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CANOPY EFFECT OF *Gmelina aborea* AND *Vitellaria paradoxa* TREE SPECIES ON SOIL PROPERTIES

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ABSTRACT

The canopy effects of two tree species (Gmelina aborea and Vitellaria paradoxa) on soil properties was investigated in a southern guinea area of Savannah ecosystem of Niger State, Nigeria. Soil samples were collected within the canopies of systematically selected Gmelina aborea and Vitellaria paradoxa trees and from adjacent open areas and analyzed. The result indicated that soils under the canopy had lower bulk density and higher porosity compared to the open area. The contents exchangeable bases, organic carbon, total nitrogen and available phosphorus were all higher under the two tree species compared to that of the open area. Amongst the two tree species, the soils under Vitellaria paradoxa had significantly lower bulk density, higher total porosity, moderately higher organic carbon and total nitrogen contents than soils under Gmelina aborea suggesting that inclusion of Gmelina aborea and Vitellaria paradoxa in the farming system by farmers in this area can likely improve soil productivity leading to lessening farmers' dependence on mineral fertilizers.

INTRODUCTION

The southern guinea savannah area of Nigeria is characterized by moderate and variable rainfall, high soil and air temperatures, low soil nutrient and organic matter reserves, leading to reduced crop yields. One of the options is the evergreen agriculture which involves the intercropping of trees in annual crop and livestock systems. Studies conducted in savannas and arid ecosystems indicated that woody plants facilitate vegetation growing beneath their canopies by ameliorating the physical environment leading to dramatic increases in crop yields and incomes, (Schroth and Sinclair, 2003). There is evidence of the use of evergreen agriculture in countries like Burkina Faso, Niger, Malawi and Zambia where farmers have successfully restored their exhausted soils with richer sources of organic nutrients, thereby dramatically increasing their crop yields and incomes (Garrity, 2011).

Evergreen agriculture modifies the plants physical environments through several mechanisms including increase in soil fertility (Belsky and Ali, 1994), trapping of windblown particles (Escudero *et al.*, 1985), or symbiotic associations with N-fixing micro-organisms (Alpert and Mooney, 1996). Other modification mechanisms include lowering of soil temperature and evaporative water losses through interception of incident radiation by tree canopies, and enhancement of soil water retention through enrichment of soil organic matter (Aguilera *et al.*, 1999). Proper selection of component tree species offers the opportunities for improving nutrient supply through nitrogen fixation and nutrient cycling, and increases direct production of food, fodder, fuel, fiber and income from products produced by the trees (Garrity, 2011). Furthermore, in areas where carbon markets are developed, integrating trees in the traditional crop based farming systems improves opportunities for rewards in the form of agricultural carbon offsets for farmers.

However, studies have indicated that the effects of trees on the soil beneath them vary strongly depending on the soil characteristics of the system and the species considered. For this reason, while selecting component tree species, care must be taken to avoid tree species that compete for resources with the component of food crops. For example, *Gmelina aborea*, which is already a natural component of farming systems across much of the Africa continent, has a unique characteristic that makes it highly compatible with food crops. Unlike most other trees, it sheds its nitrogen-rich leaves during the early rainy season and remains dormant throughout the crop growing period. The leaves grow again when the dry season begins. This make the plant avoids competition with the component for food such as lights, nutrients, or water during the growing season. *Vitellaria paradoxa* is another leguminous tree species commonly found in the savannah regions of northeast Nigeria. Its contribution to soil fertility through biological nitrogen fixation has been demonstrated in previous studies (Kumar *et al.*, 1994). In the Savannah and arid ecosystems, most scientific investigations on the effects of trees on soil properties are biased; in favour of chemical fertility with very little attention often paid to their effects on physical properties. This study was therefore conducted to evaluate the effects of *Gmelina aborea* and *Vitellaria paradoxa* (indigenous tree species) on soil chemical and physical properties in Minna, North Central Nigeria.

METHODOLOGY

Study Area

The survey was conducted in three locations in the municipality of Bida, North Central Nigeria (11^0 54'N, 13^0 05'E, with average elevations of 352 m above the sea level). *Gmelina aborea* and *Vitellaria paradoxa* are among the dominant tree species in each of the three locations chosen for the study. Long term average annual rainfall in Bida is 553 mm. analysis of a time series of rainfall records in Bida by Hess *et al*. (1995) revealed a decrease in the number of rainy days with time, while the rainfall amounts stayed unaltered. Major economic activity in the study area is farming.

Soil Sampling and Analysis

A 1-hectare quadrant containing as many matured species of *Gmelina aborea* and *Vitellaria paradoxa* as possible was carefully selected in each of the three sites chosen for the study. Soils under *Gmelina aborea* and *Vitellaria paradoxa* trees were compared with each other and with soils beyond the canopies. In each quadrant, a pair of matured *Gmelina aborea* and *Vitellaria paradoxa* trees of similar canopy size (approximately 8 m diameter) and structure, without shrubs or termite mounds under or close to their canopy and growing under similar conditions (soil type and terrain), were systematically selected for the study. Each *Gmelina aborea* had a similarly isolated *Vitellaria paradoxa* tree 20-30 m away across a level ground. Under each pair of *Gmelina aborea* and *Vitellaria paradoxa* trees, soil samples were collected from the top 0-25 cm depth at 3 m and 6 m away from the trunk, along the four cardinal directions. For each pair of tree or experimental unit, soil samples at the sampling points were combined to produce a composite sample for analysis. For each *Gmelina aborea* and *Vitellaria paradoxa* trees, soil samples from the open areas were further composited into one sample as the area was uniform in terms of slope, soil type and ground cover. Aluminium cylinders measuring 5 cm in diameter and 3 cm high were used to collect undisturbed soil core samples for soil bulk density determination (Klute, 1986). The soil samples were oven-dried at 105^0C for 24 h and analyzed at the Department of Soil Science, Federal University of Technology, Minna using the procedures described in Page *et al*. (1982) for the following: pH in H_2O at 1:1 soil: water solution ratio; electrical conductivity by 1:2.5 soil: water saturation extract; organic carbon by wet oxidation method; total nitrogen by micro-Kjeldahl technique; available P by Bray No. 1 method; Ca and Mg by Atomic Absorption Spectrophotometer (AAS) and K and Na by flame photometry method; Cation exchange capacity (CEC) by natural 1 N NH_4OAc solution saturation method; base saturation and C:N ratio by calculation.

Statistical Analysis

Data obtained were analyzed using the statistics (SX) 1989, Version 3.1. The measured physical and chemical parameters were analyzed using one way ANOVA. To obtain the relations between measured parameters, a Pearson correlation analysis was performed. The least significant difference test was used to compare treatment at the $p < 0.05$ level.

RESULTS AND DISCUSSION

Bulk Density (BD) and Total Porosity (TP)

The results of BD and TP measurements are presented in Table 1. The BD in the top 0-25cm layer of the soil varied significantly (P<0.05) among treatments with the two tree species having significantly lower BDs and higher TPs compared with the adjacent open area. The lower BD within the canopy could be partly attributed to improved macro-porosity (Table 1) and partly to dissipation of raindrop impact energy by the tree canopies (Kahi *et al*., 2009). Dispersing of weak aggregates raindrop impacts has long been recognized as one of the major sources of soil compaction on agricultural fields (Chiroma *et al*., 2004). *Vitellaria paradoxa* with more compact company structure resulted in greater reduction in BD (9.3%) and greater increase in TP (7.7%) than *Gmelina aborea* with relatively open canopy structure (3.3%) reduction in BD and 5.8% increase in TP). Visual inspection of the two tree species canopies showed a distinct difference in physical structure. *Gmelina aborea* crowns are shallow and more hemispherical in shape while *Vitellaria paradoxa* crowns are deeper and more globular, giving rise to higher shade intensity that increases the effectiveness for intercepting raindrop impacts. Therefore, the architectural and allometric differences between the canopies of the two tree species may be important factors as far as interception of raindrop impacts is concerned.

Table 1: Canopy effects of *Gmelina aborea* and *Vitellaria paradoxa* trees on soil bulk density and total porosity

Treatment	**BD (g/cm^3)**	**TP (%)**
Open area	1.29	52
Gmelina aborea	1.21	55
Vitellaria paradoxa	1.17	56
SE	**0.01**	**0.19**

The higher organic carbon content of the soils under the shade relative to that in the open (Table 2) may also have been responsible for the reduction in BD of the soils under the shade. The existence of a significant negative correlation between BD and organic carbon (r = -0.86) lend credence to this assertion (Table 3). In general, however, the reduction in soil porosity as a result of loss of aggregate and reduction of soil organic matter may explain the poor soil physical conditions of the open areas as typified by their relatively high bulk density and lower total porosity.

Soil pH and Exchangeable Acidity

The results indicate no significant differences in pH between the soils within and outside the canopies of both tree species. The surface soils in the open area had neutral pH (7.04) while those under the canopies of two tree species had slightly acidic pH (6.90 for *Gmelina* aborea and 6.93 for *Vitellaria paradoxa* (Table 2). The findings of this study are in agreement with that of Kahi *et al*. (2009) who observed a significant reduction in soil pH under the canopies of *Prosopis juliflora* and *Acacia tortilis* relative to that in the open area. In contrast, Dunham (1991) reported that soils were less acidic within than outside the canopies. These results are in contrast with the findings of previous research that showed that addition of organic matter increased pH in tropical soils (Wong *et al*., 2009). The mechanisms by which tree species influence soil acidity and exchangeable cations include inter-specific differences in the uptake of exchangeable bases, nitrogen fixation and production of litter high in organic acid content and the stimulation of mineral weathering (Githae *et al*., 2011). Giving that the soils of the study area were derived from same parent materials under same climatic conditions and topography, the observed decrease in soil pH under *Gmelina aborea* and *Vitellaria paradoxa* compared with that in the open area is likely due to turn over of litter (both leaves and roots) high in organic acid content as earlier pointed out in a similar studies (Finzi *et al*., 1998). There were significant negative correlations (Table 3) between soil pH and soil P (r =-0.96, P<0.05) and between soil pH and CEC (r =-0.99).

Table 2: Canopy effects of *Gmelina aborea* and *Vitellaria paradoxa* on Soil Chemical Properties

Treatment	pH	ECE (ds/m)	OC (%)	TN (%)	AP (ppm_	Ca (mol/kg)	Mg (mol/kg)	K (mol/kg)	Na (mol/kg)	CEC
Open	7.0	0.49	0.57	0.10	6.78	8.80	2.97	0.67	0.23	22.0
Gmelina aborea	6.9	0.59	0.60	0.16	8.43	11.37	3.43	0.73	0.27	14.20
Vitellaria paradoxa	6.9	0.68	0.73	0.43	8.55	8.40	4.50	0.90	0.27	14.07
SE	0.16	0.16	0.15	0.04	2.32	2.55	1.11	0.15	0.6	2.73

Table 3: Correlation matrix table for various soil (0-25cm depth) Physical and chemical parameters

	BD	**TP**	**PH**	**EC**	**OC**	**TN**	**AP**	**CA**	**MG**	**K**	**NA**	**CEC**
BD	-											
TP	-0.7949	-										
PH	0.8585	-0.3713	-									
EC	-0.9873	0.9687	-0.7660	-								
OC	-0.8595	0.8796	-0.4759	0.9299	-							
TN	-0.7946	0.7365	-0.3713	0.8813	0.9933	-						
AP	-0.9630	0.9837	-0.9649	0.9079	0.6901	0.0621	-					
CA	-0,00657	0.1560	-0.5680	-0.0939	-0,4535	-0.5532	0.3321	-				
MG	0.9146	0.8741	0.5778	0.9673	0.9928	0.9724	0.7718	0.3437	-			
K	-0.8963	0.8523	-0.5420	0.9554	0.9970	0.9817	0.7436	-0.3837	0.9991	-		
NA	-0.9449	0.9707	-0.9791	0.8808	0.6449	0.5527	0.9982	0.3887	0.7318	0.7017	-	
CEC	-0.9264	0.9567	-0.884	0.8547	0.6038	0.5079	0.9936	0.4366	0.6949	0.6632	0.6632	0.9986

BD:- bulk density, TP: total porosity, pH: acidity & alkalinity, OC: organic carbon, TN: total nitrogen, AP: available phosphorus, EC: effective cation, CEC: cation exchange capacity

Organic Carbon (OC), Total Nitrogen (TN) and Available Phosphorus (AP)

The contents of OC, TN and AP in the top 0-25 cm soil layer were not significantly (p>0.05) influenced by the different treatments although the values of these three parameters were generally higher under the tree canopies than in the adjacent open area (Table 2). The higher accumulations of nitrogen under the canopies of the two tree species were expected since both trees were nitrogen-fixing legumes. However, Gomez- Aparico *et al*. (2005) did not observe significant canopy effects on soil nitrogen and phosphorus even though one of the component tree was a nitrogen- fixing legume. In general, the contributions of biological nitrogen-fixation to the improvement of soil fertility have been pointed out in many studies (Gomez-Aparico *et al*., 2005; Kahi *et al*., 2009). The results of the correlation analysis showed that OC was positively correlated with TN (r = 0.99) and AP (r = 0.69) thus emphasizing the importance of soil organic matter in improving the fertility status of savannah soils (Table 3). Although milder canopy effects on soil OC and AP were found in this study, the soil under the two canopies had higher values of these two elements relative to that of the open area. Previous workers (Akpo *et al.*, 2005, Kahi *et al*., 2009) attributed the higher accumulation of carbon, nitrogen and phosphorus in the soils within canopy than in soils in the adjacent open areas to litter fall and reduced leaching under the canopy. Menault *et al*. (1985) and Wang *et al*. (2010) argued that root turnover is probably more important than litter accumulation in improving the soil fertility status within the canopy zone.

Exchangeable Cations and Cation Exchange Capacity (CEC)

No statistical significant differences (p>0.05) were observed between the soils within and outside canopy in respect of their contents of exchangeable cations and cation exchange capacity al-though there was a trend towards more Mg, K, Na and CEC in soils within than outside the canopy zone (Table 2). The observed limited effects of tree canopy on soil exchangeable cations concord with the findings of Gomez-Aparico *et al*. (2005). These workers did not observe significant differences in chemical properties between soils under tree canopies and that in the open area even when species with divergent canopy characteristics were compared in a Mediterranean setting. These workers pointed out that effects of canopy on soil properties could vary strongly depending on the characteristics of the system and the species considered. Except for Na, the correlation between CEC and other exchangeable bases were all not significant.

CONCLUSION

The results of this study indicate that *Gmelina aborea* and *Vitellaria paradoxa* improved the soil physical and chemical properties beneath their canopies with the latter being more efficient than the former. The canopy zone irrespective of species differences had lower bulk density and higher total porosity and total nitrogen. However, the two tree species failed to exert a stronger effect on soil properties such as organic carbon, available phosphorus, exchangeable potassium, and calcium, magnesium and cation exchange capacity, although in all cases they were higher under the canopies than in open interspaces. Although canopy shading appeared to be the single most important factor in the improvement of soil physical and chemical properties beneath the canopies, contribution from external sources such as animals that take shelter under the canopies and birds and large animals that transport nutrients from grasslands to the canopy zone in their food and next materials cannot be quantified. We proposed more tree species with divergent morphological characteristics be compared with a view to selecting these with proven potentials for improving soil properties in this ecosystem.

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