Agro-Science Journal of Tropical Agriculture Food, Environment and Extension
Volume 6 Number 1 January 2007 pp. 25 - 32

ISSN 1119-7455

EFFECTS OF PHOSPHORUS AND FOUR TILLAGE MULCH SYSTEMS ON THE PHYSICO-CHEMICAL PROPERTIES OF AN ULTISOL IN EASTERN NIGERIA.

Ahamefule H. E. and Mbagwu J. S. C.
Department of Soil Science, University of Nigeria, Nsukka, Nigeria.

Key words: Physical properties, chemical properties, phosphorus rates; soil management

ABSTRACT

The effects of four tillage-mulch systems on some soil physico-chemical properties of an Ultisol under cowpea (Vigna unguiculata) cultivation were investigated from the year 2004 to 2005. The tillage-mulch treatments consisted of tilled-mulched (TM), untilled-mulched (UM), tilled-unmulched (TU), and untilled-unmulched (UU) (control) plot. Differences in the infiltration rate and bulk density of the treated plots were significant at $P<0.05$. Micro-porosity, macro-porosity, total porosity, mean weight diameter of water stable aggregates and saturated hydraulic conductivity, however, did not show significance. The infiltration rates of the TM, TU, UM and UU treated plots were 0.022, 0.016, 0.012, 0.010 and 0.027, 0.019, 0.012 and 0.010cm sec^{-1} for the first and second years, respectively. The infiltration rates on tilled plots significantly ($p<0.05$) increased and doubled that of the untilled plots, while mulching significantly ($p<0.05$) increased infiltration rates on tilled plot. The TM plots increased by 23%, TU by 19% while the UM and UU plots were stable in their infiltration rates from the first to the second year. Seventeen percent of this increase was attributed to mulching while 83% to tillage. The bulk density of untilled plots (1.55 – 1.59 g cm^{-3}) were higher ($p<0.05$) than that of tilled plots (1.26 – 1.49 g cm^{-3}) while mulching tended to significantly increase bulk density on tilled plots. The mulched plots had high available P (30.54 – 40.88 mg kg^{-1}) compared to the control plot (25.50 – 26.69 mg kg^{-1}), 9 weeks after phosphorus treatment. Available P in UM plots were higher than in the other plots. These variations in available P following the tillage-mulch treatments did not result in significant changes in the tissue P of cowpea at flowering.

INTRODUCTION

Soil degradation is an urgent global issue with long-term impact on soil productivity and environmental quality. It undermines the welfare of present and future generations. Soil degradation adversely impacts on soil quality – the capability of soil for production or provision of other services beneficial to humans (Doran and Parkin, 1994). Soil quality indicators include soil chemical properties and processes (e.g. pH, cation exchange capacity, nutrient reserves, nutrient availability and ionic diffusion); physical properties and processes (e.g. texture, structure, available water capacity, pore size distribution and bulk density). Also included are biological properties and processes (e.g. soil organic carbon, microbial biomass, soil biodiversity, mineralization and respiration) and the interaction between them (Parr et al., 1992; Lal, 1994). Today, however, a lot has been added to the pool of knowledge on ways of combating soil degradation and improving or maintaining soil conditions for maximum crop yield. Lal (1993) found that tillage practices, methods of seedbed preparation and residue or mulch management have an important impact on soil degradation. Soil physical properties most impacted by tillage methods are soil water content, infiltration rate and temperature (Lal, 1976, Mengel et al., 1982; Mbagwu 1991), and soil structure (Mbagwu, 1987). De Maria et al. (1999) found that tillage practices had effect on extractable P. The need to sustain soil productivity, increase the need for conservation tillage and mulch systems. To this end, Lal and Oluwale (1983) reported that a zero tillage system used on structurally weak Alfisol, leaving mulch on the surface proved a promising alternative to conventional tillage. Physical properties like bulk density and penetration resistance were significantly decreased in the 0 – 5cm depth by mulching (Mbagwu, 1991; Franzen et al., 1994; Lal., 2000). It was also reported that mulching increased infiltration rates, reduced soil temperature and minimized evaporation (Mbagwu, 1991). From these studies, zero tillage with mulch has been advocated for use on fragile tropical soils. Nevertheless, extrapolation of these results from one ecological zone to another could be very misleading, especially on the Ultisols of southeastern Nigeria. Few tillage studies have been reported from this agro-ecological zone (Maurya and Lal, 1979). The objective of this study therefore, was to compare the effects of four tillage-mulch systems on soil physico-chemical properties of an Ultisol in southeastern Nigeria.

MATERIALS AND METHODS

The study was conducted from 2004 to 2005 in the University of Nigeria, Nsukka Teaching and Research Farm, located by latitude 06°52′ N and longitude 07°24′ E and at an elevation of about 400m above sea level. The area is characterized by a tropical climate with marked wet and dry seasons and mean annual rainfall of about 1700mm. The soil is deep, well drained and red to brownish-red in colour. It is a sandy loam Ultisol (Oxic Paleustult) belonging to the Nkpologu series (Nwadialo, 1989). Some of its pertinent properties are given in Table 1.

Table 1: Some Characteristics of the surface soil

Year	Parameter	Value
2004	Sand %	68
	Silt %	15
	Clay %	17
	Textural class	Sandy-Loam
	pH (1:25H_2L0)	4.6
	pH (0.01Mkcl)	3.8
	Organic Carbon	1.29
	Total N %	0.056
	Exchangeable bases (cmol kg^{-1})	
	Na	0.69
	K	0.02
	Ca	1.12
	Mg	3.16
	Exchangeable acidity (cmol kg^{-1})	
	Al^{3+}	1.20
	H^{+}	2.40
	ECEC	8.59
	Available P ($mgkg^{-1}$)	20.60

The site was under natural vegetation fallow, predominantly. *Pennisetum purpurem*, *Mimosa pudica* and *Cynodon dactylon* for about 10 years.

Field methods Weed was controlled on the experimental site (0.0238ha) by the application of glyphosate - a post emergence herbicide (a.i. isopropylamine) and a pre-emergency herbicide (a.i. 2-chloro –2, 6-diethyl – N (butoxy methyl) acetanilide]. A factorial combination of two tillage systems, two mulch rates and four phosphorus levels, in three replicates, were arranged in a split plot format using a randomized complete block design (RCBD). The main plot treatments were tilled-mulched TM, untilled-mulched (UM), tilled-unmulched (TU) and untilled-unmulched (UU) whereas the subplot treatments were four phosphorus rates (0,15,30 and 45 kg ha^{-1}). Subplots measured 1.0 x 2.5m. Tilling was done by traditional hoeing method to about 20cm depth, whereas in the no till treatment no further soil preparation after residue clearing was done. The mulch materials were dry elephant grass (*Pennisteum purpureum)* and *Mimosa pudica* applied at two rates (0 and 4Mg ha^{-1}) in June of each year. Core and bulk samples were collected from the surface soil in each of the 48 subplots, 4 months later (October) for the determination of some soil physical properties. The physical properties determined were: saturated hydraulic conductivity, pore size distribution, total porosity, bulk density and mean weight diameter of water stable aggregates. Infiltration rate test was done in-situ, three months after initiation of experiment, while surface soil samples were collected from each subplots, nine weeks (cowpea flowering) after phosphorus treatment for the determination of available P. Routine characterization of the soil was also done at the start of the experiment, following standard procedures (Table 1).

Laboratory studies

Saturated Hydraulic Conductivity

Cylindrical metal cores, 5.0cm length and 5.5cm internal diameter were used to collect the undisturbed soil samples. Soil loss was prevented by muslin gauze at the bottom of the column and the samples were allowed to saturate in water for 24 hours. After attaining a steady state volume of flow using a constant head permeameter (Bouwer, 1986), the transposed Darcy's equation for vertical flows of liquids was used to calculate saturated hydraulic conductivity, K_S) thus:

$$K_S = \frac{Q}{At} \bullet \frac{L}{\Delta H}$$

were Q is the steady-state volume of flow (cm^3), A is the cross sectional area of core sample (cm^2), t is time elapsed (hr), L is the length of core sample (cm) and ΔH is the change in hydraulic head (cm)

Pore size distribution

The macro- and micro-pores were the two types of pore size measured. Macro-porosity (MaP) was calculated thus:

$$M_aP = \frac{\text{Volume of water drained at 60cm tension}}{\text{Volume of bulk soil}}$$

While microporosity (M_iP) was determined after oven drying sample to constant weight at 105°C,

$$M_iP = \frac{Volume\ of\ water\ retained\ at\ 60cm\ tension}{Volume\ of\ bulk\ soil}$$

Total porosity was calculated as the sum of the macro and micro-porosities

Bulk density

Bulk density was determined by the core method (Blake and Hartage, 1986).

Mean weight diameter

The mean weight diameter of water stable aggregates was estimated by the wet-sieving technique described by Kemper and Rosenau (1986) by placing 25g of the <4.75 mm, air-dried soil samples in the topmost of a nest of four sieves of pore diameter 2, 1, 0.5 and 0.25mm

Infiltration rate

Infiltration rate test (at the soil surface) was carried out by the double ring infiltrometer technique

Available and tissue phosphorus

The Bray No 2 method was used for extraction of phosphorus (Olson and Sommes 1982), while the determination of tissue P involved wet digestion of the plant material with sulphuric acid and hydrogen perioxide. The digestate was then coloured according to the molybdenum blue method, then the absorbance was measured at 660nm (Bouma, 1983).

RESULTS

Infiltration rates

The rate of infiltration of the tillage-mulch treatments followed the order TM>TU=UM=UU in 2004 while in 2005 the order was TM>TU>UM=UU (Table 2).

Table 2: Phosphorus and tillage-mulch treatment effects on the infiltration rate (cm sec^{-1}) of an Ultisol under cowpea cover

		Phosphorus rate (kg ha^{-1})				
Year	Tillage-mulch combination	0	15	30	45	Means
2004	TM	0.021	0.022	0.022	0.022	0.022
	UU	0.010	0.010	0.010	0.010	0.010
	TU	0.017	0.017	0.014	0.016	0.016
	UM	0.012	0.011	0.012	0.011	0.012
	Means	0.015	0.015	0.015	0.015	-
2005	TM	0.027	0.027	0.027	0.028	0.027
	UU	0.011	0.010	0.010	0.010	0.010
	TU	0.019	0.019	0.019	0.019	0.019
	UM	0.012	0.012	0.012	0.012	0.012
	Means	0.017	0.017	0.017	0.017	

		$F.LSD_{0.05}$ 2004	2005
Tillage-mulch (T)	=	0.0042	0.0042
Phosphorus (P)	=	N.S	N.S
TXP	=	N.S	N.S

N.S = non significant

Table 3: Effects of tillage-mulch and phosphorus treatments on the bulk density ($g\ cm^{-3}$) of an Ultisol under cowpea cover.

Year	Tillage-mulch Combination	0	15	30	45	Means
2004	TM	1.41	1.58	1.42	1.39	1.45
	UU	1.54	1.54	1.58	1.54	1.55
	TU	1.26	1.24	1.26	1.27	1.26
	UM	1.64	1.51	1.59	1.62	1.59
	Means	1.46	1.47	1.46	1.46	
2005	TM	1.45	1.61	1.47	1.44	1.49
	UU	1.54	1.55	1.58	1.54	1.55
	TU	1.33	1.32	1.43	1.43	1.38
	UM	1.62	1.48	1.58	1.60	1.57
	Means	1.49	1.49	1.52	1.50	

		2004	2005
Tillage – mulch (T)	=	0.29	0.089
Phosphorus (P)	=	*N.S*	*N.S*
T x P	=	N.S	N.S

The TM treated plots had higher infiltration rates than the other tillage- mulch treatments. Tillage increased infiltration rates while mulching also did the same but only on tilled plots in each year of the experiment. From 2004 to 2005, TM plots improved by 23%, TU by 19% while UM and UU remained stable in their infiltration rates. Of the 23% increase in the TM plots, mulching gave rise to 17% while tillage gave 83%. This increase over the years resulted in higher infiltration rates in TU plots compared to UM in 2005. Mulching did not have a significant effect on untilled plots within and over the years.

Bulk density

The results show that the untilled and mulched plots had higher bulk densities as compared to the tilled-unmulched plots. The untilled-mulched, untilled-unmulched and tilled-mulched treatments did not show any significant differences in their effect on bulk density for the two years. However, in the first year, tilled mulched plots did not differ from the tilled unmulched plots in bulk density (Table 3).

Aggregate stability, saturated hydraulic conductivity and porosity

Mean weight diameter (aggregate stability), saturated hydraulic conductivity, macro porosity, micro porosity and total porosity did not show significant differences as a result of the tillage-mulch treatments.

Available phosphorus

Mulched plots had higher available P compared to unmulched plots in the first year, while TM and TU treated plots did not differ in their available P in the second year. The UM plots had the highest available P. It was found that mulching increased available P in untilled plots. Tillage did not significantly affect available P when the plots were under mulch, while its effect on unmulched plots was inconclusive (Table 4). There was significant interaction between tillage-mulch treatment and the various levels of phosphorous at $P<0.05$

Table 4: Influence of phosphorus and tillage-mulch treatments on available phosphorus (mg kg^{-1}) on an Ultisol under cowpea.

Year	Tillage-mulch combination	Phosphorus rate (kg ha^{-1})				Means
		0	15	30	45	
2004	TM	11.0	30.3	36.2	44.7	30.5
	UU	11.9	25.9	32.2	36.8	26.7
	TU	13.1	25.2	30.6	31.7	25.1
	UM	18.3	37.7	48.4	59.1	40.9
	Means	13.6	29.8	36.8	43.1	-
2005	TM	10.9	30.0	35.9	43.6	30.1
	UU	11.2	24.5	30.0	36.3	25.5
	TU	11.2	23.5	29.4	30.6	31.5
	UM	18.0	38.7	48.2	53.8	39.7
	Means	12.8	29.2	35.9	41.1	-

F.LSD(0.05

	2004	2005
Tillage-mulch (T)	3.11	1.93
Phosphorus (P)	1.51	1.20
T x P	*	*

* Means significant at P>0.05

Before the initiation of the experiment in 2005, a composite soil sample was taken from the plots to determine the available phosphorus (mg kg^{-1}). The TU, UU, TM and UM plots had values of 20.0, 20.0, 22.5 and 25.0 mg kg^{-1} available P. Nine weeks into the experiment the highest level of available P was in plots treated with UM and 45kg ha^{-1} P while plots treated with TM and 0 kg ha^{-1} P had the lowest values.

For all the tillage-mulch combinations, available P response to the applied phosphorus levels was linear. The best fit regression models (Table 5) for each year was obtained from the difference in available P at initiation of experiment and nine weeks after.

Table 5: Regression models relating available phosphorus (Y) (mg kg^{-1}) to applied phosphorus (X) (kgha^{-1}) for different tillage mulch combinations on an Ultisol.

Year	Tillage-mulch treatments	Regression equation	R^{2a}
2004	TM	Y=2.1 + 0.48X	0. 989
	TU	Y=2.0 + 0.22X	0.873
	UM	Y=6.5 + 0.71X	0.999
	UU	Y=0.2 + 0.36X	0.992
2005	TM	Y=0.5 + 0.45X	0.993
	TU	Y=0.6 + 0.24X	0.869
	UM	Y=11.9 + 0.5X	0.978
	UU	Y=1.4 + 0.39X	0.997

[a] All R^2 values are significant at p <0.05

The models accounted for between 86.9 and 99.9% of the variation in available P. Within each year, however, the predictive ability of the models (as measured by the magnitude of R^2) was poorer when the plots were tilled and also mulched

DISCUSSION

On the basis of a long-term experiment, Lal (2000) posited that for significant changes in soil physical properties to occur, a long period of time is required. He further noted that such experiments need to be continued for 10 – 20 years or even longer. On this premise therefore, it is not strange that there was no significant change in most of the soil physical properties determined in this experiment.

However, due to the influence of several factors of soil formation, like parent material and climate, results of experiments could vary across geographical locations. This could partly explain the significant bulk density and infiltration rate results obtained, even when other physical properties were non-significant. Mbagwu (1991) working on this soil observed that mulching improved bulk density. However, in this work, the mulch used increased bulk density. This cannot be explained currently but further investigations are still going on. Mbagwu (1991) also observed that mulching increased infiltration rate on this soil. The improved infiltration rate due to tillage must be linked to increased total porosity. Part of the mulch material could have decayed into the numerous pores on the tilled plots, serving as absorptive pads for water, thereby increasing the infiltration rates of such plots. Conversely, a significant effect of mulching on untilled plots was not observed as a result of lower total porosity occasioned by the non-breaking up of the soil. The 83% increase in infiltration rate from 2004 to 2005, actually showed the magnitude of change in soil total porosity caused by tillage. This effect of tillage on soil structure was also observed by Ojeniyi and Dexter (1983), Maurya (1986) and Mbagwu (1987). On the other hand, untilled plots are less prone to this kind of rapid physical change. The influence imposed by mulching on infiltration rate over the same period was 17%, which is ameliorative by virtue of the organic matter added to the soil by the mulch material. The organic matter hence lines the pores and surrounds soil particles with a cushioning effect, which increases the absorptive capacity of the soil. which in turn increases infiltration rate.

It is suspected that part of the tissue P in the mulch material was released into the soil over time following decomposition. This modified the effect of applied (fertilizer) phosphorus on available P in the mulched plots. Higher bulk densities and lower porosities in untilled plots, ensured that phosphorus mineralized from the fertilizer and mulch remained available within the 0 – 20cm soil depth without being lost by leaching. The mulch also reduced surface loss of P by rain splash. It is thought that tillage made the plots so porous that the mineralized phosphorus was leached below the sample depth of 0 – 20cm

CONCLUSION

It can be concluded from the study that tillage reduced bulk density and increased infiltration rate while mulching improved infiltration rate on tilled plots and available P on untilled plots.

REFERENCES

Blake, G.R., Hartage K. H. 1986. Bulk density. In methods of soil Analysis, part 1 Klute A (ed) Monograph 9. Am. Soc. Agron: Madison WI pp 363 – 375.

Bouma D. 1983. Inorganic lead phosphorus as a measure of the phosphorus status of plants. Proc. 3rd Int. Congr. Phos. Cowpea, Brussels, Belgium, pp. 195 – 207. World phosphate Institute. Casablanca. Morocco.

Bouwer H 1986. Intake rate: cylinder infiltrometer. In methods of soil Analysis, part 1, Klute, A (ed). Monograph No 9. Am. Soc. Agron. Madison, WI, pp. 825 – 844.

DeMaria, I. C. Nnabude, P. C., deCastro, O.M. 1999. Long-term tillage and crop rotation effects on soil chemical properties of Rhodic Ferralsol in Southern Brazil. Soil Tillage Res. 51: 71-79.

Doran, J. W, Parkin, T.B., 1994. Defining and assessing soil quality. In: Doran, J.W Coleman, D. C., Bezdicek, D.F. Stewart, B.A (eds), Defining Soil Quality for Sustainable Environment, Special Publication No. 35. Soil Sci, Soc. Am J. Madison, WI, pp. 3 – 21.

Franzen, H., Lal, R and Ehlers, W. 1994. Tillage and mulching effects on physical properties of a tropical Alfisol. Soil Tillage Res. 28: 329 – 349.

Kemper, D. W., Rosenau, R. C. 1986. Aggregate stability and aggregate size distribution. In: Klute, A (ed). Methods of soil Analysis part 1. ASA-SSSA, Madison, WI pp. 425 –442.

Lal, R. 1976. Soil erosion problems of Alfisols in Western Nigeria and their control. IITA: monograph No 1. Ibadan.

Lal, R. 1993. Tillage effects on soil degradation, soil resilience, soil quality and sustainability. Soil Tillage Res. 27: 1- 8.

Lal, R. 1994. Methods and guidelines for assessing sustainable use of soil and water resources in the tropics, SMSS Monograph No 21. Washington D. C 78 pp.

Lal, R. 2000. Mulching effects on soil physical quality of an Alfisol in Western Nigeria. Land Degradation Development 11: 383 – 392.

Lal, R., Oluwale, A. O 1983. Physical properties of earthworm casts as influenced by management. Soil Science. 135: 14 – 125.

Maurya, P. R. 1986. Effects of tillage and Residue management on maize and wheat yield and on physical properties of an irrigated sandy loam soils in Northern Nigeria. Soil Tillage Res. 8: 161 –170.

Maurya, P. R., Lal, R. 1979. No tillage systems for crop production on an Ultisol. In: Soil Tillage and Crop Production. IITA Proc. Ser. No. 2. (ed) Lal, R. International Institute for Tropical Agriculture, Ibadan, pp. 207 – 209.

Mbagwu, J.S.C. 1987. Effects of land use on the hydrological properties of a southern Nigeria soil. Beitrage Trop. Landwirtsch Veterinarmed 25: 375 – 382.

Mbagwu, J.S.C. 1991. Mulching an Ultisol in southern Nigeria: effects on physical properties, maize and cowpea yields, J. Sci. Food Agric. 57: 517-526.

Mengel, D. B Nelson, D. W and Hubber, D. M. 1982. Placement of nitrogen fertilizer for no-till and conventional till corn. Agron. J. 74: 515 –518.

Nwadialo, B. E. 1989. Soil-landscape relationship in the Udi-Nsukka plateau, Catena 16:11-120.

Ojeniyi, S. O., Dexter, A. R. 1983. Changes in the structure of tilled soil in growing seasons. Soil Tillage Res. 3:39-46.

Olsen, S. R. Sommers, L. E. 1982. Phosphorus in page, A. L. (Ed). Methods of soil Analysis Part 2. monogr. 9 ASA. Madison WI pp. 403 – 430.

Parr, J. F. Papendick, R. I., Hornick, S. B., Meyer, R.E. 1992. Soil Quality: attributes and relationship to alternative and sustainable agriculture. Am. J. Alternative Agric. 7: 5 – 11.