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GROWTH PERFORMANCE OF *EUCALYPTUS GLOBULUS* AS INFLUENCED BY STAND AND SITE FACTORS IN CHELELEKA CATCHMENT, CENTRAL ETHIOPIA

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AMANUEL, M. & NÄSLUND, B. Å. 1999. **Growth performance of *Eucalyptus globulus* as influenced by stand and site factors in Cheleleka Catchment, central Ethiopia.** This study was conducted on a 4-y-old fuelwood plantation of *Eucalyptus globulus* in Cheleleka Catchment, central Ethiopia. Using the General Linear Model (GLM), significant effects of stand density (number of survivors/plot) and altitude on mean tree height and mean diameter were found. As stand density increased, mean tree height and diameter increased. In this study, none of the site factors significantly influenced the number of survivors per plot. The best growth in the catchment was at altitude 2950 m a.s.l. In this topographic position, mean tree height and mean diameter at breast height were greater than those in the valley floor (2850 m a.s.l.) and in the upper parts of the catchment (3050 and 3150 m a.s.l.). Further studies on the influence of site factors on catchment microclimate in relation to tree growth are recommended.

Key words: Altitude - aspect - *Eucalyptus globulus* - growth performance - slope - soil depth - plot tree density

AMANUEL, M. & NÄSLUND, B. Å. 1999. **Prestasi pertumbuhan *Eucalyptus globulus* seperti yang dipengaruhi oleh faktor dirian dan faktor tapak di Cheleleka Catchment, tengah Ethiopia.** Kajian ini dijalankan di ladang kayu api *Eucalyptus globulus* berumur empat tahun di Cheleleka Catchment, tengah Ethiopia. Menggunakan Model Linear Am (GLM), kesan kepadatan dirian bererti (bilangan pokok yang terselamat/petak) dan altitud bagi ketinggian pokok min dan garis pusat min diperoleh. Apabila kepadatan dirian bertambah, ketinggian pokok min akan bertambah. Dalam kajian ini, tiada satupun faktor tapak mempengaruhi dengan bererti bilangan survivor bagi satu petak. Pertumbuhan yang paling baik dalam kawasan tadahan ialah pada altitud 2950 m a.s.l. Dalam kedudukan topografi ini, ketinggian pokok min dan garis pusat aras dada min adalah lebih tinggi daripada pokok yang terletak di lantai lurah (2850 m a.s.l.). Disyorkan supaya kajian yang lebih mendalam dijalankan mengenai pengaruh faktor tapak terhadap mikrocuaca tadahan yang berkaitan dengan pertumbuhan pokok.

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Both species seem to be compatible with cropping patterns in the region and hence suitable for agroforestry systems prevalent in the study area. Although *Garcinia kola* and *Ricinodendron heudelotii* do not contribute nearly as much as *Irvingia gabonensis* and *Dacryodes edulis* (Ayuk *et al.* unpublished data) to household income in the humid lowlands of Cameroon, they are valuable species. Further research needs to be undertaken in improving our understanding of the market opportunities and constraints of these species. It is also important to identify methods to quantify the non-food uses of these species.

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Introduction

Eucalyptus globulus Labil. subsp. *globulus* is the dominating tree species in the current reforestation programme on the highlands of Ethiopia, where it is grown for the production of wood for energy and construction. The success of tree cultivation depends a great deal on site factors such as altitude, aspect (compass orientation) and slope (Mitscherlich 1975, Kramer 1988), which directly influence the climatic elements of a growing site (Geiger 1965, Worrell & Malcolm 1990b). The reduction of productivity and tree growth with altitude is an example (Grace 1977, Tranquillini 1979), resulting from the general effects of altitude on meteorological variables such as air pressure, air density, vapour pressure, radiation components, air temperature and wind velocity (Barry 1992).

Temperature decline with altitude reduces the photosynthetic capacity of a plant (Tranquillini 1979), as demonstrated by Slatyer (1977). The reduction in chlorophyll content (Benecke 1972, Covington 1975), and increase in respiration (Piske & Winkler 1958) with altitude are other causes of the decline in plant photosynthetic capacity.

Differences in climatic parameters with change in altitude for the study area are well documented. The mean diurnal temperature of sites 2000 m above sea-level (m a.s.l.) and above falls by an average of 0.8 °C per 100 m rise in altitude (Gamachu 1988). With increase in altitude, wind speed increases (Geiger 1965, Barry 1992) which affects tissue temperatures, water status and the incidence of mechanical damage (Grace 1977).

Aspect and slope influence the microclimate at any site in mountains, valley basins, etc. (Geiger 1965, Barry 1992). Both affect the radiation income and soil heat flux (Rosenberg *et al.* 1983). Slope affects the receipt of radiation per unit area of absorbing surface, and soil water storage and drainage. Soils on steeper slopes dry more rapidly. The other factor included in this study is soil depth, an important pedogenic property which determines the function of the soil as a reservoir for plants' water supply and directly affects root growth.

Not only site factors, but also stand factors such as tree density, which in this study is defined as number of surviving trees/plot, modify tree growth (Kramer 1988, Wenk *et al.* 1990, Von Gadow & Bredenkamp 1991).

Because of the influence of site and stand factors on the productivity of forest land, decisions on land acquisition and investment, and the silvicultural operations in forest management, are indirectly affected (Worrell & Malcolm 1990a). An understanding of site and stand factors provides the management with important information on planting limits and for predicting the future yield of a stand (Worrell & Malcolm 1990a). The purpose of this study was therefore to investigate and identify site and stand factors which strongly influence the growth of *E. globulus* in the study area.

Materials and methods

Study area

The study was conducted in a fuelwood plantation, situated in the Cheleleka Catchment, *c.* 8 km southeast of Chancho (09° 15'N, 38° 45'E) (Figure 1), altitude 2850–3150 m a.s.l. With varied topography, a rugged and undulating surface, the study area belongs to the most heavily eroded regions of the country. The plantation was established on land formerly used for grazing and agriculture.

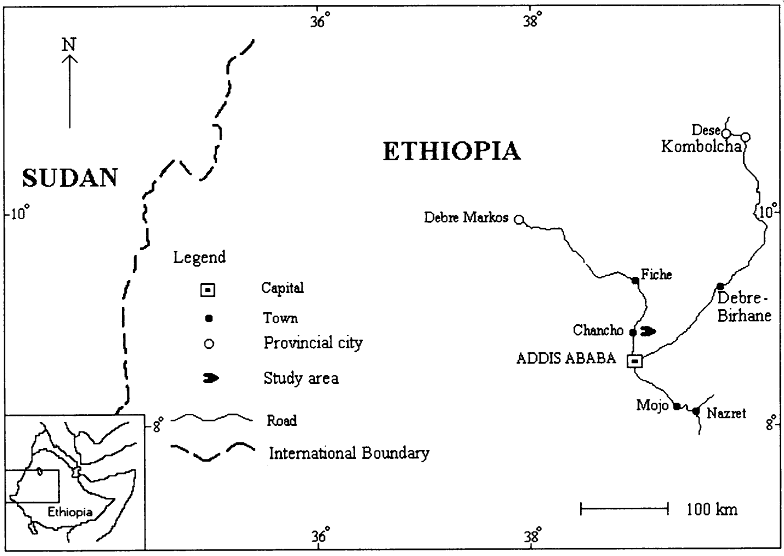

Figure 1. Map of the study area

Soils of the study area are of volcanic origin (Huffnagel 1961, Mohr 1962) and are clayey in texture. Depending on their composition and relief, the soils of the study area differed in colour. On the slopes of the catchment, soils were red to light reddish-brown, whereas in the valley bottom, they were brown to dark in colour.

Under the tree canopy, shrubs and grasses are common. The dominant shrubs along the hillside of the catchment were *Erica arborea* (2950–3150 m a.s.l.), *Rumex nervous* (2850–3150 m a.s.l.), *Rosa abyssinica* (2850–3150 m a.s.l.), *Myrsine africana* (2850–3150 m a.s.l.), *Osyris* spp. (2850–3150 m a.s.l.) and *Budleja polystachya* (2850–3150 m a.s.l.). Few remnant indigenous trees such as *Juniperus procera* (2850–3050 m a.s.l.), *Hagenia abyssinia* (2850 m a.s.l.), *Olea africana* and *Acacia abyssinica* (2850 m a.s.l.) were also found in the study area. Especially *Hagenia abyssinica* was common along stream channels in the catchment area. Herbs such as *Cypoglossum lanceolatum, Plantageo lanceolata, Satureja paradoxia, Carduus kikuyorum* and grasses such as *Sporbolus pyramidalis, Stipa capensis, Andropogon abyssinica* and *Digitaria abyssinica* were common in the study area.

Because there are no direct meteorological measurements from the study area, climatic data from Addis Ababa and Fiche (Figure1)were taken as representative for the site. The main rainy season for the study area is between June and September and the period of short rains is between March and April (Figure 2). The drier months are October to February. The mean maximum day temperatures are low during the wet seasons. According to the Ethiopian Mapping Authority (EMA) (1988), frost is frequent in valley bottoms and at higher altitudes in the study area.

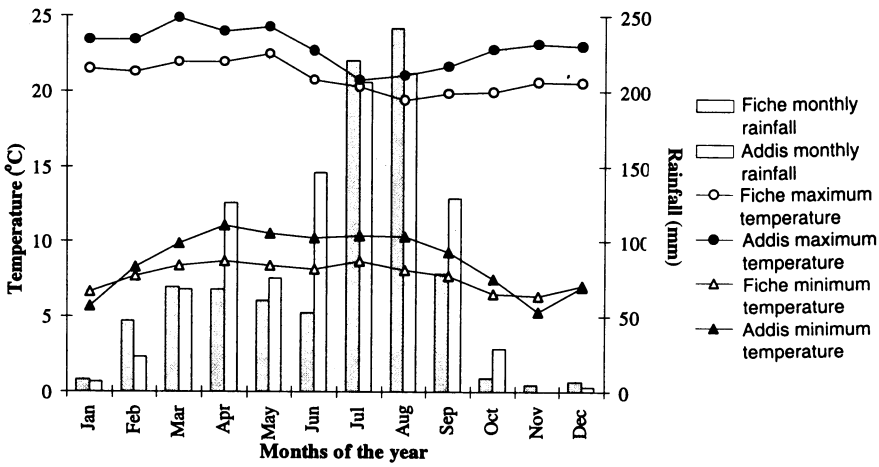

Figure 2. Mean monthly maximum and minimum temperatures and rainfall during the year for Fiche (1984–1989), and Addis Ababa (1984–1989). (Data from the Ethiopian National Meteorology Services Authority)

Field sampling

The sampling was carried out in a 4-y-old fuelwood plantation of *Eucalyptus globulus* in the Cheleleka Catchment. The catchment runs SE-NW, and includes sites of different soil depth, aspect, slope and altitude. This site was selected because it consists of an even-aged plant material raised from seeds collected from Intoto forest, at lower elevation (2550 m a.s.l.) near Addis Ababa. The seedlings were planted at a spacing of 2 × 2 m, with an initial tree density of 2500 seedlings per ha or 125 seedlings per plot (0.05 ha).

A field sampling was conducted by establishing 100 temporary circular plots (0.05 ha) between January and February 1993 (Table 1). The plots were laid out at 100 m vertical interval along four main contours spanning the upper slopes, 2850 to 3150 m a.s.l. (Figure 3). For the inventory and the establishment of the first plot, the village shown in Figure 3 was used as a reference point on the ground. To minimise the edge effect on our measurements, the first and the last plots on a transect were established inside the forest 2 to 25 m from the forest boundary.

Table 1. Numbers of sample plots, soil depths, slopes, measured number of trees, numbers of trees per plot and survival rates per plot for each altitude grouped by aspect four years after planting, in Cheleleka Catchment. Values for soil depth, slope, number of trees per plot and survival rate per plot are given as means ± s.e.

Altitude (m a.s.l.)	Aspect	Number of plots (n)	Soil depth (cm)	Slope (%)	Measured No. of trees	Number of trees per plot (0.05 ha)	Survival rate (%) per plot
3150	NE	3	42.7 ± 2.7	63.3 ± 11.7	86	28.7 ± 10.3	22.9 ± 8.3
	S	2	21.5 ± 1.5	30.0 ± 0.0	33	16.5 ± 1.5	13.2 ± 1.2
	SW	10	34.8 ± 3.2	53.5 ± 4.6	322	32.2 ± 5.3	25.8 ± 4.3
	W	3	39.3 ± 3.0	71.7 ± 11.7	51	17.0 ± 9.2	13.6 ± 7.3
	NW	2	31.5 ± 6.5	42.5 ± 12.5	53	26.5 ± 3.5	21.2 ± 2.8
	N	2	42.5 ± 2.5	72.5 ± 7.5	17	8.5 ± 3.5	6.8 ± 2.8
3050	NE	5	40.0 ± 5.8	63.0 ± 7.0	172	34.4 ± 6.1	27.5 ± 4.9
	S	7	32.9 ± 2.5	67.8 ± 4.9	335	47.9 ± 5.0	38.3 ± 4.0
	SW	9	24.2 ± 2.3	47.8 ± 5.7	295	32.8 ± 5.7	26.2 ± 4.5
	W	5	27.6 ± 2.2	58.0 ± 10.1	201	40.2 ± 5.1	32.2 ± 4.1
	NW	3	48.0 ± 5.0	65.0 ± 15.0	78	26.0 ± 1.2	20.8 + 0.9
	N	1	73.0 ± —	65.0 ± —	27	27.0 ± —	21.6 ± —
2950	NE	1	73.0 ± —	70.0 ± —	4	4.0 ± —	3.2 ± —
	SE	3	15.0 ± 1.2	51.7 ± 1.7	35	11.7 ± 2.0	9.3 ± 1.6
	S	4	20.0 ± 2.0	68.8 ± 2.4	137	34.2 ± 12.0	27.4 ± 9.6
	SW	13	22.4 ± 1.3	58.1 ± 2.8	332	25.5 ± 3.9	20.4 ± 3.1
	W	5	24.4 ± 2.1	55.0 ± 2.7	186	37.2 ± 10.4	29.8 ± 8.4
	NW	3	27.3 ± 4.3	56.7 ± 9.3	78	26.0 ± 7.0	20.8 ± 5.6
	N	6	26.7 ± 3.5	39.2 ± 6.8	220	36.7 ± 9.3	29.3 ± 7.5
2850	S	2	21.5 ± 1.5	37.5 ± 17.5	33	16.5 ± 15.5	16.5 ± 15.5
	SW	6	23.7 ± 1.7	45.0 ± 3.16	158	26.3 ± 8.9	26.3 ± 8.1
	W	2	25.0 ± 2.0	45.0 ± 10.0	60	30.0 ± 8.0	30.0 ± 8.0
	N	3	29.3 ± 1.9	41.7 ± 7.3	133	44.3 ± 9.8	44.3 ± 9.8

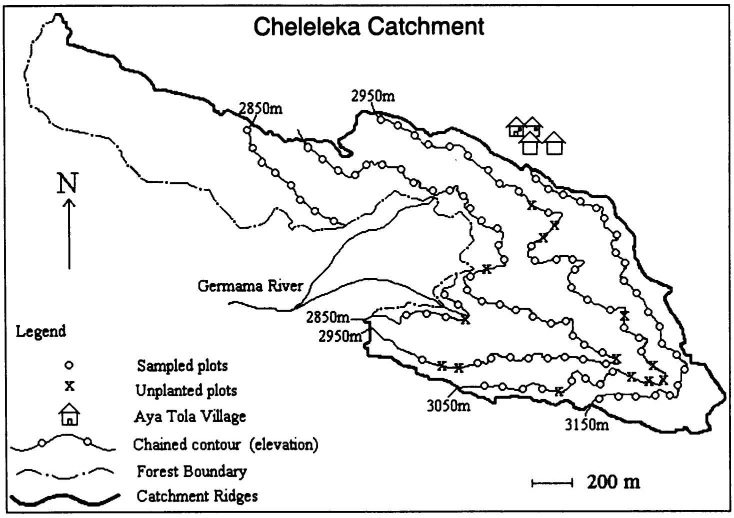

Figure 3. Systematic sampling and layout of the sampled plots at Cheleleka Catchment

All trees in a plot were counted. Tree height (m) and diameter at breast height (cm) of each tree in a plot were measured and recorded. Height and diameter were measured using an aluminium measuring pole and a calliper respectively. The following topographic variables for each plot were also measured and recorded (Table 1):

- Altitude (m a.s.l.) was measured using the Thommen Classic altimeter;
- Slope (S), the angle of inclination of the plot surface, was measured by the Suunto clinometer in percentage;
- Aspect θ (°), which is plot-surface orientation, was measured using the Silva compass by bearing from the north. For the study area, seven aspects were recorded. These were: northeast (NE), southeast (SE), south (S), southwest (SW), west (W), northwest (NW), north (N);
- The soil depth (SD) was measured using a calibrated soil-auger. At each plot, a minimum of six soil depths were randomly measured and the average was used for the analysis.

Data analysis

Means for the measured variables were computed for each plot. The effects of altitude, aspect, slope, soil depth, plot tree density and their interactions were analysed using the general linear model (GLM) procedure of the SAS software package (SAS Institute Inc. 1990). The discrete variables included in the models were altitude, aspect, slope, soil depth tree density, and their interactions. The models used were:

$$Y_1 = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 \quad (1)$$
$$Y_2 = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 \quad (2)$$
$$Y_3 = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 \quad (3)$$

where Y_1, Y_2 and Y_3 are dependent variables plot mean tree height, plot mean diameter at breast height and plot survival rate. The values $b_1 \dots b_8$ are coefficients of the independent variables in the models. The independent variables in the models given above are:

x_1 = altitude	x_2 = aspect	x_3 = slope	$x_4 = x_2 * x_3$
x_5 = soil depth	$x_6 = x_5 * x_3$	x_7 = tree density	$x_8 = x_5 * x_7$

The least square means (adjusted means) were used to assess the significance of effects, after adjusting for other terms in the model. Type III sums of squares were used to test the effects of all the main factors and interactions.

Results and discussion

Influence of site factors (altitude, aspect, slope, soil depth, and their interactions) on tree dimensions and survival

A statistical analysis was performed for the whole data set. The effects of altitude on mean tree height (MTH) [$F(3, 79) = 15.34$, $p < 0.0001$] (Table 2a) and mean diameter at breast height (MDBH) [$F(3, 79) = 10.96$, $p < 0.0001$] (Table 2b) were strongly significant. Trees at an altitude of 2950 m a.s.l. had a greater least square mean tree height (LSMTH), and least square mean diameter at breast height (LSMDBH) than those at other altitudes (Table 3a).

Four years after planting, the average survival rate in *E. globulus* plantations in the study area was $24.4 \pm 1.4\%$ which is very low. According to Pohjonen (1989), low annual rainfall (≤ 1000 mm), the desiccating dry-season winds which prevail from October to February, and the shallow soils are causes of low tree density and survival in the region. However, this study shows no statistically significant effects of any of variables tested on the survival rate (Table 2c).

Young trees of *Eucalyptus globulus* are susceptible to the African mole rat, *Tachyoryctes splendens*, root damage (Alemayehu & Million 1993, unpublished) and weed competition (Pohjonen 1989), which are probable causes of the poor survival rate in the study area.

In the study area, seedlings are planted inside micro-basins (eyebrow terraces). In a such type of plantation establishment, the pit for the seedling should be dug in the centre of the micro-basin, towards the non-fill area. However, because pit preparation and planting are easy on the fill areas of micro-basins, and because it is difficult for unskilled workers to find the centre of the micro-basin, seedlings are planted almost on the edge of the fill riser (personal observation and inquiry). Seedlings planted on the edge of micro-basins are at risk of being washed away down hill during heavy rainstorms (Vletter 1987), which may also be the cause of poor seedling survival in the study area.

Table 2. Table of multivariate analysis using the general linear models procedure

2a) Dependent variable: mean plot tree height (MTH) (m)

Source	DF	F Value	Pr > F
Altitude	3	15.34	0.0001
Aspect	6	0.80	0.5724
Slope	1	0.49	0.4862
Aspect * Slope	6	0.62	0.7100
Soil depth	1	0.02	0.8917
Slope * Soil depth	1	0.57	0.4532
Tree density	1	15.28	0.0002
Soil depth * Tree density	1	1.34	0.2510

2b) Dependent variable: mean plot diameter at breast height (MDBH) (cm)

Source	DF	F Value	Pr > F
Altitude	3	10.96	0.0001
Aspect	6	0.69	0.6619
Slope	1	0.86	0.3578
Aspect * Slope	6	0.47	0.8283
Soil depth	1	0.00	0.9643
Slope * Soil depth	1	0.50	0.4833
Tree density	1	11.26	0.0012
Soil depth * Tree density	1	2.51	0.1173

2c) Dependent variable: plot survival rate (%)

Source	DF	F Value	Pr > F
Altitude	3	1.56	0.2043
Aspect	6	0.59	0.7386
Slope	1	0.29	0.5918
Aspect * Slope	6	0.63	0.7066
Soil depth	1	2.74	0.1018
Slope * Soil depth	1	1.65	0.2031

The mean soil depth and slope of the sampled plots at each altitude and their variation within different elevations are summarised in Figure 4. The average slope per altitude class varies from 40 up to 70% (Figure 4). The soil of plot at 2950 m a.s.l. were shallow compared to those at 3150, 3050 and 2850 m a.s.l. (Figure 4a). As Figure 4b shows, plots at 2950, 3050 and 3150 m a.s.l. were steeper than plots at 2850 m a.s.l. As a result, sites on the valley bottom receive transported materials from sites above them, which may contribute to the improvement of the nutrient status of soils on the valley floor. Despite the addition of nutrients from elevated sites and low gradient, trees on the valley floor (2850 m a.s.l.) grew more slowly and were shorter than those at 2950 m a.s.l. (Table 2a). In spite of shallow soils, the growth of trees at 2950 m a.s.l. was better than that of trees grown on sites with similar slope (Figure 4b), but with deeper soils (Figure 4a) on the upper hillside of the valley (3050–3150 m a.s.l.).

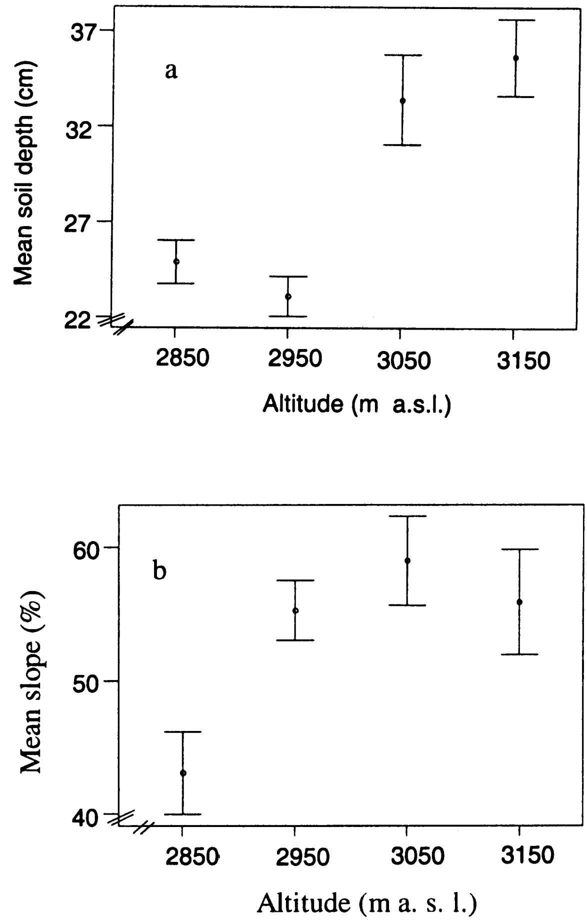

Figure 4. Altitude versus mean soil depth (a) and mean slope (b) in the Cheleleka Catchment (n=100)

The relationship between altitude and least square (adjusted) mean tree height (LSMTH), and least square mean diameter (LSMDBH) is given in Table 3. In general, as altitude increases from valley floor to tree limit, which is about 3200 m a.s.l. for indigenous trees in the region (Uhlig 1988), trees grow slower and become shorter (Tranquillini 1979, Pyrke & Kirkpatrick 1994). However, the LSMTH of trees at 2950 m a.s.l. was 8.4, 21.6, and 22.4% greater than that of trees at 2850 (p=0.0155), 3050 (p=0.0001), and 3150 (p=0.0001) m a.s.l. respectively (Table 3a). The LSMDBH at 2950 m a.s.l. was respectively greater by 6.3, 15.6 and 13.2% than those at 2850 (p=0.0506), 3050 (p = 0.0001) and 3150 (p = 0.0001) m a.s.l. (Table 3b).

Table 3. Pairwise contrast of the least square means (adjusted means) of treatments using the general linear models procedure

3a) Pairwise contrast of least square mean tree height (LSMTH) of each altitude

Altitude (m a.s.l.)	LSMTH (m)	Pr > ITI HO: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
2850	7.5016	1	.	0.0155	0.0028	0.0030
2950	8.1313	2	0.0155	.	0.0001	0.0001
3050	6.6843	3	0.0028	0.0001	.	0.8524
3150	6.6450	4	0.0001	0.0001	0.8524	.

3b) Pairwise contrast of least square mean diameter at breast height (LSMDBH) of each altitude

Altitude (m a.s.l.)	LSMDBH (m)	Pr > ITI HO: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
2850	7.2025	1	.	0.0506	0.0057	0.0506
2950	7.6835	2	0.0506	.	0.0001	0.0001
3050	6.4856	3	0.0057	0.0001	.	0.3528
3150	6.6728	4	0.0506	0.0001	0.3528	.

The most favourable location for tree growth in the study area was at 2950 m a.s.l. which may be caused by the development of 'thermal belt' around this position. As a result, valley bottoms and higher altitudes (3050–3150 m a.s.l.) become cooler than the middle slope. The development of 'thermal belt' on valleys is well documented by Geiger (1965) and Oke (1987) and its direct effect on tree growth is also discussed elsewhere (Mitscherlich 1971).

The development of a warm zone at about 2950 m a.s.l. at night results in an increase in mean temperature at this position. Due to the increased mean temperature, the growing period of trees increases (Tranquillini 1979), which probably contributed to the better performance of trees at 2950 m a.s.l.

The ground surfaces of the sampled plots with varying slopes were oriented to different aspects, i.e. north (360°), northeast (45°), etc. According to Rosenberg *et al.* (1983), differences between aspects and slopes are not critical in the receipt of direct-beam solar radiation in the tropics where the sun remains high throughout the year. Tamrat (1994), in his report on the remaining Afromontane forests on the central plateau of Ethiopia, also found no significant variation between community types of different aspects. In this study, aspect was detected to have no significant effect on tree growth in the study area and no significant influence was found on tree parameters for slope, and its interactions with aspect (Tables 2a & 2b).

Effect of plot tree density on tree growth performance

The tree density for the study area varied from 1 to 76 trees (stems) per plot (0.05 ha) and it was found to have a significant effect on plot mean tree height

(MTH) (p=0.0002) (Table 2a), and plot mean diameter at breast height (MDBH) (p=0.0012) (Table 2b).

Plots with low tree density were excessively open and were infested with weeds, mainly grasses and shrubs (personal observation). According to Daniel *et al.* (1979), tree growth is adversely affected by excessive openings. The trend lines fitted in Figure 5 show the decline of the MTH, and the MDBH as tree density decreases. When tree density is low, much of the solar radiation reaches the ground, which may lead to dominance of grass and shrubs in the site. In such conditions, because of competition in the understorey, trees do not fully utilise the water and nutrients, and their growth rate could consequently be retarded. Similar observations were also made by Spurr and Barnes (1980).

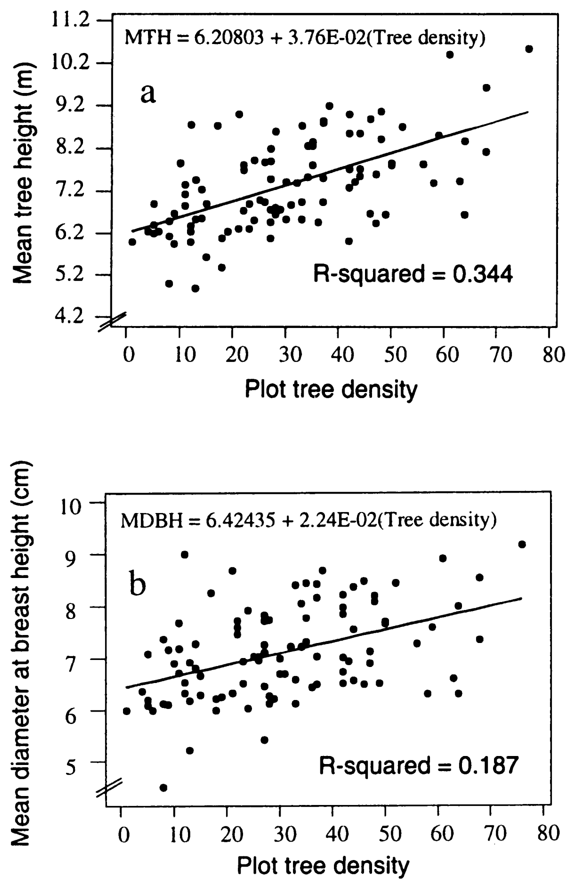

Figure 5. (a) Response of mean tree height (MTH), and (b) mean diameter at breast height (MDBH), to plot tree density after four years in the plantation of *Eucalyptus globulus* at the study area (n=100)

Conclusion and management recommendations

The results of this study show that the growth performance of *Eucalyptus globulus* on the study area was significantly influenced by tree density and altitude.

In the study area, the MTH, and MDBH of *Eucalyptus globulus* increase as plot tree density increases. In denser plots or plots with a high number of survivors, the canopy closes quickly, which may result in the suppression of the weeds. As a result, trees use sunlight, nutrients and water efficiently; thus trees in plots with high density showed better growth performance than those at lower density.

Altitude and other side factors had no significant effect on the survival rate of the regeneration material from Intoto forest. This indicates the adaptation of *E. globulus* to a range of altitude and site factors in the study area. However, the growth performance of trees from this regeneration material was poor at higher altitudes and in valley bottoms. This may be due to differences in meteorological parameters in various topographic situations, which are probably caused by the change of altitude and by the local wind circulation in the catchment. Therefore, this study suggests that further research is needed into the influence of topography on catchment microclimate in relation to tree growth.

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