V. Performance of eight tree species in the highland Vertisol areas of Ginchi, Ethiopia: Growth, foliage nutrient concentration and effect on soil chemical properties

5.1. Introduction

Vertisols are the fourth most important soil orders and cover over 10 % (12.7 million ha) of the Ethiopian landmass (BERHANU 1985). From the total coverage of Vertisols, 7.6 million ha is found in the highlands (> 1500 m.a.s.l). The distribution and diversity of trees and shrubs on Vertisols is very scarce due to mainly anthropogenic, climatic and edaphic factors (EARO (Ethiopian Agricultural Research Organization) 2000). Farmers establish *E. globulus* woodlot around the homesteads and use it for fuelwood, poles and as sources of cash. Other naturally grown *Acacia* species exist in riverbanks, grazing and croplands with a very little area coverage.

Waterlogging in the rainy season and cracking in the dry season are features of Vertisols. The cracks on Vertisols are deep and wide. Preliminary observation at Ginchi (central Ethiopia) showed up to 1.06 m depth and 0.12 m width of soil cracks on fallow lands and 0.67 m depth and 0.09 m width of cracks on cultivated lands (WORKU 1997 personal communication). When the soil form cracks tree and shrub roots break and cease anchorage and water absorption activities. This has resulted in poor adaptation of trees and shrubs on Vertisols.

Shortages of wood and improved animal feed, soil erosion, decline of soil fertility and lack of alternative fuel wood sources are critical problems in the highland Vertisol areas (ICRAF (International Center for Research in Agroforestry) 1990). Farmers on Vertisol areas demand wood mainly for fuel wood, construction poles, farm implements and charcoal making. In 1992 total requirements for wood products in the country was estimated to be 47.4 million m^3 (EFAP (Ethiopian Forestry Action Program) 1994). In 2014 total wood requirement and supply with the implementation of programs developed by EFAP is estimated to be 94.6 and 30.2 million M^{-3}, respectively. Wood requirement outweighs the supply both in Vertisol and other areas of the country.

Soil erosion and continuous cultivation with no or minimum inputs have caused depletion of soil nutrients on Vertisols. HAGUE et al. (1993) reported deficiencies of N and P on highland Vertisols. Correcting N and P deficiencies by fertilizer application alone is a challenging task in view of the high fertilizer cost and low income of the subsistent farmers. Organic resources like crop residues and cow dung are advertised as one of the options for replenishment of soil fertility. However, the attempt is challenged by competing uses of crop residues and manures for animal feed and fuel sources, respectively.

Introduction and improved management of adaptable, multipurpose trees and shrubs can be one of the strategies to minimize the current wood, feed and soil related constraints. So far, available information on the performance of agroforestry tree and shrub species on Vertisols is limited.

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

5.2. Materials and methods

5.2.1. Study site

The study was conducted from 1997 to 2002 at Ginchi research sub-center of western Shewa, Ethiopia. The sub-center is geographically located at 09^0 02’N latitude and 38^0 07' E longitudes. Altitude is 2200 m.a.s.l. The sub-center receives rain in the short and long cropping seasons. Mean annual rainfall is 1042 mm. The annual mean maximum and minimum temperatures are 25 and 7 ^{0}C, respectively. The soil is classified as Pellic Vertisol. Some of the chemical and physical properties of the top 0-15 and 15-30 cm soil layers are presented in Appendix 4.

5.2.2. Seed sources and raising of seedlings

Seeds of different agroforestry trees were obtained from Ethiopian Forestry Research Center (FRC), International Livestock Research Institute (ILRI) and Kenya Forestry Research Institute (KEFRI). Seed treatment techniques such as scarification, nipping, soaking in hot and cold water were exercised depending upon the need for the species. Treated seeds of trees and shrubs were directly sown in a polythene tube 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 tube was 15 cm height and 8 cm diameter. All pots sown with respective species were exposed to similar watering, shading, weeding and hardening practices.

5.2.3. Experimental design and management

Treatments (different 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) *Acacia abyssinica* Hochst. Ex Benth (collection from Tateke, western Shewa, Ethiopia); (ii) A. *decurrens* Willd (collection from Sebeta, south-west Shewa, Ethiopia); (iii) A. *melanoxlon* R. Br. (collection from Tateke, western Shewa, Ethiopia); (iv) A. mearnsii De Wild (collection from mortu Molosi, Kenya); (v) *A. saligna* Labill Wendl. (collection from Zwai with accession no. 7178, east Shewa, Ethiopia); (vi) *Cordia africana* Lam (collection from Sokoru, Ethiopia); (vii) *Eucalyptus globulus* Labill (collection from Deksis, Ethiopia) and (viii) *Sesbania sesban* (L.) Merr (collection from Zwai with accession no. 10865, eastern Shewa, Ethiopia).

Field preparation was begun one week before planting with hole digging at depths of 30 cm. Trees were planted on hand made broad bed and furrow (BBF) for the purpose of draining excess water. A plot consisted of five BBFs (Appendix 5). The size of a plot was 6.5 x 6 m. Each BBF was 1.2 m wide from the centers of two neighboring furrows, giving a bed 0.8 m wide for establishment of the trees. The length of each BBF was 6.5 m. The height of the BBF was 0.2 m from the furrow center and each furrow was 0.4 m wide (TEDLA et al. 1999). Each BBF had a line of five trees. The trees were planted in the center of the BBF. Distance between trees in the same line was 1.3 m while distance between the tree lines in the same plot was 1. 2 m. Distance between plots was 2 m.

5.2.4. Measurement, sampling, and soil and foliage analysis

Initial height of the different species was determined at planting (1997). Similarly, height data was taken 12, 24, 36 and 64 months after planting as described by WOOD and BURLEY (1991). Graduated stick and clinometers were used to measure tree and shrub heights. Systematic sampling was followed to select tree and shrub species for biomass determination**.** Out of the total 25 trees plot^{-1}, 16 of them were border trees. Destructive tree sampling was done at 12, 40, and 64 months from the nine central trees that were not adjacent each other. 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 stems. Each part was weighted, chopped and sub-sampled for dry matter determination. Sub-samples were oven dried at 70 ^{o}C, ground to pass through 1 mm sieve and analyzed for total N using Kjeldahl procedure (BURESH et al. 1982), P (MURPHY and RILEY 1962) and extractable K (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 36 months after planting. Sampling layers in all sampling schemes were 0-0.15, 0.15-0.3, 0.3-0.5, 0.5-1, 1-1.5 and 1.5-2 m depths (KINDU et al. 1997). The samples were analyzed for total N following the description by KEENEY and NELSON (1982). Available P was determined by Olsen method (OLSEN et al. 1982).

5.2.5. Statistical analysis

The following formula was used to calculate dry weight of the aboveground tree components.

$$\text{Dry weight}_{\text{total}} = \left[\frac{\text{Fresh weight}_{\text{total}} * \text{Dry weight}_{\text{sample}})}{\text{Fresh weight}_{\text{sample}}} \right] \quad (1)$$

Foliage to stem ratio was calculated based on the relationship between dry foliage and stem biomass. Mean values were used for plotting height, height increment, total soil N and available soil P graphs. The general linear model procedure of the SAS Program (SAS Institute 1999) was used for data analysis. Means for height growth, height increment, aboveground dry biomass and foliage nutrient (N, P and K) concentrations of the different trees were compared using the least significance difference (LSD) at $P < 0.01$.

5.3. Results

5.3.1. Growth of trees and shrubs

The height of *A. mearnsii* was higher at 12 months ($P < 0.01$) than the other tree and shrub species (Table 5.1 and Figure 5.1a). On the other hand, *A. abyssinica* demonstrated the lowest height growth at 12 months. *Acacia decurrens* and *A. mearnsrii* resulted better height growth at 24, 36 and 64 months. *Eucalyptus globulus, Acacia decurrens* and *A. mearnsrii* attained the highest growth at 64 months as compared to other indigenous and exotic tree and shrub species. Indigenous trees such as *A. abyssinica* and *C. africana* showed slow growth rates at 12, 24, 36 and 64 months. The growth rate of *S. sesban* was slow after 12 months.

Mean annual height increment of *A. abyssinica* from 12 to 24 and 24 to 36 months was uniform (Table 5.1 and Figure 5.1b). *Acacia decurrens* showed significant height increment from 12 to 24 months. Likewise, *E. globulus* resulted better height increment from 24 to 36 and 36 to 64 months than other tree and shrub species.

Table 5.1. Comparison of mean height growth and height increment (m) for eight tree species evaluated on a Vertisol area of Ginchi, central Ethiopia.

	Height growth				Height increment		
Tree and shrub species	12 Months	24 Months	36 Months	64 Months	12 vs 24 months	24 vs 36 months	36 vs 64 months
Acacia abyssinica	0.97^{e}	1.46^{d}	1.97^{e}	4.86^{cd}	0.50^{dc}	0.50^{c}	2.89^{ba}
Acacia decurrens	2.83^{ba}	5.13^{a}	6.89^{a}	9.73^{a}	2.30^{a}	1.76^{ba}	2.84^{ba}
Acacia mearnsii	3.03^{a}	4.89^{a}	6.64^{a}	9.09^{a}	1.86^{ba}	1.74^{ba}	2.45^{bac}
Acacia melanoxlon	1.76^{d}	2.65^{c}	3.90^{c}	5.65^{cb}	0.89^{c}	1.25^{bc}	1.75^{bc}
Acacia saligna	2.32^{c}	3.87^{b}	4.99^{bc}	6.63^{b}	1.55^{b}	1.12^{bc}	1.64^{bc}
Eucalyptus globulus	1.88^{d}	3.59^{b}	6.06^{ba}	9.85^{a}	1.71^{b}	2.47^{a}	3.79^{a}
Cordia africana	1.77^{d}	1.86^{d}	2.39^{de}	3.42^{d}	0.09^{d}	0.54^{c}	1.02^{bc}
Sesbania sesban	2.56^{bc}	3.49^{b}	3.73^{dc}	4.43^{cd}	0.94^{c}	0.24^{c}	0.70^{c}
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0115	0.0492

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-alue.

5.3.2. Biomass production

Dry biomass of the trees widely varied among species. *Sesbania sesban* (L.) Merr provided the highest biomass yield at 12 months. Similarly, *A. mearnsii* and *A. saligna* produced high biomass at 40 and 64 months (Table 5.2). Differences between the highest and lowest dry biomass at 12, 40 and 64 months were 1.13, 29.19 and 38.89 kg tree^{-1}, respectively. The order for biomass increment of the top four species from 12 to 40 months was *A. decurrens* (29.9) > *A. saligna* (26.8) > *A. mearnsii* (23.7) > *E. globulus* (10.4 kg tree^{-1}). Biomass increment from 40 to 64 months was not as high as that of 12 to 40 months. The highest biomass increment from 40 to 64 months was 19.26 kg tree^{-1} for *A. mearnsii* and the lowest was 3.3 kg tree^{-1} for *C. africana*. *Acacia saligna* and *E. globulus* had a foliage to stem biomass ratio > 1 at 12 months as compared to other species. The highest foliage to stem biomass ratio was 1.18 at 12 months and the lowest was 0.12 at 40 months. None of the tree species resulted in a foliage to stem biomass ratio > 0.98 at 40 and 64 months. The standard deviation (SD) for the total biomass of *A. saligna* and *A. abyssinica* at 64 months was higher than the SD of other tree species.

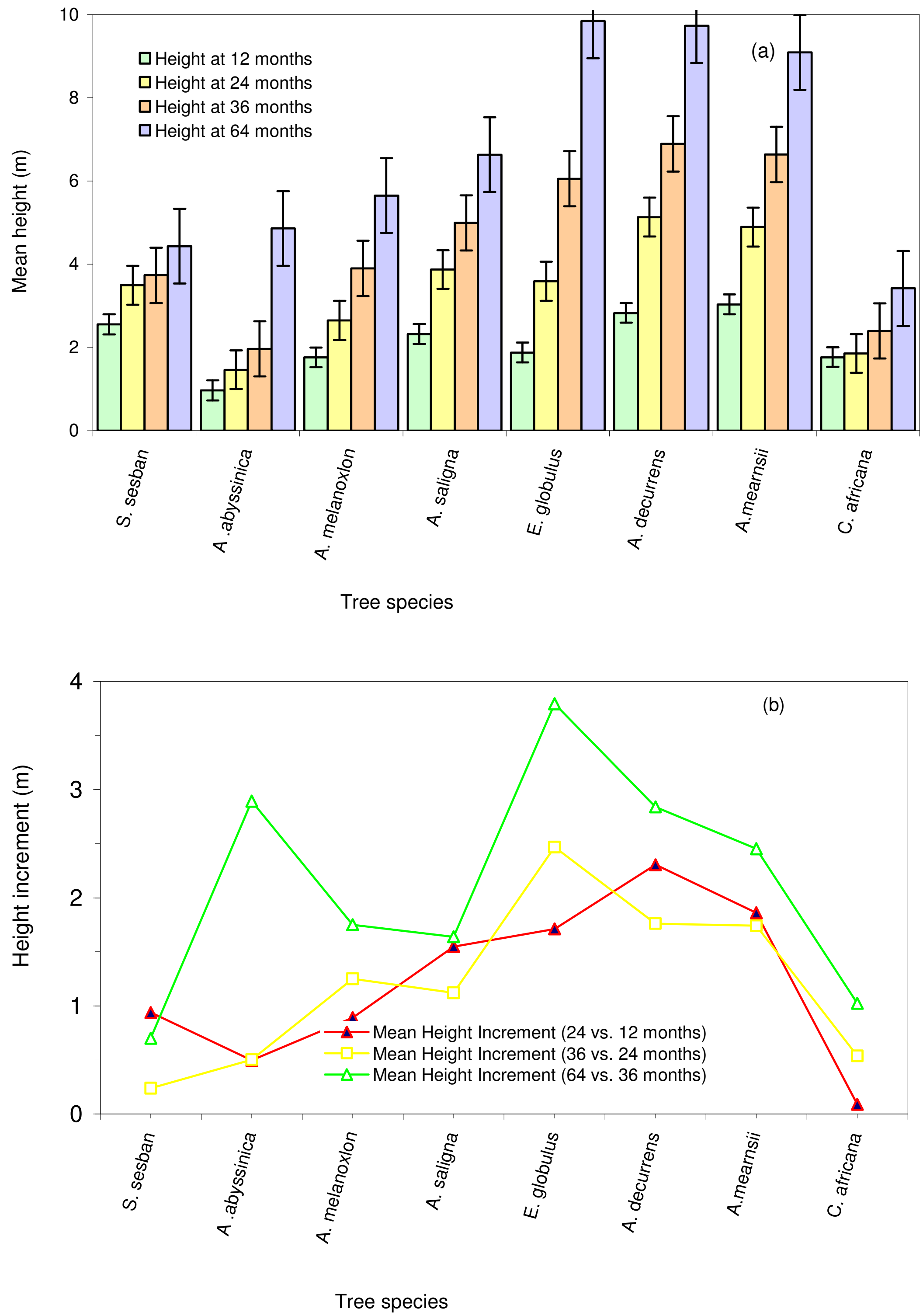

Figure 5.1. Tree species evaluated on a Vertisol area of Ginchi, central Ethiopia mean height and (b) mean height increment. Vertical bars show standard errors of the mean.

Table 5.2. Aboveground dry-biomass of eight tree species evaluated at different months on a Vertisol area of Ginchi, central Ethiopia.

	12 Months			40 Months			64 Months		
Tree and shrub species	Total dry-biomass (kg tree^{-1})	SD*	Foliage to stem ratio	Total dry-biomass (kg tree^{-1})	SD*	Foliage to stem ratio	Total dry-biomass (kg tree^{-1})	SD*	Foliage to stem ratio
Acacia abyssinica	0.21^{d}	0.11	0.50	2.71^{c}	0.90	0.56	13.67^{dc}	12.22	0.60
Acacia decurrens	1.10^{ba}	0.21	0.92	31.02^{a}	6.08	0.36	35.75^{ba}	5.20	0.36
Acacia mearnsii	1.03^{ba}	0.34	0.75	24.79^{a}	8.77	0.35	44.05^{a}	5.22	0.46
Acacia melanoxlon	0.33^{d}	0.02	0.83	3.90^{cb}	2.40	0.98	12.60^{dc}	1.05	0.87
Acacia saligna	0.80^{bc}	0.18	1.05	27.60^{a}	5.37	0.33	43.79^{a}	20.96	0.42
Eucalyptus globulus	0.79^{bc}	0.12	1.18	11.18^{b}	4.86	0.46	23.26^{bc}	3.34	0.45
Cordia africana	0.56^{dc}	0.22	0.54	1.83^{c}	0.77	0.12	5.16^{d}	2.84	0.25
Sesbania sesban	1.34^{a}	0.44	0.25	7.83^{cb}	3.17	0.20	13.40^{dc}	5.20	0.31
P-value	0.0011			0.0001			0.0008		

* Standard Deviation

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.

5.3.3. Foliage nutrient concentration

Foliage N concentration of *S.sesban* was not significantly different ($P < 0.01$) as compared to the foliage N concentration of *A. mearnsii* and *A. melanoxlon* at 12 months (Table 5.3). The three leguminous tree species (*A. abyssinica*, *A. decurrens* and *A. saligna*) and a none-leguminous species (*C. africana*) did not show significant difference for N concentration in their foliages at 12 months. Foliage N concentration was higher for all species at 40 months than 12 months. Foliage P concentration of *S. sesban* was significantly higher ($P < 0.01$) at 12 and 40 months than most other species. Potassium concentration of foliages of all trees was higher at 40 months than 12 months. *Cordia africana* followed by *S. sesban* had higher concentration of K both at 12 and 40 months.

5.3.4. Total N and available P trends

The trend of total soil N appeared to be high in the top 0 to 30 cm depths under all tree species (Figure 5.2). The stock of total N under *E. globulus* was reduced at 40 months as compared to the stock at 12 months. Total N under *A. abyssinica*, *A. saligna* and *S. sesban* was slightly greater at 40 months than 12 months. Contrary to the N content, the available P content under most species and nearly all soil depths was lower at 40 months than 12 months (Figure 5.3). Under *A. saligna*, available P below 160 cm was higher at 40 months than 12 months. *Acacia mearnsii* and *E. globulus* did not differently impact available P content at 2 m soil depth.

Table 5.3. Foliage macronutrient content of eight tree species evaluated at different months on a Vertisol area of Ginchi, central Ethiopia.

Tree and shrub species	Nitrogen (g kg^{-1})		Phosphorus (g kg^{-1})		Potassium (g kg^{-1})	
	12 Months	40 Months	12 Months	40 Months	12 Months	40 Months
Acacia abyssinica	22.3^{ba}	31.6^{b}	2.33^{a}	2.37^{b}	6.19^{cb}	12.50^{c}
Acacia decurrens	20.9^{ba}	26.7^{cb}	1.23^{b}	1.06^{c}	3.19^{cd}	6.67^{e}
Acacia mearnsii	23.7^{a}	28.5^{b}	1.23^{b}	1.17^{c}	5.83^{cbd}	7.57^{ed}
Acacia melanoxlon	23.6^{a}	24.5^{cd}	1.40^{b}	1.25^{c}	6.21^{cb}	9.63^{d}
Acacia saligna	20.3^{ba}	28.7^{b}	1.43^{b}	1.57^{c}	2.72^{d}	9.10^{ed}
Eucalyptus globulus	11.8^{b}	15.9^{e}	1.27^{b}	1.27^{c}	4.08^{cd}	9.47^{d}
Cordia africana	18.0^{ba}	18.1^{ed}	2.57^{a}	2.23^{b}	15.67^{a}	26.03^{a}
Sesbania sesban	28.1^{a}	38.2^{a}	2.80^{a}	3.40^{a}	8.33^{b}	21.23^{b}
P-value	0.2230	0.0001	0.0010	0.0001	0.0001	0.0001

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.

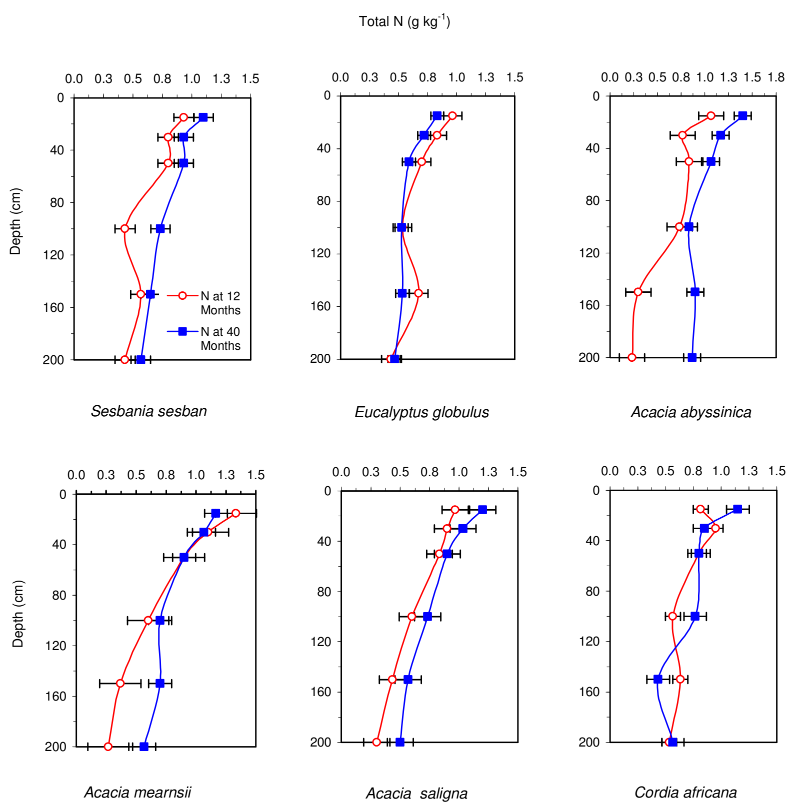

Figure 5.2. Trends of total N at 12 and 40 months under different trees on a Vertisol area of Ginchi, central Ethiopia. Horizontal bars show standard errors of the mean.

5.4. Discussion

Growth and productivity of trees depend upon the genetic, climatic, edaphic and management factors (LUGO et al. 1988). The slow growth performance of the indigenous trees like *A. abyssinica* and *C. africana* can be attributed to the genetic makeup of the species. The annual height and biomass increment of *A. abyssinica* and *C. africana* was as low as other Ethiopian indigenous tree species. Unlike *E. globulus*, *S. sesban* had low height increment from 36 vs 64 months (Table 5.1 and figure 5.1b). On the other hand, *S. sesban* produced the highest biomass at 12 months as compared to other indigenous and exotic tree and shrub species (Table 5.2). The continuity of growing and yielding high biomass depends on the lifespan of species. Short lifespan shrub species such as *S. sesban* showed higher annual height and biomass increment in its early than late ages. Our findings on height growth and aboveground biomass of *S. sesban* are in line with the findings of MENGISTU et al. (2002).

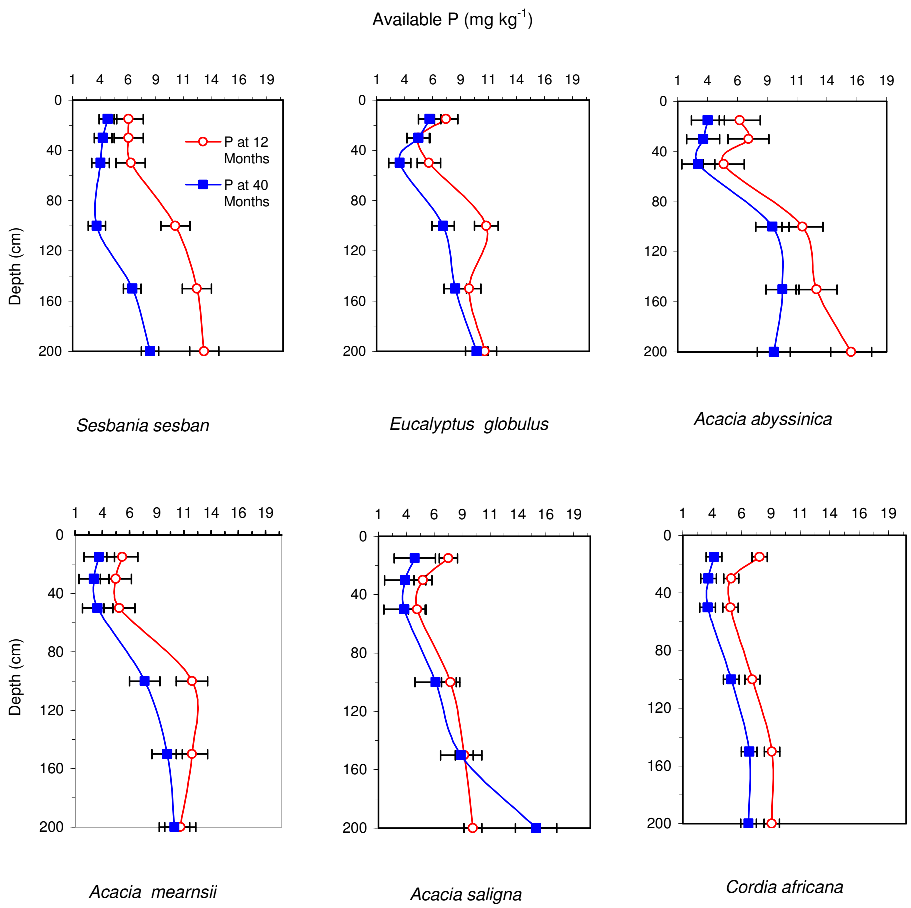

Figure 5.3. Trends of available P at 12 and 40 months under different trees on a Vertisol area of Ginchi, central Ethiopia. Horizontal bars show standard errors of the mean.

The foliage to stem biomass ratio of many of the species did not increase with time. It has rather decreased as the proportion of the stem dry biomass increased for many of the species. For *E. globulus,* foliage to stem ratio declined from 1.18 in the 12 months to 0.45 in the 64 months (Table 5.2). During the experimental period, *C. african* shed leaves more than other tree species. The low foliage to stem biomass ratio for *C. african* can be partly explained to leaf shedding. Other tree species such as *A. decurrens* and *A. mearnsii* had feathery and small size leaves. The small size and weight of leaves of the two species could be some of the reasons for the low foliage to stem biomass ratios.

The standard deviation for total dry biomass of *A. saligna* and *A. abyssinica* at the 64 months was 20.9 and 12.2, respectively (Table 5.2). Increased standard deviation for the two species could be a result of lack of sampling representative trees. Systematic sampling was followed in each experimental plot to select tree and shrub species for biomass determination**.** We used systematic sampling methods to avoid cutting of adjacently growing trees. Considerations of various criteria reduce extremes from the mean dry biomass of the trees but may lead to cutting of adjacently growing trees. Representative trees for biomass determination can be defined based on diameter, basal area and height distribution of existing stands when the experimental plots consist of more trees than the present study.

The nutrient concentration of tree foliages varies depending on species, soil type and age (JAMA et al. 2000). Similarly, the concentration and availability of nutrients under trees vary with depth of soil and distance from a tree base (MAZZARINO et al. 1991). Increasing trends of foliage and soil N for *Acacia* species and *S. sesban* in comparison with *E. globulus* can be accounted for the enhancement of biological N fixation of the former than the later. The amount of N fixed by legume tree species can be quite considerable. NDOYE and DREYFUS (1988) estimated the amount of N (43 to 102 kg N ha^{-1} y^{-1}) that can be fixed by *S. sesban*. Nitrogen concentration of the N fixing tree species was greater than the critical level of 20-25 g kg^{-1} (PALM et al. 1997). Net immobilization of N can be expected if the species with N concentration below the critical levels are used as organic fertilizer resources.

Soil N under *E. globulus* was less at 40 months than at 12 months. Most *Eucalyptus* species are known for utilizing high amount of resources to fulfill the demand for their fast growth rates (MALIK and SHARMA 1990). Poor decomposability (higher lignin and soluble polyphenols) of eucalyptus litter compared to litter from other tree species could be the other reason for decline of soil N under *E. globulus*. Like wise, the lowering of soil N in the top 30 cm soil layers under *A. mearnsii* (Figure 5.2) occurred probably due to less leaf litter of the trees and poor undergrowth of grasses and other annual plants. The absence of leaf litter and good vegetation undergrowth could have facilitated topsoil erosion and hence N depletion.

Most tree species had low foliage P concentration in comparison with N concentration. The foliage P concentration in *S. sesban* was exceptionally higher at 40 months than the other species. Like the foliage P, soil P under most species declined at 40 months as compared with 12 months. The decline of P in the foliage and the soil can be explained to the very low concentrations of available P in the sub-soil and low root length densities of the species (IAEA (International Atomic Energy Agency) 1975). The addition of available P below 150 cm soil depths under *A. saligna* at 40 months (Figure 5.3) could be attributable to the association of the tree roots with mycorrhizas. The extensive proliferation of mycorrhizal hyphae enables the exploration of greater soil volume (LAJTHA and HARRISON 1995).

5.5. Conclusions

Based on evaluation of eight tree species on Vertisols, the following were observed: (i) *Acacia mearnsii* and *A. decurrens* provided better height growth at 12, 24, 36 and 64 months, (ii) *Eucalyptus globulus* had shown higher height increment from 24 to 36 and 36 to 64 months than other species, (iii) *Sesbania sesban* had high N and P concentrations in its foliages and stems at 12 and 40 months, (iv) *Acacia mearnsii and A. saligna* were superior tree species on Vertisols in terms of biomass production at 40 and 64 months, (v) *Acacia abyssinica*, *A. saligna* and *S. sesban* slightly improved total N at 40 months as compared to 12 months, (vi) *Acacia mearnsii* lowered soil N in the top 30 cm soil layers, and (vii) Available P content under most species and nearly all soil depths was lower at 40 months than 12 months.