TREE SPECIES SCREENED ON NITOSOLS OF CENTRAL ETHIOPIA: BIOMASS PRODUCTION, NUTRIENT CONTENTS AND EFFECT ON SOIL NITROGEN

M. Kindu[1,*], G. Glatzel[1], Y. Tadesse[2] & A. Yosef[3]

[1]*BOKU-Institute of Forest Ecology, Department of Forest and Soil Sciences, University of Natural Resources and Applied Life Sciences, Peter-JordanStrasse 82, A-1190, Vienna, Austria*
[2]*PP, Haarweg 333, 6709 RZ Wageningen, Netherlands*
[3]*Bischofsholer Damm 85, Zimmer 146, 30173 Hannover, Germany*

Received June 2005

KINDU, M., GLATZEL, G., TADESSE, Y. & YOSEF, A. 2006. Tree species screened on Nitosols of Central Ethiopia: biomass production, nutrient contents and effect on soil nitrogen. Shortage of tree biomass is a severe problem in the highlands of Ethiopia. A screening trial was conducted from 1997 till 2002 to select fast growing and high biomass producing tree species, evaluate foliage and wood macronutrient contents of different tree species, and assess effect of tree species on soil nitrogen beneath their canopies. Seven tree species: (i) *Acacia decurrens,* (ii) *Chamaecytisus palmensis,* (iii) *C. proliferus,* (iv) *Eucalyptus globulus,* (v) *E. camaldulensis,* (vi) *Grevillea robusta* and (vii) *Hagenia abyssinica* were evaluated in a randomized complete block design with three replications. All species were exotic except *H. abyssinica. Grevillea robusta* exhibited slow height growth and wood production as compared with the five exotic species. *Acacia decurrens* provided the highest mean dry biomass at 64 months. Foliar N levels in *A. decurrens, C. palmensis* and *C. ploriferus* were significantly higher than those in the other four tree species. *Acacia decurrens, C. palmensis* and *C. ploriferus* are N-fixing tree species. *Hagenia abyssinica* had higher K levels in the foliage and wood. *Eucalyptus* species tended to deplete soil fertility whereas *C. palmensis* and *C. ploriferus* improved soil fertility. *Chamaecytisus* species and *A. decurrens* can be short-term options for soil fertility improvement and a source of fuelwood respectively.

Keywords: Aboveground biomass, exotic, indigenous, nitrogen, phosphorus

KINDU, M., GLATZEL, G., TADESSE, Y. & YOSEF, A. 2006. Spesies pokok yang ditanam di atas tanah Nitosol di Ethiopia Tengah: penghasilan biojisim, kandungan nutrien dan kesan terhadap nitrogen tanah. Kekurangan biojisim pokok merupakan masalah serius di kawasan tanah tinggi Ethiopia. Satu ujian penyaringan dijalankan dari tahun 1997 hingga 2002 untuk memilih spesies pokok yang tumbuh cepat dan menghasilkan biojisim yang tinggi. Ujian ini juga bertujuan untuk menilai kandungan makronutrien dedaun dan kayu spesies pokok berlainan serta mengkaji kesan spesies pokok terhadap nitrogen tanah. Tujuh spesies pokok: (i) *Acacia decurrrens,* (ii) *Chamaecytisus palmensis,* (iii) *C. proliferus,* (iv) *Eucalyptus globulus,* (v) *E. camaldulensis,* (vi) *Grevillea robusta* dan (vii) *Hagenia abyssinica* dinilai menggunakan kaedah blok lengkap rawak dengan tiga ulangan. Semua spesies ialah spesies eksotik kecuali *H. abyssinica. Grevillea robusta* menunjukkan kadar pertumbuhan dan penghasilan kayu yang lambat berbanding lima spesies eksotik yang lain. *Acacia decurrens* menunjukkan nilai biojisim kering yang tertinggi pada 64 bulan. Paras N dedaun *A. decurrens, C. palmensis* dan *C. ploriferus* lebih tinggi berbanding paras dalam empat spesies pokok yang lain. *Acacia decurrens, C. palmensis* dan *C. ploriferus* merupakan spesies pokok pengikat nitrogen. *Hagenia abyssinica* mempunyai paras K dedaun dan kayu yang paling tinggi. Spesies *Eucalyptus* cenderung mengurangkan kesuburan tanah manakala *C. palmensis* dan *C. ploriferus* memperbaikinya. Sebagai pilihan jangka pendek, spesies *Chamaecytisus* boleh digunakan untuk memperbaiki kesuburan tanah manakala *A. decurrens* sebagai sumber bahan api.

Introduction

The forest cover of Ethiopia used to be 35–40% of its total land area (EFAP 1994). As a result of clearing of forests for cultivating crops and cutting trees and shrubs for various purposes, the natural forest cover has declined to 16% of the land area in the early 1950s, to 3.6% in the 1980s and to remnants of only 2.7% in 1989 (EFAP 1994). This process of deforestation has

*E-mail: kindumeko@yahoo.com

dramatically reduced the coverage of trees and thereby created the current imbalance of wood demand and supply. The demand of the population for woody biomass continues to increase. In 2014 total wood requirement and supply with intervention is estimated to be 30.2 and 64. 6 million m^3 respectively (EFAP 1994).

Soils are depleted and unable to support crop production as a result of highly extractive farming and with minimal or no nutrient input. The majority of the cool tropical soils, including the Nitosols of Ethiopia, are deficient in N, P (Haque *et al.* 1993) and some micronutrients (Sanchez & Nicholaides 1992). Correcting these deficiencies via fertilizer application is costly and beyond the economic reach of poor farmers.

Screening and promotion of multipurpose tree species that fit the farming system is one of the strategies for improving the livelihood of the rural communities. Research, teaching and development institutions in Ethiopia had conducted multipurpose tree species screening trials in some agro-ecological zones. The output from the screening trials did not however reach many areas or was not accepted by farm communities. In most cases, there was less involvement of farmers during identification of problems and in the selection of tree species for screening. In order to overcome these problems, the tree species selection in our screening trial was based on the preference of farmers as we are convinced that participatory screening enhances subsequent promotion and adoption of tree species.

Presently, farmers of the study area depend on only a few number of species for tree products and services. Relying heavily on few species has risks and impacts on the productivity and sustainability of farming systems. A wider range of tree and shrub species would ensure resilience and decrease sensitivity to pests and diseases.

The attempt of screening high biomass producing and soil improving tree species is not a one-time activity. Many tree and shrub species that provide high biomass and improve the fertility of soils can be identified through screening programmes. It can also help to address the problem of tree species diversity.

The objectives of the study were therefore to (i) select fast growing and high biomass producing tree species, (ii) evaluate foliage and wood macronutrient contents of different tree species and (iii) assess effects of trees on soil nitrogen beneath their canopies.

MATERIALS AND METHODS

Characteristics of the study site

The study was conducted from 1997 till 2002 at the Holetta Agricultural Research Center experimental site, Central Ethiopia (38° 30' E, 9° 3' N, 2400 m asl). Mean annual maximum and minimum temperatures are 23 and 6 °C. Annual precipitation averages 1100 mm, most falling between March and October with peaks in July and August. The soil of the study area is classified as Nitosols. Some of the chemical and physical properties of the top 0–15 and 15–30 cm soil layers, which were taken prior to this study, are shown in Table 1.

Criteria and basis of tree species selection

Farmers of the study area were approached to identify their priority needs with regard to tree products and services. Most farmers wanted to plant tree species that can easily adapt to their environment, produce high biomass for fuel, and improve quality of soil and fodder. Data on soils, rainfall, temperature and altitude of representative sites in the study area were collected. Tree species for screening trial were listed based on suggestion from Agroforestree Database of the International Center for Research in Agroforesty (ICRAF) and their presence in remnant vegetation of the study area.

Table 1 Chemical and physical properties of the top soil layers at Holetta Research Center

Soil depth (cm)	Soil property							
	pH (H_2O)	Organic C (%)	Total N (%)	P (mg kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Clay (%)
0–15	5.20	2.18	0.17	4.51	7.30	2.65	1.40	80
15–30	5.36	1.87	0.17	3.49	4.50	2.61	1.30	78

Tree seed sources and soil quality

Seeds of different exotic and indigenous tree species were obtained from the Ethiopian Forestry Research Center (FRC) and International Livestock Research Institute (ILRI) (Table 2). Seed treatment was exercised for *Chamaecytisus palmensis, C. proliferus* and *Acacia decurrens*. Seeds of *Hagenia abyssinica, Eucalyptus globulus* and *E. camaldulensis* did not require treatment (Azene *et al.* 1993). Likewise, seeds of *Grevillea robusta* were not treated. The seeds of *A. decurrens* were immersed in boiling water and cooled for 24 hours. Similarly, seeds of *Chamaecytisus* species were immersed in hot water for 1 min. Treated seeds were directly sown in polythene bags that contained a mixture of local topsoil, forest soil and sand. The proportion of the soil mixture was 4 (local soil): 2 (forest soil): 1 (sand). The size of the polythene bag was 15 cm in height and 8 cm in diameter. All seeded pots were exposed to similar watering, shading, weeding and hardening practices.

Experimental design and management

Treatments (seven tree species) were laid out in a randomized complete block design (RCBD) with three replications (Gomez & Gomez 1984, Wood & Burley 1991). The tree species were: (i) *A. decurrens,* (ii) *C. palmensis,* (iii) *C. proliferus,* (iv) *E. globulus,* (v) *E. camaldulensis,* (vi) *G. robusta* and (vii) *H. abyssinica*. *Acacia decurrens, C. palmensis* and *C. ploriferus* are N-fixing tree species.

Field preparation began one week before planting. Planting holes were dug 30 cm deep. The size of the plot was 6.5 × 6 m. A plot consisted of five rows of trees. Each row had a line of five trees. Distance between trees in the same row was 1.3 m while distance between rows in the same plot was 1.2 m. Distance between plots was 2 m.

Tree and soil sampling and laboratory analysis

Of the total 25 trees plot^{-1}, 16 of them were border trees. The remaining nine central trees were experimental trees. Tree height measurements were taken at 12, 24, 36 and 64 months from the experimental date. Graduated stick and clinometers were used to measure height of the tree and shrub species. Destructive tree sampling was done at 12 and 64 months. Height and diameter distribution of the experimental trees were taken into consideration to select representative trees for biomass determination. In every destructive sampling scheme, one tree per plot was cut at the ground level. Harvested trees were separated into foliage (leaves and twigs) and wood (stem and branches). Each part was weighed, chopped and sub-sampled for dry matter determination. The foliage sub-samples were oven dried at 70 °C. The wood sub-samples were initially oven dried at 70 °C for 24 hours followed by re-drying at 105 °C to constant weight. Dried foliage and wood sub-samples were ground to pass through a 1 mm sieve and analysed for total nitrogen (N) using the Kjeldahl procedure (Buresh *et al.* 1982). Phosphorus (P) was determined following the procedure of Murphy and Riley (1962). Extractable potassium (K) was analysed according to the method of Richards (1954).

Soil auguring was carried out 12 months after planting at each plot in all the replications. To monitor changes in soil characteristics, additional samples were taken 64 months after planting. Sampling layers in all sampling schemes were 0–0.15, 0.15–0.3, 0.3–0.5, 0.5–1 and 1–1.5 m depths (Kindu *et al.* 1997). The samples were

Table 2 Scientific and family names as well as seed sources of seven tree species

Scientific name	Family	Common name	Seed sources
Acacia decurrens	Fabaceae	Green wattle	FRC
Chamaecytisus palmensis	Fabaceae	Tagasaste	ILRI
Chamaecytisus proliferus	Fabaceae	Escabon	FRC
Eucalyptus globulus	Myrtaceae	Tasmanian	FRC
Eucalyptus camaldulensis	Myrtaceae	River redgum	FRC
Grevillea robusta	Proteaceae	Silkoak	FRC
Hagenia abyssinica	Rocaceae	African redwood	FRC

FRC = Ethiopian Forestry Research Centre
ILRI = International Lifestock Research Institute

analysed for total N following the description by Keeney and Nelson (1982).

Data analysis

Height, dry biomass and nutrient content data of the tree species were tested for normality. As the dry biomass data for 64 months and height data for 24, 36 and 64 months were not normally distributed, logarithm (log to base 10) transformation was used (Gomez & Gomez 1984). The height, dry biomass and nutrient content data of the tree species were then analysed by the general linear model (GLM) procedure of the SAS Program (SAS Institute 1999). Least significant difference (LSD) was used to compare treatment means.

RESULTS AND DISCUSSION

Patterns of height growth and aboveground biomass

Acacia decurrens, E. globulus and *E. camaldulensis* provided the highest height growth at 64 months as compared with the other tree species (Table 3). The 64-month height growth (> 11 m) of *A. decurrens* from the present study was greater (50%) than the 72-month height growth of *A. decurrens* reported in central Chile (Arredondo *et al.* 1998). The edaphic and climatic conditions of our study site could be more favourable for growth of *A. decurrens* compared with the site in central Chile.

Acacia decurrens had the lowest biomass at 12 months but the highest biomass at 64 months (Table 4). Browsing by wild animals resulted in low biomass of *A. decurrens* at 12 months. The foliage and wood biomass of *A. decurrens* at 64 months were more by 87 and 80% than the foliage and wood biomass of *H. abyssinica* respectively. Similarly, *A. decurrens* at 64 months produced 5.49 kg tree^{-1} wood and 5.97 kg tree^{-1} foliage over that of *E. globulus*. The branchy and leafy nature of *A. decurrens* could have contributed to increased biomass yield. High biomass producing potential and more calorific value (18.7 MJ kg^{-1}) can make *A. decurrens* one of the priority species for energy sources (FAO 1997).

Eucalyptus globulus had significantly higher height growth at 12, 24 and 36 months than *E. camaldulensis*. Likewise, *E. globulus* produced higher total dry biomass at 12 and 64 months than *E. camaldulensis*. Altitude of the study area had slight effect on growth of *E. camaldulensis* as opposed to *E. globulus*. However, total dry biomass for 64-month-old *E. camaldulensis* (126.22 Mg ha^{-1}) in the present study was higher than the total dry biomass for 90-month-old *E. camaldulensis* (114 Mg ha^{-1}) in West Gojam, Ethiopia (Zerfu 2002).

Chamaecytisus palmensis and *C. proliferus* did not show substantial height growth difference at 12, 24, 36 and 64 months (Table 3). Similarly, the two tree species showed faster height growth in their early growth stages than late. In central Chile, Aronson *et al.* (2002) reported insignificant height increase of *C. proliferus* after three years of establishment. The three-year height growth (> 3 m) for *C. proliferus* in central Chile is in line with our findings. *Chamaecytisus proliferus* produced more dry foliage and wood biomass than *C. palmensis* at 12 and 64 months. Annual average dry biomass yield of *C. palmensis* in the present study was 14.68 Mg ha^{-1}. The annual average dry biomass of *C. palmensis* in New Zealand ranged from 12–16 Mg ha^{-1}

Table 3 Mean height of seven tree species measured at different months on Nitosols of central Ethiopia

Tree species	Mean height (m)			
	12 months	24 months	36 months	64 months
Acacia decurrens	1.49 (± 0.14) b	5.25 (± 0.23) b	8.98 (± 0.77) b	11.33 (± 1.53) a
Chamaecytisus palmensis	2.70 (± 0.03) a	4.28 (± 0.17) c	5.58 (± 0.26) c	5.97 (± 0.15) b
Chamaecytisus proliferus	2.49 (± 0.14) a	4.11 (± 0.12) c	5.99 (± 0.72) c	6.13 (± 0.91) b
Eucalyptus camaldulensis	1.81 (± 0.53) b	4.76 (± 0.91) cb	8.38 (± 0.69) b	14.20 (± 2.52) a
Eucalyptus globulus	2.77 (± 0.56) a	8.25 (± 0.24) a	10.87 (± 0.86) a	14.47 (± 0.81) a
Grevillea robusta	1.36 (± 0.25) b	2.70 (± 0.17) d	4.15 (± 0.13) d	5.30 (± 1.18) b
Hagenia abyssinica	0.59 (± 0.07) c	1.79 (± 0.47) e	2.75 (± 0.37) e	3.63 (± 1.18) c
p value	0.001	0.001	0.001	0.001

Values in parentheses are standard deviations (SD) of means from untransformed data.
Means in a column followed by the same letter do not differ significantly.

Table 4 Mean dry biomass of seven tree species at different ages on Nitosols of central Ethiopia

Tree species	Dry biomass (kg tree^{-1})			
	Foliage		Wood	
	12 months	64 months	12 months	64 months
Acacia decurrens	0.02 (± 0.01) d	11.91 (± 2.40) a	0.03 (± 0.02) d	21.93 (± 2.41) a
Chamaecytisus palmensis	1.23 (± 0.31) bc	3.93 (± 0.77) bac	2.15 (± 0.43) ba	8.28 (± 1.49) de
Chamaecytisus proliferus	1.52 (± 0.59) ba	4.57 (± 0.49) ba	2.81 (± 1.43) a	9.16 (± 1.01) dc
Eucalyptus camaldulensis	1.04 (± 0.50) bc	6.33 (± 1.02) ba	0.90 (± 0.26) dc	13.36 (± 3.15) bc
Eucalyptus globulus	1.87 (± 0.38) a	5.94 (± 4.59) bc	1.80 (± 0.37) bc	16.44 (± 0.65) ba
Grevillea robusta	0.60 (± 0.22) dc	3.88 (± 1.74) bc	0.34 (± 0.16) d	5.61 (± 1.66) fe
Hagenia abyssinica	0.70 (± 0.20) c	1.56 (± 0.99) c	0.31 (± 0.06) d	4.46 (± 2.36) f
p value	0.004	0.041	0.002	0.001

Values in parentheses are standard deviations (SD) of means from untransformed data.
Means in a column followed by the same letter do not differ significantly.

(Townsend & Radcliffe 1987). Differences in biomass production can vary depending on growing sites, planting density, age and management practices (McGowan & Mathews 1992).

Grevillea robusta exhibited slow height growth at 12, 24 and 36 months as compared with other exotic species. Similarly, it produced low biomass at 64 months. Low temperature, high altitude and high rainfall could have contributed to slow height growth of *G. robusta*. Kalinganire (1996) reported strong negative correlation of height of *G. robusta* with altitude (> 2300 m).

Hagenia abyssinica had the lowest height growth and biomass at 64 months as compared with the other species. The height growth of *H. abyssinica* can also be enhanced if the tree receives proper silvicultural management practices and planted in appropriate sites. A one-year-old *H. abyssinica* tree planted around homesteads in high altitude (3060 m asl) areas of west Shewa, Ethiopia provided a height growth of 2 m as a result of periodical side pruning. Similarly, *H. abyssinica* planted around homesteads in high altitude areas of west Shewa grew faster than the *H. abyssinica* planted in open agricultural fields (Berhane *et al.* 2004, unpublished). Better soil fertility and less frequent frosts attributed to faster height growth of *H. abyssinica* around the homesteads.

The foliage to wood biomass ratio of many of the species did not increase with time (Table 4). It decreased as the proportion of wood dry biomass increased. Foliage to wood ratio was > 1 for *H. abyssinica, G. robusta, E. camaldulensis* and *E. globulus* at 12 months while < 1 for all species at 64 months.

Macronutrient content

The foliage N contents in *A. decurrens, C. palmensis* and *C. proliferus* were significantly higher than in the other species (Table 5). *Acacia decurrens, C. palmensis* and *C. proliferus* fix N while the other four tree species do not. Nitrogen content was higher in the foliage than in the wood. Tree species with high content of foliar N can be potential sources of organic resources for improving depleted soils. A total of 40% of tree species evaluated in the present study had foliage N content > 25 mg g^{-1} which is greater than the critical level of 20–25 mg g^{-1} of most tree species (Palm *et al.* 1997). Net immobilization of N can be expected if the species with N content below the critical levels are used as organic fertilizer resources. The N contents in the wood of *C. proliferus* and *E. globulus* were high compared with other tree species.

Hagenia abyssinica had higher K content in its foliage (19.24 mg g^{-1}) and wood (4.57 mg g^{-1}) compared with the other species. Like N, K content was higher in the foliage than in the wood. The foliage K content of *H. abyssinica* (19.24 mg g^{-1}) in our study was found high as compared with the K content reported by Gindaba *et al.* (2005) for *Cordia africana* (12.8 mg g^{-1}) and *Croton macrostachayus* (12.9 mg g^{-1}). *Cordia africana* and *C. macrostachyus* are indigenous Ethiopian tree species that are integrated in various agroforestry systems. Higher K content of *H. abyssinica* could be attributed to better K extraction ability of the tree from the soil. Optimum K content in tree foliage is usually in the range of 15 to 45 mg g^{-1}. Only 43% of the species evaluated in the present study had K contents that were in the optimum range.

The foliage P content of *H. abyssinica* was significantly higher ($p < 0.001$) than that of the other species. Although P contents of foliages of the seven tree species were low, they are still within the range (1.5–2.9 mg g^{-1}) as reported for many tropical tree species (Palm *et al.* 1997). Low P content in the foliage and wood could be explained by the very low content of available P in the subsoil and the low root densities of the species (IAEA 1975).

Trends of total soil N

Total N under *E. camaldulensis* and *E. globulus* was lower at 64 months than at 12 (Figure 1). Michelsen *et al.* (1993) provided empirical evidence for soil N depletion by *E. globulus* as compared with some indigenous tree species. In the present study, *C. palmensis* and *C. proliferus* slightly increased soil N at 64 months. The N increases under the two *Chamaecytisus* species at 64 months could be due to the N-fixing capacity of the species. Ovalle *et al.* (1996) estimated an annual N fixation rate of 100 kg ha^{-1} from *C. proliferus* stands that were planted with 5000 trees ha^{-1}.

Acacia decurrens depleted N in the topsoil layers (0–15 and 15–30 cm) at 64 months as compared

Table 5 Macronutrient contents of seven tree species at 64 months after planting on Nitosols of central Ethiopia

Tree species	Nutrient content (mg g^{-1})					
	Foliage			Wood		
	N	P	K	N	P	K
Acacia decurrens	32.22 (± 2.67) a	1.62 (± 0.19) cb	10.18 (± 1.57) e	2.91 (± 0.92) ba	0.10 (± 0.03) b	1.39 (± 0.24) b
Chamaecytisus palmensis	30.72 (± 2.31) a	1.53 (± 0.11) c	17.22 (± 1.81) ba	3.30 (± 0.80) ba	0.17 (± 0.10) ba	2.41 (± 0.36) b
Chamaecytisus proliferus	30.59 (± 0.33) a	1.61 (± 0.01) cb	14.94 (± 1.02) bc	3.42 (± 0.62) a	0.14 (± 0.06) ba	1.39 (± 0.68) b
Eucalyptus camaldulensis	21.31(± 0.69) b	2.01 (± 0.49) b	10.89 (± 0.49) de	2.28 (± 0.77) ba	0.24 (± 0.05) ba	1.90 (± 0.62) b
Eucalyptus globulus	17.14 (± 1.01) b	1.64 (± 0.06) cb	13.28 (± 1.28) dc	3.34 (± 0.88) a	0.30 (± 0.12) a	1.71 (± 0.18) b
Grevillea robusta	19.04 (± 4.51) b	1.54 (± 0.12) c	14.24 (± 2.49) bc	1.98 (± 0.43) b	0.20 (± 0.14) ba	1.66 (± 0.25) b
Hagenia abyssinica	21.92 (± 7.78) b	3.01 (± 0.33) a	19.24 (± 1.69) a	2.49 (± 0.82) ba	0.22 (± 0.10) ba	4.57 (± 2.11) a
p value	0.002	0.001	0.003	0.198	0.282	0.011

Values in parentheses are standard deviations (SD) of means from untransformed data.
Means in a column followed by the same letter do not differ significantly.

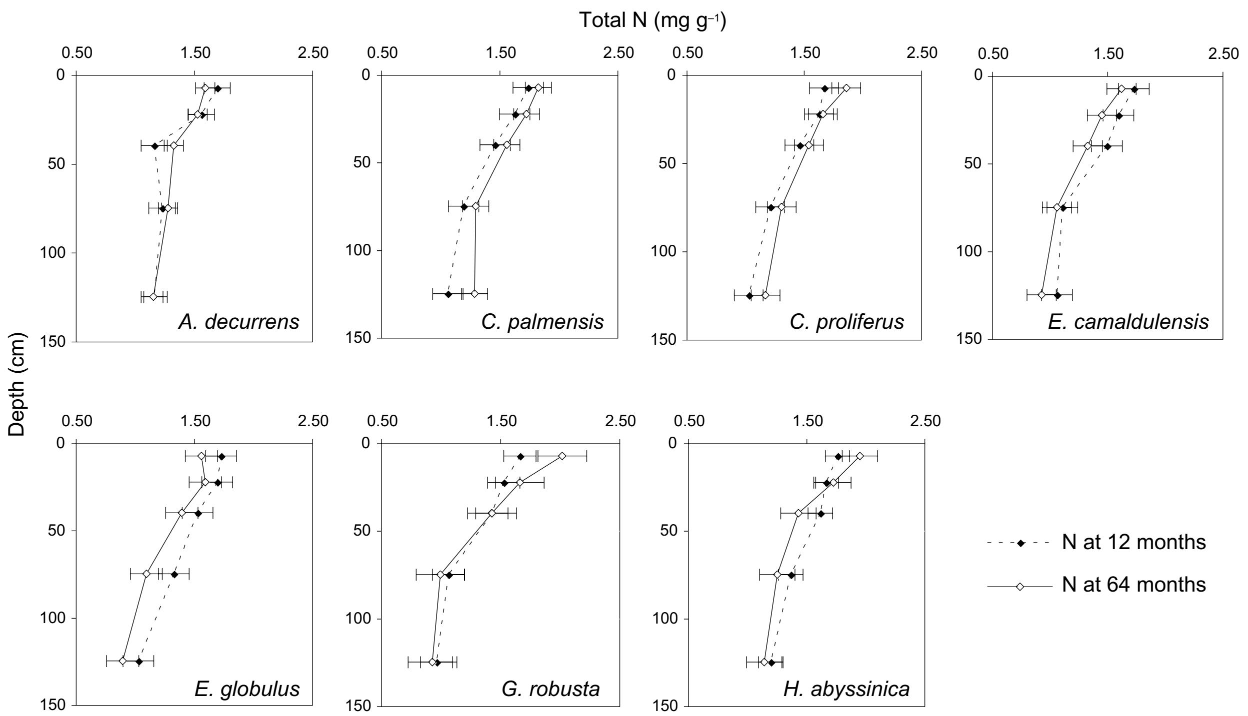

Figure 1 Trends of total N under planted tree species at 12 and 64 months. Horizontal bars show standard errors of the means.

with 12 months. On the other hand, *A. decurrens* slightly improved the soil below 30 cm at 64 months. The canopy of *A. decurrens* was dense in all the experimental plots. As a result, the floor under the canopy received little light. Grass and litter fall were not abundant under *A. decurrens* plots. Therefore, poor grass cover and low litter cover could facilitate soil erosion and hence lower topsoil N at 64 months. *Grevillea robusta* and *H. abyssinica* increased N in the top soil layers at 64 months and reduced it in the lower soil layers at 12 months. Litter deposition was high under *G. robusta* and *H. abyssinica* plots. Effective nutrient cycling and deposition of litter under the two species could be the reason for increment of N in the topsoil layers at 64 months.

CONCLUSIONS

The soil, temperature and rainfall condition at the study site were suitable for the growth and productivity of most tested species. *Chamaecytisus* species and *A. decurrens* can be short-term (5–10 years) options for soil fertility improvement and source of fuelwood respectively. Although *Eucalyptus* produces significant amount of biomass, it utilizes much of the soil nutrient resources.

ACKNOWLEDGEMENTS

The authors thank the Ethiopian Agricultural Research Organization (EARO) for financing the research work. The support from the staff of Forestry, Soil and Water Management Research divisions at Holetta is highly appreciated.

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