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Effects of land use on some structural properties of an Ultisol in south-eastern Nigeria

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A b s t r a c t. Four land use practices were investigated for their differences in soil structural properties. The land use types are native forest, grassland, oil palm/cocoyam and arable land. Structural parameters as bulk density, total porosity, water stable aggregates (WSA)> 0.25 mm, volumetric moisture content at field capacity (FC) and organic matter content. Structural properties which are affected by land use are total porosity, bulk density, and organic matter.

K e y w o r d s: structure, sustainability, porosity, aggregate stability, soil conservation

INTRODUCTION

In the Nsukka plain of south-eastern Nigeria, the farmers adapt some cultural methods in their land use system aimed at improving the soil structure to reduce the incident of soil erosion by water which is common in the area. Brewer [5] described soil structure as the physical constitution of solid soil as expressed by the size, shape and arrangements of soil particles and voids and its associated properties. Soil structure is a soil property which influences the mechanical properties of the soil, germination, root growth and soil erosion. According to Hillel [10] it is affected by changes in climate, biological activity and soil management practices. Grieve [8], Hewitt and Dexter [9] have discussed the influence of manures, fertilizers, tillage, and cropping system on soil structure. Aborisade and Aweto [1] compared the effects of some exotic tree plantations on the soil properties in south-western Nigeria. Blum and Rampazzo [4], Rampazzo *et al.* [14] showed the relevance of mineralogy and Fe-oxide in the development of soil structure.

Also in the Kangara District of India, Sharma and Aggarwal [15] assessed the structural status of soils under different land uses and observed their differences with variations in management. The soils of the Nsukka area of south-eastern Nigeria are loose and highly weathered but they support intensive agricultural activities in the agroecological zone. Some other problems which could result in low productivity can be ameliorated through the application of both organic and inorganic fertilizer but structural and other physical limitations can only be ameliorated through proper management practices.

The objective of this study was to examine the structural status of soils within the experimental farm of the University of Nigeria, Nsukka, in south-eastern Nigeria under four land use managements. These land use options are native forest land, oil palm (*Elaeis guineensis* Jacquin) inter-cropped with cocoyam (*Cocorus esculenta* L. Schott), fallow grass land and arable land. The aim was to set useful guidelines for the proper utilization and management of the soil for sustainable productivity. Native forest land use is the best land use for the promotion of better soil structure, while arable land use is the least in terms of structural development and stability. In the event of rapid deforestation due to limited land for agriculture, alley cropping may be a better alternative to native forest. Well managed agro-forestry is recommended for proper soil management and the sustainability of agricultural production in the area.

MATERIALS AND METHODS

Location of the investigated soils

The study was conducted at the University of Nigeria, Nsukka experimental farm. The location corresponds approximately to longitude 7°20' East and latitude 6°45' North. The mean annual rainfall is 1700 mm of a heavy intensity and the mean annual temperature is 24°C. The original vegetation was rainforest but as a result of massive deforestation,

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grasses and dwarf hardy shrubs including the fire resistant species have dominated the vegetation leading to deprived savanna condition [12]. Remains of the old rainforest still persist in patches.

The soil is a Typical Kandiustult (USDA) or Ferric Acrisol - sub-group level of order Ultisol (FAO) [11] and has developed mainly from False-bedded Sandstones. It is a loamy sand to sandy-clay loam and is well drained. The dominant minerals are kaolinite and Fe-oxide in the form of hematite. The soils are deep, reddish and well drained. The soils are low in organic matter and low in plant available nutrients due to losses caused by leaching as a result of high rainfall (Table 1).

Four major land uses common in the experimental farm were selected for studies. Soils selected for sampling have been under land use for not less than 10 years. The land use selected were (a) native forest referred to as forest, (b) fallow grass land, (c) land use under arable agriculture and (d) land use under palm oil plantation and cocoyam undergrowth. These are the most common land uses of the area.

In each land use, 10 samples were taken at 0-20 cm depth. All the land uses were located at the same soil series (Nkpologu series), topographically similar areas (2% slope) and at the same time.

Laboratory analyses

Soil samples collected were passed through a 2 mm sieve and the fine earth fraction was taken to the laboratory for analysis. Particle size distribution was determined using the method described by Day [7]. Bulk density was measured using the Blake [3] method. The undisturbed core samples trimmed to the exact level of the cores, were weighed, oven dried at 105°C and reweighed. Dry bulk density was calculated using the constant weight and the total volume determined. Porosity was calculated from the samples using the method described by Vomocil [17]. Particle density was calculated by the pycnometer method of Blake [3]. Water-stable aggregates > 0.25 mm were determined by the Kemper and Chepil [13] method. Moisture content was measured by the gravitational technique.

Organic carbon was determined by the Walkley-Black method as modified by Allison [2]. The percentage of organic matter was calculated by multiplying the organic carbon value by the conventional 'van Bernmelen factor' of 1.724. Each parameter was compared statistically among the four land uses with LSD at a 5% confidence interval.

RESULTS AND DISCUSSIONS

Bulk density

Table 2 shows, inter-alia, the mean values of the bulk density of soils of different land use options. Soils of the arable land use have the highest mean value of 1.83 Mg m^{-3} and soils of native forest land use yield the lowest mean value of 1.58 Mg m^{-3}. The higher bulk density value could be attributed to compaction and structural degradation. The overall effect of higher bulk density is undesirable in modern agriculture because it affects root penetration, restricts drainage and aeration and thus exposes roots to several simultaneous stresses. According to Taylor *et al.* [16] where the soil is highly compact and rigid, root growth may be confined almost entirely to cracks and cleavage planes. In this study there is a significant difference between the mean bulk density values of the four land uses (at p = 0.05) thus: arable land use > oil palm/cocoyam > grass land > forest land use. Rampazzo *et al.* [14] observed that bulk density is a good structure parameter but do not give information on the geometry and continuity of the pore system.

Table 1. Some general characteristics of the soil studied at 0-20 cm depth

Soil property	Minimum	Maximum	Mean
Clay (%)	21	42	32
Silt (%)	1	7	3
Sand (%)	54	78	68
pH	3.8	5.6	4.8
Organic matter (%)	0.31	3.2	2.5
CEC (cmol kg^{-1})	2.5	9.0	5.6
Base saturation (%)	28	55	33
Dominant mineral	Kaolinite		

Table 2. Bulk density, particle density and total porosity of the investigated soils at 0-20 cm depth

Land use	Soil structural properties		
	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Total porosity (%)
Forest	1.58 (0.13)	2.50 (0.19)	37.0 (9.0)
Oil palm/ Cocoyam	1.78 (0.13)	2.70 (0.43)	33.0 (6.5)
Grass land Fallow	1.69 (0.11)	2.59 (0.28)	37.0 (12.4)
Arable	1.83 (0.13)	2.60 (0.53)	30.0 (6.4)
LSD (0.05)	0.12*	NS	3.1*

Values in parenthesis are variations ± from the mean, * - significant at $p<0.05$, NS - not significant.

Total porosity

The total porosity of the soils ranged between 30 to 37 % (Table 2). Higher bulk density showed a decrease in the total porosity. The higher total porosity of soils under forest land use than that found in of oil palm/cocoyam and arable land, could have been as a result of the increased faunal activity observed mainly in forest and grass land use. The lower level of earthworm activities observed under arable land use is attributable to constant ploughing and structural degradation thus influencing the porosity of the soils. The thick dense grass root system not only improve aggregation within a larger soil volume but also improves aeration of the soil and thereby provides an environment conductive to fauna.

Tillage and cultivation may have been the cause of reduced total porosity in the arable soil which has the lowest average total porosity. Rampazzo *et al.* [14] showed that ploughing increases compaction within the ploughed layer and destroys mainly the 'secondary' pore system.

Particle density

The particle density followed the trend of the bulk density, but showed no significant difference among the four land use options being considered. Particle density is considered as a function of soil mineralogy and is independent of the land use types. The implication of this result is that particle density has no effect on the soil structural development with respect to the land use management studied.

Water-stable aggregates (WSA > 0.25 mm)

The percentages of water-stable aggregates (WSA > 0.25 mm) shown on Table 3 indicate that the mean value is highest in grass land use followed by forest land use while the oil palm/cocoyam and arable land uses were lower. The higher WSA in forest land use was a result of the higher organic matter accumulation in the soils of this land use option. Soil organic matter (SOM) is a well known soil binding agent which improves soil structure and is always desirable especially in low input agriculture. Also the WSA in grassland land use option was higher than that of oil palm/cocoyam land use, thus confirming the earlier observation made on oil palm/cocoyam land use as a soil conservation method. Earlier Sharma and Aggarwal [15] obtained higher percentages of WSA > 0.25 mm values in land use under tea and forest than in land use under grass land and arable cultivation were obtained earlier [15].

Moisture content

The volumetric moisture content at field capacity (FC) increase in this order; arable land use > oil palm/cocoyam > grassland > forest land. Although not statistically significant, some deduction could be made on the mean values of

T a b l e 3. Water-stable aggregate (WSA > 0.25 mm) moisture content and organic matter contents of the soil of various land use (0-20 cm depth)

Land use	Soil structural properties		
	WSA > 0.25 mm (%)	Moisture content (FC) (%)	Org. matter (%)
Forest	81.1 (2.6)	37.0 (3.3)	3.6 (0.6)
Oil palm/ Cocoyam	77.1 (5.2)	39.0 (3.7)	2.9 (0.9)
Grass land Fallow	83.6 (3.5)	38.0 (4.1)	3.2 (0.9)
Arable	76.3 (3.6)	42.0 (3.2)	3.0 (0.5)
LSD (0.05)	4.6*	2.04*	1.1*

Explanations as in Table 2.

the moisture contents of soils of the four land uses. Although, the differences could be attributed to textural differences, the soil structure also plays an important part in the moisture content at field capacity level. According to Hillel [10], soil structure affects the shape of the soil-moisture characteristic curve, particularly in the low tension range.

Organic matter

The results show that the mean percentage of organic matter is significantly greater in the forest soil than in soils of other land uses (Table 3). This result is expected because of the intense litter recycling taking place in forest soils and grassland. In the case of arable land use there is a high utilization of organic matter by crops and a high mineralisation rate due to exposure to high temperature. Organic matter input is low in oil palm/cocoyam land use thus giving rise to the low organic matter content observed in the soil.

The desirability of organic matter with regard to structural development cannot be over emphasized. Hillel [10] observed that organic matter promotes aggregate stability by reducing wettability and swelling. Perhaps this explains the lowest volumetric moisture content at field capacity as recorded in forest land use soil.

Ranking of the structural indices

There is an attempt to rank the different land uses in order of structural quality (Table 4). In the ranking, 1 shows the best structure while 4 indicates the lowest structural quality. From the ranking, land uses in terms of structural

Table 4. Ranking land use in order of structural stability

Soil structural properties	Land use			
	Forest	Oil palm/ Cocoyam	Grassland	Arable
Total porosity (%)	1	3	2	4
Bulk density (Mg m^{-3})	1	3	2	4
WSA >0.25 mm (%)	2	3	1	4
Moisture content (FC) %	4	2	3	1
Organic matter (%)	1	4	2	3
Total	9	15	10	16
Overall ranking	1	3	2	4

1= best in terms of good structure, 4=least structured.

stability could be arranged in the following order, forest > grassland > oil palm > arable land.

The structural properties or indices which are good indicators in this assessment are total porosity, bulk density, and organic matter. The percentage WSA > 0.25 mm was moderate in the prediction while the volumetric moisture content was the lowest in the indices considered. In the study of Sharma and Aggarwal [15] bulk density and total porosity were the best indices in assessing the structural quality. However, Bryan [6] concluded that the efficiency of structural indices varied with the soil type. This means that the indices that did not predict well in the soil type studied may be of high predictive value in some other soil types and other climates.

From the soil management point of view, the information derived from this study is that modern farms in the area investigated should be based on a well managed agro-forestry system. The advantage of this system is that while the soil is conserved for environmental degradation, there is high organic matter input while fuel wood is being derived from the system. Alley cropping or other tested agro-forestry systems are recommended, otherwise trees that can bear food vegetables, fruits and seeds are also suitable. As an alternative, long grass fallows are suitable but the disadvantage of this system is that with the increase in human population in the agro-ecological zone, there is a greater need for more land to be cultivated for food. Therefore the second alternative is not sustainable.

CONCLUSIONS

The results show that total porosity, bulk density, particle density and organic matter content are good indices for predicting soil structural properties. The study indicates that native forest land use option is the best land use option for promoting a better structural development. To achieve this condition in modern agriculture it is recommended that well established agro-forestry systems such as alley cropping should be established in the area to increase biomass production and consequently better aggregate stability. This is due to the rapid increase in human population leading to a scarcity of prime land for agriculture, it is difficult to keep land fallow for a long period. Well established agro-forestry is both sustainable in terms of agricultural production and provides some basic needs for the environment.

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