VI. Tree species screened on the highland Nitisol areas of Holetta, Ethiopia: Biomass production, nutrient contents and effect on soil nitrogen

6.1. 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 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 64. 6 and 30.2 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 Nitisols of Ethiopia, are deficient in N, P (HAQUE et al. 1993) and some micronutrients (SANCHEZ and NICOLAIDES 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 the 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 were convinced that participatory screening enhances subsequent promotion and adoption of tree species.

Presently, farmers of the study area depend on only a few numbers 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 continuous screening programs. Continuous screening 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 content of different tree species and (iii) assess effects of trees on soil nitrogen beneath their canopies.

6.2. Materials and methods

6.2.1. Study site

The study was conducted from 1997 to 2002 at Holetta Agricultural Research Center experimental site, Central Ethiopia (38^0 30'E, 09^0 03' N, 2400 m.a.s.l). Mean annual maximum and minimum temperatures are 23 and 6 ^{0}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 Nitisols. Some of the chemical and physical properties of the top 0-15 cm and 15-30 cm soil layers are shown in Appendix 6.

6.2.2. 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. Information on soils, rainfall, temperature and altitude of representative sites in the study area were collected. Tree species for screening trial were listed based on the suggestions from Agroforestree Database of the International Center for Research in Agroforesty (ICRAF) and their presence in remnant vegetation of the study area.

6.2.3. Tree seed sources and soil quality

Seeds of different exotic and indigenous tree species were obtained from Ethiopian Forestry Research Center (FRC) and International Livestock Research Institute (ILRI) (Appendix 7). Seed treatment was exercised for *C. palmensis, C. proliferus and A. decurrens.* Seeds of *H. abyssinica*, *E. globulus* and *E. camaldulensis* did not require treatments (AZENE et al. 1993). 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 a minute. Treated seeds were directly sown in a polythene bag 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.

6.2.4. Experimental design and management

Treatments (seven tree species) laid out in a randomized complete block design (RCBD) with three replications (WOOD and BURLEY 1991; GOMEZ and GOMEZ 1984). 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 m x 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.

6.2.5. Tree and soil sampling and laboratory analysis

Out of the total 25 trees plot^{-1}, 16 of them were border trees. The remaining nine central trees were experimental trees. Tree height measurement was conducted at 12, 24, 36 and 64 months from the experimental trees. 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 ^{o}C. The wood sub-samples were initially oven dried at 70 ^{o}C for 24 hours followed by re-drying at 105 ^{o}C to constant weight. Dried foliage and wood sub-samples were ground to pass through a 1 mm sieve and analyzed 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 analyzed 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 analyzed for total N following the description by KEENEY and NELSON (1982).

6.2.6. 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 and GOMEZ 1984). The height, dry biomass and nutrient content data of the tree species were then analyzed by the general linear model (GLM) procedure of the SAS Program (SAS Institute 1999). Least significant difference (LSD) was used to compare treatment means.

6.3. Results and discussion

6.3.1. Patterns of height growth and aboveground biomass

Acacia decurrens, E. globulus and E. camaldulensis provided the highest height growth at 64 months as compared to other tree species (Table 6.1). The 64 months height growth (> 11 m) of *A. decurrens* from the present study was greater (50 %) than the 72 months 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 favorable for growth of *A. decurrens* than the site in central Chile.

Table 6.1. Mean height of seven tree species measured at different months on Nitosols of Holetta.

	Mean height (m)			
Tree species	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

*Analysis of variance was conducted on untransformed data.
**Analysis of variance was conducted on $\log_{10}$ transformed data.
Values in parentheses are standard deviations (SD) of means from untransformed data.
P= significance level of F-test, testing the null hypothesis of no difference.
Means in a column followed by the same letter do not differ significantly at their respective P value.

Acacia decurrens had the lowest biomass at 12 months but the highest biomass at 64 months (Table 6.2). Wild animals browsing resulted in low biomass of *A. decurrens* at 12 months. The foliage and wood biomass of *A. decurrens* at 64 months was more by 80 and 87 % 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 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. A*ltitude of the study area had slight effect on growth of *E. camaldulensis* as opposed to E*. globulus.* However*,* total dry biomass for 64 months old *E. camaldulensis* (126.22 Mg ha^{-1}) in the present study is higher than the total dry biomass for 90 months old *E. camaldulensis* (114 Mg ha^{-1}) in West Gojam, Ethiopia (ZERFU 2002).

Table 6.2. Mean dry biomass of seven tree species at different ages on Nitosols of Holetta.

Tree species	Foliage and wood 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

*Analysis of variance was conducted on untransformed data.

** Analysis of variance was conducted on $\log_{10}$ transformed data.

Values in parentheses are standard deviations (SD) of means from untransformed data.

P= significance level of F-test, testing the null hypothesis of no difference.

Means in a column followed by the same letter do not differ significantly at their respective P value.

Chamaecytisus palmensis and *C. proliferus* did not show substantial height growth difference at 12, 24, 36 and 64 months (Table 6.1). Similarly, the two tree species showed faster height growth in their early than late growth stages. In central Chile, ARONSON et al. (2002) reported insignificant height increase of *C. proliferus* after three years of establishment. The three years 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} (TOWNSEND and RADCLIFFE 1987). Differences in biomass production can vary depending on growing sites, planting density, age and management practices (MCGOWAN and MATHEWS 1992).

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

Hagenia abyssinica had the lowest height growth and biomass at 64 months as compared to other six tree 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 *H. abyssinica* tree planted around homesteads in high altitude (3060 m.a.s.l) areas of west Shewa, Ethiopia provided a height growth of 2 m as a result of periodical side prunings. 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 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. It decreased as the proportion of the 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.

6.3.2. Macronutrient content

The foliage N content in *A. decurrens*, *C. palmensis* and *C. ploriferus* was significantly higher ($P < 0.002$) than in the other tree species (Table 6.3). *Acacia decurrens*, *C. palmensis*, and *C. ploriferus* fix N while the other four tree species do not. Nitrogen content is higher in the foliage of the different tree species than in the wood. Tree species with high content of foliar N can be potential sources of organic resources for improving depleted soils. Forty three percent of the tree species evaluated in the present study had a 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 content in the wood from *C. proliferus* and *E. globulus* were high as compared to other tree species.

Table 6.3. Macronutrient contents of seven tree species 64 months after planting on Nitosols of Holetta.

Tree species	Foliage and wood 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

*Analysis of variance was conducted on untransformed data.

Values in parentheses are standard deviations (SD) of means from untransformed data.

P= significance level of F-test, testing the null hypothesis of no difference.

Means in a column followed by the same letter do not differ significantly at their respective P value.

Hagenia abyssinica had higher K content in its foliage (19.24 mg g^{-1}) and wood (4.57 mg g^{-1}) than the other six tree 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 to 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 fall in the optimum range.

The foliage P content of *H. abyssinica* was significantly higher ($P < 0.001$) than that of the other tree species. Though P content of foliages of the seven tree species was low, it is still within the range (1.5-2.9 mg g^{-1}) 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 sub-soil and the low root densities of the species (IAEA 1975).

6.3.3. Trends of total soil N

Total N under *E. camaldulensis* and *E. globulus* was less at 64 than at 12 months (Figure 6.1). MICHELSEN et al. (1993) provided empirical evidence for soil N depletion by *E. globulus* as compared to 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 to 12 months. On the other hand, *A. decurrens* slightly improved the soil below 30 cm at 64 months (Figure 6.1). 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 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.

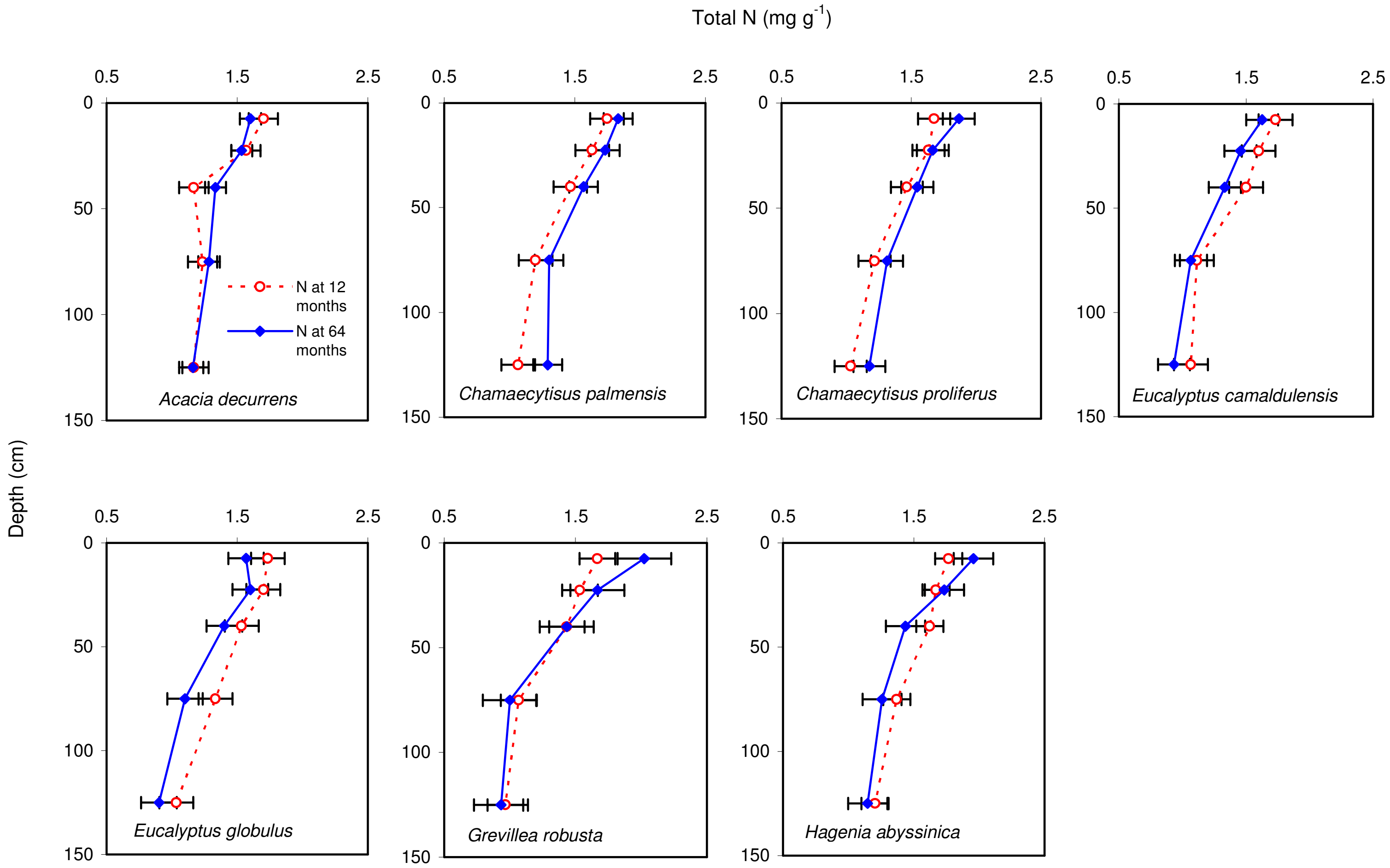

Figure 6.1. Trends of total N at 12 and 64 months under planted seven tree species on Nitosols of Holetta. Horizontal bars show standard errors of the mean.

6.4. Conclusions

The soil, temperature and rainfall condition at the study site was 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 fuel wood, respectively. Although *Eucalyptus* produces significant amount of biomass, it utilizes much of the soil nutrient resources. The depletion of soil N under *Eucalyptus* species and the dynamics of the growth of grasses beneath the canopy of *A. decurrens* require further studies. The numbers of indigenous species incorporated in the present study were few. Testing of more indigenous tree species is necessary in subsequent screening trials.