EFFECTS OF TILLAGE OPERATIONS ON THE PROPERTIES OF AN ALFISOL ON THE JOS PLATEAU, NIGERIA

Emmanuel A. Olowolafe, Obadiah A. Zailani, Joshua S. Galadima and Chinedu J. Anyamele

Department of Geography and Planning, University of Jos, Nigeria
Corresponding author: eaolowolafe@yahoo.com

Abstract
One of the major constraints to sustainable agriculture on the Jos Plateau is soil erosion. This is due to the nature of the topography of the area. Most smallholders in the area carry out tillage operations for many purposes. These include ridging across slopes to control erosion, seed bed preparations and weed control, among other operations that are done manually by using hoes. This study was conceived to determine the effects of tillage operations on some of the physical and chemical properties of the Alfisols, which are the most widely cultivated soils in the area. Two types of soil data were collected: Soil profile pits' data and surface soil data. Standard procedures were employed in the detailed laboratory determinations of soil properties. The results show that tillage operations have led to significant differences in both soil physical and chemical characteristics of the soils. Despite the fact that the conventional tillage has been practised just for only four years, the results here show that tillage practices have significantly affected the organic matter, total N, exchangeable Ca, K, Mg contents and CEC of the soils. Perhaps, this is as a result of rapid decomposition under minimum and conventional tillage due to aeration and oxidation. Therefore, tillage practices need to be carried out with caution because soils in the tropical environments generally experience the reduction of organic matter and are susceptible to degradation because of such practices.

Keywords: Tillage operations, Soil properties, Alfisols, Tropical environment

INTRODUCTION

One of the major constraints to sustainable agriculture on the Jos Plateau is soil erosion. This is due to the nature of the topography of the area. Most smallholders in the area carry out tillage operations for many purposes. These include ridging across slopes to control erosion, seed bed preparations, weed control and incorporation of crop residues and herbicides, manually by using hoes (Olowolafe and Dung, 2000). Generally, in Nigeria, ridge tillage is the practice of planting or seeding crops in rows on the top, along both sides or in the furrows between the ridges which are prepared at the beginning of every cropping season (Lal, 1990). Larger farms use plows and harrows pulled by tractors, which results in the complete inversion of the top 20 to 30 cm of the soil. However, there are some areas where no tillage operation is still being practised. No-till or zero-tillage is characterized by the elimination of all mechanical seed bed preparation except for the opening of a narrow strip or hole in the ground for seed placement (Lal, 1983). All these operations have been in practice for long without the attempt to investigate the effects of such tillage operations on the soil properties on the Jos Plateau. There is paucity of information on the effects of tillage practices on soil properties (physical, chemical and biological) in the area. Since the actual effects of tillage operations differ from one climatic area to another, among other factors (Mahboubi *et al.*, 1993), this study was conceived to determine the effects of tillage operations on some of the physical and chemical properties of Alfisols, which are the most widely cultivated soils in the area.

MATERIALS AND METHODS

Study Area

Figure 1 presents the map of Jos city which shows the study area. The city is located on the Jos Plateau in the central Nigeria and it lies between latitude 8º.30′ and 10º 30′ N and longitude 8º.20′ and 9º.30′ E. The average elevation of the study area is about 1,250 metres above sea level. Though the climate of the area is markedly influenced by its altitude and position across the seasonal migration of the Inter-Tropical Discontinuity (ITD), it is the wet and dry type classified as Tropical rainy (Aw) climate by Koppen (1923). It has a mean annual rainfall of about 1,260mm (1,050-1,403mm), peaking between July and August. The mean annual temperature is about 22ºC, but mean monthly values vary between 19.4ºC in the coolest month of December when the area comes under the influence of the cool and dry desiccating north-easterly tropical continental air mass (harmattan) and 24.5^{o}C in the hottest month of April. The soil moisture regime is ustic and the soil temperature regime is inferred to be isohyperthermic (USDA, 1999). The area lies within the northern Guinea Savanna vegetation zone, an open woodland with tall grasses (Keay, 1953). The geology of the Jos city area comprises Precambrian basement complex rocks (migmatites, gneiss and older granites) and some areas of younger granites. The experimental site lies within the area underlain by crystalline Basement Aplo-pegmatite Granite-gneiss (Macleod, et al, 1973).

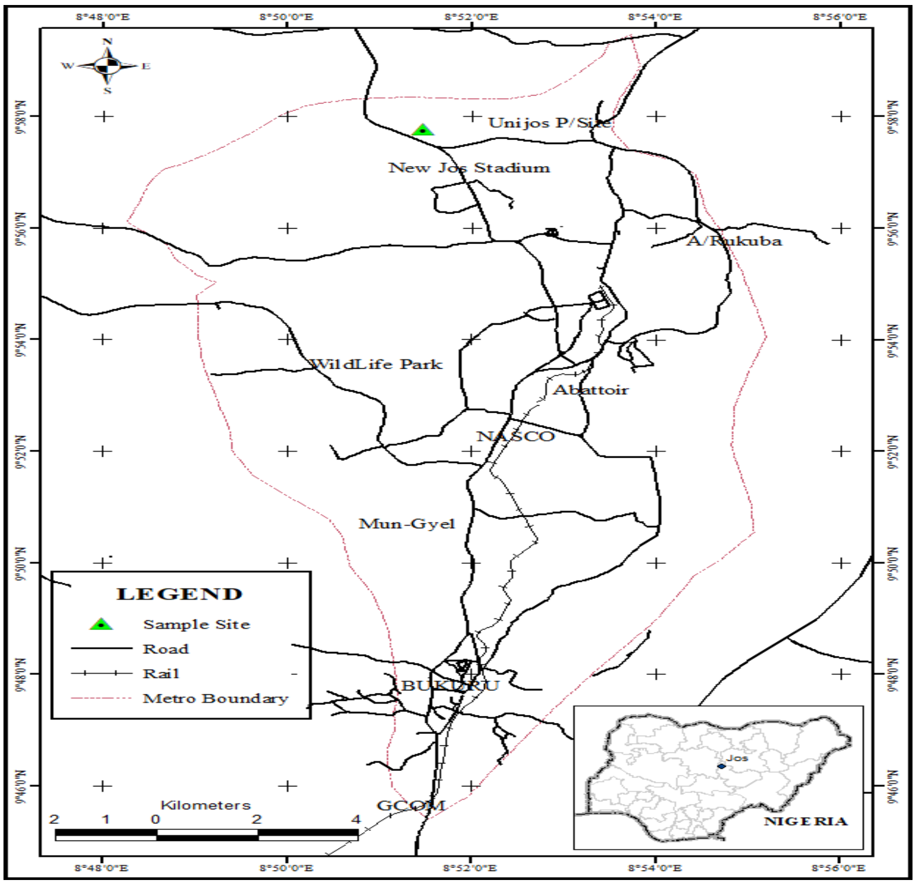

Figure 1. Jos city showing the Study Area.

Materials

The study is within the premises of the Commonwealth Comprehensive College, located to the north-west of the Jos city (Latitude 09^{o} 57' N; Longitude 08^{o} 51' E) (see Figure 1). The college was established in the year 1989. The experiment took place in the area designated for arable crop production by the staff of the College. For this study, three tillage types were considered: a). Zero tillage: this is the area where there is no form of cultivation, it is a grassland where there is no soil disturbance. Though the grasses were always regularly cut and left on the soil surface, there has not been any form of tillage at all. b). Minimum tillage: This involved the usage of simple hand tools (hoes and cutlasses), which is the usual practice in the savanna environment where old ridges from previous cultivation were split by forming a new ridge in a furrow between two old ridges (Beets, 1990; Agbenin, 1998; Olowolafe and Dung, 2000). Maize has always been cultivated on this portion for 25 years. c). Conventional tillage: During land preparation, the soil is always ploughed up to the depth of 20 cm, harrowed and ridged. The crop produced here is upland rice and it has been cultivated for only four years. NPK (20:20:20) fertilizer and chicken droppings are used as fertilizers on both farms.

Soil Sampling

Two types of soil data were collected: Soil profile pits' data and surface soil data. In each of the treatment areas (no-tillage, minimum tillage and conventional tillage), one profile pit was located in the central part of each field. Therefore, a total of three soil profile pits were dug and described according to FAO (2006) guidelines, while the soils were classified in line with USDA (1999 and 2014) Soil Taxonomy. The various genetic horizons were sampled for laboratory analysis. The second sampling concerned the surface (0 – 15cm) soils, which were collected with the use of stratified random sampling technique. An area of 30m by 20m was chosen in each of the three treatment areas. This area was divided into 6 grids of $100m^2$ each and within each of these, four sampling sites were chosen by throwing up a coin four times. The four surface soil (0-15cm depth) samples taken at the points where the coin landed, were mixed to form the composite sample, out of which sizeable portion was taken. Hence, six surface soil samples were taken from each of the three treatment sites. ANOVA test was the statistical technique used to test the significance of difference among the three treatment sites.

Methods of Soil Analysis

Standard procedures were employed in the detailed laboratory analysis. Laboratory determinations made include the following: Particle size analysis was made by using the hydrometer method outlined by Day (1965) and modified by Gee and Bauder (1986). Measurement of pH was done in a 1:2.5 suspension in water and KCl. Organic matter was determined using the Walkey and Black (1934) method of acid dichromate digestion and the titration was done with ferrous sulphate solution. Available phosphorus was extracted using dilute HCI/NH_4F as described by Bray and Kurtz (1945) while total nitrogen was determined following wet oxidation micro-Kjeldahl method (Bremner and Mulvaney, 1982). The extraction of Ca, Mg, Na and K was made using IN ammonium acetate at pH 7.0 (USDA, 1972), and Ca and Mg were measured by an Atomic Absorption Spectrophotometer (AAS) while K and Na were measured by flame photometer. The extraction for exchangeable acidity and CEC were carried out by using 1N KCl solution.

RESULTS AND DISCUSSION

Tables 1 and 2 present soil profile data and the summary of surface soil data respectively. The analysis of variance was made at a significance difference of 5%. Concerning the textural properties, table 1 shows that there is no difference in the amounts of clay, silt and sands between the first two horizons in soil profile 1, perhaps because there is no disturbance due to tillage. However, in soil profiles 2 and 3, affected by minimum and conventional tillage respectively, there are differences in the clay, silt and sand contents between their first two horizons, indicating the effects of tillage. This explains the significant difference among the three soil profiles' data in table 2 in their contents of clay, silt and sands. This may have resulted in the alteration of soil structure and porosity, with a consequent increase in infiltration and reduced runoff. Tillage operations are known to bring about the mixing and re-mixing of soil particles from the subsoils to surface soils and vice versa.

Similarly, Mbagwu and Bozzoffi (1989) reported that tillage encourages the movement of finer particles from the surface soils to sub-soils, all these may have led the differences in texture.

Table 1 does not show much difference in soil pH values among the three soil types. However, table 2 shows that there is a significant difference in the results of analysis of variance for the surface soils. It shows that surface soils with minimum tillage has the highest pH mean value of 6.11 while the those of the conventional tillage has the minimum mean value of 5.79, indicating that tillage practices lead to pH reduction. Similarly, IITA (1983) has observed relatively higher pH value of 5.9 in no-tillage surface soils compared to a value of 5.3 in a conventionally ploughed soils after growing 24 consecutive maize crops. This can be related to the influence of relatively higher organic matter contents in no-tillage soils.

Table 1 shows a general trend of decrease of organic matter down the three soil profiles. This is actually expected because the surface soil is always the receiver of leaves and organic materials before decomposition and humification processes commence. The table shows that soils with zero tillage has the maximum value of 4.48% of organic matter in the surface horizon and also the highest mean value of 4.65% from the result of ANOVA in table 2 where there is also a significant difference among the three soil types in their organic matter contents. This obviously indicates that zero tillage practice has increased the soil organic matter contents. According to Brady and Weil (1996), tillage is one of the major management practices that most influence soil organic matter contents. This is because intensive tillage aerates the soils and breaks up the organic residues and thereby increases the rates of decomposition and mineralization of soil organic matter leading to carbon loss and this is why the practice of conservation agriculture promotes organic carbon stabilization (Umar et al., 2011).

Table 1 Some of the physical and chemical properties of the soils

Sample No	Horizon Symbol	Horizon Depth(cm)	Clay %	Silt %	Sand %	Text. Class	pH (water)	OM %	TN %	Avail P ppm	Ca (meq/100g soil)	Mg	K	Na	EA(H+Al)	CEC cmol(+)/kg soil
Soil Profile No. 2: Zero Tillage																
1	Aw1	0.-15	20	18	62	SL	5.59	4.48	0.130	20	1.84	0.52	0.51	0.013	1.61	4.50
2	Aw2	15-32	20	18	62	SL	6.05	2.17	0.120	19	1.94	0.58	0.58	0.017	1.65	4.47
3	Bt1	32-56	36	23	41	CL	6.18	0.97	0.036	9	1.98	0.62	0.62	0.019	1.67	4.83
4	Bt2	56-77	38	22	40	CL	6.56	0.52	0.024	4	2.12	0.66	0.66	0.021	1.71	5.13
5	BC	77-120	40	20	40	C	6.82	0.45	0.018	3	2.17	0.67	0.67	0.023	1.74	5.22
6	C	120+	42	20	38	C	6.39	0.34	0.013	2	2.21	0.69	0.69	0.024	1.75	5.20
Soil Profile No. 2: Minimum Tillage																
7	Ap1	0.-12.	18	16	66	SL	6.02	3.79	0.120	10	1.36	0.42	0.14	0.011	1.56	3.72
8	Aw2	12.-25	20	18	62	SL	6.28	3.00	0.091	7	1.82	0.53	0.45	0.016	1.58	4.30
9	Bt1	25-50	38	22	40	CL	6.86	1.24	0.043	5	2.00	0.62	0.47	0.022	1.61	4.64
10	Bt2	50-75	48	22	30	C	6.94	0.59	0.026	3	2.12	0.64	0.52	0.029	1.62	4.82
11	BC	75-115	49	22	29	C	7.04	0.14	0.022	2	2.36	0.66	0.57	0.026	1.64	5.16
12	C	115+	49	23	28	C	7.12	0.21	0.011	2	2.42	0.68	0.9	0.028	1.65	5.27
Soil Profile No. 3: Convetional Tillage																
13	Ap1	0.-12.	18	16	66	SL	5.89	4.13	0.130	13	1.81	0.52	0.48	0.017	1.60	4.48
14	Aw2	12.-.25.	20	18	62	SL	5.97	3.79	0.120	10	1.85	0.58	0.52	0.013	1.63	4.48
15	Bt1	25-55	38	22	40	CL	6.12	0.69	0.036	7	1.96	0.62	0.57	0.022	1.63	4.70
16	Bt2	55-70	36	23	41	CL	6.16	0.59	0.024	6	2.00	0.66	0.62	0.016	1.65	4.84
17	BC	70-110	36	23	41	CL	6.22	0.45	0.018	4	1.94	0.65	0.63	0.012	1.64	4.73
18	C	110+	36	18	62	SC	6.02	0.38	0.013	2	1.82	0.54	0.58	0.014	1.61	4.54

Similarly, some other authors have affirmed that tillage practice can influence the concentration and distribution of soil organic matter (SOM) in the profile with higher SOM content in surface layers with zero tillage than with conventional tillage (Jantalia et al., 2007; Lal, 1982). Hence, the implementation of non-tillage, followed by the return of plant residue to farm land, which can be an efficient approach to raise up soil productivity and the accumulation of soil carbon (Kumar et al., 2014; Yuan, Shi & Zhao 2018), as well as to reduce GHG emissions. Globally, the shift in soil tillage practice from conventional to conservation system effectively protects the soil under cropping, increases soil quality, reduces SOM decline rate, as well as improves the endurance of the cropping system (Mehra et al., 2018).

Differences between total N levels under tillage practices in the surface soils (0-15 cm) as shown in table 2, closely followed the pattern observed for organic matter. Table 2 shows that surface soils with zero-tillage have the highest amount of total nitrogen and there is a significant difference among the soils in their contents of the element. This also shows that tillage operations have significant effects on the contents of total nitrogen. Lal (1976) observed a similar result and obtained twice the amount of total nitrogen in the no-tillage soils compared to that of conventionally ploughed soils. It is generally accepted that as a result of minimum tillage the soil organic matter increases in the upper five centimeters of a soil mainly due to the fact that the crop residues are not mechanically mixed into the soil as with conventional tillage (Baeumer and Bakermans, 1973; Lal 1976; Blevins *et al.*, 1983; Mahboubi *et al.*, 1993; Ismail *et al.*, 1994).

There is also significant difference among the soils in their available phosphorus contents and the element has the highest values in soils of zero tillage treatment both in the profile pit and surface soils (i. e. tables 1 and 2). The more phosphorus availability under zero tillage compared to conventional and minimum tillage may be due to surface placement of crop residues in zero-tillage in comparison with incorporation of crop residues with tillage as earlier observed by other researchers (Ismail et al. 1994). El-Baruni and Olsen (1979) suggested that the solubility of P is known to be enhanced by the presence of organic matter. Similarly, higher extractable P levels have been reported in zero tillage than in tilled soils (e.g. Duiker and Beegle 2006, Du Preez et al., 2001). Extractable P in zero tillage system was 42% greater at 0-5 cm, but 8-18% lower at 5-30 cm depth compared with conventional tillage (Ismail et al., 1994). Another factor that may have influenced the availability of the element is soil pH (Brady & Weil, 1996; and Landon, 1991).

Table 2 Statistical summary of the surface soil data

Treatment	**Zero Tillage**		**Minimum Tillage**		**Conventional Tillage**		**Test of Significance**		
Variables	Mean	STD.	Mean	STD.	Mean	STD.	F. Critical	F. Cal.	Significance
Clay%	21.8	1.761	11.0	3.011	21.5	3.125	3.682	31.15	Significant
Silt%	18.5	0.548	12.7	1.033	18.0	1.673	3.682	45.16	Significant
Sand%	59.7	2.280	76.4	3.933	60.5	4.750	3.682	36.72	Significant
pH	5.84	0.140	6.11	0.056	5.79	0.084	3.682	17.85	Significant
OM%	4.65	0.362	1.25	0.316	3.78	1.044	3.682	42.45	Significant
N%	0.145	0.010	0.045	0.011	0.118	0.032	3.682	39.00	Significant
AP(Ppm)	18.2	4.535	8.7	2.160	14.3	6.890	3.682	5.66	Significant
Ca (meq/100g)	1.62	0.035	1.12	0.139	1.80	0.099	3.682	74.82	Significant
Mg (meq/100g)	0.58	0.045	0.38	0.024	0.52	0.039	3.682	47.02	Significant
K (meq/100g)	0.552	0.067	0.385	0.035	0.455	0.117	3.682	6.50	Significant
EA($H^{++}A13^{+}$)	1.61	0.018	1.56	0.008	1.60	0.014	3.682	20.83	Significant
CEC (Cmol/Kg)	4.5	0.080	3.3	0.160	4.3	0.185	3.682	105.38	Significant

It becomes much more available at pH levels between 6.0 and 8.0, while it becomes less available at lower pH (< 6.0) where the element is liable to be fixed by Al, Fe and Mn (Euroconsult, 1985; Mizota & van Reeuwijk, 1989). Since the pH of surface soils with the conventional and zero tillage treatments are less than 6.0, they have higher values of available phosphorus, while the minimum tillage soils with pH of > 6.0 have lower values of the element.

In the same vein, exchangeable magnesium, potassium, acidity and cation exchange capacity have highest values in surface soils of zero tillage treatment. This also explains the significant differences among the soils in these properties as shown in table 2. This shows that tillage operations influence these soil properties. Similarly, IITA (1983) obtained the same results in Ibadan between no-tillage and conventionally ploughed soils. Likewise, Agbenin (1998) observed a higher amount of exchangeable cations in the surface soils than in the minimum and conventionally tilled area of an Isohyperthermic Typic Haplustalf at the Institute of Agricultural Research Farm, Samaru in the northern Guinea Savanna zone of Nigeria. Zero tillage conserves and increases availability of nutrients, such as K. Govaerts et al. (2007) found that the K concentration increased significantly with increasing residue retention. Higher organic carbon contents at the soil surface, commonly observed under conservation agriculture, can increase the cation exchange capacity (Duiker & Beegle, 2006). According to Lal (1979) and Aina (1979), one profound effect of tillage in soils is reduction in organic matter and CEC, among other parameters.

Several studies have indicated that one adverse effect of tillage in the tropics is the reduction of soil organic matter, plant nutrients such as nitrogen, phosphorus and exchangeable bases (Lal, 1976; Agbenin, 1998; Blanco-Canqui et al., 2005; McVay et al. 2006; Pereira et. al. 2007; Thomas et al. 2007; López-Fando & Pardo 2009; Lenart & Sławiński 2010). In general, our results are in agreement with those obtained by these studies. Despite the fact that the conventional tillage has been practised for just four years, the results here show that tillage practices have significantly affected the organic matter, total N, available K, Mg content and CEC of the soils. Perhaps, this is as a result of rapid decomposition under minimum and conventional tillage due to aeration and oxidation, as earlier explained. Perhaps, this is why some authors have remarked that large scale mechanized farms in West Africa are noted for their limited successes (Lal, 1974 and 1979; Lenart & Sławiński 2010). Such projects should be approached with caution. Unrealistic adoption of such technology from the temperate in the tropical environments can lead to disastrous consequences. Soils in tropical areas generally experience the reduction of organic matter and are susceptible to degradation because of such practices (Anda et al., 2010; Ermadani, Yulnafatmawita & Syarif, 2018).

CONCLUSION

This study concluded that tillage practices have led to significant differences in both the textural and chemical characteristics of the soils. Despite the fact that the conventional tillage has been practised for just only four years, the results here show that the practices have significantly affected the organic matter, total N, exchangeable Ca, Mg, K contents and CEC of the soils. Perhaps, this is as a result of rapid decomposition under minimum and conventional tillage due to aeration and oxidation as a result of high temperature in the tropics. Therefore, tillage practices need to be carried out with caution because soils in the tropical environments generally experience the reduction of organic matter and are susceptible to degradation because of such practices.

REFERENCES

Agbenin, J. O. (1998). Quantifying Soil Fertility Changes and Degradation Induced by Cultivation Techniques in the Nigeria Savanna. Towards Sustainable Land Use: Furthering Cooperation between People and Institutions, Vol. I. *Advances in Geo-ecology* 31, 435 – 441.

Aina, P. O. (1979). Soil Changes Resulting From Long-Time Management Practices in Western Nigeria. *Soil sci. soc. of Am. J.* 43, 173 – 179.

Anda, M., J. Shamshuddin, C. I. Fauziah, and S. R. S. Omar (2010). Increasing the Organic Matter Content of an Oxisol Using Rice Husk Compost: Changes in Decomposition and Its Chemistry." *Soil Science Society of America Journal* 74 (4), 1167–1180.

Baeumer, K. and Bakermans W. A. P. (1973). Zero-Tillage. *Adv. Agron.* 25, 77-123.

Beets, W.C. (1990). *Raising and sustaining productivity of small holder farming system in the tropics*. A Handbook of Sustainable Agricultural Development. AgBe Publishing Alkmaar, Holland, 457 - 461.

Blanco-Canqui, H., Lal, R., Owens L. B., Post, W. M., Izaurralde, R. C. (2005). Strength Properties and

Organic Carbon of Soil in the North Appalachian region. *Soil. Sci. Soc. Am. J.* 69, 663-673.

Blevins, R. L., Thomas, G. W., Smith, M. S., Frye, W. W. and Cornelius, P. L. (1983). Changes in Soil Properties after 10 Years Continuous Non-Tilled and Conventionally Tilled Corn. *Soil Tillage Res.* 3, 135-146.

Brady, N. C. and Weil, R. R. (1996). *The Nature and Properties of Soils.* 11th Edition. Prentice-Hall International, Inc.

Bray, R. H. and Kurtz, L. T. (l945). Determination of Total, Organic and Available Phosphorus in Soils. *Soil Science* 59: 39-45.

Bremner, J. M. and Mulvaney, C. S. (1982). Total Nitrogen. In: L. A. Page (Ed) Methods of Soil Analysis. Agronomy 9 monograph. American Society of Agronomy, Wisconsin, 892-901.

Day, P. R. (1965). Particle fractionation and particle size analysis. In: Black, C. A. (Ed) Methods of Soil Analysis, Part 1. Agronomy No. 9. American Society of Agrnomy, Madison Wisconsin, U. S. A.

Du Preez, C. C., Steyn, J. T., and Kotze, E. (2001). Longterm effects of wheat residue management on some fertility indicators of a semi-arid Plinthosol. *Soil Till. Res.* 63, 25-33.

Duiker, S. W. and Beegle, D. B. 2006. Soil Fertility Distributions in Long-Term No-Till, Chisel/Disk and Moldboard Plow/Disk Systems. *Soil Till. Res.* 88, 30-41

El-baruni, B and Olsen, S. R. (1979). Effects of manure on solubility of phosphorus in calcareous soils. Soil Sci. 112: 219-225.

Ermadani, H., Yulnafatmawita, A. and Syarif, A. (2018). Dynamics of Soil Organic Carbon Fractions under Different Land Management in Wet Tropical Areas. *Journal Solum* 15 (1), 26–39.

Eswaran, H., E., Berg, V. D. and Reich, P. (1993). Organic Carbon in Soils of the World. *Soil Science Society of America Journal* 57: 192–194.

Euroconsult (ILACO, B.V.). *Agricultural Compendium: For Rural Development in the Tropics and Subtropics*. Elsevier. Amsertam-Oxford-New York-Tokyo. 738pp.

FAO. (2006). Guidelines for Soil Profile Description. FAO, Rome.

Gee, G. W. and Bauder, J. W. (1986). Particle size analysis. In: Klute, A. (Ed). Methods of Soil Analysis: Tropical and Mineralogical Methods. Agronomy. Am. Soc. of Agron., Madison, Part 1. Wisconsin, 383-411.

Govaerts, B., Sayre, K. D., Lichter, K., Dendooven, L., and Deckers, J. (2007). Influence of Permanent Raised Bed Planting and Residue Management on Physical and Chemical Soil Quality in Rain Fed Maize/Wheat Systems. *Plant and Soil* 291, 39-54.

IITA. (1983). Highlights 1983. IITA, Ibadan, Nigeria.

Ismail, I., Blevins, R. L. & Frye W. W. (1994). Long-term no-tillage effects on soil properties and continuous corn yields. *Soil Sci. Soc. Am. J.* 58, 193-198.

Jantalia, C. P., Resck, D. V. S., Alves, B. J. R., Zotarelli, L., Urquiaga, S., and Boddey, R. M. (2007). Tillage Effect on C Stocks of a Clayey Oxisol Under a Soybean-Based Crop Rotation in the Brazilian Cerrado region. *Soil Till. Res.* 95, 97-109.

Keay, R. W. J. (1953). An Outline of Nigerian Vegetation. Government Printer, Nigeria.

Koppen-Geiger, (1923). Klima der Erde. Instus Perthe, Darmstadt, Germany.

Kumar, S., T. Nakajima, E. G. Mbonimpa, S. Gautam, U. R. Somireddy, A. Kadono, R. Lal, R. Chintala, R. Rafique, and N. Fausey. (2014). Long-term Tillage and Drainage Influences on Soil Organic Carbon Dynamics, Aggregate Stability and Corn Yield. *Soil Science and Plant Nutrition* 60 (1), 108–118.

Lal, R. (1975). Role of Mulching Techniques in Tropical Soil and Water Management. IITA. Technical Bulletin No 1. 38pp.

Lal, R. (1976). No tillage effects on soil properties under different crops in western Nigeria. *Soil Sci. Soc. of Am. J.* 40, 762 -768.

Lal, R. (1982). Effect of Slope Length and Terracing on Runoff and Erosion on a Tropical Soil. *IAHS Publication* 137, 23-31.

Lal, R. (1983). No-till farming: Soil water conservation management in the humid and subhumid tropics. IITA Monograph No. 2. Ibadan: International Institute of Tropical Agriculture.

Lal, R. (1990). *Soil Erosion in the Tropics: Principles and Management*. New York: McGraw-Hill.

Landon, J. R. (Ed) 1991. Booker Topical Soil Manual. A handbook for soil survey agricultural land evoluation in the tropics and subtropics. Paper-back Edition. Longman Sci. and Technical, U.K. 474pp.

Lenart, S. and Sławiński, P. (2010). Selected soil properties and the occurrence of earthworms under the conditions of direct sowing and mould-board ploughing. *Fragm Agron* 27, 86-93.

López-Fando, C. and Pardo, M. T. (2009). Changes in Soil Chemical Characteristics with Different Tillage Practices in a Semi-Arid Environment. *Soil Till Res* 104, 278-284.

Macleod, W. N., Turner, D. C and Wright, E. P. (1971). The geology of the Jos Plateau. Geological Survey Bulletin 32.

Mahboubi, A. A., Lal, R. and Faussey, N. R. (1993). Twenty-eight Years of Tillage Effects on Two Soils in Ohio. *Soil Sci. Soc. Am. J*. 57, 506-512.

Mbagwu J. S. C and Bozzoffi, S. (1989). Properties of Soil Aggregates as Influence by Tillage Practices, *Soil Use and Management*. 15, 180-188.

McVay, K.A., Budde, J.A., Fabrizzi, K., Mikha, M. M., Rice, C.W., Schlegel, A. J., Peterson, D.E., Sweeney, D.W., Thompson, C. (2006). Management Effects on Soil Physical Properties in Long-Term Tillage Studies in Kansas. *Soil Sci Soc Am J* 70, 434-438.

Mehra, P., J. Baker, R. E., Sojka, N. Bolan, J. Desbiollesk, M. B. Kirkham, C. Ross, and Gupta, R. (2018). A Review of Tillage Practices and Their Potential to Impact the Soil Carbon Dynamics. *Advances in Agronomy* 150, 185–230.
Mizota, C. and Van Reeuwijk, L. P. (1989). Clay mineralogy and chemistry of soils formed in volcanic present materials in diverse climate regions, International Soil Reference and Information Centre (ISRIC). Soil Monograph 2.

Olowolafe, E. A. and Dung, J. E. (2000). Soils Derived from Biotite-granites on the Jos Plateau, Nigeria: Their Nutrient Status and Management for Sustainable Agriculture. *Resources, Conservation and Recycling* 29, 231-244.

Pereira, J. O., Defossez, P., Richard, G. (2007). Soil Susceptibility to Compaction by Wheeling as a Function of Some Properties of a Silty Soil as Affected by the Tillage Systems. *Eur J Soil Sci* 58, 34-44.

Thomas, G. A., Dalal, R. C., Standley, J. (2007). No-till Effect on Organic Matter, Ph, Cation Exchange Capacity and Nutrient Distribution in a Luvisol in the Semi-Arid Subtropics. *Soil Till Res* 94, 295-304.

Yuan, Y., X. Shi, and Z. Zhao. (2018). Land Use Types and Geomorphic Settings Rejected in Soil Organic Carbon Distribution at the Scale of Watershed. *Sustainability* 10, 3490.

Umar, B.B., Aune, J.B., Johnsen, E.H., and Lungu, O.I. (2011).OptionsforImprovingSmallholder Conservation Agriculture in Zambia. *J. Agric. Sci.* 3, 50-62

USDA. (1972). Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples. Soil survey investigation report. No. 1.

USDA, Soil Survey Staff. (1999). Soil Taxonomy: A Basic System Of Soil Classification for Making and Interpreting Soil Surveys. Second edition. USDA Agriculture Handbook No. 436. Soil Management Support Services. Technical Monograph No. 19.

USDA, Soil Survey Staff. (2014). Keys to Soil Taxonomy. Ninth Edition. United State Department of Agriculture.

Walkey, A. and Black, C.A. (1934). An examination of the Method for Determining Soil Organic Matter and A Proposal for Modification of the Chromic Acid Titration Method. *Soil Science* 37, 29-38.