Changes in some surface soil properties of an Alfisol under long-term land uses

O. J. IDOWU
Institute of Agricultural Research and Training, Obafemi Awolowo University, P. M. B. 5029, Ibadan, Nigeria

ABSTRACT

The study investigated changes in selected soil physical and chemical properties of an Alfisol under different land uses (citrus plantation, continuous arable land, bush-fallow land, and pasture). Soil samples were collected from a plot of 20 m × 20 m (0.04 h) under these land uses and analyzed in the laboratory for selected soil physical and chemical properties. Continuous arable land had the lowest aggregate stability, followed by citrus plantation, bush fallow and pasture in increasing order. Bulk density was significantly higher in arable land compared with the other land uses. Total sand was significantly higher under arable and citrus cultivation when compared with pasture and bush-fallow land. Organic carbon was highest in pasture (2.55 %), while it was lowest in continuous arable land (0.78 %). Available phosphorus was significantly lower under citrus and bush-fallow land compared with continuous arable land and pasture. The *p*H of pasture (5.19) was significantly lower than the values for the other land uses. Continuous arable land, with a *p*H of 5.85, followed this. The *p*H of citrus plantation (6.58) and bush-fallow land (6.42) were not significantly different. This study shows that land uses can have significant impact on some surface soil properties and, thus, must be carefully managed for sustainable land use.

Original scientific paper. Received 20 Nov 01; revised 21 Jun 04.

RÉSUMÉ

IDOWU, O. J.: *Changements en quelques propriétés du sol de surface d'un Alfisol suivant les utilisations de terre à longue durée.* Les changements des propriétés chimiques et physiques sélectionnées du sol d'un Alfisol selon l'utilisation différente de terre (plantation de citrus, terre arable continue, terre de brousse en jachère et pâture) étaient enquêtés. Les échantillons de sol étaient ramassés d'un terrain de 20 m × 20 m (0.04 h) selon les utilisations de terre susmentionnées et analysés au laboratoire pour les propriétés chimiques et physiques sélectionnées du sol. La terre utilisée pour la culture arable continue avait la plus basse stabilité d'agrégat suivi par la plantation de citrus, terre de brousse en jachère et pâture dans l'ordre croissant. Densité de grosseur du sol était considérablement plus élevée sur la terre arable en comparaison avec les autres utilisations de terre. Le sable total était considérablement plus élevé selon l'arable et la culture de citrus en comparaison avec la pâture et la terre de brousse en jachère. Carbone organique étaient le plus élevé selon la pâture (2.55 %) alors qu'il étaient plus basse pour la terre arable continue (0.78 %). Le phosphore disponible était considérablement plus basse selon les citrus et les terres de brousse en jachère en comparaison avec la terre arable continue et la pâture. Le *p*H de la pâture (5.19) était considérablement plus faible que ceux des autres utilisations de terre. Cette étude montre que les utilisations de terre pourraient avoir des impacts considérables sur quelques propriétés du sol de surface donc elle doit être exploité soigneusement pour utilisation soutenue de terre.

Introduction

The relation between land use and sustainability of agricultural production has been receiving wider attention among scientists managing land use. As soil is a slowly renewable natural resource, the challenge has been how to maintain and improve soil productivity under any given land use.

With the increase in population of the developing world, the demand on arable land for production of food and fibre has been greater. Consequently, the issue of sustainable land use has come under greater scrutiny than ever before.

Several workers have reported the effects of cultivation practices on soil properties in the tropics. Juo & Lal (1977) reported a rapid decline in soil organic matter and *p*H with continuous arable cultivation of an Alfisol. They found that application of residue mulch to the soil surface under arable cultivation led to favourable soil physical characteristics as well as maintenance of organic matter.

Aina (1979), working on western Nigerian soils, reported that continuous cultivation resulted in reduced aggregation and aggregate stability, increased bulk density, reduced porosity and hydraulic conductivity. Fallow led to improvements in physical and chemical properties.

Ogunkunle & Eghaghara (1992), in a study in S. W. Nigeria, indicated that soils under varying land use types were significantly different in physical and chemical properties. Obi (1989) reported that continuous cropping on a tropical Ultisol led to a decline in organic matter content and an increase in soil acidity. Similarly, Mbagwu & Auerswald (1999) showed a close relationship between percolation stability, a measure of soil erodibility, and land uses in a tropical Ultisol.

Islam & Weil (2000), working in Bangladesh, noticed that cultivating soils after removal of the natural forest resulted in surface compaction and decreased silt and clay contents, porosity, and aggregate stability.

Consequently, land use types vary in how they affect soil properties; thus, influencing sustainability of agricultural production. While some land use types can degrade the soil rapidly, others can maintain and even improve soil properties. Therefore, the relative effects of different land use types on soil properties need to be investigated to develop an economic and sustainable management of resource for agricultural uses. This study contributes toward this goal.

The study, therefore, aims at comparing the effects of four contrasting land use types, over various periods, on surface soil properties. The land use types selected belong to the same soil mapping unit of the study area, which provides a good basis for comparison.

Materials and methods

The research farms of the Institute of Agricultural Research and Training, Moor Plantation, Ibadan, were used for the study. This area falls within longitudes 7 15' and 7 30' N and latitudes 3 45' and 4 0' E. Ibadan has a humid tropical climate with mean annual rainfall of about 1 500 mm. The soils within the area selected belong to Iwo Series ("Typic Kanhapludalfs" according to US Soil Taxonomy).

Four different land use types identified and selected within the same mapping unit for this study were continuous arable cultivation with maize/cassava intercrop for 10 years, permanent crop cultivation (*Citrus sinensis*) for 25 years, bush fallow for 6 years, and pasture (a mixture of *Cynodon dactylon* and *Centrosema pubescens*) for 30 years.

Plot of dimension 20 m × 20 m (0.04 ha) was marked out under each land use. Within this area, 20 random samples were collected from each land use at 0 - 0.15 m depth of soil.

Aggregate stability was measured by the single drop technique (Bruce-Okine & Lal, 1975). Water drops of about 5.5 mm in diameter and from a height of 1.0 m were allowed to fall on 0.5-g air-dried soil aggregates placed on a 2.0-mm sieve. The degree of aggregate stability was determined by counting the number of single water drops required to break down this soil aggregate and pass through the 2.0-mm sieve. The values of the number of drops required to break down soil aggregates were then converted to logarithm to base 10 to determine an aggregate stability index.

Bulk density was measured with cylindrical soil core of about 50 mm in height and 50 mm in diameter. Thus, the bulk density was measured only for 0 - 0.05 m.

The hydrometer method (Gee & Bouder, 1986) was used to analyze particle size for sand (20 - 2000 μm), silt (2 - 20 μm), and clay (<2 μm) fractions. A sieve was used to further separate the sand fraction into coarse sand (200 - 2000 μm) and fine sand (20 - 200 μm). Organic carbon was determined by the Walkley-Black method (Black *et al.*, 1965). The *p*H of the soil was determined in 1:2.5 soil:water ratio. Available phosphorus was determined by the Bray 1 method (Bray & Kurtz, 1945).

The SPSS software (Spssinc, 1999) was used for the statistical analysis. One-way analysis of variance was applied to various data generated from the land uses. The Student Neuman Keules test (SNK test) was used for mean separation after a significant F-ratio was detected.

TABLE 1

F-ratio and Corresponding Level of Significance of Measured Soil Properties Under Different Land Use Types

Soil property	*F-ratio*
Aggregate stability (log (10) drops)	75.1**
Bulk density (mg m^{-3})	32.0**
Sand (%)	11.1**
Coarse sand (%)	17.7**
Fine sand (%)	15.5**
Silt (%)	13.3**
Clay (%)	20.6**
Organic carbon (%)	27.2**
Available phosphorus (mg kg^{-1})	11.4**
*p*H	46.8**

** Significant at 1% level

Results

Analysis of variance showed all the measured soil properties to be significantly different among the different land uses at 1 per cent level (Table 1).

Table 2 presents mean separation results. Aggregate stability index was significantly higher under pasture, being 2.98 compared with other land uses. This was followed by the land under bush fallow (2.12), citrus (1.81), and continuous arable land (1.35) (Table 2).

Bulk density values did not differ significantly among pasture (1.21 mg m^{-3}), bush fallow (1.30 mg m^{-3}), and citrus plantation (1.26 mg m^{-3}); but it was significantly higher under continuous arable land (1.75 mg m^{-3}) (Table 2).

The total sand and coarse sand did not significantly differ under citrus plantation and continuous arable land (Table 2). However, while total sand did not significantly differ between the pasture and bush fallow lands, the coarse sand

TABLE 2

Mean Separation of Different Soil Properties Across Land Use Types

	Land uses			
Soil property	*Citrus plantation*	*Continuous arable*	*Bush fallow*	*Pasture*
Aggregate stability (log (10) drops)	1.81 b	1.35 a	2.12 c	2.98 d
Bulk density (mg m^{-3})	1.26 a	1.75 b	1.30a	1.21a
Sand (%)	84.3 b	85.9 b	80.4 a	77.1 a
Coarse sand (%)	51.8 c	63.8 c	41.9 b	31.4 a
Fine sand (%)	32.5 b	22.1 a	38.4 b	45.7 c
Silt (%)	13.4 b	9.2 a	16.0 bc	19.3 c
Clay (%)	2.3 a	4.9 c	3.7 b	3.6 b
Organic carbon (%)	1.57 b	0.78 a	1.62 b	2.55 c
Available phosphorus (mg kg^{-1})	4.69 a	11.82 b	4.89 a	10.94 b
*p*H	6.58 c	5.85 b	6.42 c	5.19 a

a, b, c, d–Mean within rows followed by the same letter are not significantly different ($P<0.05$)

fraction was significantly higher under bush fallow (Table 2).

While the fine sand content was significantly higher under pasture than the other land uses, it was lowest in continuous arable land (Table 2).

The silt content was highest under pasture, being 19.3 per cent; but it was not significantly different from that of bush-fallow land (16 %). The silt content was lowest under arable land (9.2 %) (Table 2). Though clay content was generally low among the land uses, it was significantly higher under arable land (4.9 %) compared to the other land uses, and lowest under citrus plantation (2.3 %) (Table 2).

The organic carbon content was highest under the pasture land use, being 2.55 per cent. This was followed by bush fallow (1.62 %) and citrus plantation (1.57 %). The latter were not significantly different from each other. The organic carbon content of arable land (0.78 %) was significantly the lowest (Table 2).

Available phosphorus under pasture and arable land was not significantly different. However, bush fallow and citrus plantation had significantly lower available phosphorus than pasture and arable land (Table 2).

The *p*H under the pasture (5.19) land use was significantly the lowest, followed by arable land which was 5.85 (Table 2). The *p*H of bush-fallow land (6.42) and citrus plantation (6.58) did not differ significantly (Table 2).

Discussion

In general, the aggregate stability results followed the trend of organic matter level in the land uses (Table 2). The land uses with higher organic carbon content showed a higher degree of aggregate stability index in contrast to those with lower content. This was expected, because several authors have shown the strategic role of organic matter in formation of stable soil aggregates (Piccolo & Mbagwu, 1999; Lu-Gang *et al.*, 1998). Two important components of organic matter found to be responsible for soil aggregate stability are polysaccharides and humic substances. While the former act as cement or glue in-between the soil particles, the latter interact with metal ions, oxides, hydroxide minerals, and other organic substances to form water-stable aggregates (Oades, 1989; Schnitzer, 1989).

Table 2 shows that the aggregate stability index under pasture was the highest. This may be linked to the high level of organic carbon under this land use (Table 2). Pasture, being a mixture of legume and grass, has a high turnover rate of plant residues. Additionally, the input of cattle droppings would have had a very significant impact on the long-term build up of soil organic matter. This might have contributed immensely to the stability of aggregates to falling drops. As expected, arable land had the lowest stability. This may be due to oxidation of organic matter, especially caused by exposure and frequency of tillage activities (disc harrow tillage) on this land over the years. The reduction in aggregate stability and organic matter due to continuous cultivation in the tropics have been previously reported (Aina, 1979; Juo & Lal, 1977; Obi, 1989). The bush-fallow land had significantly higher aggregate stability and more organic matter than the citrus plantation. This may be due to the predominantly grass species growing under the fallow land; thus, giving a high turnover of plant residue in contrast to only leaf litter found on the floor of the citrus plantation.

Bulk density was much lower under the untilled land uses compared to the arable cultivated land (Table 2) that had experienced repeated tillage. This confirms Aina's (1979) report that the bulk density of continuously cultivated land is much higher than that of a fallow land. The lower bulk density values under the untilled land may be related to soil organic matter and consequent increase in biotic activities (Arvidsson, 1999).

The higher contents of total sand and coarse sand under citrus plantation and continuous arable land may indicate soil erosion and degradation. Cunningham's (1963) work in Ghana infers that soils under continuous cultivation are, thus, degraded; with measurable increase in coarse-sand fraction, and a decrease in fine sand, silt and clay contents. A similar observation was recorded in Bangladesh by Islam & Weil (2000).

Field observations confirmed rills in arable land and citrus plantation. Erosion under these land uses might have led to a selective removal of small-sized particles, leaving a concentration of larger soil particles. Pasture with low-growing grasses and bush fallow with vegetation cover had relatively lower amounts of coarse sand, but higher amounts of fine sand and silt.

The relatively high level of available phosphorus under the cultivated land was due to a history of repeated application of single super phosphate fertilizer for crop production. As phosphate fertilizer can persist in the soil, its content was very high in the continuous arable land. The high level of phosphorus found in the pasture land use may be related to cow dung during the grazing period.

Although the soil *p*H of the pasture was acidic, the precise cause of this acidity is unknown. The lower *p*H under continuous arable land may be due to continuous arable cropping as observed by Juo & Lal (1977) and Obi (1989).

From the foregoing, surface soil properties are affected by different land uses. The land under pasture has the most favourable soil physical and chemical properties, except for the *p*H. There may be a need for liming the pasture land to raise its *p*H. The cause of soil acidity under this land use could also be investigated to find out if the anomaly is limited to the field chosen for this experiment, or is a general trend for similar land use in the study area. The bush-fallow land has more favourable soil physical and chemical properties when compared with the continuous arable land use. This brings to focus the beneficial effect of fallows in restoring soil productivity. Other research trials have shown similar results (Aina, 1979; Salako & Hauser, 2001).

The relatively higher concentration of coarse sand in the surface horizon under citrus plantation may indicate selective removal of smaller particles through erosion. Therefore, there may be the need to control soil erosion under the citrus canopy.

The continuously cropped arable land had, on the average, the most unfavourable soil properties. Therefore, soil erosion must be controlled on this land use. Practices such as mulching and appropriate tillage systems have been shown to greatly reduce soil erosion under continuous arable lands (Lal, 1985). Such practices should be incorporated into the farming system to ensure sustainable use of arable lands.

Conclusion

A study of comparative changes in surface soil properties under four land uses (citrus plantation, continuous arable land, bush-fallow land and pasture) led to the following conclusions:

1. The differences between the land use types in all the measured soil properties were significant at the 1 per cent level.
2. Aggregate stability was highest under pasture, followed by bush fallow, citrus plantation and continuous arable land.
3. Bulk density did not significantly differ under land use types (pasture, citrus and bush fallow) that had not been mechanically tilled, while continuous arable land had significantly higher bulk density.
4. Coarse soil particles were significantly more under the continuous arable soil and citrus plantation than the bush fallow and pasture systems. This may indicate the relative degree of erosion under these cultivation practices.
5. While organic carbon was highest under the pasture system, it was lowest under continuous arable land. Available phosphorus was significantly higher under pasture and arable land than the other land use types, possibly due to added inputs such as cow dung and phosphorus fertilizer.
6. Soil *p*H was acidic under pasture, and slightly acidic under the continuous arable land use.
7. A better management of soils under the arable and citrus land use types is needed

to enhance their sustainability for crop production.

Acknowledgement

The author is particularly thankful to Mr Adewole Johnson for assisting in field sampling and laboratory analysis.

REFERENCES

Aina, P. O. (1979) Soil changes resulting from long-term management practices in western Nigeria. *Soil Sci. Soc. Am. J.* **43** (1), 173-177.

Arvidsson, J. (1999) Influence of soil texture and organic matter content on bulk density, air content, compression index and crop yield in field and laboratory compression experiments. *Soil and Tillage Research* **49**(1-2), 159-170.

Black, C. A., Evans, D. D., White, J. L., Esminger, L. E. & Clarke, F. E. (1965) Methods of soil analysis. *Agronomy Monogram No. 9.* American Society of Agronomy, Madison, Wisconsin.

Bray, R. H. & Kurtz, L. T. (1945) Determination of total organic and available forms of phosphorus in soils. *Soil Sci.* **59,** 39-45.

Bruce-Okine, E. & Lal, R. (1975) Soil erodibility as determined by Raindrop Technique. *Soil Sci.* **119,** 149-157.

Cunningham, R. K. (1963) The effect of clearing a tropical forest soil. *J. Soil Sci.* **14,** 334-345.

Gee, G. W. & Bauder, J. W. (1986) Particle-size analysis. In *Methods of soil analysis: Part I. Physical and mineralogical methods* (ed. A. Klute), 2nd ed., pp. 383-411. ASA-SSSA: Madison, WI.

Islam, K. R. & Weil, R. R. (2000) Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. *Agric., Ecosys. Envir.* **79,** 9-16.

Juo, A. S. R. & Lal, R. (1977) The effect of fallow and continuous cultivation on the chemical and physical properties of an Alfisol in western Nigeria. *Pl. Soil* **47**(3), 567-584.

Lal, R. (1985) A soil suitability guide for different tillage systems in the tropics. *Soil and Tillage Research* **5**(2), 179-196.

Lu-Gang, Sakagami, K. I., Tanaka, H., Hamada, R. & Lu, G. (1998) Role of soil organic matter in stabilization of water-stable aggregates in soils under different types of land use. *Soil Sci. Pl. Nutr.* **44,** 147-155.

Mbagwu, J. S. C. & Auerswald, K. (1999) Relationship of percolation stability of soil aggregates to land use, selected properties, structural indices and simulated rainfall erosion. *Soil and Tillage Research* **50** (3-4), 197-206.

Oades, J. M. (1989) An introduction to organic matter in mineral soils. In *Minerals in soil environments* (ed. J. B. Dixon and S. B. Weed), 2nd ed., pp. 89-159. Soil Science Society of America, Madison, Wisconsin. pp. 89-159.

Obi, A. O. (1989) Long-term effects of the continuous cultivation of a tropical Ultisol in southwestern Nigeria. *Expl Agric.* **25**(2), 207-215.

Ogunkunle, A. O. & Eghaghara, O. O. (1992) Influence of land use on soil properties in a forest region of southern Nigeria. *Soil Use Mgmt* **8**(3), 121-125.

Piccolo, A. & Mbagwu, J. S. C. (1999) Role of hydrophobic components of soil organic matter in soil aggregate stability. *Soil Sci. Soc. Am. J.* **63,** 1801-1810.

Salako, F. K. & Hauser, S. (2001) Influence of different fallow management systems on stability of soil aggregates in southern Nigeria. *Communs Soil Sci. Pl. Anal.* **32,** 1483-1498.

Schnitzer, M. (1989) Binding of humic substances by soil mineral colloids. In *Interactions of soil minerals with natural organics and microbes* (ed. P. M. Huang and M. Schnitzer). *Soil Sci. Soc., America, Special Publication No.* **17,** 77-101. Madison, Wisconsin.

Spssinc (1999) *SPSS Base 9.0 User's Guide,* 1st ed. Pearson Publications, New York.