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Full Length Research Paper

Soil physical and chemical properties under continuous maize cultivation as influenced by hedgerow trees species on an alfisol in South Western Nigeria

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In the sub-humid tropical Africa, the pressure of diminishing land resources resulting from the rapidly increasing population has made the traditional fallow systems used for the replenishing soil fertility impossible. Alley cropping has been suggested as an alternative to bush fallowing. This study evaluated the effects of 20 years of different species of hedgerow crops on the physical and chemical properties of soil. Soil physical and chemical properties were studied under *Pterocarpus santalinoides*, *Gliricidia sepium, Enterolobium cyclocarpum* and *Leucaena* and *leucocephala* intercropped with maize (*Zea mays L.*) at a 20 years old Leventis Foundation Farm, at Ilesa in the south western part of Nigeria. Soil bulk density was significantly reduced under the hedgerow species from a maximum of 1.52 g cm^{-3} under control to 1.33 g cm^{-3} under *Pterocarpus* and *Enterolobium* hedgerows. While the soil cone penetrometer resistance index followed a similar trend, the soil field capacity was lowest under *Pterocarpus* and highest under *Leucaena* hedgerows. Soil porosity increased significantly ($p < 0.05$) from 0.38 under control to a maximum of 0.47 under *Pterocarpus*, while the hydraulic conductivity at a suction of -0.5 cm was significantly highest *Gliricidia* hedgerow. Soil pH and other chemical properties were consistently highest under *Leucaena* and consistently *Gliricidia* hedgerow. Overall among the screened hedgerow species, *G. sepium* showed the best promise in terms of improvement in both soil physical and chemical properties.

Key words: Hedgerow, alley cropping, hydraulic conductivity, *Pterocarpus, Gliricidia, Leucaena, Enterolobium,* cone penetrometer resistance, field capacity.

INTRODUCTION

Alley cropping is an agroforestry practice developed in the 1970s at the International Institute for Tropical Agriculture in Nigeria (Kang et al., 1981), in which hedgerows of trees and shrubs are established and annual crops are cultivated in the alleys between the hedgerows. The hedgerows are pruned before planting the crop and periodically while it is growing to prevent shading, with the prunings being applied to the soil as green manure and/or mulch. Between cropping cycles, hedgerows are usually allowed to grow without pruning. It was originally hoped that by incorporating fast-growing nitrogen-fixing woody perennials with crops, their abilities to cycle nutrients, suppress weeds, and reduce erosion would create soil conditions similar to those in the fallow phase of shifting cultivation. In this way, the cropping and fallow phases could take place simultaneously on the same land, allowing the land to be cropped for an extended period when long fallow periods are not feasible under the particular socioeconomic conditions. Researchers saw the technology as the combination of farmers' accumulated traditional wisdom with the efficiency of modern science (Kang, 1993). The use of alley cropping system is in response to the diminishing land resources and the inability of farmers in tropical Africa to maintain the traditional fallow systems. Under the pressure of increasing population and other competing land use demands, long fallow periods are no longer possible in densely populated areas. The possible effects of shortening of fallow cycles of productivity decline are known and well illustrated by on soil (Guillemin, 1956). Leguminous tree/

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shrubs are preferred as hedgerows because of their nitrogen fixing abilities through the activities of soil bacteria present at their rhizosphere. The trees/shrubs used in alley cropping must possess the following basic characteristics according to Kang et al. (1985). They must be fast growing, easy to establish and deep rooting system, produce heavy foliage, regenerate rapidly after pruning, have good coppicing ability, easy to eradicate, provide useful by-products and finally, must be able to fix atomspheric nitrogen if it is a legume. Other considerations include high stem ratio and the tree species with less management are more preferred, especially by the small-scale farmers. Leaf retention during the dry season is an added advantage that makes some species remains productive during the dry season when grasses and legume crops dry out. Moreover, the tree species should have the ability to withstand environmental stress, adapt to a given environment and able to grow competitively with crop species before it is selected.

Literatures are replete with the advantages of alley cropping over the use of inorganic fertilizers. The primary advantage of alley cropping system over the conventional system is that the presence of hedgerows in alley cropping allows year-round biomass production and the residues from the prunnings ensure increased soil organic matter and improved nutrient status. Results obtained from on-station experiments were promising. In Nigeria, for example, prunnings from *Leucaena leucocephala* have been shown to increase maize grain yields from 1.9 to 3.5 t ha^{-1} (Kang et al., 1981), while a *Gliricidia sepium* alley system on a degraded soil increased maize yields from 1.74 to 2.42 t ha^{-1} (Atta-Krah and Sumberg, 1988). Increases in yields of banana were obtained when alley cropped with *Enterolobium cyclocarpum*, and of cowpea when alley-cropped with *E. cyclocarpum* and *Dialium guianense* (Oko et al., 2000). In the fourth and fifth years of an alley-crop trial in Burundi, *Calliandra calothyrsus* increased maize yields by 29 - 63%; *L. diversifolia* by 27 - 43%, and *Senna spectabilis* by 24 - 38% (Akyeampong, 1999). Additionally, contour hedgerows have also been shown to successfully reduce the risk of erosion in sloping agricultural land (Agus, et al., 1997). Despite the large volume of information on the effects of alley cropping on soil fertility and crop yield, there has been little documentation on the contributions of these different hedgerow trees on some soil physical properties. Understanding the effectiveness of each tree species in soil structural amendments may assist the farmers in soil management practise. This study was therefore design to evaluate the influence of different hedgerow species on soil physical and chemical properties.

MATERIALS AND METHODS

The study area is located at the teaching and research farm of Leventis Foundation (Nigeria) Agricultural School, Imo, Ilesa, Osun State, Nigeria. It is situated approximately between latitude 7°40′ N and 4°45′ E. This area lies within the rainforest vegetation zone of Nigeria. According to Smyth and Montgomery (1962), the parent rocks consist essentially of quartz with small amounts of white micaceous minerals. Also in this area, densely wooded quartz ridges rise abruptly from the surrounding country and is elongated North-South following the strike of the rock. The soil in this study area belongs to the Okemesi series (Smyth and Montgomery, 1962). The climate representation of the area is influenced by Tropical Maritime (mT) and Tropical Continental (cT) air mass. The relative humidity, which is often high throughout the year, is as a result of dominant influence of the tropical maritime air-mass. During the rainy season however, the relative humidity of the air is hardly below 85%, whereas it may be as low as 65% during the dry season. The primary rainfall maximum is usually in the month of September, while the secondary rainfall maximum occurs in the month of July. The July to August rainfall is sandwiched between the two rainfalls maximum. Period of rainy season varies between seven and nine month allowing for two cropping seasons. The area is therefore, marked with its wet and dry seasons typical of Low land rainforest region of south western Nigeria. However, the mean annual temperature ranges from 22.0°C to 31.4°C while the mean annual rainfall is 1413 mm (Salami et al., 2003).

The plots studied were established by Leventis Foundation in 1988 for training of young people in farming entrepreneurs. The alley plot constitutes a portion of this and has been maintained under continuous maize farming for eight years prior to this study. The alley plot consists of four different hedgerow species as follows: *P. santalinoides*, *G. sepium, E. cyclocarpum* and *L. leucocephala* intercropped with maize (*Zea mays L.*). The plot used as control had oil palm (*Elaeis guineensis*) as hedgerows. The experimental design was a Randomized Complete Block arrangement with four replicates. Each sub-plot size was 4 x 20 m with a buffer stripe of 1 m within. Thus, four alleys of 4 m wide spacing of the hedgerows were planted within maize at 75 x 25 cm spacing in each treatment. In each of the sampled plots, representative soil samples were randomly collected diagonally within the 1 m stripe of the hedgerows. On each treatment, 20 random samples were taken to make a composite, which were homogenized and sub sampled for laboratory analyses. Meanwhile, soil properties such as moisture content, penetration resistance and unsaturated hydraulic conductivity were measured in situ. Soil moisture content was determined with the use of a portable time domain reflectrometry (TDR) device, while undisturbed soil samples for bulk density was taken with a 100 cm^{-3} stainless steel core. The soil hydraulic conductivity was determined at tensions of - 0.5 and -2.0 cm of H_2O with the use of a single reservoir tension infiltrometer. A standard cone penetrometer with cone angle of 30° was used to determine the soil penetrometer resistance. Soil moisture contents were taken at each point of penetration resistance determination.

Laboratory analyses

Soil particle size distribution was determined by the modified hydrometer method (Bouyocous, 1962), while the soil particle density was determined using the pcynometer method. Soil pH was determined in 0.01 M $CaCl_2$ (1:2 soil/solution ratio). Exchangeable acidity was extracted with 1.0 M KCl (Rhoades, 1982). The total exchangeable acidity (Al^{3+} + H^+) was determined by titration with NaOH, while the exchangeable Al alone was determined by titration with HCl. Exchangeable cations were extracted with 1.0 M ammonium acetate at pH of 7.0. Potassium and Na contents of the extract were determined with flame photometer, while Ca and Mg were determined with an atomic absorption spectrophotometer. The effective cation exchange capacity (ECEC) and base saturation (BS) for the soils were estimated from the data generated. The organic carbon content of the soil was determined by the modified Walkley-Black procedure (Nelson and Sommers, 1996). The soil total nitrogen was determined with the use of the auto-analyzer. The available P was

Table 1. Effects of alley species on soil bulk density (g cm^{-3}), particle density, cone index (MPa) and soil textural composition (%).

Alley species	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Cone index (MPa)
Control	53b	21a	26b	SCL	1.53a	2.47a	0.72a
Enterolobium	55ab	22a	23b	SCL	1.33b	2.41a	0.37b
Gliricidia	55b	20ab	25b	SCL	1.39ab	2.44a	0.27bc
Leucaena	52b	18c	30a	SCL	1.32b	2.47a	0.26bc
Pterocarpus	59a	16c	25b	SCL	1.33b	2.47a	0.23c

SCL = sandy clay loam
*Means in the same coloumn followed by the same alphabets are not significantly different at 5% probability based on Duncan's multiple range test.

was extracted with the Bray number one solution (Bray and Kurtz, 1965). The P in the extract was determined colorimetrically by the phospho-molybdate method using the Spectron-20 D^+ colorimeter.

Statistical analyses

Analysis of variance was performed on the data of soil properties and maize grain yield obtained from the incrementally scalped plots. The means of significant treatment effects were separated with the Duncan's multiple range test. All the tests of statistical significance were based on a 5% level of probability.

RESULTS AND DISCUSSION

Soil physical properties

The results in Table 1 show no appreciable difference in the soil textural composition under the different hedgerow species. Though the plot under *Leucaena* had the lowest sand and the highest clay contents, the reverse was the case for the plot under *Pterocarpus* with relative low clay. However, the soil of all the experimental sites had sandy clay loam texture. Thus there were no significant textural differences among the sites. Also, there was no signify-cant treatment effect on soil particle density. This is expected as soil particle density, just like texture is an intrinsic property of the soil and it is not readily influenced by soil management. Soil bulk density was however significantly higher under control (1.52 g cm^{-3}) but comparable among other plots (1.33 - 1.39 g cm^{-3}) irrespective of the hedgerow tree species. This is consistent with the findings of Alegre and Cassel (1996) who observed a signify-cantly lower bulk density under *Inga edulis* hedgerows compared to conventionally cultivated plots. Soil penetrometer resistance followed a similar pattern as the bulk density with the highest value recorded under control (0.72 mPa) while the lowest value was under *Pterocarpus*. Penetrometer resistance is an indication of soils ability to resist root proliferation and it has been found to be influenced by soil moisture content and bulk density. Generally, a value of 0.23 MPa is the critical for the roots of most crop plants (Reichert et al., 2009).

Soil field capacity (FC) was significantly influenced by the hedgerow specie (Table 2). Soils under *Pterocarpus* and *Enterolobium* hedgerows had significantly ($p < 0.05$) lowest FC at 0 - 15 cm and 15 - 30 cm depths. This was significantly lower by a magnitude of 2 compared with soils under both *Leucaena* and control treatments which had the highest FC at both 0 - 15 and 15 - 30 cm soil depths. The high clay contents of soils under both *Leucaena* and the control treatments may be responsible for their elevated FC. Clay is known to retain a high amount of moisture even at high soil potentials. Soil porosity was significantly ($p < 0.05$) highest under both *Pterocarpus* and *Enterolobium* hedgerow species and least under control. However, there were no differences between the soil porosity under control compared to both *Gliricidia* and *Leucaena* hedgerow species. Soil hydraulic conductivity at a matric suction of -0.5 cm ($K_{0.5}$) was significantly highest under *Gliricidia* and ranged from magnitudes of three to six when compared with the values under the other treatments. The $K_{0.05}$ values of the other treatments were not significantly different from one another. The hydraulic conductivity at matric suction of 2 cm (K_2) however did not show any significant difference among all the treatments.

Soil chemical properties

The soil reaction on all the treatments was acidic (Table 3). The soil under P*terocarpus* was more acidic (pH = 4.3) while the *Leucaena* treatment with a mean pH of 4.8 was least acidic. However there was no significant difference in the pH values for control, *Leucaena, Enterolobium* and *Gliricidia* treatments. The soils' exchangeable acidity (H^+ + Al^{3+}) followed a pattern similar to pH showing that H^+ contributed most to the acidity of the soil. The high acidity recorded on these soils may be as a result of the acidic nature of the parent rock coupled with the continuous use of inorganic fertilizers in absence of a liming programme. The distribution of organic matter, total N and available P did not differ significantly among the treatments.

Table 2. Soil field capacity ($cm^3\ cm^{-3}$), hydraulic conductivity ($cm\ Hr^{-1}$) and porosity as influenced by hedgerow species.

Alley species	Field moisture capacity at different depth intervals		Porosity	Hydraulic conductivity ($cmhr^{-1}$) at different suctions (cm H_2O)	
	0 -15 cm	15 - 30 cm		-0.5 cm	-2.0 cm
Control	0.27a	0.27a	0.38b	0.84b	0.15a
Enterolobium	0.13b	0.16ab	0.47a	0.83b	0.04a
Gliricidia	0.22ab	0.22ab	0.45ab	2.32a	0.02a
Leucaena	0.27a	0.28a	0.43ab	0.36b	0.26a
Pterocarpus	0.13b	0.12b	0.47a	0.39b	0.06a

Table 3. Soil pH (in $CaCl_2$), organic carbon, total N (%), exchangeable H and Al, P, K, Ca, Mg, Na, ECEC ($cmol\ kg^{-1}$) and base saturation (%) as influenced by hedgerow species.

Alley species	pH	Organic C	Total N	Available P	Exchangeable acidity		Exchangeable cations				ECEC	Base saturation
					H^+	Al^{3+}	Ca^{2+}	Mg^+	K^+	Na^+		
Control	4.7ab	1.47a	0.09a	10.11a	1.75ab	0.20b	3.00c	2.47a	0.21bc	0.20b	7.83bc	74.50b
Enterolobium	4.6ab	1.19a	0.11a	8.67a	2.08a	0.30ab	3.33bc	0.46b	0.24b	0.31a	6.61cd	64.03c
Gliricidia	4.7ab	1.47a	0.12a	12.87a	1.75ab	0.20b	2.78c	0.97b	0.17c	0.21b	5.72d	72.02b
Leucaena	4.8a	1.34a	0.11a	12.67a	1.58b	0.23b	4.85a	3.11a	0.34a	0.24b	10.33a	82.77a
Pterocarpus	4.3b	1.44a	0.12a	12.40a	2.10a	0.45a	3.38b	2.59a	0.22bc	0.20b	8.94ab	71.01b

*Means in the same coloumn followed by the same alphabets are not significantly different at 5% probability based on Duncan's multiple range test.

Exchangeable soil Ca^+ was highest under *Leucaena,* followed by *Pterocarpus* and least under control and *Gliricidia*. Meanwhile the value was higher by 1.85 cmol kg^{-1} soil compared with control while it was higher by 1.47 cmol kg^{-1} soil compared with the *Pterocarpus* treatment. The soil exchangeable Mg^{2+} followed a similar pattern again with *Pterocarpus* having a mean Ca^{2+} content of 3.11 cmol kg^{-1}. This was however not significantly different from the control and the *Pterocarpus* plots. *Enterolobium* plot had the least exchangeable soil Mg^{2+} content. Also, soil exchangeable K^+ was significantly higher by 0.13 compared with the control plot and by 0.10, 0.12 and 0.17 than *Enterolobium, Pterocarpus* and *Gliricidia* in that order. Both the soil ECEC and the bases saturation were highest on the *Leucaena* plots followed by *Pterocarpus* while the *Enterolobium* and *Gliricidia* treated plots had lower soil ECEC and base saturation compared with the control treatment.

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