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Amelioration of a Severely Degraded Alfisol by Plantations of Trees

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ABSTRACT

Although, empirical evidence from many parts of the world has indicated that plantations of certain exotic and native tree species can ameliorate soil conditions on lands, once badly degraded, and hence, improving productive potential of such lands. However, in Nigeria, there is hitherto, paucity of published statistical data and research information on the relative efficacy of tree species in ameliorating poor soil conditions with resultant improved agricultural productivity of such soils. Consequent upon this, this study was designed to evaluate ameliorating effects of certain plantation tree species on a severely degraded Alfisol. The study was carried out at Olokemeji Agricultural and Biological Experimental Station in Ikere Ekiti, Ekiti State, Nigeria, between 2011 –2016. The experiment was laid out in a randomized complete block design with three replications. The different tree species included: Gmelina arborea (GA); Leucaena leucocephala (LL); Gliricidia sepium (GS); Oxytenanthera abyssinica (OA); Hevea brasiliensis (HB); and the control (C) (i.e.check). The results obtained indicated existence of significant (P = 0.05) differences among the tree species as regards their ameliorating effects on soil chemical properties. Relative to pre-planting baseline soil data, the percentage increases in soil organic carbon (SOC), adduced to the tree species were 432, 327, 379, 286, 341 and 25% for GA, LL, GS, OA, HB, and C, respectively. Similarly, the percentage increases in total N, adduced to the tree species were 515, 590, 621, 464, 487 and 92 for the respective GA, LL, GS, OA, HB, and C. The percentage increases in available P beneath GA, LL, GS, OA, HB, and C were 387, 334, 354, 277, 306 and 32, respectively. In conclusion, the five year site occupancy by the five tree species resulted in significant improvement in nutrient status of soil in the site.

Keywords: *Amelioration, degraded, plantation, tree;*

INTRODUCTION

Improvement of soil by trees has become a central issue in agroforestry ecosystem. Studies by Aine (2012); Odua (2013); Golley (2014) had indicated that trees ameliorate poor soil conditions and improve productive potentials of lands, once degraded by agricultural and non-agricultural activities. However, Gess (2010) and Gile (2013) have recently questioned the potential of trees as soil improvers.

The long – known practices of shifting cultivation take advantage of the ameliorating effects of a period of forest fallow (Taling, 2011; Jansu, 2012; Lawel, 2014). Gross changes in agricultural productivity and plant nutrition have been documented under shifting cultivation (Jansu, 2012). Studies on the effects on soils have indicated catalogued increases in soil organic matter and accompanying increases in cation- exchange capacity during forest fallow (Ogunyemi, 2010; Atele, 2013; Alva, 2014). The importance of organic matter additions to degraded soils has been demonstrated both in young temperate – zone soils and the old, highly weathered soils of the tropics (Ogunyemi, 2010; Kimia, 2013).

During a period of forest fallow, nutrients are also accumulated. Both symbiotic and free – living nitrogen fixation may increase in the forest, but much of the nutrient increase is accomplished by the gathering of ions from a very large volume of soil and then, through litterfall an fine root turnover, concentrating them in the surface soil (Kimia, 2013).

This ameliorative process works when the site has a large rootable soil volume and a measurable amount of nutrients (Atele, 2013; Alva, 2014). The decomposing litter layer and surface soil layers are intensely perfused with fine roots and mycorrhizal hyphae, so nutrients are captured as they are mineralized, reducing leaching losses to almost zero (Vito, 2012; Carasel, 2013).

Another mechanism through which trees alter the conditions of the soil on which they grow, is the rhizosphere effects (Aina, 2010; Dudu, 2011; Bea, 2013). In the soil around the perennial roots of trees and other woody plants, a robust assemblage of organisms develops. These meso – and microfauna and microflora alter soil biological, chemical, and even physical properties very near the root and its associated mycorrhizae. This altered zone may have a profound effect on plant growth and subsequently on soil properties.

Despite a lot of empirical evidence from many parts of the world, indicating that, plantations of certain tree species can ameliorate soil conditions on lands, once badly degraded, and thus, improving productive potential of such lands. However, in Nigeria, there is paucity of published statistical data and research information on relative efficacy of tree plantations in ameliorating poor soil conditions with resultant improved agricultural productivity of such soils. To this end, this study was designed to evaluate ameliorating effects of plantations of certain tree species on a severely degraded Alfisol.

Material and Methods

Study Site

The study was carried out at Olokemeji Agricultural and Biological Experimental Station in Ikere Ekiti, Ekiti State, Nigeria, between 2011 – 2016. The soil of the study site belongs to the broad group Alfisol (SSS, 2003). The soil was strongly leached, with low to medium organic matter content. Prior to this investigation, the study site had earlier been under intensive and continuous cultivation of a variety of arable crops for many years.

Experimental Design And Treatments

The experiment was laid out in a randomized complete block design with three replications. The different tree species included: *Gmelina arborea* (GA); *Leucaena leucocephala* (LL); *Gliricidia sepium* (GS); *Oxytenanthera abyssinica* (OA); *Hevea brasiliensis* (HB); and the control (C) (i.e.check). The control treatment was a pasture of guinea grass (*Panicum maximum*).

Collection and analysis of soil samples

Prior to cropping, 35 core soil samples, randomly collected from 0 – 15 cm soil depth, were mixed inside a plastic bucket to form a composite sample, which was analyzed for chemical properties. Similarly, at the end of cropping, another sets of soil samples were collected in each treatment plot and analyzed.

The soil samples were air – dried, ground, and passed through a 2 mm sieve. The processed soil samples were analyzed in accordance with the soil analytical procedures, as outlined by the International Institute of Tropical Agriculture (IITA) (1989).

Planting

Seedlings of the plantation trees were procured from the Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State, Nigeria. After land preparation, the seedlings were planted at a spacing of 5m x 5m (400 plants ha^{-1}).

Data analysis

All the pre – and post – planting soil data collected were subjected to analysis of variance (ANOVA), and treatment means were compared, using the Duncan Multiple Range Test (DMRT) at 5% probability level.

Results

Baseline Chemical Properties of Soil in the Study Site Prior to Investigation

Table1 shows baseline chemical properties of soil in the study site before investigation.

Table1. *Baseline chemical properties of the soil prior to plantation establishment*

Soil properties	Values
pH	3.2
Organic carbon (g kg^{-1})	0.56
Total nitrogen (g kg^{-1})	0.39
Available phosphorus (mg kg^{-1})	0.53
Exchangeable bases (cmol kg^{-1})	
Potassium	0.48
Calcium	0. 60
Magnesium	0. 57
Sodium	0.52
Exchangeable Acidity	0.58
Effective Cation Exchangeable Capacity (ECEC)	2.75
Micronutrients (mg kg^{-1})	
Cu	0.76
Zn	0.81
Fe	0.70
Mn	0.68

Nutrient Composition of Leaves of the Tree Species After Five Year Site Occupancy

Table 2 shows nutrient composition of leaves of the tree species after five year site occupancy.

Changes in Soil Nutrient Status After Five Year Occupancy by Tree Species

Table 3 shows soil nutrient status as affected by five year occupancy by tree species

Relative to pre-planting baseline soil data, the percentage increases in soil pH, adduced to the tree species were 172, 88, 109, 56, 72 and 31% for GA, LL, GS, OA, HB, and C, respectively.

The percentage increases in soil organic carbon (SOC), adduced to the tree species were 432, 327, 379, 286, 341 and 25% for GA, LL, GS, OA, HB, and C, respectively. Similarly, the percentage increases in total N, adduced to the tree species were 515, 590, 621, 464, 487 and 92 for the respective GA, LL, GS, OA, HB, and C. The percentage increases in available P beneath GA, LL, GS, OA, HB, and C were 387, 334, 354, 277, 306 and 32, respectively.

The percentage increases in exchangeable K beneath GA, LL, GS, OA, HB, and C were 462, 408, 435, 338, 379 and 40, respectively. The percentage increases in exchangeable Ca beneath GA, LL, GS, OA, HB, and C were 370, 330, 350, 273, 298 and 30, respectively.

The percentage increases in exchangeable Mg beneath GA, LL, GS, OA, HB, and C were 370, 321, 344, 288, 293 and 42, respectively. The percentage increases in exchangeable Na beneath GA, LL, GS, OA, HB, and C were 363, 323, 340, 288, 306 and 40, respectively. The percentage increases in Cu beneath GA, LL, GS, OA, HB, and C were 32, 237, 222, 297, 269 and 315, respectively. The percentage increases in Zn beneath GA, LL, GS, OA, HB, and C were 31, 201, 181, 246, 222 and 262, respectively. The percentage increases in Fe beneath GA, LL, GS, OA, HB, and C were 43, 251, 226, 311, 276 and 340, respectively. The percentage increases in Mn beneath GA, LL, GS, OA, HB, and C were 32, 281, 254, 337, 307 and 357, respectively.

Table2. *Nutrient composition of leaves of the tree species after five year site occupancy*

Nutrient	Value				
	GA	LL	GS	OA	HB
Organic carbon (g kg^{-1})	0.74	0.68	0.73	1.24	2.96
Nitrogen (g kg^{-1})	0.75	0.76	0.78	0.58	0.66
C/N ratio	0.99	0.89	0.94	1.09	0.98
Phosphorus (g kg^{-1})	0.81	068	0.74	0.52	0.61
Potassium (g kg^{-1})	0.68	0.54	0.61	0.43	0.49
Calcium (g kg^{-1})	0.59	0.51	0.54	0.42	0.47
Magnesium (g kg^{-1})	0.63	0.55	0.58	0.47	0.53
Sodium (g kg^{-1})	0.56	0.52	0.54	0.47	0.50

GA: *Gmelina arborea;* **LL:** *Leucaena leucocephala;* **GS:** *Gliricidia sepium;* **OA:** *Oxytenanthera Abyssinica;* **HB:** *Hevea brasiliensis*

Table3. *Changes in soil nutrient status after five year occupancy by tree species*

Treatments (Tree species)	pH	Org. C. (g kg^{-1})	Total N (g kg^{-1})	Avail. P (mg kg^{-1})	Exch. bases (cmol kg^{-1}) K	Ca	Mg	Na	Micronutrients (mg kg^{-1}) Cu	Zn	Fe	Mn
C	4.2f	0.74f	0.75f	0.70f	0.67f	0.78f	0.81f	0.73f	3.24a	2.93a	3.08a	3.11a
GA	8.7a	2.98a	2.40c	2.58a	2.70a	2.82a	2.68a	2.41a	1.03f	1.06f	1.00f	0.90f
LL	6.0c	2.39d	2.69b	2.30c	2.44c	2.58c	2.40c	2.20c	2.63d	2.44d	2.46d	2.59d
GS	6.7b	2.68b	2.81a	2.41b	2.57b	2.70b	2.53b	2.29b	2.51e	2.28e	2.28e	2.41e
OA	5.0e	2.16e	2.20e	2.00e	2.10e	2.24c	2.21e	2.02e	3.10b	2.80b	2.88b	2.97b
HB	5.5d	2.47c	2.29d	2.15d	2.30d	2.39d	2.40d	2.11d	2.88c	2.61c	2.63c	2.77c

Mean values in the same column followed by the same letter(s) are not significantly different at P = 0.05 (DMRT). **C:** *control or check;* **GA:** *Gmelina arborea;* **LL:** *Leucaena leucocephala;* **GS:** *Gliricidia sepium;* **OA:** *Oxytenanthera abyssinica;* **HB:** *Hevea brasiliensis*

Discussion

The chemical properties of soil in the study site, prior to forest trees establishment indicated that the soil was highly acidic, with a pH of 4.2. The soil organic carbon (SOC) value of 0.56 k kg^{-1} was below the critical level of 5.8 g kg^{-1} for soils in southwestern Nigeria (Gess, 2010; Dudu, 2011). The total nitrogen of 0.39 g kg^{-1} was below the 1.5 g kg^{-1} critical level reported by Aina (2010). The K value of 0.48 cmol kg was below the 0.86 cmol kg critical level reported by Aritoff (2012). The Ca, Mg and Na values were all below the established critical levels for soils in southwestern Nigeria (Ogunyemi, 2010; Odua, 2013; Lawel, 2014).

Relative to pre – planting baseline soil data, the increases in pH of soil under the different tree species, after five year site occupancy, agree with the findings of Odua (2013); Atele (2013); Kimia (2013); Golley (2014), who noted increases in soil pH (i.e. reduced acidity) after five year site occupancy by certain tree species. The increases in pH can be ascribed to increases in exchangeable basic cations (K, Ca, Mg and Na) on the exchange sites of soil beneath the tree species after five year site occupancy (Odua, 2013; Atele, 2013; Kimia, 2013; Golley, 2014).

The increases in soil organic carbon (SOC), adduced to the various tree species, corroborate the observations of Vito (2012); Jansu (2012); Carasel (2013), who reported increases in SOC beneath tree species after five year site occupancy. These observations can be explained in the light of heavy litter, produced by the trees, which on decomposition, may have resulted in the return of a large amount of organic matter to the soil. The lowest SOC value recorded under *Oxytenanthera abyssinica* plantation can be attributed to the relatively low rate of decomposition of leaves of *Oxytenanthera abyssinica*, due to their high lignin content, as confirmed by the highest value of C/N ratio (Table 2).

The increases in total N beneath the tree plantations, corroborate the findings of Ogunyemi (2010); Lawel (2014), who reported increased total N under plantations of certain trees, especially, tree legumes.The higher percentage increase in total N, adduced to *Gliricidia sepium*, compared to what obtained beneath *Leucaena leucocephala*, can be ascribed to higher SOC value beneath *Gliricidia sepium* plantation. Consequently, it is likely that more of organic N was returned to the soil beneath Gliricidia sepium plantation than organic N returned beneath *Leucaena leucocephala* plantation.

The higher percentage increases in total N, available P and exchangeable bases beneath *Gmelina arborea*, *Leucaena leucocephala*, *Gliricidia sepium* and *Hevea brasiliensis* than what obtained under *Oxytenanthera abyssinica*, point to the superiority of these tree species to their *Oxytenanthera abyssinica* counterpart, as regards amelioration of soil conditions. The superiority of these tree species can be attributed to their deep – rootedness, which may have enhanced nutrient extraction by these tree species from a large volume of soil and concentrate them in a small volume of surface soil (Kimia, 2013). Asides, the higher percentage increases in total N, available P and exchangeable bases beneath *Gmelina arborea*, *Leucaena leucocephala*, *Gliricidia sepium* and *Hevea brasiliensis* plantations than what obtained under *Oxytenanthera abyssinica* plantation, can be ascribed to higher foliage concentrations of N, P and exchangeable bases in *Gmelina arborea*, *Leucaena leucocephala*, *Gliricidia sepium* and *Hevea brasiliensis* than foliage concentrations of N, P and exchangeable bases in *Oxytenanthera abyssinica* (Table 2). Therefore, recycling of these accumulated foliar nutrients contributes to the higher soil total N, available P and exchangeable bases beneath *Gmelina arborea*, *Leucaena leucocephala*, *Gliricidia sepium* and *Hevea brasiliensis* plantations than the concentrations of these nutrients beneath *Oxytenanthera abyssinica* plantation.

The lowest available P value, associated with *Oxytenanthera abyssinica* plantation, can be attributed to the lowest pH value of soil under *Oxytenanthera abyssinica* plantation. This is because, the availability of P in the soil, depends on pH of the soil medium, with available P decreasing with decreasing pH (Zorok, 2012; Kimia, 2013). The decreasing available P phenomenon, associated with increasing acidity or decreasing pH, is due to the conversion of P into unavailable forms under acid soil conditions, as a result of fixation by micro – nutrients, such as Fe and Al, which abound in acid soils (Zorok, 2012; Zynth, 2013).

The highest concentrations of micronutrients (Cu, Zn, Mn and Fe), observed in the control treatment plot, can be attributed to the lowest pH value of soil in the control treatment plots. This is because the availability of these micronutrients depends on their solubility, which in turn, is pH dependent, with their solubility, and hence, availability increasing with decreasing pH of the soil medium. Thus, the lowest pH value of soil in the control treatment plots accounts for the observed highest concentrations of micronutrients of soil in the control treatment plots (Aritoff, 2012; Kapa, 2013).

Although, there were increases in soil nutrients beneath the tree species and the control (pasture) after five year fallow period. However, there were higher percentage increases in soil nutrients beneath the tree plantations than soil nutrients under the control (pasture), suggesting higher ameliorating effects of tree plantation than those of pasture.

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