Effect of Soil Characteristics on Plant Growth and Productivity in Nsukka Agro-Ecological Zone of Nigeria

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Abstract

Soil structure affects plant growth in many ways. Roots grow most rapidly in very friable soil, but their uptake of water and nutrients may be limited by inadequate contact with the solid and liquid phases of the soil. This contact is much more intimate in hard soil but then the growth of the roots is strongly inhibited so that their foraging ability is poor and the plant may eventually become short of water or nutrients. Experiments were conducted in Department of Soil Science, University of Nigeria, using soil samples of disturbed and undisturbed cores collected randomly from three communities in Nsukka agro-ecological zone of Nigeria. The purpose of this study is to determine the infiltration rate, hydraulic conductivity, bulk density, porosity, aggregate stability, mean weight diameter, weight of sand and state of aggregation of the study area. The result of the study indicates that sandy soil areas are generally poor in their ability to retain water. As a result, it may not be suitable for good vegetal growth due to moisture stress. The soils of the area generally had very high porosity and permeability. Irrespective of the clay soil found in some parts of the study area which resist erosion and encourage plant growth, the aggregate stability of the area is generally low. However, many soils, even if hard, contain continuous macropores that provide niches for the roots to grow in. Soil structure not only affects the ability of roots to grow and to supply the leaves with water and nutrients; if adverse, it also induces them to send hormonal signals that slow the growth of the shoot, even if they are currently able to take up adequate water and nutrients.

Keywords: Soil Structure; Soil characteristics; Plant Growth; Farming Practices; Nsukka agro-ecological zone.

Introduction

Soil is a natural body consisting of layers (soil horizons) of mineral constituents of variable thickness, which differ from the parent materials in their morphology, physical, chemical and mineralogical characteristics (Devkota and Kumar, 2009). It is a mixture of mineral and organic constituents that are in solid, gaseous and aqueous state. Soils are made up of four basic constituent fractions comprising mineral matter, organic matter, soil water and soil air (Obi, 2000). The composition and proportion of these components greatly influence soil physical properties including soil texture, structure, porosity and the fraction of pore space in a soil.

Soil structure is defined as the physical constitution of a soil mineral as expressed by the size, shape and arrangement of the solid particles and associated voids, including both the primary particle to form compound particles and the compound particles themselves (Brewer and Steeman, 1960). Soil structure is determined by how individual soil granules clump or bind together and the arrangement of soil pores between them. It has a major influence on water and air movement, biological activity, root growth and seedling emergence. It is dependent on: what the soil developed from; the environmental conditions under which the soil formed; the clay present; the organic materials present; and the recent history of management. Charman & Murphy (1998) considered soil to be of good structure, from an agricultural perspective, when it is of "an aggregated, low density/high porosity condition".

Aggregation of primary soil particles is a critical determinant of soil structure. Other factors important in considering soil structure are: the stability of aggregates under wetting and drying conditions; the stability of aggregates to physical disturbance; the fabric and nature of the aggregates; and the profile form (referring to variation in the layers throughout the soil profile).

Agricultural practices in the humid tropics generally involve the destruction of vegetation by clearing the land for cultivation and by forest fires. These activities cause great change to the physical characteristics of the soil with the dangers of erosion increasing with increased destruction of vegetation and thereby affect the rate of plant growth and productivity (Mba, 2006). Intensive tillage on sloping land within the study area results in severe erosion. With continued erosion, tillage implements mix the subsoil material with the surface layer, reducing both the organic content and aggregation. Because of differences in the amount of residue and the intensity of tillage, different tillage systems affect the physical properties of the soil, such as water content, bulk density, penetration resistance, surface runoff, and volume of leachate and soil porosity. Changes in soil physical properties also might be expected to develop slowly after the initiation of conservation tillage. Tillage loosens the soil and decreases soil bulk density and penetration resistance by increasing soil macro porosity (Hussain, Olson and Siemens, 1998).

Traditional agricultural practices in Nsukka agro-ecological zone have generally caused changes in soil structure which have compromised aggregation and porosity. This is usually termed soil structure decline. Charman and Murphy (1998) proposed two categories of soil structure decline: cultivation and irrigation. Soil structure will decline under most forms of cultivation – the associated mechanical mixing of the soil compacts and sheers aggregates and fills pore spaces; it also exposes organic matter to a greater rate of decay and oxidation (Young & Young, 2001). A further consequence of continued cultivation is the development of compacted, impermeable layers or pans within the profile. Soil structure decline under irrigation is usually related to the breakdown of aggregates and dispersion of clay material as a result of rapid wetting.

The study of soil physical characteristics is very important in agriculture. More emphasis is usually paid to the chemical fertility of the soil than to its physical state.

Akamigbo (2000) noted that this is not enough since the physical state of the soil is very important in the response of the soil to types of manipulation. For instance, the size, shape and arrangement of the soil particles and the associated voids determine the ability of the soil to retain water and in turn, these arrangements affect air and water movement in the soils and thus, the soils ability to function (Bouma and Brown, 1982).

In Nigeria, the food security campaign has always been a priority of all Nigerian governments. Consequently, agricultural policies and strategies have been established to achieve self-sufficiency in long and short run (FAO, 1996). United States Department of Agriculture (USDA) (2008) stated that with rapidly growing population, there should be the need for an improvement in farm technologies in order to meet up the demand of the teeming population. There should be a conscious study of the physical characteristics of our soils before embarking on agricultural practices.

A number of studies have been carried out on the physical properties of soil but only very few dwelt on the structural state of the soil. For example, Obi (2000), who worked on soil physics, stated that the rate of water movement into the soil and the rate of advance of the wetting from within the soil depended primarily on the porosity characteristics, nature of the soil mineral and organic constituents of the soil. Wynne, et al (1978) in their study on variability of bulk density of soil in an irrigated field reported that the higher the bulk density, the more compacted the soil and the lower the pore spaces. Igwe and Agbatah (2008) worked on clay and silt dispersion in relation to some physiochemical properties of derived savannah soils under two tillage management practices in south eastern Nigeria and stated that soil properties which have significant role in soil formation are the oxides of Fe and Al including exchangeable cations.

It is evident therefore from the above studies that research exists in soil physical characteristics in Nigeria but none dwelt on the strength of relationship between the structure of the soil and plant growth and productivity in Nsukka area in Nigeria, which then necessitates this study. A study on the structural stability and productivity of the soil is very important because soil structure according to Bouma and Brown (1982) governs the retention and movement of water in the soil as well as the transport of dissolved components (fertilizers, pesticides, and so on) in the soil water and so affect soil productivity. For these reasons, the objectives of this study are to; (a) determine the physical properties of soil in the study area; (b) determine the strength of the relationship between soil structural stability and plant growth and productivity in the study area; and (c) recommend proper cultivation techniques to balance the stability of the soil so as to enhance plant growth and productivity.

Materials and Methods

The study area

The study area is Nsukka area of Enugu State, Nigeria. It falls within the environment described by Ofomata (1985) as lying on the North-South Nsukka-Okigwe cuesta with a `back` deep slope that forms the Nsukka plateau. It lies between longitude $7^0 20^1$E and $7^0 29^1$E and latitude $6^0 54^1$N and $7^0 00^1$N (Fig 1). The area is predominantly made up of sedimentary formations which fall into two main groups; the Ajali sandstone and Nsukka formation (Reyment, 1965). The general relief of the study area is rugged, which is part of the Udi-Nsukka plateau of the Nsukka-Okigwe cuesta, where remnants of the “African” planation surface are represented by summits of the residual hills (Ofomata, 1985). It has a tropical wet and dry (Aw type) climate according to Anyadike (2002). Approximately 89 per cent of the annual rainfall of (1, 750mm) falls in the months of April to October. The rains come in form of torrential down pours, which not only aid the incidence of soil erosion but also negatively affect crop yield. Temperatures are uniformly high with a mean annual temperature of about 26^0C. The soils in the study area fall within the broad category of ferrallitic soils described as oxisols. The soil on the hilltops is characterized by a high content of pisolitic iron stone gravel with an average diameter of 1.25 cm to 2.5cm, while finer material is scarce (Igwe, 1984). The main occupation of the inhabitants of the study area is agriculture which is characterized by bush burning.

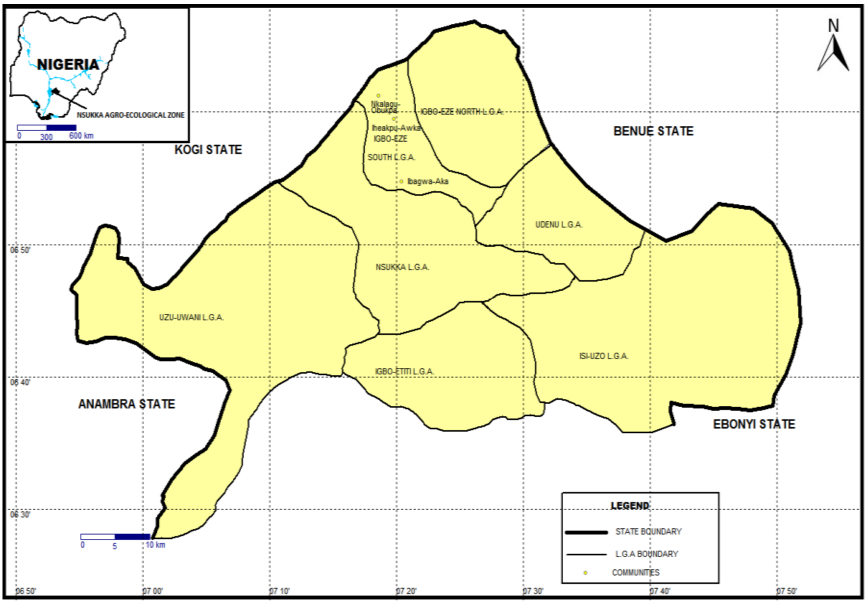

FIGURE 1: MAP OF NSUKKA AGRO-ECOLOGICAL ZONE SHOWING THE SAMPLE LOCAL GOVERNMENT AREA AND THE SELECTED COMMUNITIES
SOURCE: *ENUGU STATE MINISTRY OF TOWN PLANNIG*

Sample Collection and Analysis

One sample of undisturbed core and disturbed soil each were collected from three communities namely; Ibagwa-Aka, Iheakpu-Awka and Nkalagu-Obukpa in the study area (See Fig 1). These soil samples were taken to the University of Nigeria, Nsukka Soil Science Laboratory for analysis. The undisturbed core soil was covered with calico cloth and saturated with water for 24 hours and weighed to determine the saturation weight.

The soil samples were oven dried at 105^{0}C for 24 hours and weighed to determine the oven dried weight. When the saturation weight is subtracted from the oven dried weight, then the amount of water loss is determined.

To determine the volume of the soil, the soil was brought out of the core and weighed. The mass of the soil inside the core was determined by the weight of the empty core. The core parameters were used to find out the volume of the core. This was done by multiplying the height of the core by the diameter of the core using the equation below.

Volume $= \pi r^2 \mathrm{h}$ .... (1)

Where π is a constant (22/7); r^2 is 1/2 the diameter of the core and h is the height of the core.

Parameters Investigated

Infiltration rate: The infiltration rate was measured by means of double-ring infiltro-meter that was thrust into the soil with 7.5cm of the height exposed to the surface. The time it took the 6cm level of water to penetrate the soil profile was recorded. This experiment was repeated until constant values were obtained. These were used to determine infiltration rates.

Hydraulic Conductivity: The undisturbed core soil sample were saturated in pan of water for 24 hours and weighed. The core samples were also subjected to tension of 60cm. It was oven dried for 105^{o}C and weighed. The moisture at 60cm tension, saturation weight and oven dry weight were also determined. The hydraulic conductivity was calculated using Simmons (2008) equation after Darcy's (1857) transposed equation as shown below:

$$Ks = \frac{Qe}{S(H+e)}$$

.... (2)

Where ks is saturated hydraulic conductivity, Q is volume of water collected per unit area; e is the thickness of soil bed in cm; S is the area of soil bed in cm^2 and H is water head in cm. The hydraulic conductivity (Ks) for each of the communities was used to determine the permeability class of each soil sample.

Bulk Density: The undisturbed core soil sample that was used to determine the hydraulic conductivities were oven dried at temperature of 105^{0}C for 24 hours. The bulk density for each of the segments was determined using the Simmons (2008) equation as shown below:

$$\text{Bulk density} = \frac{Mass\ of\ oven\ dry\ soil\ (g)}{Volume\ of\ oven\ dry\ soil\ (cm^3)}$$

.... (3)

Porosity: To determine the total porosity, the bulk density was divided by the particle size density (which is a constant of 2.65) and subtracted by one, then the answer was multiplied by 100. This was done using the following formula (Simmons, 2008):

$$\text{Total porosity} = 100\left(1 - \frac{BD}{PD}\right) \quad \text{............................ (4)}$$

Where BD is the bulk density and PD is the particle density.

Aggregate Stability: Two disturbed soil samples were collected randomly from the three locations in the study area. Among the two soil samples collected from each community, one was near the erosion site (NES) and the other, was far from the erosion sites (FES). The choice of collection was dictated by common sense. Soil samples were taken to the University of Nigeria, Nsukka Soil Science Laboratory for analysis.

The soil samples were passed through a set of sieves within the range of 2mm to 0.25mm. 25gm of the soil sample was weighed from 2mm sieve. Samples in 1mm, 0.5mm and 0.25mm was soaked in water for 5minutes. They were oven dried and weighed to determine the fractions of soil as if there was a normal rainfall. The values under 0.25mm to 2mm was summed up and subtracted from 25gm to get the values under < 0.25mm.

Mean Weight Diameter: To get the average, the formula is shown below:

$$\text{Average} = \frac{Value\ Difference}{25\ (total\ weight)} \times 3.375\ \text{(Mean) .... (6)}$$

The summation of the averages will give the mean weight diameter (M W D).

Weight of Sand: The soil samples from 2mm to 0.5mm was collected and soaked in 0.1Normal sodium hydroxide for 24 hours. After soaking, it was passed through 0.5mm sieves, the remainder were collected, oven dried and weighed to determine the weight of sand.

State of Aggregation and Aggregate Stability: The state of aggregation and aggregate stability was determined using the following formula (Simmons, 2008):

$$\text{State of aggregation} = \frac{2-0.5-wt\ of\ sand}{25\ (total\ weight)} \times \frac{100}{1} \quad (7)$$

$$\text{Aggregate stability} = \frac{2-0.5-wt\ of\ sand}{25-wt\ of\ sand} \times \frac{100}{1} \quad (8)$$

Data analysis

Simple regression and correlation analysis were carried out to obtain the strength of relationship between soil characteristics and plant growth and distribution.

Results and Discussion

The summary of the particle size distribution are presented in table 1. From the result obtained, it is apparent that sand is the particle size fraction. Except for Nkalagu Obukpa where clay was discovered around Aku area. The sandy nature of the soil observably might have been derived from the type of parent material present. The findings of Jungerius (1964) adding support to the above result, observed that soil around Nsukka were deep, porous red soil derived from sandstone deposits. As in Ibagwa Aka and Iheakpu Awka area, the soil textural class significantly influences plant growth and consequently crop yield. A soil that is predominantly sand as in the case of Ibagwa Aka tends to be highly susceptible to erosion because of lack of cohesion and does not encourage plant growth. This is why soils around Ngwo-Adada in Ibagwa-Aka area could be easily detached and transported. It could be inferred that, the widespread sheet and rill erosion all over the study area as well as low crop yield might be attributed partly to the sandy nature of its soil as observed in the six soil samples (Antwi, et al, 2000, Ezechi, 2000)).

Benneth, Casali, Robinson and Kadary, (2002) observed that soils with moisture content causes an increase in erosion rate and thereby reduction in crop yield while Jankauska (1998), reported that a decrease in field capacity especially in severely eroded slope would consequently bring about reduction in soil fertility. Sandy soils are generally poor in their ability to retain water. As a result, it may not be suitable for good vegetal growth due to moisture stress. The role of vegetal growth on erosion control has been thoroughly reviewed by researchers such as Mba (2006); Descroix, Digonnet, Gonalez Barries,Viramontes and Bollery (2002) and Gobin, Campling, Poesen, Deckers and Feten (2002).

Table 1: The particle size distribution and textural class of the study area.

Study Area	% Clay	% Silt	Total Sand % T.S.	Fine Sand % F.S.	Coarse Sand % C.S.	Textural Class T.C.
Ibagwa- NES Aka FES	23	4	72	19	53	Sandy clay loam SCL
	16	2	82	21	61	Sandy loam SL
Iheakpu- NES Awka FES	14	2	84	18	66	Sandy loam SL
	20	4	76	19	56	Sandy loam SL
Nkalagu- NES Obukpa FES	54	13	32	28	5	Clay C
	36	7	56	29	29	Sandy clay SC

(NES means **N**ear **E**rosion **S**ite, FES means **F**ar from **E**rosion **S**ite)

The result of the hydraulic conductivity and porosity analyses are presented in Table 2. The data indicated that hydraulic conductivity of the three communities vary, while Ibagwa-Aka is 36, Iheakpu-Awka is 35 and Nkalagu-Obukpa is 134. This could be due to the textural differences. A soil which is high in sand or has low clay content (Nkalagu-Obukpa in the sample area) is bound to have a high hydraulic conductivity value (Raymond, Miller and Roy, Donahue, 1995). Therefore, soil samples with high amount of sand content had higher hydraulic conductivity values relative to other soil samples.

Table 2: The Hydraulic Conductivity and Porosity of the study area

Study area	Hydraulic conductivity	Bulk density	Porosity	Kcm/hr
Ibagwa-Aka	36	1.41	46.79	24.44
Iheakpu-Awka	35	1.44	45.66	23.76
Nkalagu-Obukpa	134	1.62	61.13	90.98

The porosity derived from the hydraulic conductivity determination indicated that for the soil samples, the porosities were generally high. For instance, Ibagwa-Aka has 46.79, Iheakpu-Awka has 45.66 and Nkalagu-Obukpa has 61.13. These values indicate that the soils generally had very high porosity and rapid permeability (Table 2).

Although higher porosity and permeability entails increased water percolation, the textural class of the soil coupled with poor vegetation and other anthropogenic activities may induce or aggravate erosion which will consequently affect the yield of crops. For instance, within Ngwo-Adada area of the study area and even other areas within the sampled communities (Table 3)

The result for the aggregate stability of the area indicates low resistance to erosion processes such as detarchment and runoff (NES, FES) (Table 3). Irrespective of the clay soil found at Nkalagu-Obukpa which supposes to resist erosion and encourage plant growth, the aggregate stability of the communities is generally low. This indicates that coupled with the textural class, the soil of the study area can not resist erosion processes, thereby leading to increase in the erosion rate which in turn reduces the yield or growth of plants. Observably, therefore, strength and stability are necessary if soil is to retain its structure against imposed stresses. These imposed stresses may be natural such as raindrop impact, or may be anthropogenic such as those imposed by vehicular traffic (Dexter, 1996).

Table 3: The aggregate stability of study area

Study area	2mm	1mm	0.5mm	0.25mm	< .25	Mean weight diameter (MWD)	State of aggregation	Aggregate stability
Ibagwa-NES	01.3	4.06	4.76	8.71	9.34	0.4613	12.04	14.26
Aka FES	0.12	4.93	4.68	6.96	8.31	0.59799	16.88	21.65
Iheakpu-NES	1.18	3.86	4.47	7.55	8.94	0.54795	15.28	18.81
Awka FES	0.30	3.86	4.38	7.22	9.24	0.558	16.76	20.29
Nkalagu-NES	13.57	2.72	1.20	1.14	6.37	2.0801	27.6	57.69
Obukpa FES	0.17	1.23	5.84	9.55	8.21	0.45625	27.60	27.98

Table 4 below shows correlation coefficients for the linear relationship between some structural features and plant growth and distribution. Simple regression and correlation analysis as described by Obi (2000) were used to estimate the strength of relatedness between some soil structural features and plant growth and distribution.

Table 4: Shows the correlation coefficients for the relationship between some soil structural features and plant growth and distribution.

Variables	Y1	Y2	Y3	Y4	Y5
X1	-0.63*	-0.63*	-0.41	-0.19	-0.42
X2	0.23	0.42	0.66*	0.46	0.35
X3	0.85*	0.80*	0.65*	0.71*	0.42
X4	0.82*	0.75*	0.51*	0.67*	0.78*

Y1 = Hydraulic Conductivity
Y2 = Total Porosity
Y3 = Plant Growth
Y4 = Plant Distribution
Y5 = % of water at saturation
* = Significant at 5% level

X1 = Bulk Density
X2 = Mean Weight Diameter
X3 = Aggregate Stability
X4 = Organic Matter Content

The correlation coefficients of the relationship between some soil structural features and plant growth and distribution indicates that bulk density (X1) had a negative correlation with hydraulic conductivity (Y1); porosity (Y2); moderately negative correlation with plant growth (Y3); percentage of water at saturation (Y5) and very low negative correlation with plant distribution (Y4). This means that as the density of the soil increases as a result of compaction, the ease with which water move through pore spaces (hydraulic conductivity) greatly decreases and the pore spaces in the soil also decreases (aeration, porosity). This in turn moderately affects the percentage of water at saturation in the soil with the result that plant growth decreases and plant distribution minimally also decreases.

Also, the mean weight diameter (X2) had a strong positive significant correlation with plant growth (Y3); moderate positive significant correlation with total porosity (Y2); plant distribution (Y4); low positive significant correlation with hydraulic conductivity (Y1) and percentage of water at saturation. Furthermore, aggregate stability (X3) correlates positively and strongly with the hydraulic conductivity, porosity, plant growth and distribution but had a moderate positive significant correlation with percentage of water at saturation. This means that as the ability of the soil aggregates to resist degradation increases, the ease with which the water move through pore spaces and the measure of pore spaces in the soil highly increases. The result is that plant becomes more balanced to absorb water from the soil which leads to increase in plant growth, plant distribution and also the percentage of water at saturation. The correlation was significant ($P = 0.05$).

Organic matter content (X4) had a strong positive significant correlation with hydraulic conductivity, total porosity, plant growth and distribution as well as percentage of water at saturation. This means that as the organic matter content increases, movement of water through pore spaces and the measure of pore spaces highly increases. This leads to increase in plant growth and distribution as well as increase in percentage of water at saturation.

The importance of improving soil structure

The benefits of improving soil structure for the growth of plants, particularly in an agricultural setting include: reduced erosion due to greater soil aggregate strength and decreased overland flow; improved root penetration and access to soil moisture and nutrients; improved emergence of seedlings due to reduced crusting of the surface and; greater water infiltration, retention and availability due to improved porosity.

Summary and conclusion

The effect of soil structure on plant growth and distribution was studied. The arrangement of soil particles and associated voids determined the ability of a soil to retain water and fertility and in turn, these arrangements affected plant growth and distribution in the soils studied. The variations in the textural classes of the soils studied resulted in the differences in their hydraulic conductivities.

Bulk density had little effect on the changes in the structural pattern of these soils. Variations in porosity, organic matter content and aggregate stability resulted in changes in the structural pattern of the soils, which consequently affected the water holding capacities, plant growth and distribution as well as the hydraulic conductivities of the studied soils.

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