The Effects of Land Configuration and Wood-Shavings Mulch on the Properties of a Sandy Loam Soil in Northeast Nigeria. 1. Changes in Chemical Properties

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Summary

*In the savanna region of Nigeria, the search continues for practices that will improve the productivity of the fragile soils characterized by low organic matter and plant nutrients, poor structure and very high permeability. A 4-year (1999-2002) field experiment was conducted to determine the effects of land configuration and wood-shavings mulch on soil chemical properties under rainfed sorghum. The treatments were Flat Bed (FB as control), Open-ridge (OR), Tied-ridge (TR,) Flat bed with wood-shavings mulch (FBM), Open-ridge with wood-shaving mulch (ORM) and Tied-ridge with wood-shavings mulch (TRM). Wood-shavings at the rate of 5 t/ha were used in 1999 but the rate was increased to 10 t/ha during subsequent years to ensure adequate soil coverage. Soil samples from 0.075 m depth were obtained at the end of the third (2001) and fourth (2002) cropping seasons and analysed for pH, organic carbon (OC), total nitrogen (TN), available P (AP), exchangeable acidity, exchangeable K^+, Ca^{++} Mg^{++} and Na^+. The results indicate that over the 4-year study period, the topsoil in all the treatments acidified but the rate of acidification was much faster in bare treatments (FB, OR and TR) than in the mulched treatments (FBM, ORM and TRM), irrespective of tillage methods. In 2002; OC, TN and AP in the top 0-0.075 m layer of the wood-shavings amended soil were 24-29, 15-23 and 92-112% higher, respectively, than in the unamended control. OC in this soil layer correlated with TN (r= 0.98**) and AP (r= 0.97**). Similarly, the three bare treatments experienced a rapid loss in exchangeable K^+, Ca^{++} Mg^{++} and Na^+ between 1999 and 2002 but the reduction was much greater in OR and TR treatments compared to the FB treatment. FBM, ORM and TRM treatments significantly improved the topsoil fertility with respect to exchangeable K^+, Ca^{++} and Mg^{++} content. This was attributed to the release of these exchangeable cations from the decomposing organic mulch. These results demonstrate the potential of combining ridge tillage with residue mulch in improving the fertility status of the coarse textured soils in the savanna region of northeast Nigeria.*

Résumé

Effets de la configuration du terrain et du paillage à la sciure de bois sur les propriétés d'un sol sablo-limoneux dans le nord-est du Nigeria.
1. Changement dans les propriétés chimiques du sol

*Dans les régions de savane du Nigeria, les recherches se poursuivent sur les pratiques permettant d'améliorer la productivité des sols fragiles caractérisés par un faible taux de matière organique et d'éléments nutritifs, une faible structure et une perméabilité très élevée. Une étude de terrain a été conduite sur 4 ans (1999-2002) pour déterminer les effets de la forme du terrain et du paillage à la sciure de bois sur les propriétés chimiques du sol en culture pluviale de sorgho. Les traitements comprenaient: le semis à plat (SP, témoin), semis sur billons ouverts (SO), le semis sur billons cloisonnés (SC), semis à plat + paillage à la sciure de bois (SPP), semis sur billons ouverts + paillage (SOP), et le semis sur billons cloisonnés + paillage (SCP), 5 t/ha de sciure de bois étaient utilisés en 1999, mais les années suivantes 10 t/ha ont été appliquées afin d'assurer une meilleure couverture du sol. Les échantillons de sol ont été prélevés à une profondeur de 0,075 m à la fin de la troisième (2001) et quatrième (2002) saisons de culture et ont été analysés pour déterminer le pH, le carbone organique (CO) l'azote total (NT) le phosphore absorbable (PA), l'acidité échangeable, les ions K^+, Ca^{++}, Mg^{++} et Na^+ échangeables. Les résultats montrent que sur les 4 années d'études, la couche superficielle du sol dans tous les traitements a été acidifiée mais le taux d'acidification était plus marqué dans les traitements sur sol nu (SP, SO, SC) que dans les traitements sous paillage (SPP, SOP, SCP) sans tenir compte des méthodes de préparation du sol. En 2002, le CO, le NT et le PA dans l'horizon superficiel du sol de 0,075 m amendé avec paillage à la sciure de bois étaient respectivement 24-29, 15-23 et 92-112% plus élevés que dans le témoin non amendé. Le CO dans cette couche de sol était en corrélation avec le NT (r=0,98**) et le PA (r= 0,97**). De même, les trois traitements à nu ont connu une perte rapide en K^+, Ca^{++}, Mg^{++} et Na^+ entre 1999 et 2002 mais la baisse était surtout élevée dans les traitements SO et SF comparés au traitement SP. Les traitements SPP, SOP*

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et SFP ont, de façon significative, amélioré la fertilité de la couche superficielle en ce qui concerne la teneur en K^+, Ca^{++} et Mg^{++} échangeables. Ceci était attribué à la libération des cations échangeables à partir de la matière organique (paillage) en décomposition. Ces résultats montrent l'intérêt de combiner le billonnage avec l'application d'un paillage à base de sciure de bois pour l'amélioration du statut de la fertilité des sols à texture grossière des savanes du nord-est du Nigeria.

Introduction

Most parts of the arid and semi-arid regions of northeast Nigeria, as well as in other parts of the tropics, are exposed to short duration intense rainstorms. These short duration rainfall events seal the soil surface, reduce infiltration and cause considerable runoff and soil erosion (8). The resulting increase in erosion and runoff during such intense rainstorms in turn affect soil chemical properties such as organic matter, soil nutrients and pH (13, 18).

Tillage practices capable of improving the productivity of these fragile and nutrient poor soils are needed. Ridge tillage is a cultural practice widely used throughout the world with many different modifications but with the same goal; to prepare a seedbed that is elevated above the mean land surface of the field (10). Ridges have been shown to be advantageous in concentrating the top fertile soil layer and for conserving water on some nutrient-deficient savanna soils of Nigeria (14).

Studies conducted in the neighbouring Niger Republic revealed that combining the land configuration practice of ridge tillage with crop residue mulch was found to be effective in reducing soil degradation resulting from nutrient mining and wind erosion (5). Numerous studies conducted in the semi-arid West Africa have shown that tillage practices that leave crop residues on the surface maintain soil fertility (4, 5) and conserve moisture while increasing crop yields (1, 6). However, most of these studies utilized small grain straw as mulch material. None of these studies utilized wood-shavings although several studies conducted elsewhere have demonstrated their potential for nutrient cycling (16, 20). Chipped wood from certain tree or shrub species, are increasingly considered as a potential organic amendment in agricultural soils (15). Following their fragmentation into small chips and their incorporation into soil, they release nutrients and are further degraded by soil microorganisms (11). Wood-shavings are generated in huge amounts by furniture factories and timber sheds spread all over northeast Nigeria. In Maiduguri where the study was carried out, it is estimated that at least 105 metric tonnes of timber are brought in daily from the western part of the country. Despite the magnitude of these wastes generated daily and the possible adverse effects on the environment, no serious attempts have been made either for their effective utilization or safe disposal.

The objective of our research was to evaluate the effects of ridging and wood-shavings mulch on chemical properties of a coarse-textured soil in a semi-arid region of northeast Nigeria.

Materials and methods

Description of experimental site

The experimental field is situated at the University of Maiduguri Teaching and Research Farm (11° 54'N, 13° 5'E) in northeast Nigeria. Longterm average annual rainfall in Maiduguri is 553 mm, and the distribution is unimodal, starting on average in mid-June and lasting until the end of September (9). The soils at the experimental site are classified as Typic Ustipsamments (22), loosely aggregated with a sandy loam surface texture (6).

Experimental layout

The four-year field experiment was initiated in 1999 and consisted of six treatments in a randomized complete block design with four replications. The experimental plots measured 10 m long and 5 m wide with an average of < 2% slope. Sorghum (var. *Paul Biya*) was sown manually between 11th July and 2nd August depending on the year at a spacing of 0.75 m between and 0.45 m within rows. Sorghum plants were thinned to two seedlings per stand at about 2-3 weeks after planting (WAP) each year. Recommended rates of N, P and K (60: 30: 30) were applied to all the experimental plots just prior to planting each year with the N applied in two split doses, half at planting and the remaining half at 4 WAP. All plots were weeded manually at 4 weeks interval each year. The sorghum plant was harvested between 2nd and 26th November each year.

The experimental treatments consisted of Flat bed (FB), Open-ridge (OR), Tied-ridge (TR), Flat bed with mulch (FBM), Open-ridge with mulch (ORM), and Tied-ridge with mulch (TRM). The FB treatment did not receive any land configuration practice. The OR treatment was established by constructing ridges of

Table 1
Selected properties of the soil of the experimental site and the wood-shavings prior to initiation of the experiment

Property	Topsoil (0-0.075 m depth)	Wood-shavings
pH (1:2.5, H_20)	5.61	ND
ECe (dS/m)	0.03	ND
Organic C (%)	0.38	36
Total N (%)	0.066	0.14
P ($mg.kg^{-1}$)	4.20	82.8
Exchangeable cations	($Cmol{\cdot}kg^{-1}$)	
K	0.17	1.76
Ca	2.70	4.70
Mg	1.90	1.93
Na	0.22	ND
H + Al	0.23	ND
CEC	4.99	ND
Particle size distribution (%)		
Sand	69.74	NA
Silt	18.23	NA
Clay	12.03	NA
Texture	Sandy loam	NA

ND= not determined NA= not applicable

about 0.15 to 0.20 m high at 0.75 m apart. The TR treatment was similar to OR except that dikes 0.15 to 0.2 m in height were established in the furrows at intervals of 2 m to create a series of micro basins for soil water conservation. Ridges and dikes were established manually using a hoe each year prior to planting. FBM was established by applying wood-shavings uniformly on the surface of a flat bed to act as both a surface mulch and organic manure. Wood-shavings in the ORM and TRM treatments were surface applied in the furrow positions. In all the mulched treatments, wood-shavings were added about 2 WAP each year. During the 1999 cropping season, a mulch rate of 5 t/ha was used, this was increased to 10 t/ha during subsequent years to ensure a more adequate soil coverage. Selected properties of the wood-shavings and the soils of the experimental site (sampled before the commencement of the trial in 1999) are given in table 1.

Soil sampling and analysis

Prior to commencement of the experiment in 1999, one composite soil sample from the surface 0-0.075 m layer of each treatment plot was taken for chemical analysis. Additional composite samples from the top 0-0.075 m layer in each treatment plot were collected in the sorghum row just before seeding in the third and fourth year of the experiment. Samples collected were analysed for selected fertility indicators using standard procedures described in detail by Page *et al.* (17). In 1999 only, samples (0-0.15 m depth) from one replicate of each treatment, were taken for soil textural analysis (<2 mm fraction) in the sorghum rows using the Bouyoucos (7) hydrometer method.

Analysis of variance was carried out on all measured parameters and treatment means were compared using the least significant difference (LSD) test at $P< 0.05$. Measured data were related to each other by correlation.

Table 2
Effects of land configuration and wood-shavings mulch on soil pH (H_2O, 1:2.5) and exchangeable acidity (EA) in the third (2001) and fourth (2002) years of the experiment

	FB*	OR	TR	FBM	ORM	TRM	$LSD_{0.05}$
PH							
2001	4.41	4.52	4.59	4.77	4.72	4.69	0046
2002	4.38	4.46	4.53	4.72	4.68	4.66	0.054
EA							
2001	0.36	0.34	0.32	0.25	0.26	0.27	0.026
2002	0.39	0.37	0.35	0.29	0.27	0.29	0.026

*FB= flat bed, OR= open-ridge, TR= tied-ridge, FBM= flat bed + mulch, ORM= open-ridge + mulch, TRM= tied-ridge + mulch.

Table 3
Effects of land configuration and wood-shavings mulch on soil pH (H_20, 1:2.5), and the contents of exchangeable acidity, K^+, Ca^{++}, Mg^{++}, Na^+ and CEC in the surface 0-0.075 m layer at the end of the third (2001) and fourth (2002) cropping seasons

	FB*	OR	TR	FBM	ORM	TRM	$LSD_{0.05}$
Exch. K^+							
2001	0.15	0.13	0.12	0.20	0.19	0.18	0.039
2002	0.13	0.12	0.10	0.22	0.20	0.20	0.019
Exch. Ca^{++}							
2001	2.37	2.30	2.10	3.10	3.00	3.00	0.269
2002	2.30	2.10	2.00	3.00	3.20	3.10	0.249
Exch. Mg^{++}							
2001	1.80	1.70	1.60	2.30	2.10	1.90	0.243
2002	1.70	1.50	1.50	2.40	2.20	2.20	0.207
Exch. Na^+							
2001	0.19	0.17	0.16	0.23	0.22	0.22	0.025
2002	0.18	0.15	0.15	0.24	0.22	0.22	0.041
CEC							
2001	4.51	4.23	3.98	5.80	5.51	5.30	0.553
2002	4.34	3.87	3.75	6.16	5.82	5.72	0.461

*FB= flat bed, OR= open ridge, TR= tied ridge, FBM= flat bed + mulch, ORM= open ridge + mulch, TRM= tied ridge + mulch.

Results and discussion

Soil pH and exchangeable acidity

Averaged across all treatments, soil pH decreased from an initial value of 5.61 in 1999 to 4.62 in 2001 and 4.57 in 2002. Although the surface soil pH in all treatments decreased as a result of continuous cropping over the four year study period, the decrease was, however, most pronounced in the unmulched treatments, and to a lesser extent in the mulched treatments (Table 2). Since no other amendments were added to the soil but wood-shavings mulch, the lower rate of acidification in the mulched treatments compared to the unmulched treatments may be attributed to the addition of basic cations particularly K^+, Ca^{++} Mg^{++} and Na^+ released during wood-shavings decomposition (Table 3).

In the case of K^+, the addition of small quantities through dust deposition on mulched plots may also have contributed (12). Enrichment of an appalachian mine soil with basic cations such as K^+, Ca^{++} and Mg^{++}, following the application of wood-chips had earlier been reported (20). On the other hand, the acidification in the unmulched treatments (FB, OR and TR) may be attributed to nutrient mining, loss of buffering capacity as a result of the decline in organic carbon content, leaching of nutrients and the loss of soil and organic matter by wind erosion (5). Total exchangeable acidity was significantly correlated with pH (r= - 0.97 and r= - 0.96) for the 2001 and 2002 cropping seasons, respectively. Because of the lower rate of acidification in the mulched treatments compared to the unmulched treatments, the mulched treatments maintained exchangeable acidity levels slightly above the initial value in both 2001 and 2002. The observed effect may be the result of complexing of Al by organic compounds released following the decomposition of the added organic material (5).

Exchangeable cations and cation exchange capacity (CEC)

Over the four-year study period, annual application of wood-shavings on the surfaces of either the flat bed or ridged plots significantly ($P< 0.05$) improved the fertility status of the sandy loam soil with respect to K^+, Ca^{++} and Mg^{++} (Table 3). On the other hand, the fertility of the topsoil in the unmulched treatments (FB, OR and TR) generally decreased with the decrease being much greater in the OR and TR treatments compared to the FB treatment. Such a rapid deterioration in soil quality following continuous cropping in the absence of organic amendment input has also been observed by other workers in the same region (5, 19). On average, mulching increased (relative to the 1999 level) the content of exchangeable K^+ in the topsoil by 20-33% by the third year (2001) and 54-69% by the fourth year (2002). In a similar study, Schoenholtz *et al.* (20) also observed up to 13% increase in exchangeable K^+ after only two weeks of addition of wood-chips to an appalachian mine soil. Similar treatment differences were also observed for exchangeable Ca^{++} (Table 3). Whereas the mulched treatments irrespective of tillage methods maintained exchangeable Ca^{++}, Mg^{++} and Na^+ levels equal or slightly above the initial values in both years, a reduction in the contents of

Table 4
Effect of land configuration and wood-shavings mulch on organic carbon, total nitrogen and available phosphorus in the end of the third (2001) and fourth (2002) years of the experiment

Treatment	Organic carbon (%)		Total nitrogen (%)		Available phosphorus (mg.kg^{-1})	
	2001	2002	2001	2002	2001	2002
FB*	0.35	0.34	0.062	0.060	2.8	2.6
OR	0.31	0.28	0.056	0.055	2.4	2.2
TR	0.32	0.28	0.058	0.056	2.6	2.4
FBM	0.42	0.44	0.071	0.074	5.3	5.5
ORM	0.41	0.42	0.068	0.072	4.9	5.2
TRM	0.40	0.42	0.066	0.069	4.7	5.0
$LSD_{0.05}$	0.024	0.022	0.0021	0.0023	0.275	0.255

*FB= flat bed, OR= open-ridge, TR= tied-ridge, FBM= flat bed + mulch, ORM= open-ridge + mulch, TRM= tied-ridge + mulch.

exchangeable Ca^{++}, Mg^{++} and Na^{+} was observed in the bare treatments (FB, OR and TR).
Ridging and mulching significantly ($P< 0.05$) affected the topsoil CEC in both 2001 and 2002 with the mulched treatments having significantly ($P< 0.05$) higher CEC compared to the unmulched treatments (Table 3). In general, the values of CEC reported in this study are low (CEC< 7 cmol.kg^{-1}) which is an indication of their poor potential to retain plant nutrients.

Organic carbon (OC), total nitrogen (TN) and available phosphorus (AP)
The different management practices significantly ($P< 0.05$) influenced the contents of OC, TN and AP in the top 0-0.075 m layer over the 4-year study period (Table 4). Whereas the bare treatments (FB, OR and TR) maintained OC levels slightly below the initial value in both 2001 and 2002, a significant increase in the content of OC was observed for the mulched treatments (FBM, ORM and TRM). Similar treatment differences were observed for TN and AP in both 2001 and 2002.

The increase in OC content over the initial value after 3-years of annual additions of wood-shavings were 11% for FBM, 9% for ORM and 5% for TRM. The corresponding increases following 4-years of wood-shavings application were 16% for FBM, 11% for both the ORM and TRM treatments. Similar increases of between 3 and 8% in TN and 12 and 26% in AP were observed following 3-years of wood-shavings application. The corresponding increases at the end of the fourth year (2002) of the experiment were 5-15% for TN and 19-31% for AP. Since no other amendments were added to the soil apart from the wood-shavings mulch and in view of the fact that carbon additions resulting from leaf litter are virtually similar for all treatments, the observed increases in OC, TN and AP contents in the mulched plots may be attributed to the release of these elements from the decomposing wood-shavings mulch (20). For a similar coarse-textured mine soil, Schoenholtz *et al.* (20) found increases of up to 18% OC, 10% TN and 19% AP after only 3-years of application of wood-chips. Studies have shown that during early stage of wood chip decomposition, lignin is first transformed into polyphenols and humic substances by the basidiomycetes fungi, and subsequently incorporated into soil organic matter (3, 21). Lalande *et al.* (15) found up to 24- and 8-fold increase in fungal population following the first and second years, respectively, of wood chip addition. This stimulation of fungal activity lead to a significant increase in the content of OC and TN compared with the unamended soil. Therefore, the observed increase in OC and TN content following third (2001) and fourth (2002) years of wood-shavings addition is expected, since wood chip which contains appreciable amounts of cellulose and lignin is preferentially attacked by fungi (2, 21).
The main practical problem associated with the use of soil amendments rich in lignin is their high C:N ratio, which favours N immobilization by microorganisms (23). Although the N immobilization effect of the added wood-shavings was not investigated in the present study, their high C:N ratio may have stimulated N immobilization by microorganisms as was the case in similar studies. For example, Lalande *et al.* (15) observed a rapid decline in NO_{3^-} –N in the first year following the addition of chipped wood from twigs but no such effect was observed in the second year. In our study, the added inorganic –N– fertilizer may have at least to some degree counteracted the immobilization effect of the added wood-shavings as was observed in the increase in OC and TN in the third (2001) and fourth (2002) year (Table 4).
However, the fertility level of the topsoil layer in the flat and ridged plots without mulch progressively declined over the 4-year study period. Such progressive decline in soil fertility following continuous cropping without the return of organic amendment has also been observed by previous workers in the study area (6, 19). The results of the correlation analysis carried out on the data for the year 2002 showed that OC is positively correlated with TN ($r= 0.98$) and AP ($r= 0.97$) thus emphasizing the importance of soil organic matter in improving the fertility status of these coarse textured soils.

Conclusion

These results indicate that over the 4 - year period of our study, the bare and ridged plots without mulch experienced a rapid acidification and a loss in nutrient elements. On the other hand, the practice of no-tillage or ridge tillage farming with adequate retention of wood-shavings on the soil surface maintained a high level of soil fertility and slowed down the rate of acidification. Such improvement in soil quality was much greater in the flat bed with mulch than in either the open-ridge with mulch or tied-ridge with mulch. These results demonstrate the value of wood-shavings as a fertilizer material. It is therefore concluded that in the savanna region of northeast Nigeria, the practice of no-tillage with adequate retention of residues on the soil surface be encouraged over and above the practice of ridge-tillage with or without mulch.

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