Nig J. Biotech. Vol. 24 (2012) 13-19
ISSN: 0189 17131
Available online at www.biotechsocietynigeria.org.

NIGERIAN JOURNAL OF BIOTECHNOLOGY

Changes in some soil physical properties and yield of maize Grown in an ultisol as affected by three legumes.

Okonkwo C. I., Alu, M.O., and Ngene, P.N.
Department of Soil and Environmental Management
Ebonyi State University, Abakaliki

(Received 16.04.12, Accepted 06.08.12)

Abstract

The declining productivity of the soils in the Abakaliki agro-ecological zone of the South East Nigeria led to the conduct of a study on the physical properties of an Ultisol amended with pruning acting in alley cropping system. The study was established in a randomized complete block design with five treatments and four replications. Treatments included 7.5t ha^{-1}of pruning from an existing alley cropping system of three legumes: *Leuceana leucocephala*, *Gliricidia sepium* and *Cajanus cajan* incorporated into the soil as amendment; fertilizer and control with no application of either pruning or fertilizer. Results showed a significant reduction in soil bulk density as well as the surface penetration resistance in the plots where pruning were applied. The total porosity, gravimetric moisture content, water stable aggregates (WSA > 0.5mm) and water infiltration were all increased with the incorporation of pruning. The highest soil organic matter content of 4.98g kg^{-1} was obtained in plots amended with *Cajanus cajan* pruning. Grain yield of 3.01 t ha^{-1} was obtained in the alley plots amended with *Gliricidia sepium* pruning. The results showed that continuous application of pruning from alley cropping system can sustain the soil physical properties of an Ultisol in Abakaliki.

Keywords: Alley cropping, pruning, soil physical properties, crop performance.

Correspondence: *okonkwoclem@yahoo.com*

Introduction

It has been estimated on global scale, that millions of hectares of cultivated land are lost to agricultural production each year because of soil degradation FAO [1983]. Land degradation leads to reduced land production. The reduced land productivity is a very serious problem, which affect negatively the well being of the predominantly agrarian communities in the humid tropics.

The rapidly growing population demands over available quantities of food, fiber and fuel from the land have resulted in the land being farmed continuously and intensively. Environmentally sound traditional farming practices attuned to low population densities have not been able to adjust rapidly enough to decreasing land resident ratios resulting in practices that are environmentally damaging Okonkwo *et. al.* [2008].

Juo and Lal [1997] stated that most soils in the tropics, have low organic matter content and water retention capacity, are structurally unstable to pelting rain drops, have shallow effective rooting depths, and low activity clays. Soil organic matter content is an important factor that regulates nutrient and water retention capacities, stabilizes soil aggregates by reducing slaking and subsequent crust development and sustains economic levels of crop productivity. However, the maintenance of high level of organic matter is a very difficult problem. Prevailing high temperature regime in the tropics also increases the rate of decomposition of organic matter content kang and Ghuman [1991]. Consequently, soils that do not have a protective vegetative cover, are subject to such process as high surface soil temperature, crusting and reduction in water transmission properties and accelerated run-off and erosion.

An important option of ensuring continuous supply of organic matter is the incorporation of woody species into crop production system by means of alley cropping. Alley cropping system ensures the addition of large amounts of organic materials from the pruning as mulch or green manure, which can have favourable effects in the physical and chemical nature of soil environment [Okonkwo, *et. al.*, 2008]. The addition of mulch can lower soil temperature, reduce evaporation and improve soil structure, resulting in better infiltration, reduced run-off and improved water use efficiency Lal and Gummings [1986].

The aim of this study was to examine the effect of incorporation of pruning from three leguminous trees in alley cropping system on soil physical properties of an Ultisol and yield of maize.

Materials and Methods

The trial was carried out in an existing alley cropping system of three legume trees established in 1991, in the experimental farm of the Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki, between 2009 and 2010. Abakaliki lies at latitude 06^0 04^1N, and longitude 08^0 065^1E. The average annual rainfall ranges between 1500 mm – 2000 mm in a bimodal distribution with a mean of 1750mm. The main rainfall season is from April to August and a minor season from August to October. The mean monthly daily temperature ranges from 27 to 31^0C. Abakaliki agricultural zone lies within the Asu river group and consists of olive – brown sandy shales, fine-grained sand stones and mudstones. The soils are shallow, with unconsolidated parent materials (shale residuum) within 1m of the soil surface [Anikwe, et al. 1999]. It belongs to the order Ultisol within Ezzamgbo soil association and classified as typic Haplustult [Nnabude and Mbagwu 2001]. The vegetation of the area has been modified by man resulting in secondary scrubby bushes dominated by herbaceous weeds such as *Eupatorium ordoratum*, *Panicum maximum*, *Andropogon tectorum*, *Aspilia africana* etc.

The alley cropping system was established in a randomized complete block design (RCBD). The treatments were made up of:

- 7.5 t ha^{-1} *Leucaena leucocephala* pruning,
- 7.5t ha^{-1} *Gliricidia sepium* pruning,
- 7.5t ha^{-1} *Cajanus cajan* pruning,
- 200 kg ha^{-1} NPK fertilizer.
- Control plots with no pruning or fertilizer.

The above specified weights of fresh pruning were spread uniformly in the alley plots and incorporated manually by hoe to a depth of 0-20cm; in seed beds that measured 15m x 4m. Maize variety Oba Supper-2 was planted at one week after incorporation, at a planting distance of 25cm intra-row and 75cm inter-row spacing. The beds were kept weed free manually using hoe. The hedgerow trees were pruned periodically to prevent shading, and pruned materials removed from the plots to avoid compounding of nutrients in the alley plots.

Soil Sampling: Auger soil samples were randomly taken plot by plot from the alley cropping system before land preparation to form composite samples. The samples were air-dried, sieved with a 2mm aperture sieve. Five undisturbed soil core samples were taken plot by plot for analysis of initial soil bulk density using a 100 cm^3 cores at 0-10cm. Another five auger samples were also taken at 0-10cm in each plot for the determination of gravimetric soil moisture content. Soil surface resistance to penetration measurements were also taken from ten locations in each plot using a pocket penetrometer with 0.05m in diameter 'blunt ended' tip (Model 06^n.01 from Eijkelkamp Agrisearch Equipment). The resistance to penetration measurement was made to the depth of 0.05m at 90^0 angles. Measurements for the soil bulk density, total porosity, gravimetric moisture content and soil resistance to penetration, were carried out at maize tasseling. Plant height, and shoot dry weight were also measured at tasseling. Grain yield was harvested in a 3.5m x 14.5m area. The grain yield was harvested at 14% field moisture content.

Analytical Methods: Air-dried sieved composite soil was analyzed for soil organic C by the Walkley and Black method [Nelson and Sommers, 1982]. Organic matter was calculated from the organic carbon using a constant 1.724. Soil pH was determined in water using a 1:1 soil-water suspension. Calibration was done at pH 4.01 and pH 7.0 and the measurement done with an Orion 920A meter. Particle-size distribution was determined by the hydrometer method Gee and Bauder [1986]. Dry soil bulk density (Bd) was determined by the core method Blake and Hartage [1986]. Total porosity (Tp) was calculated from dry bulk density data with assumed particle density (Pd) value of 2.65 gcm^{-3} as follows:

$$Tp = 100\ (1 – Bd/Pd)$$ [Nnabude and Mbagwu, 1999]

Gravimetric moisture content (Gmc) was determined using a pressure plate apparatus at 10kPa field capacity, Stolte [1997]. The rate of water infiltration into the soil as influenced by pruning was determined using a double ring infiltrometer method described by Bouwer [1986]. In this method, double ring cylindrical metals with the diameters 30 and 40 cm for the inner and outer rings, respectively, were driven 10 cm deep into the soil of representative plots. Water was ponded at constant depth into two cylinders and the rate at which water moved into the soil was measured. This was done at the end of the first and second cropping seasons. Aggregate stability was measured at the macro level (WSA > 0.5mm) and micro level (dispersion ratio (DR) of % silt + clay dispersed in water to that dispersed in Calgon [Kemper and Rosenu 1986] and the Middleton [1930] DR, respectively.

Data Analysis: Data from the physical properties of the soil and maize yield were subjected to analysis of variance (ANOVA) tests. Where the F – values were significant at P = 0.05 level and the LSD was calculated using Fishers least significant difference method, Steel Torrie [1980].

Results and Discussion

The soil properties of the alley cropping system are presented in Table 1. Some of the physical properties were either high or low. The bulk densities were high ranging between (1.67 in *Cajanus* to 1.75 in *Leuceana* alley plots) while total porosity (34% *Leuceana* to 37% *Cajanus*) and the gravimetric moisture content was equally low 15%, 18% and 20% in the *Leuceana, Gliricidia* and *Cajanus* alley plots respectively. The soil texture was sandy loam and the bulk density was relatively high. However, surface soil resistance to penetration was high.

Effect of Pruning on Soil Physical Properties: Results of the effect of the incorporated pruning on the soil bulk density, total porosity, gravimetric moisture content and surface soil resistance to penetration are shown in Table 2. The soil bulk density decreased in all the alley cropping plots amended with pruning relative to the initial soil bulk density and the control plots. The incorporation of pruning of the different hedgerow trees in the second year further reduced soil bulk density relative to the initial soil bulk density and the control plots. The reduction in soil bulk density from the initial value represented 6% and 10% in the *L. leucocephala* pruning amended plots in the first and second year respectively, 6% and 11% in 2009 and 2010 in the *G. sepium* and 7% and 16% in *C. cajan* pruning amended plots in 2009 and 2010 respectively. The lowest soil bulk density of 1.40gcm-^{3} and 1.21gcm^{-3} were obtained in 2009 and 2010 respectively in plots amended with *C. cajan* pruning. The relative reduction in soil bulk density of the alley cropping plots could be attributed to the level of organic matter of the amended plots particularly in plots that received *C. cajan* pruning in the second year trial. With respect to the pruning types and their resultant effect to the soil bulk density, there were no statistical difference among amended plots in 2009 but *L. leucocephala* was significantly different ($p < 0.05$) relative to *G. sepium* and *C. cajan* in 2010. Soil bulk density of the control plots were significantly different ($p < 0.05$) relative to any of the amended plots. The fertilized plots also showed significant difference ($p < 0.05$) to the plots amended with *C. cajan* pruning in 2009 but became significantly different ($p<0.05$) to all the other plots in 2010. There were no statistical difference between the fertilized and the control plots.

Table 1. Properties of the Soil before planting (0- 20cm)

Soil Properties	Values			Remarks
	Leuceana	Gliricida	Gliricida	
pH($H_2$0)	4.8	4.8	4.9	Strongly acid
OC (gkg^{-1})	1.53	1.78	1.95	Low
Om (gkg^{-1})	2.64	3.07	3.37	Low/High
Sand	67%	63%	60%	-
Silt	21%	23%	26%	-
Clay	12%	14%	14%	-
Texture	SL	SL	SL	-
Bd (gcm^{3})	1.75	1.70	1.67	High
Tp (%)	34%	36%	37%	Low
Gmc	15%	18%	20%	Low
SRP (kgcm^{3})	4.19	4.14%	4.05	High

Total porosity and gravimetric moisture content were inversely related to the soil bulk density. In the two years trial, total porosity was in the order of *C. cajan* > *G.sepium* > *L. leucocephala* > fertilizer > control plots. In the first and second year trials, the amendment of soil with *L. leucocephala, G .sepium* and *C. cajan* pruning improved total porosity over the initial soil porosity by 10%, 12% and 16%in 2009 and 14%, 18% and 22% in 2010 respectively. Also the *C. cajan* improved total porosity relative to fertilizer plots by 16% and 26% in 2009 and 2010 respectively. Similarly, *C. cajan* increased relative to the control by 20% (2009) and 32% (2010).

This result was in line with the assertion of Soane [1990] who observed that when the organic material is mixed with mineral soil, not only will the bulk density be reduced but also the porosity will be increased. The gravimetric moisture content was affected by the incorporation of pruning. The gravimetric moisture content of 42% and 50% were obtained in plots amended with *C.cajan* pruning in 2009 and 2010.

Table 2. Soil bulk density, total porosity, gravimetric moisture content and surface resistance to penetration.

Treatments	Bd (gcm^3)		Tp(%)		Gmc (%)		SRP($kgcm^3$)	
	b	a	b	a	b	a	b	a
Leuceana	1.53	1.45	42	45	30	37	2.6	2.04
Gliricidia	1.49	1.30	43	48	39	43	2.5	1.82
Cajanus	1.40	1.21	47	53	42	49	2.2	1.35
Fertilizer	1.62	1.60	34	39	23	28	3.04	3.9
Control	1.72	1.81	32	31	22	18	3.41	3.0
LSD (0.05)	0.16	0.31	3.40	3.67	2.22	2.43	0.64	0.12

Bd = Bulk density, Tp = Total porosity, Gmc = Gravimetric moisture content,
SRP = Surface resistance to penetration, a = 2009, b = 2010.

These were 36% and 42% above the control plots for the two years. Also, incorporation of pruning increased the gravimetric moisture content by 17%, 36% and 36% in 2009 in the *L. leucocephala, G. sepium* and *C. cajan* alley plots respectively and 42%, 40% and 42% in 2010 for the same alley plots respectively relative to the initial soil value (Table 1). This implied that pruning influenced gravimetric moisture content of the soil. Surface soil resistance to penetration was affected by the different pruning. Lower measures of resistance to penetration were observed in the plots receiving pruning. The measures of resistance in this trial could be said to be governed by two factors namely; pruning and tillage. Whereas, the initial soil resistance to surface penetration was 4.19 Kg cm^{-2} (Table 1), the values obtained in the tilled control plots with no pruning and fertilizer was 3.0kg cm^{-2}, in 2009 and 3.4kg cm^{-2} in 2010. This gave 16% and 11% reduction in resistance to surface penetration relative to the initial value in the two years trial respectively. In the alley plots where pruning were incorporated soil resistance to surface penetration reduced by 24%, 25% and 34% (for *L.leucocephala*, *G.sepium*, and *C.cajan* respectively) in the first year and 34%, 40% and 52% in the second year for the surface layer relative to the initial values. The soil surface resistance to penetration could also be said to be inversely related to the total porosity of the soil. As the total porosity was increasing the soil surface resistance to penetration decreased. Similarly the measure of resistance increased with increase in soil bulk density. Therefore, the organic matter content (Table 3) of the soil had significant influence on both the soil bulk density and the soil resistance to surface penetration. This showed that increasing level of organic matter was sustained with addition of pruning and also reduced the two soil physical parameters. Among the various treatments, the control plots with low organic matter were significantly different ($p < 0.05$) relative to all the alley plots where pruning were incorporated. Therefore pruning incorporation in the alley cropping system led to significant lowering of surface resistance to penetration values, relative to the initial values, the control and fertilized plots. This could probably improve root penetration. Ball *et al*. (2007) found that root growth was severely limited at a penetration resistance of 3.6 kg cm^{-2} in conventionally tilled soil. This level was higher than any of the values obtained in this study.

The results of incorporated pruning on the macro-aggregate stability as percent of water stable aggregate (WSA)> 0.5mm are shown in Table 3. Percent water-stable aggregates were highest in plots amended with *C. cajan pruning* (67% and 61%) in the first and second years respectively. Compared to the control plots, the values represented relative increase of 48% and 50% in the two years of study respectively. The significant contribution of the pruning to the aggregate stability particularly the water stable aggregate (WSA<50mm) could be linked to the level of organic matter (Table 3). The considerable increase in the soil organic matter content in 2010 might be responsible for the stability of the macro-aggregate. Acton *et al.,[*1963] observed that polysaccharide (a constituent of organic matter) correlates very well with aggregate stability. At the micro-aggregate level, the DR for soils amended with pruning and having an average DR>85% in 2009 and 96% in 2010, could be regarded as highly dispersive. All the pruning amended plots showed significant differences in the DR relative to the control and the fertilized plots. However, the DR used for measuring stability did not show consistency because the levels obtained in the two years varied. The results obtained in this study therefore agreed with the works of Mbagwu and Ekwealor [1990] who reported that massive application of organic waste is needed to make substantial improvements in the stability of micro-aggregates.

Infiltration as a function of time under the different treatments is shown in Table 4. Both cumulative and final infiltrations were high in 2010 with the highest infiltration rate of 1380 mm h^{-1} in the C. cajan plots. The cumulative and final infiltration rate decreased in both the fertilizer and control plots in the second year of the trial. There were significant differences among treatments in all the different aspect of infiltration processes studied. The C. cajan was significantly different relative to the other treatments. The time for the final infiltration to occur was lowest in all the alley plots, ranging from 56 min to 74 min in 2009 and 40 min to 53 min in 2010, while there was an increase from 97min in 2009 to 101min in 2010 in the fertilizer plots and 107 min in the control (2009) to 128 min (2010).

Table 3. Effect of incorporated pruning on Macro(WSA > 0.5mm (%)) Micro (DR) aggregate stability and organic matter (%) .

Treatments	WSA>0.05mm		DR(%)		Organic matter	
	2010	2009	2010	2009	2010	2009
Leuceana	52.8	43.2	72.4	90.8	3.17	3.70
Gliricidia	57.1	46.1	88.7	97.5	3.38	4.22
Cajanus	68.6	60.5	95.5	100.0	4.36	4.98
Fertilizer	31.4	28.3	68.3	80.4	2.88	3.05
Control	24.3	20.7	50.9	71.6	2.88	2.64
LSD (0.05)	2.8	2.3	3.4	4.1	0.21	0.47

WSA = Water stable aggregate, DR = Dispersion ratio

Table 4. Effect of pruning on cumulative infiltration (I), Final infiltration (R) and time to reach final infiltration (T).

Treatments	CI(cm)		FI(mmh^{-1})		T(min)	
	2010	2009	2010	2009	2010	2009
Leuceana	210	170	577	980	74	65
Gliricidia	360	298	729	1140	67	53
Cajanu	420	320	940	1380	56	40
Fertilize	170	200	600	450	97	101
Control	110	105	208	277	107	128
LSD (0.05	42.43	22.61	92.40	66.31	16.32	14.37

The results obtained in this trial, showed that irrespective of the pruning type, their incorporation into the soil had the potential of improving and sustaining soil physical condition.

Crop Performance: In 2009, crop performances were lowest in the control plots (Table 5). In the first year of cropping, fertilizer application resulted in the highest plant height (112cm) and shoot dry weight (88.7g Plant^{-1}). Similarly, there was no significant difference ($p<0.05$) in grain yield between plots receiving fertilizer and those treated with pruning. However, in the second cropping year the plots treated with pruning showed significant difference ($p<0.05$) in crop performance over the fertilized plots.

Table 5. Crop performance as influenced by incorporated pruning

Treatments	Plant Ht (cm)		SDW g plant^{-1}		Grain yield t ha^{-1}	
	2nd	1st	2nd	1st	2nd	1st
Leuceana	108	127	67.8	72.1	2.41	2.66
Gliricidia	110	139	78.5	96.3	2.87	3.01
Cajanu	96	118	56.2	64.2	2.04	2.43
Fertilize	112	109	88.7	60.2	2.65	2.01
Control	66	62	32.3	29.2	0.96	0.77
LSD (0.05	12.4	13.7	8.42	8.73	0.41	0.48

Ht = Height, Wt = Weight, 1st = 2009, 2nd = 2010.

The highest plant height (139cm) and shoot dry weight (96.3g $plant^{-1}$) were obtained in the plots amended with *G. sepium* pruning. Grain yield of 3.01 t ha^{-1} was also obtained in the *G. sepium* plots in 2010. This was significantly different ($p<0.05$) relative to both the fertilized and control plots. Treatments with higher plant height and shoot dry weight also had higher grain yield. This is evidenced in the performance of maize in plots amended with pruning and inorganic fertilizer. The results from this study showed that the management practices that reduced soil compaction appeared to have increased crop performances particularly grain yield.

Conclusion

The results of this study showed that the use of pruning from hedgerow trees in alley cropping in soil management practices significantly affected soil physical properties (bulk density, total porosity, gravimetric moisture content and surface resistance to penetration) and crop performance. The bulk density and surface resistance to penetration decreased in all plots amended with pruning, while the total porosity and gravimetric moisture content increased over the initial soil level, the fertilized and control plots. The maize yield was significantly different in the hedgerow alley plots incorporated with pruning relative to the control. This study showed that the physical properties of soils can be effectively improved with continuous application of pruning materials over time.

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