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Comparison of Some Soil Chemical Properties in Four *Terminalia superba* Plantations and a Natural Tropical Forest in Mayombe, Congo

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Abstract: A comparative study was carried out in Mayombe, between the soil of the natural forest and the soil under four *Terminalia superba* plantations of 7, 12, 32 and 48 years old. Ten composite soil samples were collected from ten systematically located squares (1 m^2, four cores from each square) in each plantation. The goal was to evaluate the impact of reforestation on soil pH, exchangeable cations, base saturation, CEC and phosphorus in the 0-10 cm layer. The results showed that soil pH was 4.63 in natural forest and between 4.97 and 5.84 in plantations. Ca content was higher in the 7 year old plantation (7.83 cmol kg^{-1}) than in natural forest (3.14 cmol kg^{-1}). Mg was 3.27 cmol kg^{-1} in the young plantation and 1.41 cmol kg^{-1} in forest. K exhibited a low content in the plantations and high content in natural forest. Base saturation varied between 48.6 and 100%. The CEC was almost a steady state. All soil properties showed an initial increase in the seven years after reforestation. The increase was followed by a general decrease with aging of plantations. Despite this decline, the positive Deterioration Index (DI) recorded suggested that reforestation with *T. superba* slightly improved the soil attributes, except in the case of K and CEC in which a negative DI was obtained.

Key words: *Terminalia superba*, pH, exchangeable cations, phosphorus, deterioration index

INTRODUCTION

The Mayombe is a low mountain located in the South-Western of Congo and it is covered by a natural forest. *Terminalia superba* (*T. superba*) is one of the most important native tree species of this forest. Since 1950, *T. superba* is the main species use for reforestation in the Mayombe area. The monoculture plantations of *T. superba* cover a total of 14000 ha in this area. The purpose of these plantations is for wood supply. Conversion of natural forest to tree plantations may influence many natural phenomena and ecological processes, leading to a change in soil properties. Clearing of forests and their subsequent conversion into plantation may change water holding capacity, structural stability and compactness, nutrient supply and storage and the biological life of the soils (Wairiu and Lal, 2003; Rasiah *et al*., 2004; Yimer *et al*., 2007). Studies in the tropics have shown significant changes in soil organic carbon following conversion of natural forest into cultivation and these changes have been shown to affect soil fertility (Brown and Lugo, 1990; Dominy *et al*., 2002). Lepsch *et al*. (1994) and Yimer *et al*. (2007) have also indicated that forested lands converted into cultivated areas in tropical regions undergo important changes in soil properties, including loss of organic matter, increase in bulk density and decrease in pH and exchangeable cations. Investigations into the physical and chemical characteristics of the soil and its environment could be used to evaluate the impacts of land use on soil fertility (Jaiyeoba, 1998; Singh *et al*., 2002).

Apart an initial investigation (Bernhard-Reversat and Tchibinda Pemo, 1988) reported on litterfall and nutrient variations in *T. superba* plantations of different ages (Goma-Tchimbakala *et al*., 2005; Goma-Tchimbakala and Bernhard-Reversat, 2006) no other study addressed the impact of conversion of native forests into monoculture of *T. superba*. The aim of this study is to assess the impact of reforestation with *T. superba* on soil chemical properties in the Mayombe in comparison with natural forest soil properties.

MATERIALS AND METHODS

Site description: The study sites were previously described by Goma-Tchimbakala and Bernhard-Reversat (2006). Briefly they are located in the Mayombe area at 4°3’S, 12°4’E and above mean sea level 30 m altitude. Mean annual rainfall is 1250 mm. Relative humidity is high (about 85%) throughout the year. The temperature ranges from 28°C in the rainy season to 18°C in the dry season. The desaturated ferralitic soil (Jamet and Riffiel, 1976) lies

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on sandy-clayey or clayey-sandy material resulting from the weathering of cretaceous green rock and dolomitic limestone. In this study the clay content in the surface soil has a narrow range from 27 to 29% (Table 1). *Terminalia superba* plantations were established by the National Reforestation Service (SNR) after clearing the forest and burning all plant residues. Four plantations of 7, 12, 32 and 48 years old were chosen for this study. The undergrowth vegetation was well developed in the planted plots and the Fabaceae, Annonaceae, Euphorbiaceae, Moraceae, Marantaceae and Menispermaceae were the most well-presented plant families. The nearby natural forest was used for comparison with the planted plots. The most represented tree families in the natural forest were the Caesalpinaceae, followed by the Rubiaceae and the Euphorbiaceae. All the stems larger than 10 cm diameter at breast height (DBH) were listed (Table 2) together with the plants of the understory.

Soil sampling and laboratory analyses: Soil samples were taken from the upper 0-10 cm layer. Ten composite soil samples were collected from ten systematically located squares in each plantation type and natural forest. Each composite soil sample was combined from four cores from a square of 1 m^2. Samples for chemical analyses were air-dried and then passed through a 2 mm soil sieve. The pH was measured in a soil suspension with a soil-water ratio of 1/2.5. Exchangeable cations (Ca, Mg, K) were analyzed after extraction with 1M ammonium acetate at pH 7. Exchangeable Ca and Mg were determined using atomic absorption spectrophotometer while exchangeable K was

Table 1: Average particle size distribution of the surface soil under *T. superba* plantations and natural forest

		T. superba			
Soil properties	Natural forest	7 years	12 years	32 years	48 years
Sand	53.8±0.3	54.5±0.2	54.3±02	53.8±0.3	52.6±0.2
Silt	18.1±0.3	16.2±0.3	16.6±0.3	17.6±0.3	18.8±0.2
Clay	27.9±0.2	28.6±0.3	28.7±0.3	27.3±0.2	28.4±0.2

Table 2: Woody species in the Bilala forest

Family	Species	Family	Species
Acantaceae	*Thomadersia laurifolia*	Fabaceae	*Pterocarpus soyauxii*
Anacardiaceae	*Pseudospondias microcarpa*	Flacourtiaceae	*Calancoba glauca*
	Sorindeia juglandifolia	Irvingiaceae	*Irvingia grandifolia*
Anisophylleaceae	*Anisophyllea purpurascens*	Lecythidaceae	*Petersianthus macrocarpus*
	Polyalthia suavolens		
	Annonidium mannii	Meliaceae	*Carapa procera*
	Uvariodendron molundense	Mimosaceae	*Pentaclethra macrophylla*
	Uvariopsis congolana		*Piptadeniastrum africanum*
		Myristicaceae	*Staudia stipitata*
Apocynaceae	*Pleiocarpa mutica*		*Coelocaryon preussi*
	Rauwolfia obscura		
		Ochnaceae	*Campylospernum descoingsii*
Burseracea	*Dacryodes pubescens*		*Campylospernum elongatum*
	Santiria trimera	Olacaceae	*Diogoa zenkeri*
			Strombosia grandifolia
Caesalpiniaceae	*Cynometra lujae*		*Strombosia pustulata*
	Dialium dinglagei		
	Dialium pachyphyllum	Rubiaceae	*Aïda micrantha*
	Gilletiodendron pierranum		*Pauridiantha mayumbensis*
	Loesenera gabonensis		*Rothmannia munsae*
	Tessmania Africana		*Cephaelis peduncularis*
	Euclinia longiflora		
Clusiaceae	*Allanblackia floribunda*	Rutaceae	*Fagara macrophylla*
	Garcinia kola		
	Garcinia punctata	Samydaceae	*Microdesmis puberula*
	Mammea africana	Sapindaceae	*Chytranthus atroviolaceus*
	Pancovia floribunda		
Ebenaceae	*Diospyros dendo*		
	Diospyros fragrans	Sapotaceae	*Gambeya Africana*
	Diospyros hoyleana		*Omphalocarpum elatum*
	Diospyros stimulans		
Sterculiaceae	*Cola gelleti*		
Euphorbiacea	*Drypetes gossweleri*		*Cola nitida*
	Drypetes leonensis	Styracaceae	*Afrostyrax lepidophyllus*
	Plagiostyles africana		
	Ricinodendron heudelotii	Violaceae	*Rinorea oblongifolia*

From Goma-Tchimbakala and Bernhard-Reversat (2006) determined by flame photometry. Cation Exchange Capacity (CEC) was estimated by titration after distillation of ammonia that was displaced by sodium. Base saturation (BS%) was calculated by dividing the sum of the base forming cations (Ca, Mg, K) by CEC of the soil and multiplied by 100. Bicarbonate-extractable P was determined by extraction in 0.5M sodium bicarbonate with pH of 8.5 followed by an automated continuous flow procedure based on the method of Murphy and Riley (1962) to measure P in the extracts. All the analyses were carried out in the laboratory of IRD at Pointe-Noire.

Data analysis: When evaluating the impact of reforestation on soils, the soil status under a new land use is commonly compared to native vegetation (Islam and Weil, 2000). We assessed changes in soils under *T. superba* plantations by computing soil deterioration index (DI) (Adejuwon and Ekanade, 1988; Islam and Weil, 2000; Lemenih *et al.*, 2004). DI was calculated as the difference between the mean values of individual soil properties under different *T. superba* plantations and the values of the same soil properties under natural forest and expressed as a percentage of the value under the natural forest. These percentage changes were then summed across all soil properties to compute a cumulative soil DI. This cumulative DI was used as an index of soil degradation or improvement. Statistical differences were tested using two-way analysis of variance (ANOVA). The Protected Least Significant Difference (PLSD) Fisher test was used for mean separation when the analysis of variance showed statistical differences. All statistical analyses were performed using Stat View 5.0 (SAS Inst. Inc.).

RESULTS

Soil pH: The results showed that reforestation affected soil pH ($p<0.001$; Fig. 1). Soil pH was high under the young (7-12 years old) *T. superba* plantation than under the semi mature and mature (32 and 48 years old) plantations. However there was no significant difference between pH in soil under these plantations. In all cases soil pH in plantations was higher than in natural forest ($p<0.0001$; Fig. 1).

Exchangeable cations, base saturation and CEC: The reforestation influenced the distribution of Ca in the soil ($p<0.0001$). The highest Ca concentration was observed in the 7 year old plantation, while the lowest concentration was in the mature plantations (Fig. 2). The ANOVA showed no significant differences in Ca content between the semi mature and mature plantations (32 and 48 years). Comparison of mean differences revealed that Ca concentration under plantations was significantly higher than the concentration observed in the native forest. Exchangeable Mg was greater in soil under the 7 year old plantation than in the other situations (Fig. 2). There was no significant difference between the Mg

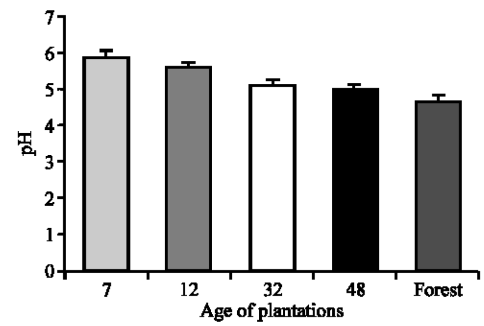

Fig. 1: Soil pH in *T. superba* plantations and natural forest

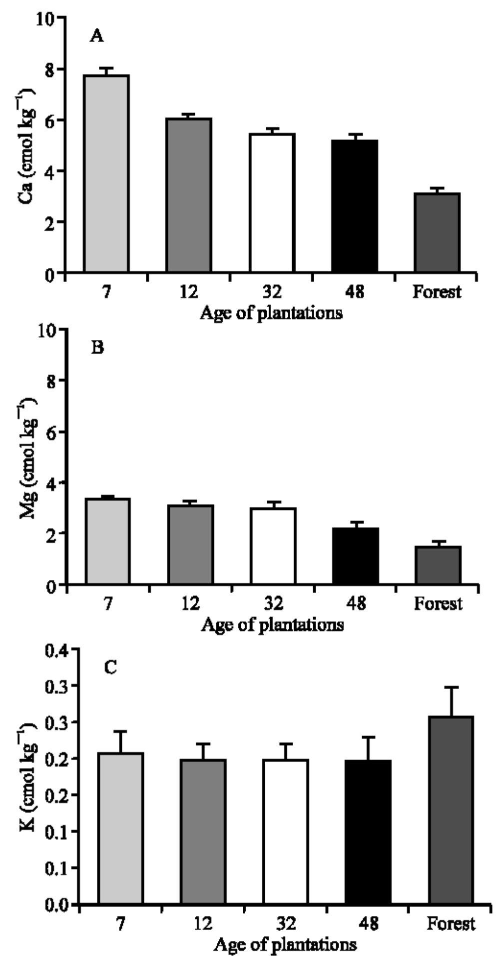

Fig. 2: Exchangeable cations in soil under *T. superba* plantations and natural forest

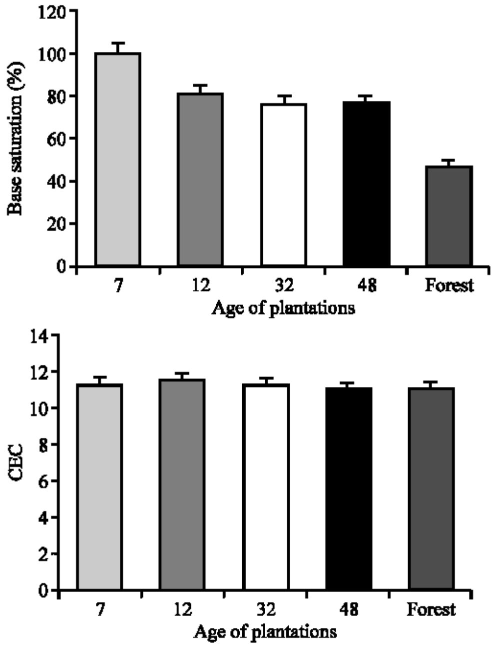

Fig. 3: Base saturation and CEC in soil under *T. superba* plantations and natural forest

content of soils under the 12 and 32 years-old plantations. However the Mg content of soil in these two plantations was higher than in the 48 year old plantation. The level of Mg was low in the natural forest compared to plantations. Exchangeable K concentration in the soil of the native forest was significantly higher than in the plantations ($p<0.001$). Comparison among plantations showed similar exchangeable K levels (Fig. 2). Base saturation showed significant differences between the plantations ($p<0.001$; Fig. 3). Base saturation under the 7 year old plantation was higher than under plantations of 12, 32 and 48 years old. In these latter plantations base saturation was between 76.6 and 81.6%. The soil under the 48 year old plantation had the weakest base saturation amongst plantations. In all cases base saturation under natural forest was lower than under plantations. Cation exchange capacity was between 10.9 and 11.5 under *T. superba*, while it reached 11.1 in native forest (Fig. 3) but the differences between the plantations and between the plantations and the native forest were not significant ($p>0.05$).

Soil phosphorus: Soil phosphorus content was significantly higher in the 7 year old plantation than in the other plantations ($p<0.05$; Fig. 4). Soil phosphorus under the 12 year old plantation was higher than under the 32 and 48 year old plantations. However these 2 plantations showed no significant difference in P concentration.

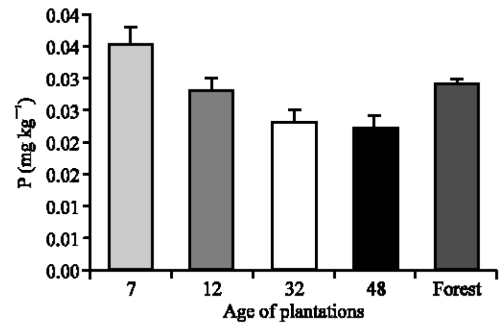

Fig. 4: Available phosphorus in soil under *T. superba* plantations and natural forest

Table 3: Deterioration index (DI %) for some soil properties in the 0-10 cm layer under *T. superba* plantations calculated as the relative difference between mean values of individual soil properties under *T. superba* plantation to baseline values of the same soil properties under natural forest

Soil properties	*T. superba* 7 years	12 years	32 years	48 years
pH	26.1	20.3	10.4	7.3
CEC	1.8	3.6	1.8	0.0
Base saturation	113.7	74.4	63.7	65.6
Exchangeable Ca	149.4	94.9	75.5	69.4
Exchangeable Mg	131.9	117.7	109.2	48.2
Exchangeable K	-19.2	-23.1	-23.1	-23.1
Available P	20.7	-3.4	-20.7	-24.1
Overall DI	424.3	284.4	216.8	143.4

Similar P concentrations were observed in the native forest and in the 12 year old plantation. The P level in native forest was low compared to the 7 year old plantation, but this level was higher than in the 32 and 48 year old plantations.

DI for *T. superba* plantations: The results showed that most soil properties contributed with positive values to the cumulative DI (Table 3). The DI for exchangeable Ca, exchangeable Mg and base saturation were the most important factors that enhanced the cumulative DI under the *T. superba* plantations. Except for the DI of available P (+20) under the 7-year old *T. superba* plantation, the exchangeable K and available P contributed negatively to the cumulative DI under plantations (Table 3). The results (Table 3) showed a general decline of the individual and cumulative DI with the older plantations.

DISCUSSION

Among the numerous causes of changes in nutrient availability along successional gradients, some are due to differences in litter quality and nutrient status, patterns of biomass accumulation, root nutrient uptake, canopy interactions and leaching as well as alterations due to the microclimate and soil biological community (Hagen-Thorn *et al.*, 2004). Except for the first seven years after planting, the trends observed in this study indicated a general decline for pH, exchangeable cations, base saturation and P but not for cation exchange capacity.

Soil pH: In this study, pH in the natural forest falls in the range between 3.1 and 4.6 of the soil of Mayombe area (Jamet and Rieffel, 1976). In the closed system the pH will mostly reflect the element return to the soil in relation to nutrient demand and uptake for each species. The slight increase in pH during the 7 first years after planting was probably due to the effects of ash and the lack of leaching from litterfall and litter decomposition. After this period the difference in soil pH and its change with aging might be caused by: (i) The increase of the litterfall, litter decomposition and leaching and the nutrient uptake. This finding is in agreement with the results obtained by others on deforestation and burning followed by planting (Grove *et al.*, 1986; Jain and Singh, 1998; O'Connell *et al.*, 2000). (ii) A decrease in base cations due to translocation from the surface soil to plant biomass in the plantations (Binkley and Giardina, 1997). In this study these hypotheses are strongly suggested by the decrease in Exchangeable Ca, Exchangeable Mg and base saturation and their differences among the plantation ages in the upper 0-10 cm of the soil.

Exchangeable cations, Base saturation and CEC: The relationship between plantation age and nutrient availability differed considerably between nutrients. The stocks of Ca and Mg in the soil were higher in *T. superba* plantations than in natural forest in which a larger proportion of base elements are certainly retained in the biomass. The high Ca and Mg stocks in the above-ground in plantations were due to the translocation from the biomass to the soil through litterfall and litter decomposition. In ferralitic soils the threshold of deficit is 0.30 cmol kg^{-1} and that of a deficiency is 0.15 cmol kg^{-1} for Mg (Moukam and Ngakanou, 1997). The exchangeable Mg concentration found in plantations and in natural forest is higher than these thresholds. These soils may be considered as well provided in magnesium. The positive effect of *T. superba* on Ca and Mg concentrations may be caused by rapid cycling of these elements in litter and through fall. This hypothesis was supported by the positive DI obtained for Ca and Mg. Present results were in agreement with the finding of Brais *et al.* (1995). However the decrease observed with plantation aging could be explained by rapid recycling of the elements (Yamashita *et al.*, 2008), the increase of root volume and subsequent uptake. Ca decrease was less pronounced than that of Mg. Some of these changes were related to species composition and litter quality (Goma-Tchimbakala and Bernhard-Reversat, 2006). Exchangeable K showed an initial increase due to the weak uptake by the roots. Afterwards, the lack of differences in exchangeable K among the plantations is likely due to its high mobility in soil-plant systems. The negative DI obtained for exchangeable K with plantation aging may be explained by the gap between the input through decomposition (Mishra *et al.*, 2003), litterfall and uptake and subsequent incorporation into the biomass (Zhang *et al.*, 2007). Differences in base saturation among plantations and between natural forest and plantations were significant. The young plantations had a higher base saturation than semi-mature and mature plantations. Among the tree plantations, soil under the 7 year old *T. superba* plantation had the highest base saturation. The high Ca concentration was the main factor contributing to the increase in base saturation in the plantations. Present results were in agreement with the finding of Mishra *et al.* (2003), under *Eucalyptus tereticornis*. On other hand the soil under natural forest in general had a lower base saturation than under plantations. The positive DI found under plantations indicated that *T. superba* plantations induced an improvement of soil attributes despite the decrease observed with aging.

Soil phosphorus: The DI indicated regular degradation of P under plantations with aging. Differences in soil P with plantation age were caused mostly by differences in root uptake and turnover. The degradation is more pronounced in the mature plantation than in the younger plantation, assuming that the root distribution and activity were more important in the mature plantation. The subsequent effect was the decrease of P concentration due to a stronger demand for vigorous growing of 32 and 48 year old *T. superba* plantations and their understory. The decrease of P following conversion of native forest to monoculture was observed by several authors. Montagnini (2000) in his study observes the decrease of P on *Terminalia amazona* that occurs during the five years following the plantation establishment. Okoro *et al.* (2000) claimed that the conversion of natural forest to monocultures of *Terminalia ivorensis* or *Tectona grandis* in Nigeria resulted in significant decline of available P. Present results were similar to those of Chamshama *et al.* (2000) in teak plantations. These authors observed that the available P decreased in both young and semi-mature teak plantations (30 years).

CONCLUSION

It is reasonable to expect some variations in the soil attributes among the sites studied here. Soil chemical characteristics in the mature *T. superba* plantation were, however, very close to that of the natural forest. The exchangeable cation concentrations in the mature plantation were slightly different from the soil of natural forest, resulting in larger differences in base saturation and soil acidification. However, these changes do not seem to alter the ecosystem functions. Observations of CEC showed almost a steady state, suggesting the trend towards the chemical attributes of natural forest. Present results showed that the main perturbations introduced by the plantation of indigenous trees are not long lasting and that the recovery capacity of the soil attributes is high. This resilience may be linked to the fast decomposition of organic matter in a wet hot climate and to the presence of the forest undergrowth, which increases the biodiversity in the litter system. This could be improved by forestry practices such as keeping natural forest stands between the plantations and stopping slash and burn.

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