10-20	6.20	1.41	87.2	6.0	6.8	Loamy sand	0.088	0.133	0.162
20-30	6.05	0.98	83.2	6.0	10.8	Loamy sand	0.097	0.155	0.179

Effect of Core Sizes on Bulk Density

There were differences in bulk density values with respect to core size (Fig.1). The 5cm height x 5cm diameter (C1) and 10cm height x 10m diameter (C4) gave the same bulk density value of 1.5gcm^{-3} and that of the 10cm height x 5cm diameter (C3) was 1.6 gcm^{-3}, although these three were not significantly different. However, results showed that the bulk density of soil collected with core size 5cm height x 10m diameter (C2) differed significantly from the other three sizes with a bulk density of 1.7 gcm^{-3} ($P < 0.05$).

This suggests that the dimensions of the cores used affected bulk density values and not the volume of the soil collected. A uniform ratio of height to diameter of core will likely give similar values. A shorter but wider core had higher values than longer but narrower cores.

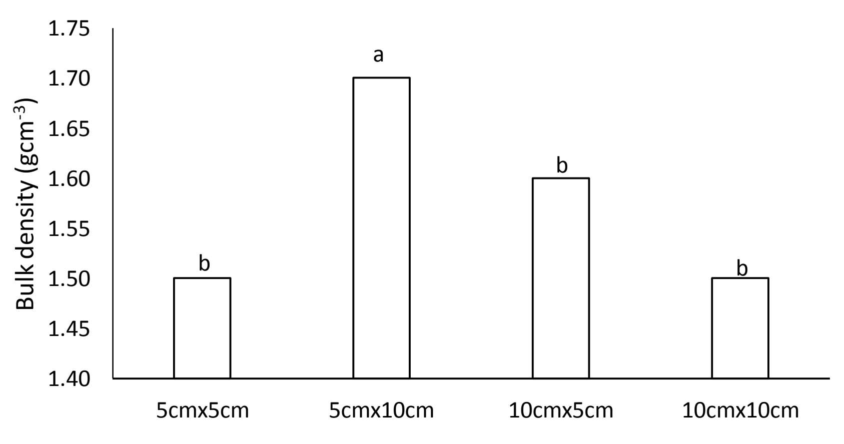

Fig. 1: Effect of Core Size on Bulk Density

Effect of Depth of Measurement on Bulk Density

The bulk density values generally increased with depth (Fig. 2). This has been reported severally (Mbonu 2003, Mbonu and Opara-Nadi 2008, Kamalu and Orji 2018 and Orji and Amaechi 2019). The 0-10cm depth had an average value of 1.5 gcm^{-3}, differed from that of the 10-20cm and that of 20 -30cm (P>0.05). Generally, the bulk density at the different depth were not high. This could be as a result of improvement on soil structure with the fallow period. The values are in conformity to the SSSA bulk density values for loamy sandy soils

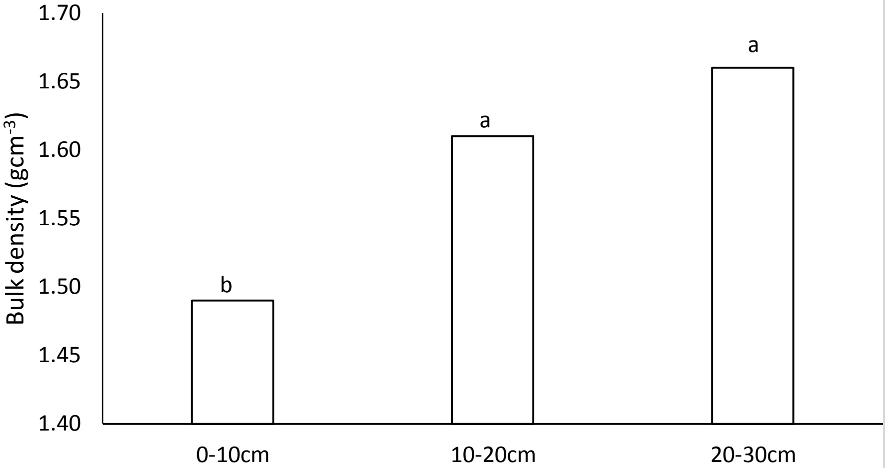

Fig. 2: Effect Of Depth of Measurement On Bulk Density

Effect of Moisture Content on Bulk Density

The moisture contents at the time of sampling for the various times and depth is as shown on Table1. The low moisture content (MC1) ranged between 0.080 to 0.097gg^{-1}, the medium moisture content (MC2) ranged between 0.133 to 0.155gg^{-1} and high moisture (MC3) ranged between 0.168 to 0.179gg^{-1} across the three depths. Moisture content generally increased with depth.

The effect of varying moisture content on bulk density is as shown on Fig.3. The values also ranged between 1.5 to 1.7gcm^{-3}. The highest value was recorded for the medium moisture content (MC2). The values of bulk density were not different when samples were collected at both the MC1 and MC3 but differed when collected at the MC2 content of determination. This suggests that moisture content will affect bulk density determination. On highly cultivated and clayey soils, bulk density of soil when dry and wet are usually higher than when moist. This has shown to be different for loamy sand which are more loose than clayey soils.

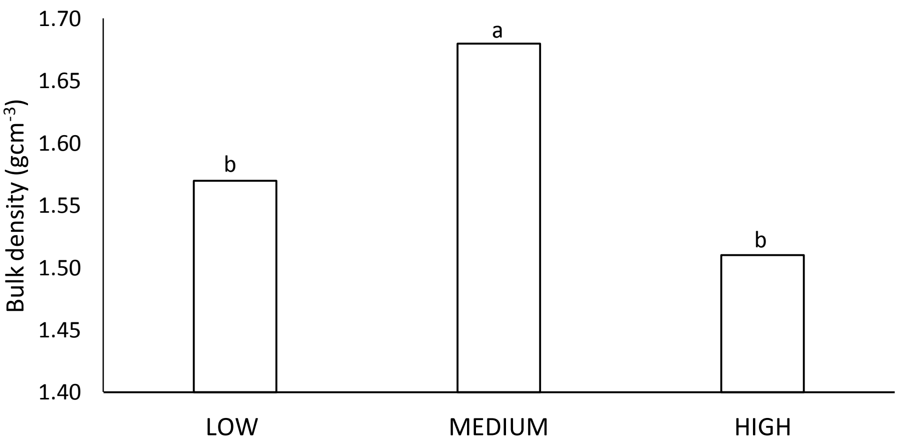

Fig. 3: Effect of Moisture Content on Bulk Density

Effect of Core Size and Moisture Content on Bulk Density

For all core sizes, bulk density values increased with moisture content (MC1 and MC2) but reduced at the highest moisture content - MC3 (Fig.4). For all core sizes bulk density of soils at the MC2 had the highest value (1.6, 1.7, 1.8 gcm^{-3}) except for the 10cm x 10cm core (1.5 gcm^{-3}).

Results also showed that at the highest moisture content of measurement, the bulk density value was the same for all core sizes, with a value of 1.5 gcm^{-3}. This suggests that sampling soil at moisture contents between 0.080 and 0.141 gg^{-1} gave relatively same bulk density values, while sampling at Moisture contents greater than 0168gg^{-1} gave lower bulk density values irrespective of core size.

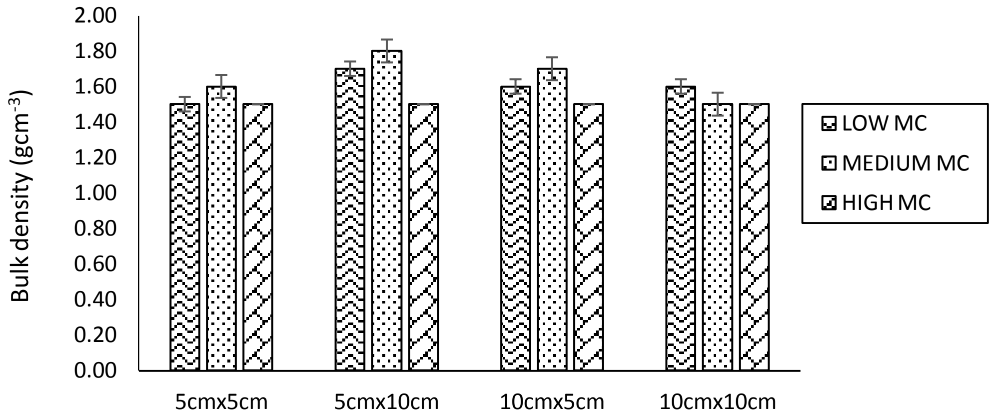

Fig. 4: Bulk Density as affected by Core Size and Moisture Content

Effect of Moisture Content and Depth of Measurement on Bulk Density

For all moisture contents MC1, MC2 and MC3, the bulk density values increased with depth; except for the high MC which remained the same for all depths (Fig. 5). There are previous reports that bulk density values generally increase with depth; as earlier mentioned in this discuss. This suggests that sampling for bulk density for this loamy sand textured soil, at moisture content higher than 0.141gg^{-1}, may give a misleading value.

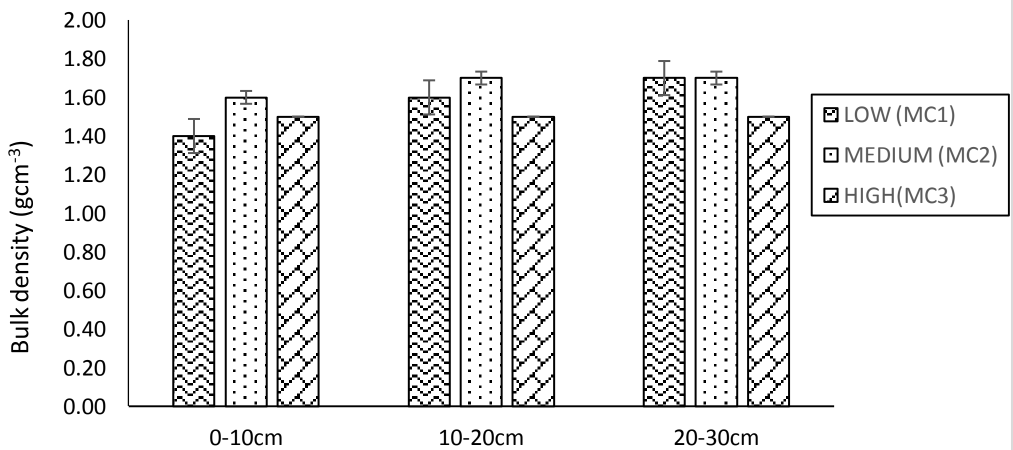

Fig.5: Bulk Density as Affected by Moisture Content and Depth

Effect of Core Size and Depth of Measurement on Bulk Density

The 5cm x 10cm core (C2) generally gave the highest bulk density values at all depths of measurement. The bulk density value with the C2 was 1.8 and 1.7gcm^{-3} at the 10-20cm and 20-30cm respectively and 1.5$gmcm^{-3}$ at the 0-10cm depth. These values were significantly different from one another ($P<0.05$).

All the other core sizes gave bulk density values that were not significantly different at the three depths of measurement.

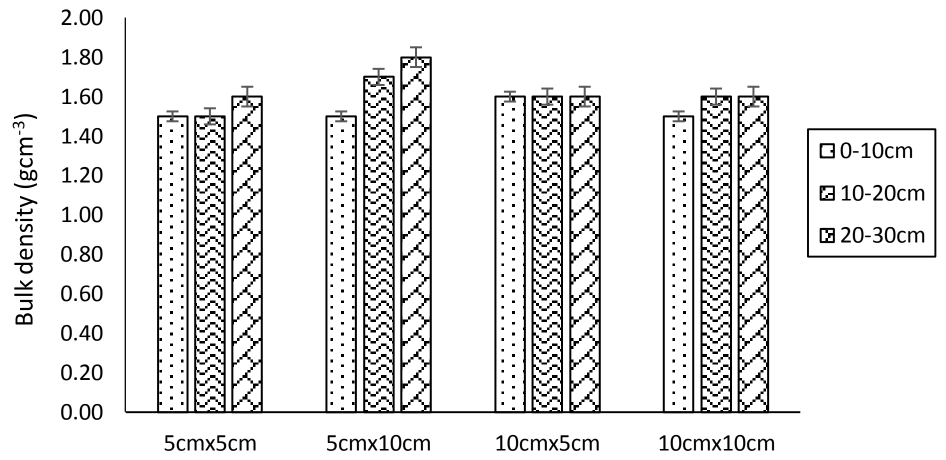

Fig.6: Bulk Density as affected by Core Size and Depth

Combined effect of Core Size, Depth and Moisture Content on Bulk Density

The combined effect of core size, moisture content at time of sampling and depth of determination is as shown on Table 2. At the highest moisture content (MC3), there were generally, no significant differences in bulk density values for all core sizes and at all depths. The trend was different with the medium moisture content (MC2). Here bulk density values varied with depth and core size. The 5cmx10cm (C2) core size had the highest bulk density values at all depths with values 1.70, 1.86 and 2.03gcm^{-3} for the 0-10, 10-20 and 20-30cm depths. At the low moisture content (MC1), all core sizes gave relatively similar bulk density values at similar depths; except for C2.

Table 2: Combined effect of Core Size, Depth and Moisture Content on Bulk Density

Core size	Bulk Density								
	Low MC			Medium MC			High MC		
	0-10cm	10-20cm	20-30cm	0-10cm	10-20cm	20-30cm	0-10cm	10-20cm	20-30cm
5cmx5cm	1.37	1.53	1.66	1.50	1.53	1.66	1.53	1.53	1.53
5cmx10cm	1.62	1.85	1.86	1.70	1.86	2.03	1.45	1.51	1.61
10cmx5cm	1.50	1.56	1.63	1.50	1.74	1.69	1.46	1.54	1.48
10cmx10cm	1.48	1.58	1.64	1.44	1.55	1.58	1.44	1.53	1.51

IV. Conclusion

The core method is the most common method of measuring bulk density. This study has attempted assessing the effect of varying core sizes, moisture content and depth of determination on bulk density values.

The results show that core size will affect the volume of soil used in determination of bulk density. However, the dimension of height to diameter of core used affected soil bulk density data not the volume of soil collected. The 5cmx5cm (C1) and the 10cmx10cm (C4) gave similar values, while the 5cmx10cm gave values that were quite significantly higher than the other sizes. Bulk density values, generally increased with depth, except for samples taken at the high moisture content (MC3). The moisture content at the time of determination significantly affected bulk density values. The were no differences in bulk density values, when samples were taken at the high moisture content (MC3), across all depths and core sizes used. Results also showed that bulk density values were of samples collected at the medium moisture content (MC2) were significantly higher than the other moisture contents.

Except for C2, all the other core sizes gave relatively similar bulk density values at the low moisture content (MC1). The MC1 with core sizes that have relatively proportional height and diameter proportions are therefore recommended for sampling for bulk density.

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