SOIL CHEMICAL CHARACTERISTICS IN A NATURAL FOREST AND A *CUPRESSUS LUSITANICA* PLANTATION AT WEST KILIMANJARO, NORTHERN TANZANIA

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MARO, R.S., CHAMSHAMA, S.A.O., NSOLOMO, V.R. & MALIONDO, S.M. 1993. Soil chemical characteristics in a natural forest and a *Cupressus lusitanica* plantation at West Kilimanjaro, northern Tanzania. A comparison of soil chemical properties under a *Cupressus lusitanica* plantation and an adjacent natural forest was carried out at West Kilimanjaro, northern Tanzania. Results showed that the natural forest had higher amounts of organic matter, total nitrogen and exchangeable sodium in some soil horizons than the plantation forest. Levels of available phosphorus and exchangeable calcium and potassium did not differ significantly between the two forest types but the organic layer under the cypress plantation was significantly more acidic than that under the natural forest. The possibility of these changes affecting future productivity of successive rotations of plantation forests is discussed using results of this study and others from literature. It is concluded that further investigation of soil properties (biological, physical and chemical) under plantation forestry is necessary using permanent sample plots so that long term effects on site productivity could be correlated with the yield of successive rotations.

Key words: *Cupressus lusitanica* - soil chemical properties - Tanzania - plantation - natural forest

MARO, R.S., CHAMSHAMA, S.A.O., NSOLOMO, V.R. & MALIONDO, S.M. 1993. Cirian kimia tanah dalam hutan asal dan ladang *Cupressus lusitanica* di Kilimanjaro Barat, Tanzania utara. Satu perbandingan cirian kimia tanah ladang *Cupressus lusitanica* dan hutan asal yang berhampiran telah dijalankan di Kilimanjaro Barat, Tanzania utara. Keputusan telah menunjukkan bahawa hutan asal mempunyai jumlah bahan organik, jumlah nitrogen dan sodium yang boleh ditukar yang lebih tinggi di beberapa ufuk tanah berbanding hutan ladang. Paras posforus yang boleh didapati serta kalsium dan potassium yang boleh ditukar tidak menunjukkan perbezaan yang bererti antara kedua-dua jenis hutan tetapi lapisan organik diladang cypress lebih asidik dari hutan asal. Kemungkinan perubahan-perubahan ini mempengaruhi produktiviti pusingan sesaran hutan ladang di masa depan dibincang, menggunakan keputusan dari kajian ini dan dari lain-lain penerbitan. Adalah dirumuskan bahawa kajian lanjut sifat-sifat tanah (biologi, fizikal dan kimia) hutan ladang perlu diadakan dengan menggunakan plot sampel kekal supaya kesan jangka panjang terhadap produktiviti tapak dapat dikaitkan dengan hasil dari pusingan sesaran.

Introduction

Plantations of exotic tree species were established in Tanzania around the 1950s when *Pinus patula, P. elliottii, Cupressus lusitanica, Tectona grandis* and some *Eucalyptus* species were planted in areas cleared of native forests. The planting was largely encouraged by the high growth rates of the exotic trees which by far exceeded those of the indigenous forests. For example, *P. patula* and *C. lusitanica* have an average increment of 25-30m^3 ha^1 y^1 while the native miombo woodlands have an increment of 1-2m^3 ha^1 y^1 (MNRT 1987).

Pure stands of exotic trees, now covering 80,000 *ha* in Tanzania, have been found to be ecologically different from indigenous forests in terms of organic matter production, soil conditions and the type of vegetation growing on the forest floor (Lundgren 1978). Changes in soil properties due to the introduction of plantation forests may either favour an increase in the nutrient status of a soil (*e.g.* Iyamabo 1973, Chijioke 1980) or result in a decline of nutrients (*e.g.* Rennie 1962, Wilde 1964, Hamilton 1965, Robinson 1967, Will 1968) or have no significant changes on soil (*e.g.* Kadeba & Onweluzo 1976, Adejuwon & Ekanade 1988). However, biological, physical and chemical properties of soil in plantations are greatly influenced by management practices during establishment, tending and harvesting (Lundgren 1978, Evans 1982, Raison *et al.* 1982, Maganga & Chamshama 1984, Shepherd 1986).

Although soil changes may begin during conversion of the natural forests into plantation monocultures, research on the extent of changes in chemical properties has only covered a small proportion of these plantations in Tanzania (*e.g.* work by Lundgren 1978). As soil conditions may differ from one geographical area to another, there is need to monitor them in all locations where plantation forests are established. Such information could be necessary in explaining future changes in site productivity under various rotations of plantation monocultures. Comparing some chemical properties of soils in a natural forest and an adjacent first rotation *C. lusitanica* stand was therefore undertaken in this study at West Kilimanjaro, northern Tanzania.

Materials and methods

The study was conducted in the West Kilimanjaro forest plantation area (36° 30', 37° 10'E and 2° 2', 3° 10'S) at 2300 *m* altitude. Mean annual rainfall of the area is 750 *mm* and the monthly mean temperature maxima and minima are 27°C and 7°C respectively. Soils, derived from volcanic ashes, are red and grey-brown clay loams and were classified according to FAO - UNESCO system by Samki (1977) as Dystric Cambisols. The earliest volcanic activity of the Kilimanjaro mountain has been dated as Miocene to Pliocene and activity has continued through Pleistocene into recent times with decreasing frequency and importance (NSS 1987). Soils may have developed therefore from volcanic ash, scoria, redeposited ash, mud flow materials and weathering products of lava with rocks of variable mineral composition.

The natural vegetation is composed of sub-montane rain forest dominated by broad leaved tree species. Establishment and tending of the cypress plantation was done through the "Taungya" system during the first five years of growth until the time when the canopy closed.

Paired soil samples were collected from five randomly selected mature first rotation cypress compartments (14 to 22 *y* old) and their adjacent natural forest, using the boundary between them as a transect. After every 10*m* along the transect, sample plots were established 5*m* on either side, that is in the cypress plantation and the natural forest. A total of 75 plots were established in each type of forest and in each plot, soil samples were collected in the organic layer - which included litter (L), fermentation (F), and humic (H) layers; and at 0-10*cm* and 10-50*cm* depths. In total, 450 soil samples were collected, 225 from each forest type.

Later, the soil samples were air-dried, sieved and analyzed for chemical properties. Organic matter content was determined by the ignition method, total nitrogen by the micro-Kjeldahl method, available phosphorus by the Bray-1 method, and after leaching with 1N neutral ammonium acetate, exchangeable cations (Ca, K and Na) were determined by the flame photometer (Juo 1979). Soil reaction (pH), was also determined in a 1:2 soil-water paste (Uriyo & Singh 1974).

Data from the analyses were compared for each parameter between the two types of forests using the paired t-test at $p<0.05$, $p<0.01$ and $p<0.001$ levels of significance.

Results and discussion

Organic matter content and total nitrogen

In both forest types, as expected, there was more organic matter in the organic layer, followed by 0-10 and 10-50*cm* depths respectively (Table 1). However, the organic layer of the natural forest had significantly more organic matter than that of the cypress plantation ($p<0.01$). There were no significant differences in organic matter content in soils of the two forests collected at 0-10 and 10-50*cm* depths.

Total nitrogen was significantly higher in both the organic and 0-10*cm* layers of the natural forest than in the plantation forest ($p<0.05$) with no significant

Table 1. Mean, standard deviation and range of organic matter content at different soil depths in a natural forest and an adjacent *Cupressus lusitanica* plantation at West Kilimanjaro, Tanzania

	Organic matter content (%)		
	Organic layer	0-10 *cm*	10-50*cm*
Natural forest	29.09 ± 8.45 (9.2 - 44.8)	16.06 ± 3.62 (7.6 - 23.0)	10.50 ± 3.65 (1.2 - 20.2)
C. lusitanica	23.51 ± 7.92 (12.0 - 46.8)	15.26 ± 4.49 (5.8 - 24.6)	10.84 ± 6.47 (4.0 - 37.8)
Level of significance	**	NS	NS

** = Significant at $p<0.01$, paired t-test;
NS = Not significant.

differences between the 10-50*cm* layers of the two forest types (Table 2). Both forest types had relatively high values of percentage nitrogen in all profiles. In the organic layers, the values are comparable to those at Olmotonyi, Tanzania obtained in a similar study (Lundgren 1978).

Table 2. Mean, standard deviation and range of total nitrogen at different soil depths in a natural forest and adjacent *Cupressus lusitanica* plantation at West Kilimanjaro, Tanzania

	Total nitrogen (%)		
	Organic layer	0-10 *cm*	10-50 *cm*
Natural forest	2.03 ± 0.85 (1.75 - 2.17)	1.015 ± 0.74 (0.465 - 1.37)	0.455 ± 0.132 (0.07 - 0.985)
C. lusitanica	1.26 ± 0.34 (0.805 - 1.58)	0.595 ± 0.163 (0.088 - 0.956)	0.406 ± 0.087 (0.077 - 0.838)
Level of significance	*	*	NS

* = Significant at $p<0.05$, paired t-test ; NS = Not significant.

The results show the commonest characteristics of forests whereby top soils contain more organic matter, and hence more total nitrogen than the subsoil layers due to the contribution of litter (Aweto 1981, 1988). However, the occurrence of more organic matter content in the natural forest could be attributed to a number of factors including the diversity of vegetation cover. Similarly, the availability of more total nitrogen is a result of the presence of more organic matter in the natural forest and due to rapid mineralization of litter in the top soil of the natural forest, a process which has been found to be higher than in a cypress plantation (Lundgren 1978). This faster mineralization could also be due to the diversity of the litter substrate under the natural forest contributed by the various species which occur together. Lastly, the lack of erosion in the natural forest (compared to the occasional sheet erosion in the cypress plantation) results in the conservation of organic matter and total nitrogen.

Available phosphorus and exchangeable calcium, potassium and sodium

There were no significant differences ($p<0.05$) in the levels of available phosphorus and exchangeable calcium and potassium at all profile depths between the natural and cypress forests (Tables 3 and 4 respectively). Calcium levels were high in both types of forests. This is not surprising because the soils of the study area are Cambisols with a clay loam texture. Lundgren (1978) reported similar levels of calcium for a volcanic soil at Mount Meru forest plantation in northern Tanzania. In the organic and 0-10 *cm* layers, the amount of exchangeable sodium was not significantly different between the two forests but was higher in the 10-50 *cm* layer of the natural forest ($p<0.05$).

Different from results of this study, in Kenya, Robinson (1967) found less available phosphorus in a cypress plantation. Under broad leaved plantation trees in Nigeria, Adejuwon and Ekanade (1988) found lower levels of phosphorus than in an adjacent tropical rain forest.

Varying results have also been found in the amount of exchangeable cations between plantations and natural forests. Decline in levels of exchangeable bases has been recorded in conifer plantations in Australia (Hamilton 1965), Kenya (Robinson 1967), and in New Zealand (Will 1968). Under broad leaved trees in Nigeria, Iyamabo (1973) and Chijioke (1986) reported an increase in total exchangeable basic nutrients. However, similar to results of this study, in a pine plantation (Kadeba & Onweluzo 1976) and broad leaved tree plantations (Adejuwon & Ekanade 1988) there were also no significant differences in levels of exchangeable cations in the top soil between the plantations and their adjacent natural forests.

Table 3. Mean, standard deviation and range of available phosphorus at different soil depths in the natural forest and *Cupressus lusitanica* plantation at West Kilimanjaro, Tanzania

	Available phosphorus (*ppm*)		
	Organic layer	0-10 *cm*	10-50*cm*
Natural forest	14.7 ± 4.53 (7.9 - 23.54)	12.24 ± 3.24 (5.66 - 22.44)	13.7 ± 4.59 (8.6 - 23.74)
C. lusitanica	15.58 ± 4.3 (9.88 - 27.62)	13.3 ± 4.1 (5.94 - 21.72)	11.44 ± 4.57 (4.6 - 22.08)
Level of significance	NS	NS	NS

NS = Not significant.

Results on soil studies under plantation forests differ from one geographical region to another when the same tree species is involved. There are a number of reasons which may explain these differences. For example, it has been observed that the abundance of soil nutrients is controlled by several factors including the intrinsic soil nutrient status (Aweto 1988). Since the soils of the study area are volcanic in origin and are comparatively rich in nutrients, this could have contributed to the unchanged levels of available phosphorus and exchangeable calcium and potassium especially if the amount absorbed by the cypress plantation is not significant enough to alter the intrinsic levels. It has also been postulated by Will (1968) that demands for soil nutrients by tree crops are at peak during the establishment phase. After canopy closure, additional growth consists of accumulation of wood which is a tissue with lower nutrient content, and tree nutrient demand is met through internal nutrient recycling. This means mature trees like the cypress under this study demand less nutrients from the soil and may thus allow enough time for replenishment to take place. Also the breakdown of litter by microbial activity makes available the nutrients which supplement those lost or absorbed by the trees.

Table 4. Mean, standard deviation and range of exchangeable calcium, sodium and potassium at different soil depths in a natural forest and an adjacent *Cupressus lusitanica* plantation at West Kilimanjaro, Tanzania

		Organic layer	0-10 *cm*	10-50*cm*
Calcium (*me*/100*g*)	Natural forest	6.62 ± 2.34 (2.65 ± 13.3)	4.66 ± 1.82 (2.1 - 8.0)	4.78 ± 2.73 (1.5 ± 11.3)
	C. lusitanica	6.22 ± 1.6 (2.1 - 11.25)	4.76 ± 2.18 (1.5 - 8.5)	4.22 ± 2.4 (1.5 - 9.6)
	Level of significance	NS	NS	NS
Potassium (*me*/100*g*)	Natural forest	0.426 ± 0.159 (0.241 - 0.74)	0.287 ± 0.179 (0.026 - 0.656)	0.293 ± 0.208 (0.051 - 0.68)
	C. lusitanica	0.41 ± 0.111 (0.056 - 0.633)	0.323 ± 0.154 (0.072 - 0.615)	0.316 ± 0.181 (0.049 - 0.597)
	Level of significance	NS	NS	NS
Sodium (*me*/100g)	Natural forest	0.047 ± 0.017 (0.016 - 0.074)	0.044 ± 0.016 (0.017 - 0.067)	0.042 ± 0.02 (0.017 - 0.1)
	C. lusitanica	0.048 ± 0.016 (0.017 - 0.078)	0.048 ± 0.016 (0.017 - 0.068)	0.036 ± 0.018 (0.013 - 0.085)
	Level of significance	NS	NS	*

* = Significant at p<0.05, paired t-test; NS = Not significant.

Table 5. Mean, standard deviation and range of soil pH at different depths in a natural forest and adjacent *Cupressus lusitanica* plantation at West Kilimanjaro, Tanzania

	Soil reaction (pH)		
	Organic layer	0-10*cm*	10-50*cm*
Natural forest	7.26 ± 0.27 (6.86 - 7.67)	7.06 ± 0.34 (6.11 - 7.75)	6.85 ± 0.40 (5.60 - 7.42)
C. lusitanica	6.96 ± 0.30 (6.53 - 7.64)	6.98 ± 0.36 (6.19 - 7.65)	6.89 ± 0.40 (6.05 - 7.79)
Level of significance	***	NS	NS

*** =Significant at p< 0.001, paired t-test; NS = Not significant.

Soil reaction (pH)

Table 5 shows the mean soil pH, standard deviation and range for the natural forest and the cypress plantation. The mean soil pH values in both types of forests were around neutral but more alkaline in the natural forest. In the organic layer, pH was significantly lower in the cypress plantation than in the natural forest ($p<0.001$) although in its present level this difference could be biologically insignificant. There were no significant pH differences between the two forests in the 0-10 and 10-50*cm* layers. Lower pH in the cypress organic layer could be an indication of the contribution of litter. Lundgren (1978) had attributed lower pH in conifer plantations to the participation of humic acid which is a result of inhibited litter decomposition. Under broad leaved trees in Nigeria there was an increase in pH towards alkalinity as compared to the adjacent rain forest (Adejuwon & Ekanade, 1988). Results on pH in soils under plantation monocultures can therefore also vary depending on the intrinsic pH of the soil and the type of tree species growing on the site.

Conclusion

This study has revealed the existence of significant changes in levels of organic matter, total nitrogen, exchangeable sodium and pH in some soil horizons under a cypress plantation.

These results and work elsewhere (as cited in this report) have shown that depending on the type of tree species planted, the intrinsic nutrient levels of a soil and the management practices carried out, changes in nutrient levels will occur and definitely affect the productivity of tree crops. For example, changes in pH may result in the availability of nutrients against the needs or in favour of the species planted.

Since only few forest plantations in the world have reached second rotation (Evans 1990), the relationship between crop productivity and long term nutrient changes may not as yet be readily visible. However, in the long run, the uniformity, high growth rate, short rotations and high productivity exhibited by some plantation species may result into declining soil nutrients if management practices do not favour their conservation or replacement. Further monitoring of soil changes is therefore necessary and should include establishment of permanent sample plots in both the plantations and their adjacent natural forests to elucidate the correlation between nutrient changes and the productivity of plantation forests.

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