COMPARISON OF SOME CHEMICAL PROPERTIES OF SOIL UNDER TEAK AND NATURAL FORESTS AT MTIBWA, MOROGORO, TANZANIA

S. A. O. Chamshama, A. G. Mugasha*, J. M. Sanga

Department of Forest Biology, Faculty of Forestry, Sokoine University of Agriculture, P.O. Box 3010, Morogoro, Tanzania

&

L. Nshubemuki

Tanzania Forest Research Institute, P.O. Box 1854, Morogoro, Tanzania

Received December 1997

CHAMSHAMA, S. A. O., MUGASHA, A. G., SANGA, J. M. & NSHUBEMUKI, L. 2000. **Comparison of some chemical properties of soil under teak and natural forests at Mtibwa, Morogoro, Tanzania.** This study was initiated to compare some soil chemical properties of natural forests and first rotation teak plantations at Mtibwa Forest Project, Morogoro, Tanzania. A total of 240 soil samples were taken from 24 paired plots, i.e. 24 plots from each teak plantation and from the adjoining natural forests. These samples were analysed for pH, electrical conductivity (EC), total N, available P and exchangeable cations. The soil pH and exchangeable cations from the teak plantations were not significantly different ($p < 0.05$) from the natural forests. The soil EC within 0–70 cm depth in young teak plantations decreased by 24% while in semi-mature teak plantations it increased by 36% as compared to the adjoining natural forests. In general there was a decrease in the young plantations but an increase in the semi-mature plantations in total N. In both young and semi-mature stands there was a decrease in available P. The results of this study suggest that there is a need for continued monitoring of soil chemical properties in teak plantations since there are indications of changes in soil properties.

Key words: Soil - chemical properties - teak - *Tectona grandis* - natural forests

CHAMSHAMA, S. A. O., MUGASHA, A. G., SANGA, J. M. & NSHUBEMUKI, L. 2000. **Perbandingan ciri-ciri kimia tanah di bawah hutan jati dan hutan asli di Mtibwa, Morogoro, Tanzania.** Kajian ini adalah untuk membandingkan beberapa ciri kimia tanah di hutan asli dan putaran pertama ladang jati di Mtibwa Forest Project, Morogoro, Tanzania. Sejumlah 240 sampel tanah diambil dari 24 petak secara berpasangan, iaitu 24 petak dari setiap ladang jati dan dari hutan asli yang berdekatan. Sampel ini dianalisis bagi pH, kekonduksian elektrik (EC), jumlah N, P tersedia dan kation boleh tukar. pH tanah dan kation dari ladang hutan berbeza dengan tidak bererti ($p < 0.05$) dari hutan asli. EC tanah dengan kedalaman antara 0–70 cm di hutan

**Author for correspondence.*

jati muda merosot sebanyak 24% manakala di ladang jati separa-matang ia bertambah sebanyak 36% dibandingkan dengan hutan asli berdekatan. Secara umumnya, terdapat pengurangan dalam jumlah N di ladang hutan tetapi berlaku penambahan di ladang separa-matang. Di kedua-dua dirian muda dan separa-matang, terdapat pengurangan dalam P tersedia. Keputusan kajian ini menunjukkan bahawa pemantauan secara mapan perlulah dibuat ke atas ciri-ciri kimia tanah di ladang jati kerana terdapat tanda-tanda berlakunya perubahan dalam ciri-ciri tanah.

Introduction

Over-exploitation of valuable indigenous tree species such as *Milicia excelsa, Dalbergia melanoxylon, Pterocarpus angolensis, Hygenia abysinica* and *Ocotea usambarensis* for various purposes has resulted in a gradual decline in supply of these species. To meet future demand of high quality timber, it has been deemed necessary to establish plantations of fast growing species.

Plantations of fast-growing exotic tree species were introduced into Tanzania during the first half of this century when *Pinus patula, P. radiata, P. elliottii, Tectona grandis, Cupressus lusitanica* and some eucalypts were planted in several areas. The planting was highly encouraged by the high growth rates of these trees which far exceeded those of indigenous tree species. Thus, on suitable sites *P. patula* and *C. lusitanica* have a mean annual volume increment of 25–35 m^3 ha^{-1} y^1 while that of teak is 20–25 m^3 ha^{-1} y^1. In contrast, fire ravaged miombo woodlands have an average mean annual increment of 1–2 m^3 ha^{-1} y^1 (Ahlback 1988). In addition, lack of planting of indigenous hardwoods was exacerbated by lack of silvicultural and management knowledge.

Tectona grandis L.f. (teak) is one of the world's finest hardwoods. In Tanzania, it is grown on plantation scale at the Mtibwa and Longuza Forest Projects. The total area of teak plantations in these two projects is 2970 ha (3.3% of the total industrial plantations in Tanzania). The Commonwealth Development Cooperation (CDC) is currently planting teak on a large scale in the Kilombero Valley, Morogoro Region (Jacovelli & Msomba 1995).

Exotic tree species have been found to have effects on soil properties differing from those of indigenous natural forests in terms of organic matter accumulation, soil conditions and type of vegetation growing on the forest floor (Lundgren 1978, Maro *et al.* 1993). Changes in soil properties may either favour an increase in nutrient status of soil (Iyamabo 1973, Chijioke 1980) or result in deterioration of nutrient status (Wilde 1964, Hamilton 1965, Robinson 1967, Will 1968, Kadeba & Onwehizo 1976, Rennie 1982).

The effects of fast-growing monocultures on soil biology, physical and chemical properties are greatly influenced by tree species and management practices during establishment, tending and harvesting (Lundgren 1978, Raison *et al.* 1982, Maganga & Chamshama 1984, Shepherd 1986, Evans 1992). Mongia and Bandyopadhyay (1994) studied soil properties under natural forests and mature teak plantations in the Andaman Islands, India. They observed that soil contents of N, P, K, organic matter and soil pH were lower under teak than in natural forests. In contrast, Choubey *et al.* (1987) observed that organic C and N, P and K were higher under the teak plantations than under adjoining natural forest in Madhya Pradesh, India. They, however, observed that pH was slightly lower under teak plantation than in the natural forests. Adejuwon and Ekanade (1988) observed that at 15 years after the tropical rain forest was replaced by teak plantations in the Ikere Forest Reserve, Ondo State, Nigeria, most soil properties were not significantly different from those in the rain forest.

Research on the effect of fast-growing monoculture plantations on soil properties in Tanzania and areas with similar site conditions has covered few species and few sites (Lundgren 1978, Maro *et al.* 1993). Since the effect of plantations on soil properties is a function of tree species, stand age, management practices and site conditions, there is a need to monitor soil properties in representative forest plantations in Tanzania. The objective of the present paper is to compare selected soil properties in first rotation teak stands and adjacent natural forests at Mtibwa Teak Forest Project. The hypothesis to be tested is that teak plantations have no effect on selected soil properties.

Materials and methods

Study area

The study was conducted in Mtibwa Forest Project (6°- 6° 10" S, 37° 40" - 37° 45" E; 460 m asl). The area receives about 1200 mm mean annual rainfall and there are two rainy periods, i.e. short rains from November to December, and long rains from March to May, and sometimes up to early June. Mean annual temperature is about 25.5 °C.

The project area is divided into two blocks, Mtibwa and Lusunguru. The Mtibwa block has level to slightly rising topography and is dominated by Pellic Vertisols developed on quarternary alluvial and lacustrine deposits (UNESCO/FAO 1977). The soil texture ranges from loam to clay. On the other hand, the Lusunguru block has rolling to undulating topography dominated by Eutric Fluvisols (UNESCO/FAO 1977). This block exhibits significant variation in soil texture ranging from sandy to loamy soils. The original vegetation types were: a) moist miombo woodland that was composed of *Brachystegia* as a dominant species. At lower toposequence positions this gives way to *Acacia* woodland; b) the ground water forests originally containing mvule (*Milicia excelsa*), *Khaya anthotheca*, *Antiaris* species and *Sterculia* species; and c) dense grass - the original grasses were *Panicum maximum* and some tall elephant grasses.

Selection of study compartments

This study was carried out in two blocks, i.e. Mtibwa and Lusunguru. Mtibwa block has semi-mature teak plantations planted between 1961 and 1984. It is made up of 11 compartments covering 690 ha. The Lusunguru block has 15 compartments planted between 1954 and 1984 and covers 687 ha.

Prior to the selection of study compartments, the area was reconnoitered and all teak compartments adjoining natural forests and whose slope was less than 30% were listed. These compartments were then grouped into two age classes, i.e. equal or less than 15 (young stands) and equal or greater than 30 (semi-mature stands) years. Within each group, random sampling of the study compartments (Table 1) was carried out. The selection of plantation compartments was based on the following criteria:

- The compartment has an undisturbed (besides fire incidences) natural vegetation lying adjacent to it.
- Both the compartment and its adjacent natural vegetation lie along the same contours, such that each pair of plots (one plot in natural forest and the other in plantation) can be established on the same contour.
- The compartment age is within the desired age class.

Table 1. List of selected *Tectona grandis* study compartments and associated stand attributes at Mtibwa Forest Project, Morogoro, Tanzania

Compt. No.	Age (y)	Mean DBH (cm)	Mean height (m)	Area (ha)	Total stand density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Other comments
			Lusunguru Block				
15	15	22.4	15.7	8.2	1560	32	Undulating topograph, well drained soil, not thinned
Trial plot LRX1	31	37.0	26.8	10.2	900	60	Undulating topograph, well drained soil, not thinned
6B	32	38.4	27.2	13.1	850	64	Undulating topograph, well drained soil, not thinned
			Mtibwa Block				
8	30	36.2	27.6	7.9	950	56	Level area, alluvial soil, poorly drained, thinned stand
2	14	18.6	14.8	6.5	1550	28	Flat area, alluvial soil, poorly drained, stand not thinned
15	33	40.1	27.9	12.0	900	72	Flat area, alluvial soil, poorly drained, stand not thinned

Soil sampling and analysis

In each sampled teak compartment, soil was investigated as follows. Two parallel transects, i.e. one in a teak compartment and the other in the adjoining natural forest, were laid out. Each transect was located about 30 m from the interface of the two vegetation types. Three to five pairs of sample plots each measuring 10 m in diameter were laid out along the two transects, i.e. one plot of each pair in a teak plantation and the other one in the adjoining natural forest. Each set of paired plots was located on the same contour line. Thus, range of distance of 60 m was maintained between plots of the same pair which was necessary to minimise variations due to differences in soil types. Within each plot, four pits were randomly dug. Within each pit, soil samples were taken at 0–10, 10–20, 20–30, 30–50 and 50–70 cm depths. The maximum soil sampling depth was 70 cm because the maximum rooting depth was within 60–70 cm soil depth. For each plot, soil samples were bulked by soil depth, mixed thoroughly and a subsample taken for selected chemical analysis. A total of 240 bulked subsamples of soil were taken: 24 subsamples for each sampling depth from plantations and natural forests.

In the laboratory, soil samples were air dried and sieved through 2-mm sieve. Soil pH and electrical conductivity (EC) were determined in 1:2 ratio of soil water paste using pH and EC meters respectively. For determination of total N, soil samples were digested in concentrated sulphuric acid followed by oxidation with hydrogen peroxide (Lowther 1980). Total N in digest was determined by the micro-Kjeldahl's procedure. Soil available P was determined by the Bray-1 method. Exchangeable cations were extracted by neutral ammonium acetate followed by analysis with flame emission spectrophotometry.

Statistical analysis

To test the hypothesis that teak plantations have no effect on a chemical property of the soil, data were sorted into two age classes (semi-mature and young plantations), and soil depth. For each age class and soil depth, the data were subjected to a one-way ANOVA. The relative change in the soil property was determined from:

$$\text{Relative change (\%)} = [(\text{natural forest} - \text{plantation}) / \text{natural forest}] \times 100 \quad \ldots\ldots 1$$

Results and discussion

Soil pH and electrical conductivity

In neither the plantations (of both ages) nor in the natural forest was there any change in soil pH with soil depth (Table 2). Significant pH differences between the plantation and natural forest soils were noted at 30–50 cm depth (young plantation only). Similar results have been observed by Choubey *et al.* (1987), who observed a decrease in soil pH under teak plantations compared with soil under adjoining natural forest. These workers also observed that pH under both areas decreased with increasing age of plantation. Contrary to our results, there were significant pH differences between natural forests and cypress plantations in the 0–10 and 20–50 cm depths at West Kilimanjaro, Tanzania (Maro *et al.* 1993). A decrease in soil pH has also been observed under teak plantations as compared with adjoining natural forest dominated by *Dipterocarpus* (Mongia & Bandyopadhyay 1994). The lack of effect of teak plantations on top soil pH at Mtibwa may be related to the fact that its litter decomposes fast releasing cations which are either taken up by plants or leached out of the system. The lack of change in soil pH under teak plantations at Mtibwa may also be related to rapid loss of cations as a result of fires which are common in young plantations. Maro *et al.* (1993) observed that the pH in soil under plantation monocultures varied depending on the intrinsic pH of the soil and the type of tree species growing on the site.

Table 2. Mean and relative changes in pH between the natural forests and *Tectona grandis* plantations at different soil depths in Mtibwa, Tanzania

	Soil depth (cm)					
	0–10	10–20	20–30	30–50	50–70	Mean
			Young teak plantations			
Natural forest	6.70	6.60	6.84	7.00	6.90	6.81
T. grandis	6.65	6.75	6.65	6.45	7.00	6.70
F-ratio[1]	0.23	0.21	1.71	6.75*	0.16	-
Relative change (%)[2]	-0.75	+1.14	-2.78	-7.86	+1.45	-1.62
			Semi-mature teak plantations			
Natural forest	6.38	6.35	6.50	6.60	6.62	6.49
T. grandis	6.50	6.58	6.80	7.02	6.95	6.77
F-ratio[1]	1.05	2.20	2.01	4.24	2.11	-
Relative change (%)[2]	+1.87	+3.67	+4.60	+6.32	+5.30	+4.36

[1]* - significant at $p < 0.05$,
[2]change in selected chemical property calculated using equation 1.

Under both vegetation types, soil EC decreased with soil depth (Table 3) but teak plantations had no significant effect ($p > 0.05$) on EC. These results suggest that the two vegetation types had similar concentration of total soluble salts content.

Table 3. Mean and relative changes in electrical conductivity (EC) (ds m^{-1}) between the natural forest and *Tectona grandis* plantations at different soil depths in Mtibwa, Tanzania

	Soil depth (cm)					
	0–10	10–20	20–30	30–50	50–70	Mean
			Young teak plantations			
Natural forest	6.160	0.065	0.040	0.028	0.020	0.063
T. grandis	6.083	0.055	0.043	0.033	0.028	0.048
F-ratio[1]	4.48	0.23	0.03	0.86	2.45	-
Relative change (%)[2]	-48.1	-15.4	+7.50	+17.9	+40.0	-23.8
			Semi-mature teak plantations			
Natural forest	6.112	0.057	0.032	0.020	0.010	0.046
T. grandis	6.170	0.065	0.037	0.027	0.015	0.063
F-ratio[1]	1.43	0.26	0.41	1.18	2.14	-
Relative change (%)[2]	+52.0	+14.0	+3.7	+35.0	+50.0	+35.9

[1]* - significant at p <0.05,
[2]change in selected chemical property calculated using equation 1.

Total nitrogen

As would be expected, total N decreased with soil depth both in the teak plantations and in the natural forests. Although no significant differences between the two vegetation types were revealed, total N was higher in the natural forest as compared to teak plantation (Table 4). Higher total N in the natural forest's top soil layers as compared with plantations of fast-growing species has been reported elsewhere (Choubey *et al.* 1987, Maro *et al.* 1993) and may be related to higher demand and uptake of N by young teak. The slightly higher total N in the natural forests may also be attributable to their greater species diversity of vegetation cover and presence of more organic matter (Lundgren 1978, Maro *et al.* 1993). The decrease in total N in young teak plantations at Mtibwa may also be related to volatilisation losses. This is because young teak plantations have regularly been subjected to brush fires.

In semi-mature teak plantations there was more total N within 0-30 cm soil depth than in the adjoining natural forests. Similar results have been observed in Madhadya Pradesh, India (Choubey *et al.* 1987). In contrast, Mongia and Bandyopadhyay (1994) observed a decline in soil content of N under teak plantations as compared to adjoining natural forests dominated by *Dipterocarpus*. A modest increase in total N in the top soil in semi-mature teak stands compared with natural forests at Mtibwa may be related to an increase in species diversity in the forest floor of semi-mature teak stands. During the course of this study we observed dense undergrowth, and there were no signs of occurrence of fire in these stands in the recent past.

Table 4. Mean and relative changes in total nitrogen (%) between the natural forest and *Tectona grandis* plantations at different soil depths in Mtibwa, Tanzania

	Soil depth (cm)					
	0–10	10–20	20–30	30–50	50–70	Mean
			Young teak plantations			
Natural forest	0.219	0.233	0.168	0.050	0.040	0.142
T. grandis	0.201	0.203	0.137	0.033	0.028	0.120
F-ratio[1]	0.05	1.51	0.00	2.55	2.46	-
Relative change (%)[2]	-8.2	-12.9	-18.5	-34.0	-30.0	-15.2
			Semi-mature teak plantations			
Natural forest	0.138	0.140	0.109	0.095	0.099	0.166
T. grandis	0.180	0.152	0.124	0.073	0.079	0.112
F-ratio[1]	0.53	0.06	0.20	2.24	0.58	-
Relative change (%)[2]	-23.3	-7.9	-13.8	-23.2	-20.2	-34.0

[1]* - significant at $p<0.05$,
[2]change in selected chemical property calculated using equation 1.

Available phosphorus

Only in the 0–10 cm soil depth in young teak plantations was the available P concentration significantly different (lowest) from the corresponding soils under natural forests (Table 5). Decrease in available P in teak plantations may be indicative of higher P uptake by teak and immobilisation within young and semi-mature teak biomass. Decrease in available P may also be due to cutting natural forest and burning during site preparation and occasional fires in teak plantations. Jordan (1985) suggested that cutting and burning of forests result in quick scarcity of P in tropical soils due to destruction of mechanism of P mobilisation when the natural forest is cut and burned. Decrease in available P in broad-leaved tree plantations as compared to natural forests has been observed in Nigeria (Adejuwon & Ekanode 1988). Mongia and Bandyopadhyay (1992) observed that Bray's P decreased when virgin tropical rain forests were replaced by plantation crops including teak. Decrease in available P has also been observed in *Cupressus lusitanica* plantations in Kenya (Robinson 1967), under *Pinus caribaea* and cocoa plantations in Nigeria (Egunjobi 1991), and under teak plantations in Tamil Nadu in India (Prasad *et al.* 1985) as compared to natural forests. Maro *et al.* (1993) observed that there was no change in available P in cypress plantations as compared to adjoining natural forests in West Kilimanjaro, Tanzania. In contrast, increased availability of P has been observed under the teak plantations than under adjoining natural forests (Choubey *et al.* 1987) and under *Gmelina arborea* plantation as compared to lowland natural forests (Egunjobi 1991). These differences may be attributable to the degree of site disturbance during site preparation and intensity of fires used for site preparation and age of stands studied.

Table 5. Mean and relative changes in available P (ppm) between the natural forest and *Tectona grandis* plantations at different soil depths in Mtibwa, Tanzania

	Soil depth (cm)					
	0–10	10–20	20–30	30–50	50–70	Mean
			Young teak plantations			
Natural forest	41	28	21	25	10	25
T. grandis	8	26	16	17	17	17
F-ratio[1]	17.58**	0.16	0.28	0.63	1.15	-
Relative change (%)[2]	-80.5	-0.7	-23.8	-32	+70.0	-33.6
			Semi-mature teak plantations			
Natural forest	19	51	43	12	20	29
T. grandis	12	26	21	18	17	18
F-ratio[1]	1.110	1.11	1.70	1.98	0.45	-
Relative change (%)[2]	-35.3	-49.0	-51.0	+50.1	-15.0	-34.8

[1]* - significant at $p<0.05$,
[2]change in selected chemical property calculated using equation 1.

Exchangeable cations

No significant differences between plantation soils and natural forest soils were detected in levels of exchangeable cations (Na, Ca, K) (Tables 6 and 7). The only significant difference was shown by the decrease in exchangeable Mg in the young teak plantations in the 0–10 cm soil depth. In general, however, there was an increase in exchangeable cations in the teak plantations as compared to the natural forests (Tables 6 and 7). Under another Verbenaceae, *G. arborea*, Chiijioke (1980) also observed that exchangeable K, Ca, and Mg increased compared with natural forests. In contrast, Egunjobi (1991) observed that exchangeable K, Ca and Mg under *Pinus caribaea* and cocoa stands declined significantly when compared with soils from adjoining lowland natural forests in Nigeria.

Table 6. Mean and relative changes in exchangeable cations between the natural forests and 14–15-y-old *Tectona grandis* plantations at different soil depths in Mtibwa, Tanzania

	Soil depth (cm)					
	0–10	10–20	20–30	30–50	50–70	Mean
			K (cmol(+).kg^{-1})			
Natural forest	3.49	2.50	4.13	5.04	4.06	3.84
T. grandis	4.14	3.80	5.22	5.28	2.90	4.27
F-ratio[a]	0.31	0.67	0.77	0.23	2.12	-
Relative change (%)[b]	-19.1	+51.8	+26.5	+4.7	-28.4	+11.1
			Ca (cmol(+)kg^{-1})			
Natural forest	2.68	2.78	2.12	2.55	1.63	2.35
T. grandis	3.52	3.67	3.38	3.34	3.58	3.50
F-ratio	1.09	0.32	1.17	1.16	1.13	-
Relative change	+31.1	+32.0	+59.4	+31.0	+120.0	+48.0
			Mg (cmol(+)kg^{-1})			
Natural forest	2.85	1.86	2.62	2.67	1.70	2.34
T. grandis	1.28	1.65	2.12	1.63	1.75	1.68
F-ratio	7.89*	0.13	0.35	2.31	0.00	-
Relative change (%)	-55.1	-11.5	-51.7	-39.1	-4.3	-28.0
			Na (cmol(+)kg^{-1})			
Natural forest	4.47	4.09	4.04	4.39	4.78	4.36
T. grandis	4.55	4.65	4.53	7.51	5.94	5.43
F-ratio	0.02	0.35	0.36	1.52	1.33	-
Relative change (%)	+1.6	+13.2	+12.0	+71.0	+24.1	+24.7

[a]* - significant at $p<0.05$, [b]change in selected chemical property calculated using equation 1.

Choubey *et al.* (1987) observed that exchangeable K was higher under teak plantations than under adjoining natural forests. On the contrary, Mongia and Bandyopadhyay (1994) observed that exchangeable K was lower under teak stands than in natural forests. Prasad *et al.* (1985) observed that there was a decline in exchangeable Mg under teak as compared to natural forests in Tamil Nadu, India. Our results and those in the literature show that the effect of plantation forests on soil differ from one geographical region to another when the same tree species is involved. Some reasons which may explain these differences have been summarised by Maro *et al.* (1993).

Table 7. Mean and relative changes in exchangeable cations between the natural forests and 30–35-y-old *Tectona grandis* plantations at different soil depths in Mtibwa, Tanzania

	Soil depth (cm)					
	0–10	10–20	20–30	30–50	50–70	Mean
			K (cmol(+) kg^{-1})			
Natural forest	2.90	3.05	3.94	3.92	4.97	3.77
T. grandis	3.71	2.79	3.22	3.74	5.62	3.82
F-ratio[a]	0.41	0.08	0.30	0.06	0.03	-
Relative change (%)[b]	+24.1	-8.5	-18.0	-4.5	+13.1	+1.2
			Ca (cmol(+)kg^{-1})			
Natural forest	3.70	3.48	1.78	2.57	4.97	3.30
T. grandis	3.72	1.85	2.12	2.24	5.62	3.11
F-ratio	0.00	2.78	0.45	0.19	2.91	-
Relative change	+0.51	-46.7	+18.9	-13.0	+13.1	-5.8
			Mg (cmol(+)kg^{-1})			
Natural forest	1.71	2.14	2.53	1.79	1.71	1.19
T. grandis	1.58	1.51	1.73	1.43	1.22	1.49
F-ratio	0.06	0.80	1.87	0.36	1.09	-
Relative change (%)	-7.7	-29.6	-31.5	-20.2	-28.7	-24.4
			Na (cmol(+)kg^{-1})			
Natural forest	4.71	5.11	4.63	5.29	4.97	4.94
T. grandis	4.98	4.39	6.09	3.84	5.62	4.98
F-ratio	0.34	0.28	1.38	4.37	0.00	-
Relative change (%)	+5.9	-14.0	+31.5	-27.4	+13.1	+0.9

[a]* - significant at $p<0.05$, [b]change in selected chemical property calculated using equation 1.

Acknowledgements

We are grateful to the Sokoine University of Agriculture for funding, the Director of the Forestry and Beekeeping Division in the Ministry of Natural Resources and Tourism for permission to work in their forests, the management of Mtibwa Forest Project for logistical support during data collection and soil sampling, and E. Mtengeti and A. F. Siamba for assistance with the chemical analysis of all soil samples. We would also like to thank J. B. Hall and an anonymous reviewer for their criticisms and suggestions to improve the manuscript. This paper is based on a special project report submitted by the third author in partial fulfilment of the requirement for the B.Sc. (Forestry) degree.

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