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Differences in Soil Micronutrient properties of Restored and Secondary Dry Semi-Deciduous Forests in Ghana

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ABSTRACT

Restoration in the tropics with mixed native forest tree species is gaining prominent attention. This is because mixed forest plantations have high capacity to sequester carbon, protect watershed , increase and preserve biodiversity and general recycling of macronutrients as well as ecosystem functioning. However, the effect of mixed native or indigenous tree species plantations on topsoil micronutrients has received little or no prominence in most restoration research objectives in the tropics. This study seeks to determine the effect African mahogany species on topsoil micronutrients levels following restoration of degraded dry semi-deciduous forest reserve in Ghana. Changes in the soil micronutrients levels were evaluated 10 years after restoration of degraded dry-semideciduous forest reserve site with mixed mahogany species and compared them with adjacent degraded site which had undergone natural regeneration and slow succession process following last bush fire of the area. ANOVA was employed in the statistical analyses. The restored site recorded significantly higher amounts of Cu (P= 0.047) and Mn (P=0.021) as compared to the degraded site. However, there were no significant differences in Fe and Zn concentrations in the top soils of both studied sites. This study suggests the use of mixed African mahogany species in restoration of degraded forest will enhance ecosystem function and increase the levels of these two major micronutrients in deficient soils.

KEY WORDS: Restoration, micronutrients, mixed plantations, mahogany species, natural regeneration.

INTRODUCTION

The high forest zone in Ghana is estimated to cover an area of about 8,525,063 Ha [42,1,45] out of which1,694,859 Ha constitute Dry semi-deciduous forest zone (DSFZ). DSFZ serves as a buffer between the savannah in the north and the moist semideciduous forest zone in the south. DSFZ is home to a number important tropical timber species such as *Khaya anthotheca*, *Pericopsis elata*, *Argomuellera macrophylla* and many other species which are considered very rare or extinct in other high forest zones in the country [28, 23]. However, due to periodic wild fires part of 40 protected forest reserves totaling 3575 Km^2 in DSFZ is considered completely degraded and hence cannot be classified as forest, little under 0,2% which is considered to be the best part of these forest reserves, is categorized as partly degraded [28,25]. Moreover, the degraded sections of the forest reserves are usually invaded by grasses such as *Imperata cylindrica, Pennisetum purpureum, Panicum maximum*, *Andropogon* species and broad leaves weeds like *Chromolaena odorata* and *Lantana camara.* Due to the presence of these weeds and limited or virtually absence of tree seeds in soil seedbank natural regeneration is impaired. Thus, the obvious option to overcome this barrier and accelerate regeneration and natural succession is through restoration with mixed tree plantations as rehabilitative tools [9, 11].

In order to mitigate the continuous decline in forest cover of these forest reserves as a result of anthropogenic disturbances, calls for restoration through reforestation and afforestation by use of mixed indigenous tree species. Additionally, through understanding of socioeconomic drivers underline periodic bush fires of the area. Tree plantations have propensity to influence soil chemical and physical properties [22]. Tree plantations particular native species have been used in reforestation in the tropics to accelerate restoration of degraded forest sites [10].There is an abundance of literature that examines the effect of tropical mixed plantation and monoculture on soil macronutrients [33 ,7 ,41,34,47 ,36], carbon sequestration [10,5,37] and biodiversity in restored ecosystem [24, 35, 13, 16, 31] . However, research works on effect of mixed native species plantation or pure stand on micronutrients in restoration of degraded sites are limited. Nevertheless extensive works have been done on effect of plantation on Boron or vice versa in boreal forest ecosystems [30, 19, 43, 44, 2] .The importance of micronutrients in forest tree plantation ecosystems is evident in the

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studies of Raupach and Clarke (1978)[38] and Hagen-Thorn and Stjernquist (2005)[22]. However, in spite of their importance in forest tree growth and productivity, micronutrients have received little attention as compared to macronutrients.

In this study micronutrients concentrations in the top soils of formerly degraded dry semi-deciduous forest sites, which had been restored with African mahoganies plantation were compared with those from the degraded dry semi-deciduous forest site, which is slowly undergoing natural regeneration and succession. It was hypothesized that soil micronutrients concentrations would be higher under the restored site with African mahogany plantation than the natural regeneration site.

MATERIALS AND METHODS

Study site

In 2000 the Forest Research Institute of Ghana (FORIG) established experimental mixed plantation plots of African mahoganies and other indigenous important commercial timber tree species in the degraded portion of Pamu-Berekum forest Reserve near Twumkrom in the dry semi-deciduous forest zone (Figure 1). The objective were to generate baseline data on the use of native tree species in rehabilitating degraded forest for nationwide implementation of restoration projects and to identify underline socioeconomic drivers of periodic bush fires for policy intervention. The forest reserve is located at an elevation 665m above sea level, 27.7Km north-west of Dormaa Ahenkro (7.42°N, 2.83°W), Brong Ahafo Region of Ghana. The area has tropical climatic conditions with annual mean temperature of approximately 30^{o}C and mean annual rainfall 1400mm [23]. Soils of the study area are mostly forest ochrosols and oxysols, well-drained soils in the weathering products of intermediate or moderately acidic rocks. The ochrosols soil is the most important soil in the forest zone of Ghana [8, 3, 12]. These soils under FAO classification will be termed as Ferralsols and Acrisols [27, 20].

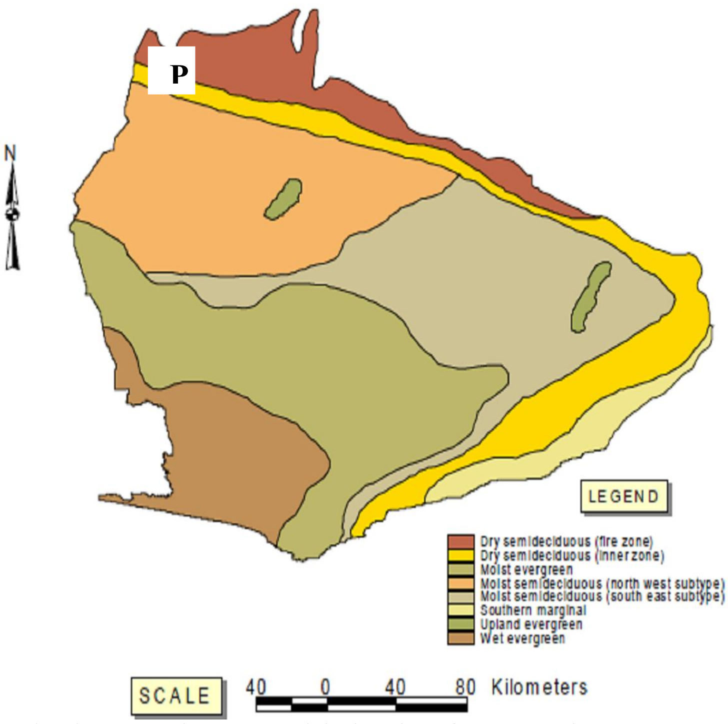

Figure 1. Map of High forest zone showing vegetation types and the location of Pamu-Berekum Forest Reserve (P) in Ghana: (Source, Affum-Baffoe, 2011) [1]

Sampling design and data analyses

The mixed plantation stand of African mahoganies in the restored or rehabilitated forest site consists of the following species; *Khaya anthotheca (Welw.) C*, *Entandrophragma utilis (Dawe &Sprague)* and *Khaya grandifoliola C. DC*. The vegetation in the degraded site which undergone natural regeneration and slow succession process following periodic bush fires is dominated by weeds such *Imperata cylindrica*, *Chromolaena odorata*, *Pennisetum purpureum, Panicum maximum* and *Andropogon* species. Additionally, the degraded site is interspersed with various native tree species some of which have commercial value. The mixed plantations at restored site were 10 years old at the time of data collection. Similarly, the degraded site had not seen any fire out-break for 10 years span, under this static conditions and absence of both anthropogenic and natural disturbances, the site was regenerating naturally but at a slow pace because of high incidence of weed invasion.The mahogany species were planted at spacing of 3m X 3m with substitution design [29].The experimental design was Completely Randomized Design (CRD) with two treatments and four replicates constituting total area of 8ha. The treatments were mixed mahogany plantation and natural regeneration. Each treatment was allocated a plot of an area 1ha (100m X100m) and it was replicated four times. Thus, each treatment covers total area of 4ha. For the purposes of soil sample collection and data generation, each 100m X100m plot was divided into 25 subplots of dimensions of 20m X 20m. However, 10 subplots were randomly selected from 25 subplots per plot and per each treatment. A subplot was further divided into 25 arrays or grids (4m X 4m). Every second grid was systematically selected moving from east to west direction with the aid of handheld GPS. Soil samples were collected from the middle of each selected grid with auger at depths of 0-10cm, 10-20 cm and 20-30cm and then bulked as a one unit or composite sample for chemical analysis. The concentration of Cupper (Cu), Manganese (Mn), Iron (Fe) and Zinc (Zn) were analysed by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES, Optima 3000 DV Perkin-Elmer) after equilibrium extraction of a 20g (dry weight) soil sample in 100ml 0.1M acid Na-EDTA (pH 4.6) for Cu and Zn and in 100ml of a 0.1 M solution of $BaCl_2$ for all other elements [22,211]. The soil pH was measured at a soil distilled water ratio of 1:2.5 with an Orion Research digital Ionalyzer [7]. One-way analysis of variance (ANOVA) was carried out on the top soil micronutrients characteristics and chemical reaction (pH) to determine the differences between soils of restored and natural regenerated forest site. Additionally, two-way ANOVA with site and depth as factors were performed on soil micronutrient characteristics. The statistical analyses were performed with XLSTAT software package (Addinsoft SARL, Paris, France, 2009) on Excel platform.

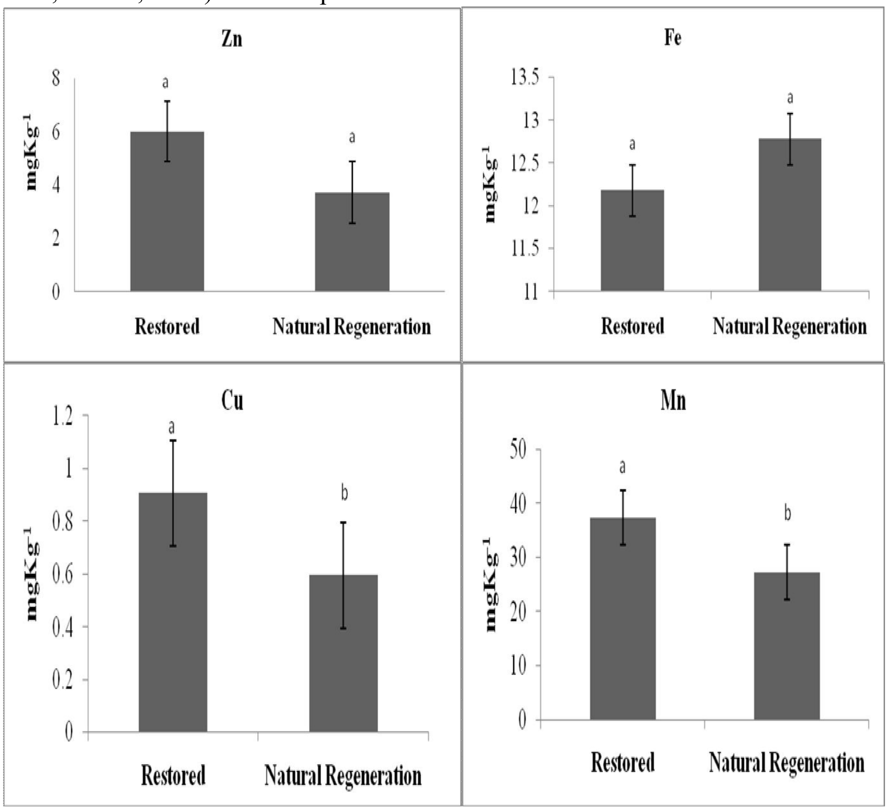

Figure 2: Comparison of four major micronutrients Zinc (Zn), Copper (Cu) ,Iron (Fe) and Manganese (Mn) levels in restored mixed plantation site with African mahoganies and natural regeneration site composed of grasses interspersed with trees in Dry Semi-deciduous forest zone of Ghana. The values are mean with corresponding standard error bar. Standard error bars with different letters are significantly different (Tukey Post hoc test; P<0.05).

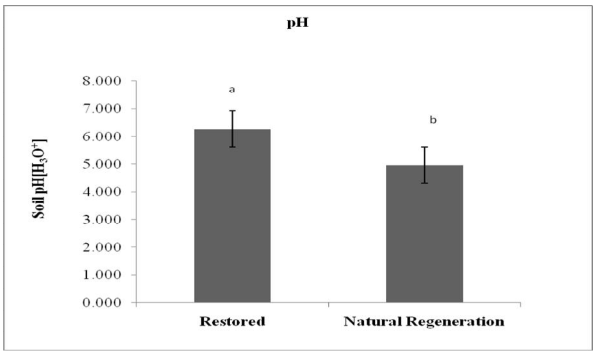

Figure 3. Comparison of soil pH at African mahogany plantation site and natural regeneration site. The values are means with corresponding standard error bar. Bars with different letters are significantly different (Tukey Post hoc test; P<0.05)

Table 1. The results of one-way analysis of soil micronutrients between restored site with African mahoganies plantation and natural regeneration site. The Mean values of the soil chemical properties for both sites and their respective standard Error of the Mean (Means ± Se), Critical *F*-values and probability level (*P*) of significant.

Micronutrients	Restored site (n=20)	Natural Regeneration site (n=20)	F	*P*-value
Zn	5.985±1.730	3.730±0.691	1.465	0.236^{ns}
Cu	0.905±0.137	0.595±0.057	4.327	**0.047***
Fe	12.178±1.577	12.775±0.913	0.108	0.745^{ns}
Mn	37.344±3.049	27.263±2.788	5.954	**0.021***
pH	6.23± 0.128	4.96±0.245	9.266	**0.005****

ns: not significant, P>0.05; *P<0.05; **P<0.01

RESULTS

Figure 1 shows the average micronutrient concentration in milligrams per Kilogram of topsoil for restored and natural regeneration sites. The restored site with mixed mahogany plantation recorded the highest amount of Zn (5.99±1.73mgKg^{-1}), Mn (37.34 ±3.05 mgKg^{-1}) and Cu (0.91±0.14 mgKg^{-1}) as compared to degraded site under natural regeneration. However, higher amount of Fe (12.78±0.91mgKg^{-1}) was recorded in the top soils of natural regeneration site as compared to restored site. Fe is the only micronutrient occuring in higher concentration at degraded site amongst the four micronutrients considered in the studies. The pH levels in the top soils of the natural regeneration site declined (4.43±0.245) as compared to restore site (6.23±0.128) (Figure 2). The average amounts of Cu in the restored site with mixed African mahogany plantation was significantly higher (F=4.96, P=0.047) as compared to the natural regeneration site (Table 1).Similarly, the concentration of Mn was significantly higher (F=5.95, P=0.021) in the top soils of the restored site than natural regeneration site. In addition, the differences in pH levels of the soils between both sites were significant (F=9.27, P=0.005). However, the soils at the degraded site were more acidic, whereas the soils under mahogany plantations range between slight acidic. Similar, results were obtained for two-way analysis of variance .The pH varied across the sites (F=8.155, P=0.009) but did not differ within the soil profile (F=0.160, P=0.956) at both sites (Table 2). Moreover, all the characters considered in the study with depth as a factor in two-way ANOVA were not significant. Nevertheless, with site as a factor or hierarchal level, Mn (F=5.627, P =0.026) and Cu (F=4.640, P=0.041) were significantly different in two-way ANOVA, with exception of Fe (F= 0.094, P=0.762) and Zn (F=1.561, P=0.224) (Table 2).

Table 2. The summary results of two-way ANOVA of micronutrient concentrations in the topsoil (0-30cm) with site and depth as factors. The sites are restored secondary forest and natural regenerated secondary forest.

Factor	Soil property	df	F	Pr > F
Site	pH	1	8.155	0.009**
	Mn	1	5.627	0.026*
	Fe	1	0.094	0.762^{ns}
	Cu	1	4.640	0.041*
	Zn	1	1.561	0.224^{ns}
Depth	pH	4	0.160	0.956^{ns}
	Mn	4	0.615	0.656^{ns}
	Fe	4	0.090	0.985^{ns}
	Cu	4	1.506	0.232^{ns}
	Zn	4	1.460	0.245^{ns}

ns: not significant, P>0.05; *P<0.05; **P<0.01

DISCUSSIONS

The results showed that there were considerable differences between both sites in terms of four micronutrients considered in this study. It is evident that mixed mahogany plant influenced the soil chemistry in particular the pH in water. The difference in micronutrient pools reflects how these nutrients are recycling in both sites. Additionally it indicates the demand for these elements in relation to return to soil and uptake by plant species at both sites in particular African mahogany species. The most interesting results are the higher concentrations of Mn and Cu beneath mixed mahogany plant stands as compared to natural regeneration site. This may be to the fact that these two nutrients are actively mined and recycle by mahogany species through their biomass than other species on regenerated site which is dominated by grasses. The higher concentration of Mn recorded at mixed mahogany plantation site is not uncommon.

Hill et al (2001) [26] reported high bioaccumulation of Mn in *Eucalyptus* sub-genus s*ympyomyrtus*. In similar research, Jobbagy and Jackson (2003) [15] reported significant higher amount of Mn concentrations in the soils and in the leaves of Eucalyptus plants used in afforestation than comparative adjacent grassland species and in the soil. Micronutrient concentrations vary among plant species, and individual species and families can behave as bioaccumulators of certain metals [14]. Additionally, there is evidence of plants growing under certain specific elemental deficient soils or low concentrations having high concentrations of said element in their tissues as compared to the soils beneath [46]. Other work has shown that Mn concentration in the bark and wood of red fir (*Abies magnifica*) can increase over 3-17 year period, even though the total amount of Mn in forest ecosystem remained the same [32,39].This suggest that plant species have differential influence on the soil nutrient or elemental pool dynamisms [4,6]. However, Fe and Zn distribution in the soils at both sites were not significantly different. Thus, amplifying or suggesting that high concentration of Cu and Mn may be purely due to uplifting and recycling at mixed plantation site. Secondly Fe and Mn share similar geochemical behaviour. Moreover, the concentrations of Fe at both sites were almost the same, which was a significant deviation from the behaviour of Mn. In addition, all the four micronutrients did not show variation as moving down the soil profile across both sites. The role of litter fall from tree species in these two contrasting site is important in recycling micronutrients. The concentrations of Cu and Mn in the leaves of some forest tree species tend to be high than in wood biomass [40] .The large amount of Cu and Mn in restored or mixed mahogany plantation site might have been recycled through litterfall. However, Gallardo et al. (1998b) [18] reported that large amount of Mn, Cu, Fe and Zn in soils of *Castanea sativa* and *Quercus pyrenaica* stand as due to litterfall. Nonetheless, in another study, Gallardo et al. (1998a) [17] maintained that greater proportion of Mn and Cu were exclusively returned to the soil through leaching from the stand canopy by rainfall.

The study has shown considerable differences in micronutrient concentration between mixed mahogany plantation site and natural regeneration site. The restored site with mixed mahogany species recorded considerable higher concentration of Mn and Cu in the soils. A practical application is that integration of these forest tree species in agroforestry system in areas showing deficiency in these elements will go a long way to improve productivity. Moreover, mahogany species could serve as an ideal to tool to catalyze restoration of degraded forest and facilitate ecosystem functioning.

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