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Effect of African Mahogany Species on Soil Chemical Properties in Degraded Dry Semi-deciduous Forest Ecosystems in Ghana

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ABSTRACT

The present study assesses the effect of mixed mahogany plantation on the chemical properties of the soil after 10 years from establishment in degraded semi-deciduous dry forests in Ghana. The specific aims were to evaluate the impact of mixed mahogany plantation on the soil chemical characteristics to a depth of 30 cm. With the exception of available P, all the chemical characteristics of the soil [the soil pH, Ca, Mg, base saturation, total exchangeable base (TEB) and CEC, organic carbon, organic matter and organic N] showed significantly higher values for soils sampled from mixed mahogany plantation stands when compared to the adjacent unreforested degraded site. In particular, the soil pH was significantly ($P<0.0001$, t-test) higher beneath mixed plantation stands (6.23) when compared to the adjacent unreforested degraded forest site (4.96). The degraded site recorded significantly ($P<0.000$, t-test) higher amounts of Al. The results showed a significant decline in the levels of all the chemical properties of the soil, considering that the depth of the soil profile at both sites. Mixed plantation of African mahogany species could be used as tool to catalyze natural regeneration and to facilitate restoration of degraded forest ecosystems in Ghana. © 2012 Friends Science Publishers

Key Words: Mixed plantation; Indigenous tree species; Nutrient recycling; Restoration

INTRODUCTION

Tree plantation plays a major role in soil formation, and tree species differ in their effects on the soil characteristics and process (Vinton & Burke, 1995; Rhoades & Binkley, 1996) in ways that influence the functioning and structure of the ecosystem (Pastor *et al*., 1987). The quality of the soil organic matter is one of the main soil properties that can be directly influenced by tree species through the incorporation of dead tissue with a different chemical composition (Constantinides & Fownes, 1993; Paul *et al.*, 2002; Resh *et al.*, 2002), which may alter the nutrient cycling throughout the ecosystem. The use of fast-growing indigenous tropical tree species to rehabilitate and restore many degraded tropical forest ecosystems is based on this potential of different species to influence the soil fertility and ecological processes (Brown & Lugo, 1994). Most of the concerns in particular with the use of exotic tree species in restoration and afforestation programmes have been related to the depletion of the soil fertility and the reduction in water recharge (Calder *et al.*, 1992; Abbasi & Vinithan, 1997). However, mixed native plantations have been shown to improve the soil fertility in the long term (Parrotta, 1992; Fisher, 1995; Montagnini, 2000). Native tropical tree species have been used in reforestation to accelerate restoration of degraded forest sites (Lugo, 1992a, b; Parrotta, 1992, 2003). This is due to the fact that tree plantations remove the barriers to secondary succession by providing a habitat for seed dispersers, suppressing weeds and by improving the microclimate for the establishment of native species in the understory (Parrotta, 1993; Hagger *et al*., 1997; Binkley & Resh, 1998). However, the soil fertility at plantation sites is still a key concern in any restoration project especially in fragile ecosystems. The dry semi-deciduous forest zone is one of the fragile ecosystems in Ghana which might be due to a transition between the high forest zone in the south and the savannah in the north. High pressure on the natural resources from anthropogenic disturbances and periodic bush fires affect and often interrupts the succession process, with the consequence of an expansion of the savannah southward to previous forest zone (Abebrese, 2002). This problem is exacerbated by the colonization and invasion of species like *Imperata cylindrica, Pennisetum Purpureum and Chromolaena odorata*, which suppress the natural regeneration of the forest (Abrebrese, 2002). As a result, the obvious option to accelerate natural regeneration is through restoration by using indigenous tree species in mixed plantations. Moreover, mixed plantations of African mahogany species have been proposed for reforestation effort and to restore

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ecosystem function of the dry semi-deciduous forest zone in Ghana. The use of indigenous tree species in plantations and restoration of degraded landscape is quite a new paradigm in Ghana. Hitherto, the Government of Ghana took the necessary measures by introducing the National Forest Plantation Development Programme (NFPDP) to plant 20000 ha of indigenous tree species including African mahoganies (Domson & Vlosky, 2007; FAO, 2010). Seven years after inception of NFPDP, 12314.8 ha of indigenous tree species including African mahogany had been planted in the degraded forest reserves through Modified Taungya System. However, there is lack of information on how mahogany species affect nutrient dynamics of already degraded soils of the area. The aim of this study was to examine the effect mixed plantation of African mahoganies species on the chemical properties of the soils in the degraded tropical dry semi-deciduous forest zone in Ghana.

MATERIALS AND METHODS

Study species: African mahogany is collective trade name given to tropical timber species belonging genera *Khaya* and *Entandrophragma* of family Meliaceae. The species used in mixed plantation for the restoration of degraded forest site and to catalyze natural regeneration were *Entandrophragma utile* (Dawe & Sprague)*, Khaya anthotheca* (Welw.C.DC. & *K. grandifoliola* C. DC).

E. utile is a very large emergent tropical forest tree which may grow up to over 60 m in height, with a diameter at breast height (dbh) of more than 2.5 m (Jansen, 1974; Burkill, 1997). *E. utile* is distributed throughout West and Central Africa. In Ghana, *E. utile* occurs in moist deciduous high forests, dry semideciduous ecotype, and transitional formations (Hawthorne & Gyakari, 2006). *K. anthotheca* (Welw.C.DC.) is a very large emergent deciduous tree that attains height of approximately 55−65 m and dbh up to 4−6 m (Maroyi, 2008). *K anthothec*a has wide distribution range, from Sierra Leone to Uganda. In Ghana, *K. anthotheca* is more or less restricted to dry semideciduous forest zone. *K. grandifoliola* (C. DC.) is a large dominant forest tree that attains an average height of approximately 40 m and a dbh up to 1.2−2 m (Opuni-Frimpong, 2008). *K. grandifoliola* is distributed between savannah gallery and dry semi-deciduous forest zone in Ghana. The distributional range of *K. grandifoliola* in dry semi-deciduous forest zone overlaps with *K. anthotheca*, hence people tend to confuse these two species of Khaya.

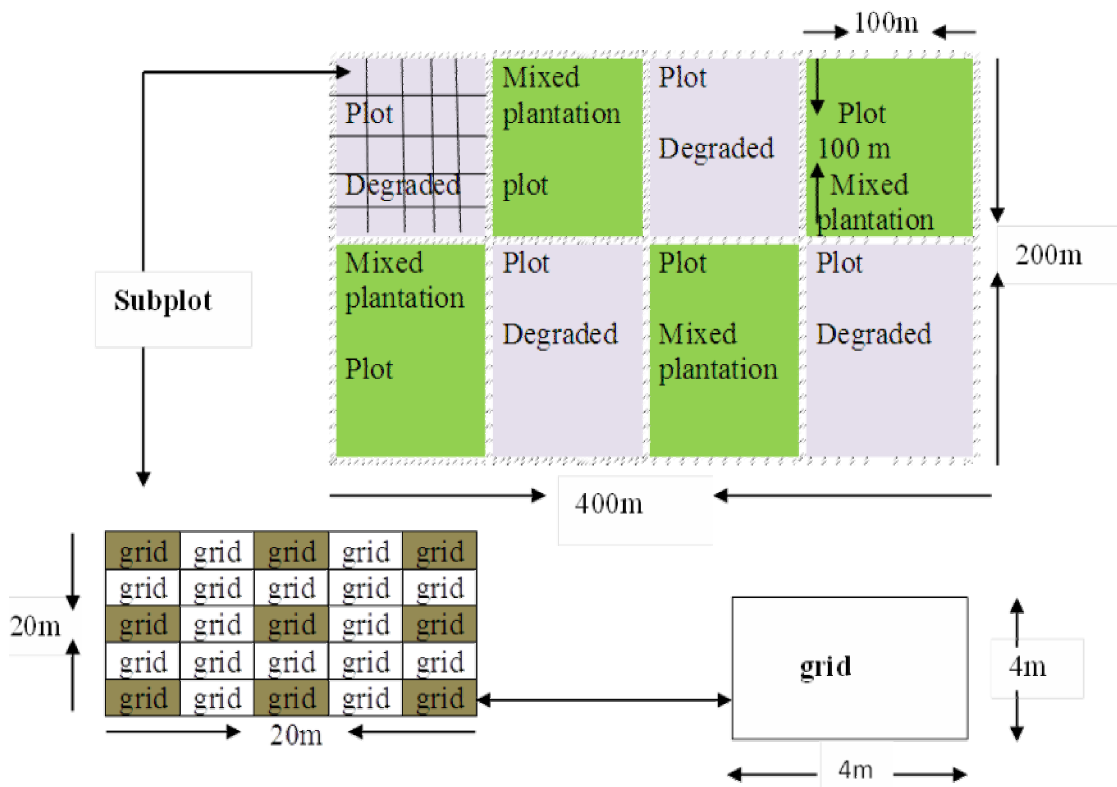
Study area: The study was conducted in the Dormaa District, Brong Ahafo Region of Ghana, in the dry semi-deciduous forest zone of Pamu-Berekum forest reserve from April through July, 2010. Pamu-Berekum forest reserve covers an area of 189 km^2 and it is located at longitude 3° 30´W and latitudes 7° 30´N, with altitude of approximately 665 m above sea level. The area has tropical climatic conditions with the highest mean temperature of about 30°C, which occurs between March and April and the lowest mean temperature is about 26.1°C in August. The area has a pronounced dry season, with mean annual rainfall of approximately 1450 mm (Hall & Swaine, 1976). The soils in this zone are grouped under forest oxysols and ochrosols under the Ghana soil classification (Brammer, 1962). Based on FAO classification, these soil types would be termed as Ferralsols and Acrisols, respectively (Greenland & Kowal, 1960; ISSS/ISRIC/FAO, 1998).

The degraded portion of the forest reserve is invaded by weeds as a result of periodic bush fires and long history of wild fires. This has changed part of the original forest into savannah woody land and presence of fires resistance species. However, there are isolated patches of forest with substantial trees cover dominating the landscape, and if the area is well protected from fire or further disturbances it has the potential to recover through natural regeneration. The rampant space of fires in the area is stemmed from the fact that the site forms part of dry semi-deciduous forest zone, which borders the savannah to the north of the country.

K. anthotheca, K. grandifoliola and *E. utile* were planted on four plots of size 1ha each in random manner at spacing of 3 m × 3 m using substitution design (Kelty & Cameron, 1995). The mixed plantation plots were interspersed with four degraded plots of 1ha each as control for basis of comparison (Fig. 1). The planted tree were not given any treatment apart from initial weeding and tending to ensure establishment. The degraded plots were allowed to go through natural regeneration and succession. However, the two contrasting plots the mixed plantation and degraded sites had the same edaphic and biotic characteristics prior to the establishment of mixed plantation. The only differences between the two plots were the fact that one was planted with mixed mahogany species and the other through process of natural regeneration without further disturbances; for 10 year period. During this period care was taken to protect the experimental sites from further wild fire outbreaks. Moreover, the degraded plots were not disturbed during the planting of mixed species plots apart from demarcation exercise.

Sampling design: The experiment design was Completely Randomized Design (CRD) with two treatments and four replicates (Fig. 1). The treatment were mixed plantation of African mahogany species on post fire degraded site and fire degraded site allowed to regenerate naturally. Each treatment has plot area of 1 ha and total area of 4 ha. The 1 ha plot (100 m × 100 m) for each treatment was divided into 20 m × 20 m subplot, thus creating 25 subplots per plot (Fig. 1). Soil samples were taken from 10 subplots, which were randomly selected from 25 subplots in 100 m × 100 m plot. The procedure involved dividing the selected subplot (20 m × 20 m) into 4 m × 4 m grids or arrays (Fig. 1). With the help of handheld Global Positioning system (GPS), moving from East to West direction, every 2nd grid was systematically selected for soil sample collection (Fig. 1). The soil samples were obtained from 9 of such grids or

Fig. 1: Layout of the experimental design involving restored site with mixed plantations and degraded site undergoing through natural regeneration. Soil samples were collected from the middle or centre of every 2nd grid or array (shaded in brown) as shown in diagram. NB: The layout is not up to scale



arrays per subplot. The soil samples were collected with a help of soil auger from the middle of each grid or array. Three bulk composite samples were collected for each subplot for chemical analysis at the depths of 0−10, 10−20 and 20−30 cm.

Laboratory and statistical analysis: The soil samples were air-dried and screened through 2 mm sieve. The soil pH (water) was measured at a soil to distilled water ratio of 1:2.5 in suspension with an Orion Research digital Ionalyzer. Available phosphorous in soil was determined by the Bray No. 1 method (Bray & Kurtz, 1945). Total nitrogen was analyzed with the Kjeldahl procedure described in Bremner and Mulvaney (1982). Soil Organic matter and percentage carbon were determined by the Walkley-Black method (Nelson & Sommers, 1982, 1996). Exchangeable Cations Ca, Mg, K and Na were determined by displacement with 1 M ammonium acetate at pH 7 and subsequent measurement by atomic absorption spectrometry for Ca and Mg and emission spectroscopy for K and Na. Exchangeable-titratable acidity, consisting of various forms of Al, was determined in 1 M KCl and the extractants titrated to a pH 8 as described by Rayment and Higginson (1992). The effective cation exchange capacity (CEC) was determined by summation of exchangeable bases (Ca^{+2}, Mg^{+2}, K^{+}) and exchangeable acidity (Drechsel *et al.*, 1991; Sumner & Miller, 1996; Russell *et al.*, 2007). The base saturation was determined as the sum of the exchange cations divided by the cations exchange capacity expressed in percentage (Fitzpatrick, 1986). Total Exchangeable Bases (TEB) is the sum of the concentration of Na, K, Mg and Ca (Swaine, 1996). For statistical analysis of the differences between the soil parameters, two types of testing procedures were used. First, Student's t-test was used to test significance of differences in mean values for two independent samples (mixed plantation of African mahogany species & degraded forest site). However, this was under assumption of normal distribution of values (Goon *et al.*, 1975). Secondly, ANOVA was carried out on the soil parameters in order to determine whether there were any differences in the soil depth between the mixed plantation and the degraded forest site. The Tukey HSD test ($P<0.05$) was used for the post hoc comparisons when ANOVA detected significant differences. All statistical analyses were performed with the XLSTAT software package (Addinsoft SARL, Paris, France, 2009) on an Excel platform.

RESULTS

Soil pH and exchangeable cations: The soil pH was slightly higher underneath the mixed mahogany plantation stand (6.23±0.12) as compared to the degraded forest site (4.96±0.11) and this was significantly different ($P<0.0001$, t-test) between the two sites (Table I). The soil pH values in the mixed mahogany plantation plots were somewhat higher than those recorded in the degraded forest site, which averaged between 6.33, 6.23 and 6.12 at the depths of 0−10 cm, 10−20 cm and 20−30 cm, respectively whereas there were much lower pH values in the degraded forest plots, which averaged approximately 5.15 (0−10 cm), 4.82 (10−20 cm) and 4.91 (20−30 cm) (Table II). In general, the pH differed significantly down the soil depth in both sites (F=44.2, P<0.0001). The general trend was decrease in pH levels down the profile at both contrasting sites. However, there was a slightly higher base saturation under the mixed mahogany plantation than the degraded forest site (P<0.0001, t-test). There was a decrease in the base saturation down the profile at both sites (F=10.49, P<0.0001) (Table II). The soil cation exchange capacity (CEC) was higher under the mixed mahogany plantation (P<0.0001, t-test), as were the exchangeable cations Ca (P<0.0001, t-test) and Mg (P<0.0001, t-test). However, the following exchangeable cations were higher under the

Table I: Independent t-test of the top soil (i.e. a mixture of all the top soil depth classes) chemical properties under the African mahogany mixed plantation and the degraded forest site, Means and corresponding standard errors (se)

Measure	Mixed Plantation	Degraded forest site	Significance
Soil variables	**Mean ± se**	**Mean ± se**	***P*-value (2-tailed t-test)**
pH (H_2O)	6.23±0.12	4.96±0.11	0.0001
Organic C (%)	2.94±0.32	1.03±0.07	0.0001
Organic Matter (%)	5.07±0.54	1.78±0.13	0.0001
N (%)	0.25±0.03	0.19±0.01	0.0250
P (ppm)*	0.17±0.07	0.33±0.08	0.1650
K (meq/100 g)	0.12 ± 0.01	0.59±0.07	0.0001
Na (meq/100 g)	0.04 ± 0.01	0.10±0.01	0.0001
Ca (meq/100 g)	12.43±1.28	4.33±0.62	0.0001
Mg (meq/100 g)	14.00±2.04	0.80±0.09	0.0001
Al (meq/100 g)	0.10± 0.00	2.16±0.26	0.0001
TEB (meq/100 g)	26.59± 2.57	5.82±0.76	0.0001
ECEC (meq/100 g)[#]	26.69±2.57	7.97±0.55	0.0001
Base saturation (%)	99.57±0.04	68.99±4.37	0.0001

*Available Brays P in part per million; [#] Effective cation exchange capacity

Table II: Chemical characteristics of the top soil layers (0−10, 10−20, 20−30 cm depth) in the mixed plantation (African mahoganies plantation) and the degraded forest site. The values represent the means and the corresponding standard error of the means. The results of one-way ANOVA are represented as a column for each soil chemical attribute

		Soil Chemical Variables (Mean ± se)						
Soil Depth	**Location**	**pH (H_2O)**	**Organic C (%)**	**Organic matter (%)**	**N (%)**	**P -Bray (ppm)**	**K (meq/100 g)**	**Na (meq/100 g)**
0−10 cm	Mixed plantation	6.33±0.17^{a}	4.37±0.28^{a}	7.53±0.48^{a}	0.38±0.02^{a}	0.52±0.26	0.20±0.01^{cd}	0.06±0.003^{bc}
	Degraded forest site	5.15±0.26^{b}	1.28±0.15^{c}	2.21±0.26^{c}	0.23±0.01^{b}	0.47±0.18	0.86±0.10^{a}	0.13±0.016^{a}
10 cm−20 cm	Mixed plantation	6.23±0.19^{a}	2.30±0.23^{b}	3.96±0.49^{b}	0.20±0.02^{bc}	0.25±0.14	0.10±0.01^{d}	0.04±0.003^{b}
	Degraded forest site	4.82±0.19^{b}	1.01±0.09^{c}	1.74±0.15^{c}	0.19±0.01^{bc}	0.40±0.16	0.47±0.09^{b}	0.09±0.013^{c}
20 cm−30 cm	Mixed plantation	6.12±0.16^{a}	2.16±0.19^{b}	3.71±0.32^{b}	0.19±0.02^{c}	0.22±0.16	0.09±0.01^{bc}	0.03±0.002^{b}
	Degraded forest site	4.91±0.11^{b}	0.81±0.06^{c}	1.40±0.10^{c}	0.15±0.02^{bc}	0.07±0.03	0.44±0.10^{d}	0.09±0.011^{c}
Significance	P-values	0.0001	0.0001	0.0001	0.0001	0.433	0.0001	0.0001
	F-values	44.220	46.939	46.910	19.962	1.003	18.680	16.268

		Soil variables (Mean ± se)					
Soil Depth	**Site**	**Ca (meq/100 g)**	**Mg (meq/100 g)**	**Al (meq/100 g)**	**TEB (meq/100 g)**	**ECEC (meq/100 g)**	**Base saturation (%)**
0−10 cm	Mixed plantation	14.65±2.47^{a}	23.23±0.91^{a}	0.09±0.02^{c}	38.12±2.46^{a}	38.22±2.46^{a}	99.72±0.02^{a}
	Degraded forest site	6.61±1.37^{bc}	1.14±0.12^{c}	1.37±0.43^{b}	8.75±1.54^{c}	10.12±1.16^{c}	77.65±6.39^{ab}
10 cm−20 cm	Mixed plantation	11.42±1.52^{ab}	10.53±2.22^{b}	0.09±0.02$_{c}$	22.09±2.24^{b}	22.19±2.24^{b}	99.52±0.07a
	Degraded forest site	3.81±0.49^{c}	0.67±0.14^{c}	2.33±0.46^{ab}	5.04±0.69^{c}	7.36±0.31^{c}	68.43±7.59^{b}
20 cm−30 cm	Mixed plantation	11.20±1.32^{ab}	8.26±1.22^{b}	0.09±0.02^{c}	19.57±1.19^{b}	19.67±1.19^{b}	99.48±0.04^{a}
	Degraded forest site	2.56±0.32^{c}	0.59±0.14^{c}	2.79±0.31^{a}	3.67±0.49^{c}	6.46±0.43^{c}	61.42±8.67^{b}
Significance	P-values	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	F-values	11.090	64.132	18.250	66.392	62.290	10.496

Similar superscript letters within a column indicates that the means were not significantly different between the depths of each treatment (Tukey Post hoc test; $P<0.05$); TEB = Total exchangeable bases; ECEC= Effective cation exchange capacity degraded forest site than the mixed mahogany plantation site: K (P<0.0001, t-test), Na (P<0.0001, t-test) and Al (P<0.0001, t-test). In general, the values of the exchangeable cations decreased down the soil depth at both contrasting sites (Table II). The total exchangeable bases (TEB) were higher (P<0.0001, t-test) at the mixed mahogany plantation site (26.29±2.57) than the degraded forest site (5.82±0.76) (Table I). A similar pattern is seen with the TEB ratings between the sites with the lower soil depths having smaller values of TEB (F=66.39, P<0.0001) (Table II).

Soil organic matter and carbon: The total percentage of Carbon(C) and organic matter of the soils under the mixed mahogany plantation site averaged between 2.94±0.32 and 5.07±0.54, respectively and these were much higher (P<0.0001, t-test) than at the degraded forest site, where they averaged between. 1.03±0.07 and 1.78±0.13 (percentage of C & organic matter respectively). The C and organic matter concentration in the soil decreased down the profile at both sites. The mixed mahogany plantation site recorded a percentage of C of 4.37, 2.23 and 2.16 within the soil class depths of 0−10 cm, 10−20 cm and 20−30 cm respectively. Similarly, the degraded forest site recorded a percentage of C of 1.28, 1.01, and 0.81 at the soil class depth intervals of 0−10 cm, 10−20 cm and 20−30 cm respectively (F=46.93, P<0.001) (Table II). However, a similar trend was observed with respect to the percentage of organic matter within the soil depth class intervals at both sites (F=46.91, P<0.0001).

Nitrogen and phosphorus: In general, the mixed mahogany plantation site recorded the highest (P<0.001, t-test) percentage of organic nitrogen (N) (0.25±0.003) when compared to the degraded forest site (0.19±0.13) (Table I). In the mixed mahogany plantation site, the percentage of organic N decreased down the soil profile according to the following values: 0.38±0.02 (0−10 cm), 0.20±0.14 (10−20 cm) and 0.19±0.02 (10−20 cm), whereas at the degraded forest site, slightly lower values were recorded: 0.23±0.01 (0−10 cm), 0.19±0.01 (10−20 cm) and 0.15±0.02 (20−30 cm) (Table II). This was a significant difference (F=19.96, P<0.0001) between the mixed mahogany plantation and the degraded forest site. However, the concentrations of available phosphorous (P) in the soils at both sites were not significantly different (F=1.003, P>0.433; P>0.1650, t-test) (Table II).

DISCUSSION

Soil pH and exchangeable cations: This study shows that the mixed plantation of African mahoganies and degraded forest ecosystems can function under the same environmental conditions and exhibit different effects on the soil nutrients. In general, the mixed plantation forest site with mahogany tree species showed an improved soil fertility status as compared to the degraded forest site. The slight elevation in pH underneath mixed native plantation as compared to degraded natural regeneration site is in line with the studies of Goma-Tchimbakala *et al*. (2008).

They reported variation in soil pH levels of approximately 4.69 and 4.97 at natural regeneration and *Terminalia superba* plantation sites, respectively. However, Parrotta (1999) made similar observation in studies involved *Casuarina equisetifolia* and *Leucaena leucocephala*. The ability of tree species to effect or influence soil pH and for that matter chemical reaction is not uncommon. Russell *et al.* (2007) evaluated effect of five tropical tree species on soil chemical properties and observed general acidification of three species (*Pentaclethra macroloba*, *Hyeronima alchorneoides*, *Virola koschnyi)* with exception of two species of *Vochysia,* which elevated soil pH. However, *Eucalyptus and Albizia* species have been implicated to decrease soil pH or cause soil acidification (Rhoades & Binkley, 1996; Parrotta, 1999). Thus, suggesting that the influence of tree species in either directions of soil pH scale is species specific (Hagen-Thorn *et al.*, 2004). Nevertheless variation soil pH with respect to tree species interaction may be also due to differences in soil types (Chijicke, 1980; Sanchez *et al.*, 1985). The high pH values of the soils under the mixed mahogany plantation stand as compared to soils at the degraded forest site is very encouraging, considering the fact that in Ghana the iron and aluminium toxicity are problems. The high CEC, TEB, Ca and Mg values recorded at the mixed plantation site and the corresponding low values of Al, Na and K is indicative of high pH levels recorded beneath the soils of mixed African mahogany plantation stand (Oates & Kamprath, 1983; Moukam & Ngakanou, 1997; Goma-Tchimbakala *et al.*, 2008). The positive effect of the mixed plantation on Ca and Mg may be caused by a rapid cycling of these elements in the litter and through tree fall. In fact, various authors have pointed out significant extraction of Ca from the soil by some plants, which is then accumulated in the biomass in the form of calcium oxalate (Arnott & Pautard, 1970; Webb, 1999; Hudgins *et al*., 2003; Franceschi & Nakata, 2005). This could have tremendous effect on Ca recycling and soil pH by causing it to increase as the case may be of the soils under mixed mahogany plantation. Indigenous mixed tree plantations are known to increase the CEC of the soils, because of high inputs of organic matter into the soils (Haynes & Naidu, 1998). The high levels of CEC in the soils beneath mixed mahogany plantation site has direct relationship with high pH of the site as compared to degraded natural regeneration site. The low values of K recorded at the mixed mahogany plantation site may be due to the fact that K is actively mined, or it may likely be due to its mobility in the soil-plant system. It is not surprising to find a low concentration of Al values at the mixed plantation site as compared to the degraded forest site: there is direct relationship between the Al levels and the soil pH. Low pH soils tend to have high levels of Al (Andersson, 1992; Abreu Jr., 2003), as may be the case at the degraded forest site. A direct effect of decline in soil pH is an increase in exchangeable Al on the exchange complex with corresponding decline in exchangeable Ca, Mg and K. The percentage of the base saturation provides a valuable indicator of the "base status", which is often related to the amount of leaching. Lower base saturation values correspond to higher leaching (Haynes & Goh, 1980; Ouimet *et al*., 1995). High base saturation values were recorded for the mixed plantation stand. Characteristically the upper depth of soils at the mixed mahogany plantation site shows a high base saturation as a result of the corresponding CEC values and the TEB, of which Ca and Mg make up the largest proportions. The high CEC values, pH elevation and decline in Al amounts of the soils under mixed mahogany plantation is an indicative that these species could improve the soil fertility status and an ideal tool for restoring degraded forest ecosystem.

Soil organic matter and carbon: In general the soil organic C and organic matter concentrations decreased with the increasing depth at both sites. The soil C and organic matter concentrations were higher under the mixed mahogany plantation as compared to the degraded forest site. Similarly, Fisher (1995) and Montagnini (2000) reported increases in the soil organic C under a tree plantation just after 3 years of establishment in a degraded pasture and decreased under the pasture that was used as a control. The amount of carbon increased under a hard wood plantation (Mahogany) and a reduction in the carbon concentration in the soils under softwood (mixed pine, spruce, etc.) (Paul *et al*., 2002). It has been observed that a 35% increase in soil C following a reforestation and afforestation of cultivated lands (Johnson, 1992). Moreover, Yao *et al*. (2010) reported that the soil organic C content decreased from a natural forest to a multispecies tree plantation and then to a monoculture forest plantation. However, there is a direct relationship between the amount of soil C and organic matter, which invariably depends on litter fall (Cuevas & Lugo, 1998). In general, mixed native tree species employed in restoration or rehabilitation of degraded sites tend to have a high amounts of above ground biomass and associate litter (DeBell *et al*., 1997; Cuevas & Lugo, 1998; Parrotta, 1999; Singh & Singh, 2006), which contribute immensely to soil C and organic matter as compared to degraded forest sites predominately dominated by grasses(Rhoades, 1997). The amount of organic carbon and organic matter depends on the quality and quantity of the litter fall and below ground biomass as well as microclimatic and edaphic conditions of the area (Lal, 2005). One major observation is that the mixed plantation involving mahogany species produce more biomass than the sparsely tree dominated degraded forest site for the period under consideration. The slow pace at which natural regeneration and succession dynamics occurring at the degraded site could also contribute to low level of soil carbon and organic matter. To a large extent the amount of soil organic carbon and organic matter are directly influence by tree species and their levels are species specific.

Nitrogen and phosphorous: The mean value of total nitrogen is higher in the mixed plantation when compared to the degraded forest site. Similar results have been reported by other researchers (Firn *et al*., 2007; Zeugin *et al*., 2010). Hansen and Dawson (1982) observed that mixed plantation led to an increase in soil N in comparison to monoculture plantations (FAO, 1992). This differential effect could be attributed to many factors. First, there is a direct relationship between the soil organic matter and N (Feichtinger *et al.,* 2004), which also depends on litter fall. Mixed species plantation has been reported to have a positive effect on the biomass production, litter fall and nutrient pools (Potvin & Gotelli, 2008; Oelmann *et al.,* 2010). High quality litter leads to formation of high quality organic carbon and N in the mineral soil. Secondly lack of adequate tree cover in the degraded site is associated with less litter fall to augment nitrogen stocks in the soil. Additionally, the degraded site has high evaporation rate as compared to mixed plantation stand leading moisture deficit in the soil, which slows down decomposition and subsequent mineralization of limited litter on the soils. However, differences in tree composition of both sites could also explain the observed variation in N concentration. Soluble N concentration in the soil depends on the litter species (Magill & Aber, 2000). Tree species can differ in their mechanisms of rate of nutrient input, outputs and cycling.

There is a relationship between the amount of available P in the soil and the intensity of disturbances. As anthropogenic disturbances increase, available P decreases (Palmer *et al.,* 2005). In absolute terms, the degraded forest site recorded lower values of available P as compared to the mixed plantation site. This may stem from the effect of the disturbances. Okoro *et al.* (2000) reported that the conversion of natural forest to monocultures of *Tectona grandis* in Nigeria resulted in a significant decline of available P. However, there was no significant difference between the mixed plantation and the degraded forest site. Generally, P has been proposed as the nutrient most likely to be limited in low tropical forests (Vitousek & Sanford, 1986; Raaimakers, 1994).

The study shows that for the purposes of reforestation and restoration of degraded dry semideciduous forest zone in Ghana, the use of mixed mahogany tree species may have positive effects on the soil nutrient characteristics. Thus, mixed mahogany species can be used in plantations as an appropriate management option to serve a dual role of accelerating the natural regeneration and recovery of species-rich forest ecosystems, whilst improving degraded soils.

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REFERENCES

Abbasi, S.A. and S. Vinithan, 1997. Ecological impacts of eucalypts - Myths and realities. *Indian Forest.,* 123: 710–735

Abebrese, M.O., 2002. *Tropical secondary forest management in Africa: Reality and perspectives, Ghana Country Paper, in: Proceeding*. Workshop on Tropical Secondary Forest Management in Africa Reality and perspectives. In collaboration with ICRAF and CIFOR Nairobi, Kenya, 9‒13 December 2002.FAO, Rome, Italy. Available at: http://www. fao.org/docrep/006/J0628e /J0628E53.htm#Top OfPage [cited on 26 December, 2010]

Abreu, Jr. C.H., T. Muraoka and A.F. Lavorante, 2003. Relationship between acidity and chemical properties of Brazilian soils. *Scientia Agricola*, 60: 337–343

Andersson, M., 1992. Effect of pH and aluminum on growth of *Galium odoratum* (L) Scope in flowing solution culture. *Environ*. *Exp. Bot*., 32: 497–504

Arnott, H.J. and F.G.E. Pautard, 1970. Calcification in plants. *In*: Schraer, H. (ed.), *Biological Calcification: Cellular and Molecular Aspects*, pp: 375–446. Appleton-Century-Croft, New York, USA

Brammer, H., 1962. *In*: Wills, J.B. (ed.), *Soils, Agriculture and Land Use in Ghana*, pp: 88–126. Oxford University Press, London

Bray, R.H. and I.T. Kurtz, 1945. Determination of total organic and available forms of phosphorus in soil. *Soil Sci*., 59: 39–45

Bremner, J.M. and C.S. Mulvaney, 1982. Nitrogen-total. *In*: Page, A.L., R. H. Miller and D. R. Keeney (eds.), *Methods of Soil Analysis*, Part 2, 2nd edition. *Agronomy*, 9: 595–624

Binkley, D. and S.C. Resh, 1998. Rapid changes in soils following Eucalyptus afforestation in Hawaii. *Soil Sci. Soc. America J*., 63: 222–225

Brown, S. and A. Lugo, 1994. Rehabilitation of tropical lands: a key to sustaining development. *Restor. Ecol*., 2: 97–111

Burkill, H.M., 1997. *The Useful Plants of West Africa*, 2nd edition, Vol. 4, p: 969. Royal Botanical Gardens Kew, London

Calder, I.R., R.L. Hall and P.G. Adlard, 1992. *Growth and Water Use of Forest Plantations*, p: 381. Wiley and Sons, New York, USA

Chijicke, E.O., 1980. *Impacts on Soils of Fast-growing Species in Lowland Humid Tropics*, p: 111. FAO Forestry Paper No. 21 Rome, Italy

Constantinides, M. and J.H. Fownes, 1993. Nitrogen mineralization from leave sand litter of tropical plants: relationships to nitrogen, lignin and soluble polyphenol concentration. *Soil Sci. Soc. American J*., 53: 1707–1711

Cuevas, E. and A.E. Lugo, 1998. Dynamic of organic matter and nutrient return from litterfall in stands of ten tropical tree plantation species. *For. Ecol. Manage*., 112: 263–279

DeBell, D.S., T.G. Cole and C.D. Whitesell, 1997. Growth, development and yield in pure and mixed stands of *Eucalyptus* and *Albizia*. *Forest Sci*., 43: 286–298

Domson, O. and R.P. Vlosky, 2007. *A Strategic Overview of the Forest Sector in Ghana*. Louisiana Forest Products Development Center Working Paper No. 81

Drechsel, P., B. Glaser and W. Zech, 1991. Effect of four multipurpose tree species on soil amelioration during tree fallow in central Togo. *Agroforest. Syst*., 16: 193–202

FAO, 2010. *Global Resources Assessment 2010*. Country Report, Ghana, FRA 2010/077, Rome

FAO, 1992. *Mixed and Pure Forest Plantation in the Tropics and Subtropics,* p: 152. FAO Forestry Paper No. 103

Feichtinger, F., E. Erhart and W. Hart, 2004. Net N-mineralisation related to soil organic matter pools. *Plant Soil Environ*., 50: 273–276

Firn, J., P.D. Erskine and D. Lamb, 2007. Woody species diversity influences productivity and soil nutrient availability in tropical plantations. *Oecologia*, 154: 521–533

Fisher, R.F., 1995. Amelioration of degraded rain forest soils by plantations of native tress. *Soil Sci. Soc. America J*., 59: 544–549

Fitzpatrick, E.A., 1986. *An Introduction to Soil Science*, 2nd edition. Longman

Franceschi, V.R. and P.A. Nakata, 2005. Calcium oxalate in plants formation and function. *Annu. Rev. Plant Biol.*, 56: 41–71

Greenland, D.J. and J.M.L. Kowal, 1960. Nutrient of the moist tropical forest of Ghana. *Plant Soil,* 12: 154–174

Goma-Tchimbakala, J., J.M. Moutsambote and S. Makosso, 2008. Comparison of some soil chemical properties in four Terminalia superba Plantations and a Natural Tropical Forest in Mayombe, Congo. *J. Appl. Sci.*, 8: 4152–4158

Goon, A.M., M.K. Gupta and B. Dasgupta, 1975. *Fundamentals of Statistics*, pp: 427–469. World Press, Calcutta, India

Hagger, J., K. Wightman and R. Fisher, 1997. The potential of plantations to foster woody regeneration within a deforested landscape in lowland Costa Rica. *Forest Ecol. Manage*., 99: 55–64

Hagen-Thorn, A., I. Callesen, K. Armolaitis and B. Nihlgard, 2004. The impact of six European tree species on the chemistry of mineral topsoil in forest plantations on former agricultural land. *Forest Ecol. Manage*., 195: 373–384

Hall, J.B. and M.D. Swaine, 1976. Classification and Ecology of Closed-Canopy Forest in Ghana. *J. Ecol*., 64: 913–951

Hansen, E.A. and J.O. Dawson, 1982. Effect of *Alnus glutinosa* on hybrid popular height growth in a short-rotation intensively cultured plantations. *For. Sci*., 28: 49–59

Hawthorne, W.D. and N. Gyakari, 2006. *Photoguide for the Forest Trees of Ghana: A Tree-spotter's Field Guide*, pp: 1–432. Oxford Forestry Institute, Department of Plant Sciences, UK

Haynes, R.J. and R. Naidu, 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. *Nutr. Cycl. Agroecosyst*., 51: 123–137

Haynes, R.J. and K.M. Goh, 1980. Some observations on surface soil pH, base saturation and leaching of cations under three contrasting orchard soil management practices. *Plant Soil,* 56: 429–438

Hudgins, J.W., T. Krekling and V.R. Franceschi, 2003. Distribution of calcium oxalate crystals in the secondary phloem of conifers: a constitutive defense mechanism. *New Phytol*., 159: 677–690

ISSS/ISRIC/FAO, 1998. *World Reference Base for Soil Resources*. International Soil Reference and Information Centre (ISRIC). FAO, Rome. World Soil Resources Reports 84

Jansen, J.W.A. Ir., 1974. *Timber trees of Liberia*. UNDP/SF/FAO College of Agriculture and Forestry Project University of Liberia<ftp://ftp.fao.org/docrep/fao/008/ae893e/ae893e00. pdf > Accessed 9th March, 2011

Johnson, D.W., 1992. Effects of management on soil carbon storage. *Water Air Soil Poll*., 64: 83–120

Kelty, M.J and I.R. Cameron, 1995. Plot designs for analysis of species interactions in mixed stands. *Commun. Forest. Rev*., 74: 322–332

Lal, R., 2005. Forest soils and carbon sequestration*. Forest Ecol. Mange.,* 220: 242–258

Lugo, A.E., 1992a. Comparison of tropical tree plantations with secondary forests of similar age. *Ecol. Monogr*., 62: 1–41

Lugo, A.E., 1992b. Tree plantations for rehabilitating damaged forest lands in the tropics. *In*: Wali, M.K. (ed.), *Ecosystem Rehabilitation: Ecosystem Analysis and Synthesis*, pp: 247–255. SPB Academic Publishing, Hague, The Netherlands

Magill, A.H. and J.D. Aber, 2000. Dissolved organic and nitrogen relationship in forest litter as affected by nitrogen deposition. *Soil Biol. Biochem*., 32: 603–613

Maroyi, A., 2008. *Khaya anthotheca* (Welw.) C.DC. *In*: Louppe, D., A.A. Oteng-Amoako and M. Brink (eds.), *Plant Resources of Tropical Africa,* 7: Timbers 1, pp: 324–329. PROTA Foundation, Wageningen, Netherlands/Backhuys Publishers, Leiden, Netherlands /CTA, Wageningen, Netherlands

Montagnini, F., 2000. Accumulation in above-ground biomass and soil storage of mineral nutrients in pure and mixed plantation in humid tropical lowland. *Forest Ecol. Manage*., 134: 257–270

Moukam, A. and D. Ngakanou, 1997. The fertility status of surface soils in the humid forest zone of Southern Cameroon. *African Crop Sci. J*., 5: 273–284

Nelson, D.W. and L.E. Sommers, 1982. Total carbon and organic matter. *In:* Page, A.L., R.H. Miller and D.R. Keeney (eds.), *Methods of Soil Analysis: Chemical and Microbiological Properties*, pp: 539–579. Agronomy 9, part 2. American Society of Agronomy Inc. and Soil Science Society of America, Madison, Wisconsin, USA

Nelson, D.W. and L.E. Sommers, 1996. Total carbon, organic carbon, and organic matter. *In:* Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A.Tabatabai, C.T. Johnson, and M.E. Sumner (eds), *Methods of Soil Analysis*, Part 2, 2nd edition, *Agronomy*, 9: 961–1010. American Society of Agronomy, Inc., Madison, Wisconsin, USA

Oates, K.M. and E.J. Kamprath, 1983. Soil acidity and liming: I. Effect of the extracting solution cation and pH on the removal of aluminum from acid soils. *Soil Sci. Soc. America J*., 47: 686–689

Oelmann, Y., C. Potvin, T. Mark, L. Werther, S. Tapernon and W. Wilcke, 2010. Tree mixture effects on aboveground nutrient pools of trees in an experimental plantation in Panama. *Plant Soil*, 326: 199–212

Okoro, S.P., I.T. Aighewi and C.O Osgie, 2000. Effect of selected monoculture plantations species on humid tropical soils of Southern Nigeria. *India J. Agric. Sci*., 70: 105–109

Opuni-Frimpong, E., 2008. *Khaya grandifoliola* (C. DC.). *In*: Louppe, D., A.A. Oteng-Amoako and M. Brink (eds.), *Plant Resources of Tropical Africa*, 7: Timbers 1, pp: 329–333. PROTA Foundation, Wageningen, Netherlands/Backhuys Publishers, Leiden, Netherlands/CTA, Wageningen, Netherlands

Ouimet, R., C. Camiré and V. Furlan, 1995. Effect of soil base saturation and endomycorrhization on growth and nutrient status of sugar maple seedlings. *Canadian J. Soil Sci*., 76: 109–115

Palmer, D.J., D.J. Lowe, T.W. Payn and B.K. Hock, C.D.A. Mclay and M.O. Kimberley, 2005. Soil and foliar phosphorus as indicators of sustainability for Pinus radiate plantation forestry in New Zealand. *Forest Ecol. Manage*., 220: 140–150

Parrotta, J.A., 1992. The role of plantation forests in rehabilitating degraded tropical ecosystems. *Agric. Ecosyst. Environ.,* 41: 115–133

Parrotta, J.A., 1993. Assisted recovery of degraded tropical lands: plantation forests and ecosystem stability. *In*: Paoletti, Foissner and Coleman (eds.), *Soil Biota, Nutrient Cycling and Farming Systems*. Lewis Publishers, Boca Raton, Florida, USA

Parrotta, J.A., 1999. Productivity, nutrient cycling, and succession in single and mixed species plantations of Casuarina equisetifolia, Eucalyptus robusta and Leucaena leucocephala in Puerto Rico. *Forest Ecol. Manage*., 124: 45–77

Parrotta, J.A., 2003. The role of plantation forests in rehabilitating degraded tropical ecosystems. *Agric. Ecosyst. Environ*., 41: 115–133

Pastor, J., R.H. Gardner, V.H. Dale and W.M. Post, 1987. Successional changes in nitrogen availability as a potential factor contributing to spruce declines in boreal North America. *Canadian J. Forest Res*., 17: 1394–1400

Paul, K.I., P.J. Polglase, J.G. Nyakuengama and P.K. Khanna, 2002. Change in soil carbon following afforestation. *Forest Ecol. Manage*., 168: 241–257

Potvin, C. and N.J. Gotelli, 2008. Biodiversity enhances individual performance but does not affect survivorship in tropical trees. *Ecol. Lett.,* 11: 217–223

Raaimakers, D., 1994. *Growth of Tropical Rain Forest Tree as Dependent on Phosphorus Supply*. Tropenbos Series 11, Wageningen, The Netherlands

Rayment, G.E. and F.R. Higginson, 1992. *Australian Laboratory Handbook of Soil and Water Chemical Methods*. Inkata Press, Melbourne, Australia

Resh, S.C., D. Binkley and J.A. Parrota, 2002.Greater soil Carbon sequestration under Nitrogen-fixing trees compared with Eucalyptus species. *Ecosystems,* 5: 217–231

Rhoades, C.C., 1997. Single-tree influence on soil properties in agroforestry: lessons from natural forest and savanna ecosystem. *Agroforest. Syst*., 35: 71–94

Rhoades, C. and D. Binkley, 1996. Factors influencing decline in soil pH in Hawaiian Eucalyptus and Albizia plantations*. Forest Ecol. Manage*., 80: 47–56

Russell, A.E., J.W. Raich, O.J. Valverde-Barrantes and F.R. Fisher, 2007. Tree species effects on soils properties in experimental plantations in tropical moist forest. *Soil Sci. Soc. America J.,* 71: 1389–1397

Sanchez, P.A., C.A. Palm, C.B. Davey, L. Szott and C. Russell, 1985. Tree crops as soil improvers in the humid tropics? *In*: Cannell, M.G.R. and J.E. Jackson (eds.), *Attributes of Trees as Crop Plants*, pp: 327–358. Institute of Terrestrial Ecology, Natural Environment Research Council, Huntington, UK

Singh, A.N. and J.S Singh, 2006. Experimental on ecological restoration of coal mine spoil using native trees in dry tropical environment, India: a synthesis. *New Forest.,* 31: 25–39

Sumner, M.E. and W.P. Miller, 1996. Cation exchange capacity and exchange coefficients. *In*: Sparks, D.L. (ed.), *Methods of Soil Analysis*, Part 3, pp: 1201–1229. SSSA Book Ser. 5 SSSA, Madison, Wisconsin, USA

Swaine, M.D., 1996. Rainfall and soil fertility as factor limiting forest species distribution in Ghana. *Ecology*, 84: 419–429

Vinton, M.A. and I. Burke, 1995.Interactions between individual plant species and soil nutrient status in short grass steppe. *Ecology*, 76: 1116–113

Vitousek, P.M. and R.L. Sanford, 1986. Nutrient cycling in moist tropical forest. *Annu. Rev. Syst*., 17: 137–167

Webb, M.A., 1999. Cell-Mediated crystallization of calcium oxalate in plants. *The Plant Cell,* 11: 751–761

Yao, M.K., P.K.K. Angui, S. Konate, J.E. Tondoh, Y. Tano, L. Abbadie and D. Benest, 2010. Effects of land use types on soils organic carbon and nitrogen dynamics in Mid-West Cote d'lvoire. *European J. Sci Res*., 40: 211–222

Zeugin, F., C. Potvin, C.J. Jansa and M. Scherer-Lorenzen, 2010. Is tree diversity an important driver for phosphorus and nitrogen acquisition of a young tropical plantation. *Forest Ecol. Manage*., 260: 1424–1414

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