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

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Summary

Mulching and ridge tillage are proven technologies for improving soil productivity in semi-arid regions. Yet data quantifying the combined influences of these practices are limited. Our objectives were to determine the changes in selected physical properties of a sandy loam after 4-years of annual tillage and wood-shavings mulching. The tillage and wood-shavings treatments consisted of: Flat bed (FB), Open ridge (OR), Tied-ridge (TR), FBM, ORM and TRM were same as FB, OR and TR, respectively except that wood-shavings at a rate of 10 t/ha were surface applied ≈ 2 weeks after sowing each year to serve as both a mulch and an organic amendment.

At the end of the trial in 2002, bulk density, penetration resistance, total porosity and soil water content from each of 0-0.075, 0.075-0.15 and 0.15-0.30 m depths were determined. Composite samples from the surface (0.075 and 0.075-0.15 m) layers from 3 replicates of each treatment were also collected for the determination of wet aggregate stability and from 0-0.15 m and 0.15-0.30 m layers for determination of saturated hydraulic conductivity (K_{sat}).

After 4 years of annual tillage and addition of wood-shavings, soil bulk density and penetration resistance were consistently lower and total porosity higher in the FBM, ORM and TRM treatments than in the FB, OR and TR treatments.

Penetration resistance in all treatments was strongly related to soil water content. A 'hoe pan' was established below 0.15 m depth beneath the furrows of the ridged treatments. This could be attributed to human traffic during field operations and ponding of water, which occurred in the furrows following heavy rains.

Wet aggregate stability estimated as the proportion of aggregates of size > 0.25 mm (macro-aggregates) in the 0-0.15 m layer were significantly ($P< 0.05$) higher under FBM, ORM and TRM than under FB, OR or TR treatments. K_{sat} was not influenced by either tillage or wood-shavings treatments but were higher for the mulched plots than for the bare treatments in both soil layers.

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.

2. Changements dans les propriétés physiques

Le paillage et le billonnage sont des techniques connues pour améliorer la productivité des sols dans les régions semi-arides. Jusque-là les données quantifiant les effets de ces pratiques sont limitées. Notre objectif est de déterminer les changements dans les propriétés choisies d'un sol sablo-limoneux après 4 ans de préparation du sol et de paillage à l'aide de la sciure de bois. Les traitements consistaient en: semis à plat (SP), semis dans le sillon ouvert (SO), semis dans le sillon fermé (SF), semis à plat + paillage à la sciure de bois (SPP), semis dans le sillon ouvert + paillage à la sciure de bois (SOP), et semis dans le sillon fermé + paillage (SFP) étaient respectivement similaires aux SP, SO, SF à l'exception du fait que de la sciure de bois à raison de 10 t/ha y avaient été appliqués annuellement 2 semaines après semis pour servir aussi bien de paillage que d'amendement organique. A la fin de l'essai en 2002, la densité apparente du sol, la résistance à la pénétration, la porosité totale et la teneur du sol en eau de chacune des profondeurs des sols suivantes: 0-0,075; 0,075-0,15 et 0,15-0,30 m ont été déterminées. Les échantillons composites des horizons de surface (0,075 et 0,075-0,15 m) provenant des 3 répétitions de chaque traitement ont été aussi prélevés pour la détermination de la stabilité de l'agrégat humide et des horizons 0-0,15 et 0,15-0,30 m pour la détermination de la conductivité hydraulique saturée (K_{sat}). Après 4 ans de préparation de sol et de d'addition de copeaux de bois, la densité du sol et la résistance à la pénétration étaient inférieures de façon consistante et la porosité totale était supérieure dans les traitements SPP, SOP et SFP par rapport aux traitements SP, SO et SF. La résistance à la pénétration dans tous les traitements était fortement en relation avec la teneur en eau du sol. Une semelle de labour s'était formée à 0,15 m en dessous des sillons. Ceci pourrait être attribué au passage des personnes lors des travaux de préparation des sols et à la stagnation de l'eau dans les sillons suite aux fortes pluies. La stabilité de l'agrégat

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humide calculée comme pourcentage des agrégats de taille > 0,25 mm (macro-agrégats) dans l'horizon 0-0,15 m était significativement plus élevée (P< 0,05) pour les traitements SPP, SOP et SFP que pour les traitements SP, SO et SF. K_{sat} *n'était pas influencée ni par le travail du sol, ni par les traitements à la sciure de bois, mais les valeurs obtenues étaient plus élevées pour les parcelles sous paillage que les traitements sur sols nus dans les deux horizons du sol.*

Introduction

Ridge tillage (RT) is a conservation tillage system that is fast gaining popularity in many dryland areas of the world (7, 8, 12). RT has been shown to improve crop growth by decreasing soil density and reducing soil resistance to root elongation (17, 26). However, the occurrence of high strength at or near the soil surface of a ridge-tilled row has been reported (1), although others found bulk density and soil strength at the surface 0-0.075 m depth to be the least in the row and the highest in the trafficked interrow (15). Numerous studies have documented increased bulk density and soil strength in trafficked interrow compared with non-trafficked interrows and rows (6, 14). While these studies documented the changes in soil physical properties created by vehicular traffic during ridge formation, only few studies have documented changes in soil physical properties brought about by the use of simple implements such as hand hoe particularly with regard to compaction in the furrow position.

Combining land configuration practices with organic solid waste management such as coir dust (22) and grass barrier strip (27) had been shown to improve soil properties and crop yields. Whereas the fertilizer value of wood-shavings mulch had been demonstrated in several studies (4, 21, 23), none where its effect on soil physical properties were seem to be the primary focus. The specific objective of this study was to establish the effectiveness or other wise of combining the land configuration practices of open and tied ridging with wood-shavings mulch for improving the physical properties of a coarse textured soil in northeast Nigeria.

Materials and methods

Site description and experimental design

This experiment was conducted at the teaching and research farm of the University of Maiduguri (11° 54' N, 13° 5' E) in northeast Nigeria between 1999 and 2002. Longterm (30 years) average annual rainfall in Maiduguri is 553 mm and the soils at the experimental site are classified as *Typic Ustipsamments* (25). The experiment was established as a randomized complete block design with six treatments and four replications. The treatments were: 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 kind of land configuration practice. Ridges were formed manually with a hoe at 0.75 m apart and 0-0.15-0.20 m high for the OR and TR treatments. Ridges for the TR and TRM treatments were tied at 2 m intervals to create a series of basins for water conservation. For the mulch treatments, wood-shavings at the application rate of 10 t/ha were applied to the surface to act as both a mulch and organic manures at approximately 2 weeks after planting (WAP) each year. The size of the treatment plots was 10 m x 5 m with an average of < 2% slope. On all treatment plots, residues from the previous seasons harvest were carefully packed and removed prior to planting in each year. Sorghum (var. Paul Biya) was sown manually using a hoe to a depth of approximately 2-3 cm at the furrow positions in the ridge treatments and row positions in the flat beds.

Determination of physical parameters

Bulk density, total porosity, penetration resistance and soil moisture content

Triplicate undisturbed soil core samples 0.03 m in diameter and 0.05 m in height were used for the determination of bulk density and total porosity. Cores were collected from three replicates of each treatment at each of the three depths, 0-0.075 m, 0.075-0.15 m and 0.15-0.30 m. Penetration resistance was determined using a standard cone penetrometer with a cone base diameter of 0.15 m and cone angle 30° operating at 1829 $mm.min^{-1}$ penetration speed. Gravimetric moisture content from each of the three depths was determined at the time when all cone resistance and bulk density measurements were made. Total porosity was computed from the relationship:

$Tp= (1 - B_d/P_d) \times 100$

Where T_p is total porosity, B_d is bulk density and P_d is particle density (2.65 g/cm^3).

Measurements of bulk density, penetration resistance and total porosity were made from the row positions of flat beds and furrow positions of ridge treatments. All measurements were made approximately one week after crop harvest in 2002.

Aggregate stability

Undisturbed core samples used for the determination of aggregate stability were collected at the end of the fourth year of the trial in November, 2002. At sampling, 10 samples from 3 replicates of each treatment were collected from the 0-0.075, 0.075-0.15 and 0.15-0.30 m depth intervals and combined to produce a composite sample from each depth. Immediately after collection, samples were sieved through a 4 mm mesh and stored in sealed plastic bags under refrigerated condition until analysis. Wet sieving procedure of Kemper and Chepil (9) was used to determine the mean weight diameter (MWD) of the wet aggregates in this study.

Saturated hydraulic conductivity (K_{sat})

For the measurements of K_{sat}, a stainless-steel ring 0.1 m in diameter and 0.1 m height was used to collect samples at each of 0-0.15 and 0.15-0.30 m depth intervals in the furrow and row positions of the ridged and flat bed treatments, respectively. The K_{sat} of the 0-0.15 and 0.15-0.30 m layers were measured on samples collected after the crop harvest of the fourth year cropping season in November 2002 using the falling head permeameter method of Klute (11).

Statistical analysis

ANOVA was performed on all measured data using randomized complete block design. Treatment means were compared using least significant difference (LSD) test at a probability of 5%. All measured parameters were related to each other by regression.

Results and discussion

Bulk density (B_d) and Total porosity (T_p)

Results of soil B_d and T_p measurements for the various treatments made at the end of the fourth cropping season of the study (2002) are presented in table 1.

Over the three depths, mean B_d in the mulched treatments were significantly ($P< 0.05$) lower than in the bare treatments, irrespective of tillage methods. The decrease in B_d with the addition of wood-shavings is expected since the density of the wood-shaving fragments is relatively low (23) compared to that of the mineral soils. Further more, the discontinuities between the wood-chips and the soil matrix might have also contributed to further loosening the soil. Although B_d increased with depth for all treatments, variations

Table 1
Mean comparisons of bulk density, total porosity, penetration resistance and soil water content among treatments and depths

Depth (m)	FB*	OR	TR	FBM	ORM	TRM	Mean	LSD for treatments within depths
			Bulk density, mg.m^{-3}					
0-0.075	1.44	1.47	1.48	1.35	1.39	1.37	1.42_{y}**	0.064
0.075-0.15	1.46	1.48	1.50	1.37	1.41	1.39	1.44_{y}	0.056
0.15-0.30	1.50	1.51	1.52	1.51	1.50	1.51	1.51_{y}	NS***
Mean	1.47^{b}	1.49^{ab}	1.50^{a}	1.41^{c}	1.43^{c}	1.42^{c}		
LSD for depths within treatments	0.024	0.023	$2.0x10^{-16}$	0.021	0.031	0.039		
			Total porosity (%)					
0-0.075	45.53	44.57	44.17	49.07	47.57	48.30	46.53_{x}	2.427
0.075-0.15	44.90	44.17	43.37	48.30	46.77	47.57	45.84_{x}	2.133
0.15-0.30	43.40	43.03	42.67	43.03	43.40	43.03	43.09_{y}	NS
Mean	44.61^{b}	43.92^{bc}	43.40^{c}	46.80^{a}	45.91^{a}	46.30^{a}		
LSD for depths within treatments	0.929	0.831	NS	0.873	1.216	1.507		
			Penetration resistance (kPa)					
0-0.075	661.9	735.5	772.2	550.2	583.7	560.7	644.0_{y}	128.75
0.075-0.15	822.7	850.3	887.1	614.1	786.6	703.2	777.2_{z}	110.35
0.15-0.30	910.1	946.8	979.0	960.6	896.3	951.4	940.7_{x}	NS
Mean	798.2^{b}	844.2^{ab}	879.4^{a}	708.3^{c}	755.3^{bc}	738.4^{bc}		
LSD for depths within treatments	126.75	45.56	32.93	64.11	70.68	100.98		
			Soil water content (gravimetric) at the time of measurement of penetration resistance (%)					
0-0.075	6.43	6.10	5.97	7.47	6.87	7.30	6.69_{x}	NS
0.075-0.15	5.50	5.27	5.10	6.57	5.90	6.20	5.76_{y}	0.381
0.15-0.30	4.70	4.60	4.50	4.50	4.90	4.63	4.64_{z}	0.187
Mean	5.54^{bc}	5.32^{c}	5.19^{cd}	6.18^{a}	5.89^{ab}	6.04		
LSD for depths within treatments	0.400	0.200	0.151	0.583	0.378	1.489		

*FB= flat bed, OR= open ridge, TR= tied ridge, FBM= flat bed + mulch, ORM= open ridge + mulch, TRM= tied ridge + mulch.
**Values for main effects followed by the same letter within a column (x, y, z) or row (a,b,c,d) are not significantly different at P< 0.05.
***NS= not significant.

The decrease in B_d with the addition of wood-shavings is expected since the density of the wood-shaving fragments is relatively low (23) compared to that of the mineral soils. Further more, the discontinuities between the wood-chips and the soil matrix might have also contributed to further loosening the soil. Although B_d increased with depth for all treatments, variations in B_d among treatments was however confined to the soil surface (0-0.15 m depth). Coincidentally, both B_d and penetration resistance in each of the 0-0.075 m and 0.075-0.15 m depths of OR and TR were greater than in the other four treatments (Table 1). It was clear from the two soil properties that a compact layer had developed beneath the furrow positions of these two treatments. This compact layer also known as 'hoe pan' or 'plough pan' is a common feature in cultivated soils with macrostructure (2) and is thought to be caused by human traffic during field operations and ponding which often occurs in the furrow positions immediately after heavy rains (17).
The different management practices only significantly ($P< 0.05$) influenced the T_p in the top 0-0.075 and 0.075-0.15 m soil layers (Table 1). Below 0.15 m depth, no significant differences in T_p were observed among the various treatments. T_p in general followed a trend quite opposite to that of B_d, with the T_p increasing as B_d decreases. The data in table 2 shows that T_p in both 0-0.075 and 0.075-0.15 m soil layers were consistently lower in the bare treatments than in the mulch treatments irrespective of tillage method.

Averaged across depth, OR and TR treatments resulted in T_p reductions of 1.5 and 2.7%, respectively, relative to the FB treatment. It is worth noting that the magnitude of this reduction in T_p is slightly greater than the magnitude of the increase in B_d. This implies that compaction due to ridging has a greater effect on T_p than on B_d which is in agreement with the findings of Onofiok (20) who compared changes in soil physical properties due to different tillage practices.

Penetration resistance (PR) and Soil water content (SWC)

Means of soil PR at various depths for the various treatments are shown in table 1. The PR clearly reflected the differences in B_d as indicated by the highly significant relationship (r= 0.95, r= 0.94 and r= 0.74) at the three depths (0-0.075, 0.075-0.15 and 0.15-0.30 m) respectively between the PR and B_d. The results indicate that for all treatments, both PR and B_d increased with depth and this finding is in agreement with findings of earlier studies (15, 17). Significant differences in PR measured at the end of the trial were only found at 0-0.075 and 0.075-0.15 m depths where FBM, ORM and TRM had significantly ($P< 0.05$) lower values than the OR and TR treatments at 0-0.075 m depth. Given that the B_d and PR at the upper 0-0.15 m layer were always lower in ridged plots with mulch as compared with the ridged plots without mulch, the reductions in B_d and PR of the "ridged with mulch" treatments can therefore be attributed to the additions of the wood-shavings mulch rather than to ridging per se which is in agreement with earlier observations (3). The data on PR corroborates that of B_d measurements confirming the existence of a zone of compaction below 0.15 m depth.
It is well known (5) that cone index measurements are very sensitive to variations in soil water content.

Table 2
Proportion of water-stable aggregates from the various soil layers remaining in the various size classes after vertically oscillating for 20 times

Sampling depth (m)	Aggregate diameter (mm)	Tillage systems (% remaining of oven-dry sample initially added)						
		FB*	OR	TR	FBM	ORM	TRM	SE ±
0-0.075	> 2 mm	0.23^{c**}	0.21^{c}	0.18^{c}	1.60^{a}	1.42^{b}	1.38^{b}	0.057
	1-2 mm	3.44^{c}	3.32^{cd}	3.22^{d}	4.14^{a}	4.03^{ab}	3.87^{b}	0.068
	0.5-1 mm	6.13^{c}	6.01^{c}	5.89^{c}	7.69^{a}	7.29^{ab}	7.11^{b}	0.176
	0.25-0.5 mm	8.96^{b}	8.84^{b}	8.80^{b}	11.14^{a}	10.89^{a}	10.85^{a}	0.171
	< 0.25 mm	81.24^{a}	81.62^{a}	81.91^{a}	75.43^{c}	76.37^{bc}	76.79^{b}	0.430
0.075-0.15	> 2 mm	1.14^{a}	1.12^{a}	0.11^{a}	1.20^{a}	1.31^{a}	1.28^{a}	0.057
	1-2 mm	2.39^{c}	2.33^{c}	2.28^{c}	2.58^{bc}	3.09^{a}	2.94^{ab}	0.132
	0.5-1 mm	4.66^{b}	4.51^{b}	4.43^{b}	4.98^{ab}	5.65^{a}	5.48^{a}	0.224
	0.25-0.5 mm	6.98^{cd}	6.68^{cd}	6.54^{d}	7.69^{bc}	8.76^{a}	8.62^{ab}	0.427
	< 0.25 mm	84.83^{a}	85.36^{a}	85.64^{a}	83.55^{ab}	81.19^{c}	81.68^{bc}	0.703
0.15-0.30	> 2 mm	0.13^{a}	0.11^{a}	0.11^{a}	0.14^{a}	0.11^{a}	0.12^{a}	0.013
	1-2 mm	2.06^{a}	2.03^{a}	2.02^{a}	2.08^{a}	2.02^{a}	2.03^{a}	0.023
	0.5-1 mm	4.46^{a}	4.41^{a}	4.35^{a}	4.52^{a}	4.32^{a}	4.37^{a}	0.129
	0.25-0.5 mm	6.51^{a}	6.39^{a}	6.18^{a}	6.53^{a}	6.12^{a}	6.35^{a}	0.152
	< 0.25 mm	86.84^{a}	87.06^{a}	87.34^{a}	86.73^{a}	87.24^{a}	87.13^{a}	0.268

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

** Means within a row having same superscript letter are not significantly different ($P< 0.05$).

Concurrent measurements of SWC and PR at various depths showed that SWC was significantly correlated with PR (r= - 0.94, r= -0.92 and r= -0.70) for the 0-0.075 m, 0.075-0.15 m, and 0.15-0.30 m depths, respectively). SWCs for the three depth increments at the time of PR measurement ranged from 5.19 to 6.18% (wt/wt) and were significantly ($P< 0.05$) different among treatments. Averaged over the three depths, mean SWCs in the FB treatment was lower by 10, 4 and 8% than the FBM, ORM and TRM treatments, respectively. The dependence of PR on SWC has already been established and it has been shown that PR increases with decreasing SWC due to increasing cohesion (10).

Aggregate stability

The percentages of aggregates in each size class at the 3 depths of measurement are presented in table 2. Significant differences ($P< 0.05$) in the proportion of aggregates of the various class sizes measured at the end of the trial were only found at the surface 0-0.075 and 0.075-0.15 m soil layers. Below 0.15 m in the soil profile, no significant differences exist in the proportion of aggregates of each size class. In general, however, there was a significant ($P< 0.05$) reduction in the proportion of aggregates of size > 0.25 mm (macro-aggregates) in the upper 0-0.075 and 0.075-0.15 m soil layers of the bare treatments relative to the mulch treatments, irrespective of tillage methods. The proportion of the macro-aggregates in the top 0-0.075 m layer were 19, 18, 18, 25, 24 and 23%, respectively, for FB, OR, TR, FBM, ORM and TRM plots, thus suggesting that organic matter addition increased the proportions of the macro-aggregates and reduced those of the micro-aggregates (< 0.25 mm) on these coarse textured soils. The higher values associated with the mulch treatments could be ascribed to the high organic matter accumulation under the mulch treatments (4) as has been observed by other authors who have compared the stability of aggregates between tillage treatments where residues were left on the surface and those where residues were removed (24, 27). The regression equation describing the relationship between soil organic carbon and percent of aggregate >1 mm diameter at the 0-0.075 m depth interval is:

$$MA= -3.6 + 22 (OC).$$

Where MA is percent of aggregate > 1 mm diameter and OC is soil organic carbon. In this linear relationship, 94% of the variation in MA was explained by variations in OC. The percent of aggregates > 0.84 mm in diameter, which has been used by many researchers to assess the relative susceptibility of soils to erode (24), strongly correlated with OC. Since the lower the OC, the more weakly structured the aggregates are, it is reasonable to infer from these results that soils in the bare treatments (FB, OR and TR) were less stable and more prone to breakdown by slaking as compared to the mulched treatments (FBM, ORM and TRM) as earlier observed by Mbagwu and Bazzoffi (18). These authors showed that the larger the amount of soil organic matter, the more resistant the aggregates to dispersion by water. In a similar investigation, Lalande *et al.* (13) observed that an increase in fungal population following addition of chipped wood on to a sandy loam soil lead to an increase in the stability of the soil macro-aggregates larger than 250 µm. Fungi are particularly effective in producing mucilage and possibly other compounds that increase binding. Microorganisms other than fungi have also been implicated with the production of polysaccharides and lipids, both of which contribute to soil stabilization after organic additions (29). In contrast, N'dayegamiye and Angers (19) did not detect any measurable improvement in aggregate stability after 9 years of annual addition of wood residues.

Saturated hydraulic conductivity (K_{sat})

Treatment differences in K_{sat} due to tillage and residue management were not observed in both the surface (0-0.15 m) and subsurface (0.15-0.30 m) layers (Table 3) which concurred with the results of Sharratt (24).

Table 3
Saturated hydraulic conductivity of the surface (0-0.15 m) and subsurface (0.15-0.30 m) layers as affected by land configuration and wood-shavings mulch

Treatments	Saturated hydraulic conductivity ($mm.h^{-1}$)	
	0-0.15 m	0.15-0.30 m
FB*	2.8	2.8
OR	2.7	2.6
TR	2.6	2.4
FBM	3.3	2.7
ORM	2.9	2.8
TRM	3.0	2.7
$LSD_{0.05}$	NS**	NS

*FB= flat bed, OR= open-ridge, TR= tied-ridge, FBM= flat bed + mulch, ORM= open-ridge + mulch, TRM= tied-ridge + mulch.
**NS= not significant

In this study, however, high within-treatment variance might have precluded the detection of significant differences among treatments. In the surface 0-0.15 m layer, K_{sat} under the bare treatments was lower (ranging from 2.6 to 2.8 $mm.h^{-1}$) than in the mulch treatments (value ranging from 2.9 to 3.3 $mm.h^{-1}$). A similar trend was observed for the 0.15-0.30 m depth but the differences in K_{sat} values among treatments was much narrower (Table 3). In general, however, the reduction in soil macroporosity as a result of the loss of aggregate stability and reduction of soil organic matter (4) may explain the decrease in the saturated hydraulic conductivity of the bare treatments.

Conclusion

The results of our 4-year study showed that combining the land configuration practices with mulching improved soil porosity, bulk density and soil strength and reduced the susceptibility of the soil to erosion (greater percent non-erodable aggregates). Although the magnitude of improvement in the soil quality is relatively small, such changes may exert some influence on crop growth. No-tillage and ridging (open or tied) in the absence of residue mulch led to deterioration in soil quality as evidenced by loss of soil porosity and a decline in non-erodible aggregates with greater decline observed for the ridge treatments than for the no-tillage.

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