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Full Length Research Paper

Assessment of effects of controlled land use types on soil quality using inferential method

Ande, O. T.[1]* and Onajobi, Jide[2]

[1]Institute of Agricultural Research and Training, Obafemi Awolowo University, Ibadan, Nigeria.
[2]Federal College of Agriculture, Moor Plantation, Ibadan, Nigeria.

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The experiment was carried out to study the effect of improved land use types on soil quality. Surface soils were collected from four land use types including: cowpea, pasture, gliricidia and secondary forest which were used as the control. The samples were subjected to physical and chemical analyses. The extent of change in soil quality was assessed using inferential method. The results showed that cowpea soil was most degraded while gliricidia improved the soil quality significantly in organic C content. The inferential method showed that the most degraded soil parameter was aggregate stability, which under cowpea was 75.3% degradation. Eight properties were higher in soil quality than the control under gliricidia. The properties include moisture content, %C, CEC with organic matter contributing the highest (42.3%) change in soil fertility. All the properties were inferior to secondary forest in bulk density, porosity and hydraulic conductivity. The improved land uses quality compared favorably with natural vegetation with exception of aggregate stability in cowpea plot. The order of soil quality improvement was gliricidia > pasture > cowpea.

Key words: Controlled land use types, soil quality, inferential method.

INTRODUCTION

Soil quality relates to "inherent attributes of soils that are inferred from soil characteristics" (SSSA, 1987) and refers to the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994). The following minimum data set has been proposed by Doran and Parkin (1996) for soil quality measurement: texture, depth of soil, infiltration, bulk density, water holding capacity, soil organic matter, microbial biomass C and N, potentially mineralizable N, and soil respiration. Others include gravel content, porosity, particle size distribution, available phosphorus, exchangeable bases, acidity and base saturation, pH and electrical conductivity. Soil quality can be categorized into soil physical properties and soil fertility. Soil's physical quality relates to the status of those physical properties that influence biomass productivity and the environment (Lal, 1994). Assessment of soils physical quality involves evaluating numerous properties, including bulk density, aggregation, infiltration rate, moisture retention, characteristics and pore size distribution, soil texture and structure, gravel content. The key properties that determine soils physical quality differ among soils and eco-regions (Lal, 1994).

Most areas of land previously developed from tropical rainforest have been degraded because of land misuse, adoption of productivity – mining, cultural practices and use of resource – based rather than science-based production systems. These entire phenomena affect the quality of soils. One of the biological means of restoring degraded soils is by improved fallow. Such include planting of leguminous tree like gliricidia (*Gliricidia sepium*) in agro forestry system (Kang et al., 1999). Gliricidia has ability to stabilize the soil for erosion control, for reclamation of land or land infested with noxious weed and it serves as good source of green manure. Nutrients mining and soil degradation are usually considered as problems in arable farms. Likewise many believe that pastures improve soil quality due to animal manure.

*Corresponding author. E-mail:funmiande@yahoo.com.

Research has also indicated the ability of gliricidia to improve soil quality. The use of green manure crops (e.g. cowpea) in a cultivation cycle is aimed at replenishing organic matter, at the same time adding any available nitrogenous materials and protecting soil during periods of high erosion hazard (Skerman, 1986). It is also used to protect the soil. Green manure crops increased fertility by mineralization of the annual leaf drop from the legume and accumulation of combined nitrogen through symbolic nitrogen fixation by nodules growing on the roots of the leguminous plants. Cover and green manure crops are often fertilized for vigorous growth so that extra organic matter may be plowed into the soil. Also the plant food requirements of legumes differ considerably from those of the grass because properly inoculated legumes can fix atmospheric nitrogen and it responds strongly to phosphorus in both seedlings of several legumes (Modison and Gilbert, 1986).

The soils of Institute of Agricultural Research Training (I. A. R. and T) have been under arable cultivation for more than 30 years. Conventional method of chemical fertilizer application had been considered to improve productivity on these soils but this had not been found effective in terms of soil physical qualities improvement. Controlled land uses and management practices are being considered to improve soil fertility. These include changes from maize cultivation to cowpea, pasture, alley cropping and use of legumes in soil improvements. The aim was to achieve sustainable land uses where good production is achieved and soil qualities are not degraded. There is a need to study the impact of these land use types to greater details. Therefore, the aim of this research was to assess effects of the controlled land use types on soil quality.

MATERIALS AND METHODS

Location of the study area

The study was conducted within the Institute of Agriculture Research and Training (I.A. R. and T), Moor Plantation, Ibadan, Southwestern Nigeria. The natural vegetation is transitional between the tropical rainforest and savanna, but most of which has given way to arable farming.

Climate

The climate of Ibadan transitional is between the humid and sub humid tropical, with an annual rainfall of 1,436.2 mm, with two peak distribution pattern (June and September) and 5 dry months in the year, mean temperature of 26.30°C with February and March as the hottest months; mean relative humidity of 75% and potential evapotranspiration (PET) of 109 mm (Moorman, 1975).

Geology

Acid pre-cambrian basement complex rocks underlay the study area. They consist mainly of granitic gneiss, migmatities, micashists, quartzites and marble that have emplaced within them smaller bodies of granite or syenite (CCTA/ CSA, 1961; Smyth and Montgomery, 1962; D'Hoore, 1964).

Field survey

Four different land use patterns were studied. Three bulk surface samples were taken from each land management area for both physical and chemical analysis from their surface soils (0 – 20 cm). The sampled land uses were pasture, gliricidia, cowpea and secondary forest.

History of land use

Cowpea

The plot has been under cowpea cultivation for about 10 years to date. It was formerly being used for maize but its low fertility and yearly usage resulted to change in land use over the year. Mucuna is usually sown before cowpea for soil quality improvement. The mucuna is usually ploughed in before cowpea is sown.

Gliricidia

This plot has been used for alley cropping before being abandoned about 8 – 10 years ago. The alley cropping includes a row of gliricidia followed by two rows of maize plant. When the experiment was concluded the gliricidia was left on the plot.

Secondary forest

This piece of land has been under secondary forest for more than 20 years. The canopy were not fully formed with underground thickets, herbs, e.t.c.

Pasture

The pasture was established more than 15 years ago. There was constant animal grazing. The pasture was on an undulating surface between upper to lower slope which could be marshy during rainy season similar to other land use plots. The pasture is made up of *Cynodon dactylon*, *Andropogon gayanus* and C*entrosema pubescence*

Laboratory analyses

Samples collected from the study sites in three replicates and were subjected to laboratory analysis. They were processed for chemical and physical analysis of the fine earth (<2 mm) fractions with the standard analytical method used at the I. A. R. and T. soil laboratory. The gravel contents above 2 mm were weighted and recorded.

Particle size analysis of the 2 mm fraction was by the hydrometer method as described by Bouyoucos (1962) using 10% sodium hexametaphosphate as the dispersing agent; pH (1.1; soil: water) was determined electrometrically using the glass electrode. Organic carbon was determined using Walkey and Black (1934) digestion method.

Exchangeable acidity (A13+) was extracted with 1 N KCI and titrated with 1 N ammonium acetate. Ca^{2+} and Mg^{2+} were read by atomic absorption spectrophotometer while K^+ and Na^+ were read with flame photometer. Effective cation exchange capacity (ECEC) was by the summation of exchangeable bases and acidity but cation exchange capacity (CEC) was the summation of exchangeable bases. Available phosphorus was extracted by Bray-1 extractant (Bray and Kurtz, 1945). The base saturation was calculated as ratio of exchangeable bases to the cation exchange capacity expressed in percentage. Bulk density was determined using core

Table 1. Differences in soil properties among land uses.

Soil property	Cowpea soil	Pasture	Gliricidia soil	Secondary forest
Physical				
Sand %	76.73^{a}	68.07^{b}	76.73^{a}	67.40^{b}
Silt %	15.48^{b}	21.98^{a}	16.48^{ab}	21.58^{a}
Clay%	7.78^{a}	9.95^{a}	6.78^{a}	14.84^{a}
B.D (g/cm^{3})	1.50^{a}	1.39^{b}	1.29^{b}	1.18^{c}
Porosity%	44.457^{c}	47.54^{bc}	51.153^{ab}	53.873^{a}
M C	5.47^{d}	23.69^{a}	18.86^{b}	14.45^{c}
K. Sat (mm/hr)	109.77^{ab}	73.63^{b}	155.92^{a}	172.41^{a}
G. Content%	29.86^{a}	6.92^{b}	28.29^{a}	23.07^{a}
Agg. Sta. %	4.94^{c}	14.99^{b}	19.32^{a}	20.06^{a}
Chemical				
Org. Carbon%	5.21^{a}	4.38^{b}	4.81^{ab}	3.38^{c}
Total N %	0.072^{a}	0.065^{a}	0.069^{a}	0.055^{b}
pH (H_2O)	6.17^{a}	5.95^{a}	5.90^{a}	5.80^{a}
AV.P (Mg/kg)	4.74^{a}	5.34^{a}	5.90^{a}	6.023^{a}
K	0.223^{a}	0.180^{b}	0.210^{ab}	0.213^{ab}
Ca	0.913^{ab}	0.937^{a}	0.927^{ab}	0.897^{b}
Mg Cmol/kg	0.803^{a}	0.827^{a}	0.837^{a}	0.823^{a}
Na	0.380^{a}	0.380^{a}	0.393^{a}	0.390^{a}
CEC	2.320^{a}	2.300^{a}	2.360^{a}	2.317^{a}
B S%	95.860^{a}	95.857^{a}	95.927^{a}	95.860^{a}

MC: moisture content; G. content: gravel content ; agg. sta.: aggregate stability; AV.P ; available phosphorus; BS: base saturation.

sampler method which is calculated by dividing the mass of the soil by volume of the soil, aggregate stability was determine by wet sieving, porosity was calculated using the relationship (1 – BD/PD) x 100, where BD = Bulk density, PD = Particle density = 2.65 gcm-3 (for mineral soils) while hydraulic conductivity (K.sat) was determined by constant head method.

The results were subjected to statistical analysis to know the effect of different land use types and improved fallow on soil quality. From the statistical analysis inferential method was used to determine rate of soil degradation or improvement among land use types, where the land uses occupy similar landscape position.

Inferential method involved subtracting the mean of the land use from that of the mean of secondary forest (control) and dividing it by the mean of secondary forest (control), it is then multiplied by 100 to convert to percentage: (X0 – X1/ X0) x 100 where X1 is the land use type mean, X0 is the mean for control (secondary forest).

RESULTS AND DISCUSSION

Table 1 showed the result of the physical and chemical properties with the analysis of variance. Highest mean in clay content (14.84%) was recorded in secondary forest but it was not significantly different from the others. There was significantly lower gravel content in pasture. This could be attributed to grass roots ability to hold fine soil particles from being eliminated or eroded. The lowest and best bulk density was recorded in the secondary forest (1.18 gcm^{-3}) while the highest was on cowpea plot followed by pasture. The higher bulk density in cowpea and pasture soils could be attributed to effect of mechanization and trampling of livestock, respectively. The best porosity and hydraulic conductivity (K.sat) was recorded also in secondary forest (172.41 mm/h) followed by gliricidia soil (155.92 mm/h) (Table 1) but were not significantly different. Moisture content range between 5.47% in cowpea soil to 23.69% in pasture. The lowest value in cowpea soil could be attributed to the effect of exposure due to cultivation. Cowpea soil was significantly different from gliricidia soil in six physical properties (aggregate stability, bulk density, porosity, moisture content, hydraulic conductivity and silt) (Table 2). Cultivated/cowpea soil differs from pasture in eight physical properties which are aggregate stability, bulk density, porosity, moisture content, hydraulic conductivity, silt, sand and gravel content. The cowpea plot differs from secondary forest in seven physical properties (aggregate stability, bulk density, porosity, moisture content, hydraulic conductivity, sand and silt), therefore secondary forest resulted to better soil quality in terms of bulk density, aggregate stability, porosity, moisture content, hydraulic conductivity and clay content.

The chemical analysis showed that pH varied from slightly acidic to moderately acidic (6.17 to 5.80) but was not significantly different. Highest content of percentage carbon (5.12%) and percentage total nitrogen (0.072%) were recorded in cowpea soil followed by gliricidia soil (4.81% carbon and 0.069% nitrogen), pasture (4.38%

Table 2. Significantly different soil Properties between land use pairs.

Land use pair	Number of properties	Soil property	
		Physical	Chemical
Cp – Gl	8	Bulk Density, porosity MC, K. Sat., Silt, AS;	C. K^+
Cp – Ps	11	Bulk Density, porosity K. Sat, Gravel Content, Sand, Silt, AS	C. K^+, Ca^{2+}
Cp – Sf	11	Bulk Density, porosity MC, K. Sat, Sand, Silt, AS	C, N^{2+}, K^+, Ca^{2+}
Ps – Gl	10	Porosity, Moisture. Content, K. Sat, Gravel Content, Sand, Silt, AS	C, K^+, Ca^{2+}
Ps – Sf	10	Bulk Density, porosity, MC, K. Sat,Gravel Content, AS	C, N^{2+}, K^+, Ca^{2+}
Gl – Sf	8	Bulk Density, porosity, MC, Sand, Silt	C, N^{2+}, Ca^{2+}

Cp, Cowpea; Gl, gliricidia; Ps, pasture; Sf, secondary forest; MC, moisture content; AS, aggregate stability.

Table 3. Assessment of controlled land uses with inferential method.

Soil properties	Cowpea %	Pasture %	Gliricidia %
Sand	13.8	1.0	13.8
Silt	28.2	1.8	23.6
Clay	47.5	32.9	54.3
Bulk density	27.0	18	0.1
Porosity	17.5	11.7	5.0
Moisture content	62.11	63.9*	30.5*
Hydraulic conductivity	36.3	57.3	9.56
Gravel content	29.4	70*	22.6
Aggregate stability	75.3	25.3	3.6
Carbon	51.4*	29.5*	42.3*
Total nitrogen	30.9*	18.2*	25.5*
pH	6.3*	2.5*	1.7*
Available Phosphorus	21.3	11.3	7.2
Potassium	4.7*	15.5	1.4
Calcium	1.8*	4.5	3.3*
Magnesium	2.4	0.5*	1.7*
Sodium	2.6	2.6	0.8*
CEC	0.1*	0.7	1.9*

Values with * show improvement in quality while values without show level of degradation in comparison with secondary forest.

carbon and 0.065% nitrogen) and secondary forest (3.38% carbon and 0.055% nitrogen) (Table 1). Therefore percentage carbon and nitrogen appreciate more in cowpea soil than gliricidia soil and secondary forest. The animal droppings were also a good source of nitrogen under pasture. Phosphorus was not significantly different in all the land uses though it was higher under secondary forest (6.023 mg/kg) (Table 1).

Potassium and calcium were low varying between 0.223 to 0.18 Cmol/kg and 0.937 to 0.897 Cmol/kg, respectively. Potassium was significantly higher in cowpea soil (0.223 Cmol/kg) only while calcium was only significantly higher in pasture (0.937 Cmol/kg) than secondary forest (0.937 Cmol/kg). Magnesium and sodium were medium varying from 0.803 to 0.837 Cmol/kg and 0.380 to 0.393 Cmol /kg respectively; but they were not significantly different. Likewise cation exchange capacity (CEC) was low. However, all the soils have high base saturation values but were not significantly different from another.

Cowpea soil appreciated in carbon and nitrogen content and soil pH than in secondary forest. The higher values could also be attributed to effect of mucuna being ploughed in before cowpea cultivation, cowpea ability to fix nitrogen and easy decomposition of legumes. Other chemical properties were not significantly different from another. Therefore physical properties were more variable than chemical properties.

Table 3 showed the rate of degradation/improvement of soil quality using inferential method. Highest soil degradation was recorded for aggregate stability (75.3%) under cowpea soil followed by moisture content 62.11%, clay content 47.5%, hydraulic conductivity 36.3%, bulk density 27%, and available phosphorus 21.3% (Table 3). Therefore the aggregates were least stable under cowpea and will control the other parameters like moisture content, hydraulic conductivity and nutrient movement in soil water. The degradation in aggregate stability could be attributed to effects of mechanization on soil properties.

The inferential method also showed that most degraded soil property under pasture was hydraulic conductivity (57.3%) followed by clay content, 32.8% and aggregate stability 25.3% (Table 3). In gliricidia soil the degradation was highest in clay (54.3%). This could be attributed to lack of full canopy formation since the place was under alley cropping before. However, the eight parameters including chemical properties (cation exchange capacity, sodium, magnesium, calcium, nitrogen and carbon) and lowest aggregate degradation gave gliricidia soil better quality. The result also showed that there was more improvement in some properties in gliricidia soil than others when compared with secondary forest. Percentage carbon, moisture content, total nitrogen, calcium and cation exchange capacity appreciated by 42.3, 30.5, 25.5, 3.3 and 1.9%, respectively. There was improvement in eight soil properties (moisture content, carbon, nitrogen pH, calcium, magnesium, sodium and cation exchange capacity) in gliricidia soil over secondary forest, while five (moisture content, carbon, nitrogen, pH and magnesium) were recorded in pasture and six (carbon, nitrogen, pH, potassium, calcium and cation exchange capacity) in cowpea soil (Table 3). The highest soil improvement over secondary forest in pasture was 63.9% for moisture content followed by carbon with 51.4 and 42.3% for cowpea and gliricidia soils, respectively.

The order of soil degradation therefore was cowpea > pasture > gliricidia. Therefore, the order of soil improvement or amelioration compared with secondary forest was gliricidia > pasture > cowpea. The most degraded soil was cowpea soil under mechanized soil tillage.

Conclusion

The study was conducted to carry out effects of land uses and improved fallow on soil quality. The different land cover resulted to different soil quality. Cowpea soil was most degraded because of mechanization which resulted to high aggregate instability. While gliricidia soil was best in terms of soil quality because it improved better than secondary forest in eight parameters (moisture content, percentage carbon, total nitrogen, pH, calcium, magnesium, sodium and cation exchange capacity), however carbon, nitrogen and pH were higher in cowpea soil because of mucuna being used to improve soil quality. Therefore the order of soil quality degradation was cowpea > pasture > gliricidia.

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