# Eucalyptus species performance under short rotation conditions on the Vumba highlands in Zimbabwe.

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**Accepted 29 June 2006**

## Abstract

The performance of *Eucalyptus grandis, Eucalyptus globulus* and *Eucalyptus saligna* established at 1515, 1333, and 1190 stems/ha on various sites was evaluated at Vumba in the Eastern Highlands of Zimbabwe. Height, diameter at breast height (DBH) and survival were determined using standard forestry procedures. The trial was established in a randomized block design with three replications. Data were analysed through one-way analysis of variance (ANOVA) at 95 % confidence level using SPSS. *E. grandis* and *E. saligna* performed significantly ($P< 0.05$) better than *E. globulus* in growth and survival after one and four years. Survival after one year was significantly ($P < 0.05$) different across the sites. After four years, survival was significantly ($P < 0.05$) different across sites, species and planting densities. In conclusion this research recommends that for afforestation purposes *E. grandis* and *E. saligna* be planted at a density of 1333 stems/ha on Vumba.

**Key words:** Eucalyptus, growth performance, planting density, survival.

## Introduction

The world's rapidly rising population requires most countries to make the best possible use of their land resources for agriculture, forestry and conservation. Ability to predict where and how well particular plants are likely to grow is vital for land-use planning (Booth, 1996). This is particularly important in the forest industry, considering that the demand for paper products, fuelwood, sawn timber and other wood products is increasing. These products are vital commodities for the growth and development of every country (FAO, 2000). To meet the increasing demand, raw materials must be made available mostly from the tropics and from short rotations of fast growing species. Investment in fast growing single stem tree crops on monoculture plantations in most tropical countries is assuming more importance in maintaining and increasing the world supply of fuelwood, poles, pulp and paper. Currently, eucalyptus and pines are the most commonly grown species in tropical timber plantations (Evans, 1992) accounting for 43 % of all tropical plantation area (FAO, 2000). The rationale for such plantations is that species can be selected for specific or various purposes and technologies. The plantations are tailor-made to achieve the required objectives and are grown over rotations of less than 10 years. Productivity of tropical plantation forests grown on short to medium-term rotation lengths varies greatly from 1 - 2 $m^3$/ha/annum to 25 - 30 $m^3$/ha/annum (FAO, 2000). These short rotation forests have become a reality in many parts of the world in the last twenty years.

Jacobs (1979), listed factors affecting tree plantation yield, among them soils, species, spacing, site-species matching, silvicultural treatment, pests and diseases. Climate has an important influence on plant growth. It is particularly useful as a means of predicting where particular plants will grow, as climatic conditions can be reliably estimated for most locations around the world (Booth, 1996). For each genus, there are some species, which seem to grow better than others almost everywhere (Jackson and Ojo, 1973). The choice of initial spacing is normally determined by the end use of the plantation material, and to some extent by tree form.

Site-species matching is basically a starting point and an integral part of any tree improvement programme. Eucalyptus species have made history in their plasticity and ability to adapt well to areas where they are considered exotic (Jacobs, 1979). Besides this, their fast growth rate has given them much more popularity as they bring quick solutions to fibre and energy problems, environmental rehabilitation and carbon sequestration in most parts of the world. This research focused mainly on the effect of planting density and site-species matching on plantation productivity of *E. grandis* (Rose or Flooded gum), *E. globulus* (Tasmanian blue gum) and *E. saligna* (Sydney blue gum) which are native to Australia.

## Materials and Methods

### Study Area

Vumba is in the Eastern Highlands of Zimbabwe (32°50′E, 19°02′S). Three sites on the Vumba Mountains namely Hoboken, Excelsior and Mapoff were chosen for their distinctly different altitudes and soils. Hoboken is characterized by fine and silty sands and lies at an altitude of 1100 m above sea level (a.s.l) while Excelsior has sandy clay and sandy loams at 1500 m a.s.l. Mapoff is mainly characterised by sandy loams at 1250 m a.s.l.

Vumba experiences a daily average temperature of about 15 °C and 21 °C during winter and summer respectively. The mean annual precipitation is 1200 mm, most of which falls from November to April. On higher ground, showers and drizzle are sometimes experienced. The geology consists of igneous rocks, mainly of plutonic origin exposed by erosion. The most common rocks are granites, which produce highly acidic soils suitable for plantation forestry. In some areas, deep sandy-loam, acidic (pH about 5.5) soils occur because of leaching caused by high precipitation.

### Methodology

*E. grandis, E. saligna* and *E. globulus* were selected for the trial. *E. grandis* seed was purchased from the Forest Research Station, Harare (s/no 28672 category GG2), whilst *E. saligna* was from John Meikle Forest Research Station, Mutare (s/no 25959, 4th generation select seed) and *E. globulus* from Bunnings Forest Products, Western Australia (s/no W122L select seed). The nursery was raised from August 1997 to February 1998. The three species were established on a four year rotation in February 1998 in a randomized block design with three replications on each site at the following spacings and planting densities, 2.2 m×3.0 m (1515 stems/ha), 2.5 m×3.0 m (1333 stems/ha) and 2.8 m×3.0 m (1190 stems/ha). After one year, the trees were measured for DBH to the nearest centimetre using a diameter tape and tree height to the nearest metre, using a height rod. Tree survival was also determined. After four years, the trees were re-assessed for growth performance and height was measured using a Suunto hypsometer.

### Data analysis

Data were analysed using SPSS for Windows 1996 version 10. Species, site and planting density variations were tested for significance through one-way ANOVA. Differences between means were tested using LSD post-hoc tests at 0.05 level of significance. The following model was used:

$$Y_{ijkl} = \mu + S_i + P_j + K_k + (SxP)_{ij} + (SxK)_{ik} + (PxK)_{jk} + e_{ijkl}$$

Where $Y_{ijkl}$ =response variable, $\mu$ = population mean; S=site; P=species; K=planting density; $i^{th}$ survival; $j^{th}$ height; $k^{th}$ DBH, e=random error.

## Results

### Growth characteristics of the species at one year after establishment.

Survival, DBH and height performance of the species across sites is summarised in Table 1.

### Survival

Comparison of species survival showed significant ($P < 0.05$) differences at Excelsior and Mapoff. The trend was *E. saligna>E. grandis>E. globulus* with 85.96 %, 82.91 % and 65.95 % at Excelsior whereas at Mapoff, it was *E. globulus>E. saligna>E. grandis* with 97.12 %, 95.60 % and 91.63 %, respectively.

Survival comparison by planting density within sites was also significant ($P < 0.05$) for Excelsior and Mapoff. At Excelsior, it was 1333 >1515 >1190 stems/ha with 96.89 %, 89.72 % and 87.06 % whereas at Mapoff the ranking was 1190 >1515 >1190 stems/ha with 97.01 %, 94.37 % and 92.97 %, respectively.

Survival comparison of planting density within species was significantly different ($P < 0.05$). Within *E. grandis,* the trend observed was 1190 >1333 >1515 stems/ha with mean survivals of 95.40 %, 94.33 % and 88.73 %, respectively. Within *E. globulus,* the ranking was 1515 >1333 >1190 stems/ha with mean survival percentages of 98.16, 96.97 and 90.09, respectively. Within *E. saligna*, there was no significant ($P > 0.05$) survival difference between the planting densities of 1333 and 1190 stems/ha. However, 1515 stems/ha had a lower ($P < 0.05$) survival of 94.07 % compared to 1333 (95.59 %) and 1190 (95.60 %) stems/ha.

**Table 1:** Mean height, DBH and survival one year after establishment.

| Site | Species | Planting density (stems/ha) | Survival (%) ±SE | Mean DBH (cm)±SE | Mean Height (m)±SE |
|---|---|---|---|---|---|
| Excelsior | *E.grandis* | 1515 | 70.84±1.86 | 5.64±1.19 | 5.92±0.79 |
| | | 1333 | 99.88±0.24 | 5.02±1.62 | 5.28±1.01 |
| | | 1190 | 86.63±1.70 | 3.00±1.20 | 3.69±1.02 |
| | *E.globulus* | 1515 | 94.78±1.55 | 3.79±1.21 | 3.91±1.02 |
| | | 1333 | 95.48±1.10 | 3.35±1.23 | 4.52±1.05 |
| | | 1190 | 82.84±1.19 | 3.08±2.08 | 3.82±1.80 |
| | *E.saligna* | 1515 | 95.52±0.08 | 2.58±1.76 | 3.16±1.22 |
| | | 1333 | 95.30±1.61 | 3.83±1.75 | 3.47±1.44 |
| | | 1190 | 91.73±1.15 | 1.91±1.97 | 3.73±1.34 |
| Hoboken | *E.grandis* | 1515 | 95.52±1.03 | 3.73±2.16 | 4.39±1.83 |
| | | 1333 | 99.79±0.30 | 5.45±1.73 | 6.33±1.31 |
| | | 1190 | 99.84±0.25 | 4.91±4.85 | 5.70±1.33 |
| | *E.globulus* | 1515 | 99.91±0.16 | 3.48±1.18 | 4.68±1.32 |
| | | 1333 | 99.75±0.51 | 3.06±1.24 | 4.54±1.35 |
| | | 1190 | 91.54±0.94 | 2.48±1.14 | 3.82±1.42 |
| | *E.saligna* | 1515 | 95.20±1.24 | 3.84±1.75 | 4.84±1.62 |
| | | 1333 | 91.57±1.30 | 4.69±2.52 | 5.20±1.80 |
| | | 1190 | 95.40±1.23 | 3.71±2.01 | 4.35±1.46 |
| Mapoff | *E.grandis* | 1515 | 91.84±0.71 | 5.39±1.03 | 5.99±0.81 |
| | | 1333 | 83.33±1.66 | 3.96±1.73 | 4.97±1.56 |
| | | 1190 | 99.78±0.45 | 4.38±1.29 | 5.06±1.22 |
| | *E.globulus* | 1515 | 99.78±0.45 | 3.19±1.29 | 3.81±1.17 |
| | | 1333 | 95.68±1.11 | 3.39±1.12 | 4.04±1.04 |
| | | 1190 | 95.89±1.13 | 3.14±1.50 | 4.03±1.44 |
| | *E.saligna* | 1515 | 91.49±1.05 | 3.58±1.08 | 4.28±0.99 |
| | | 1333 | 99.89±0.22 | 3.16±0.60 | 3.80±0.76 |
| | | 1190 | 95.43±2.01 | 4.39±1.09 | 4.95±0.74 |
| Significance | Site | | *** | * | *** |
| | Species | | *** | *** | *** |
| | Planting density | | *** | *** | *** |
| | Site x Species | | *** | *** | ** |
| | Site x Planting density | | *** | *** | *** |
| | Species x Planting density | | *** | ns | ns |

Means within the same column are significantly different at * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$, ns = not significant

**DBH performance**

Breast height diameter comparisons of the species within sites indicated significant (P < 0.05) differences. At Excelsior, the trend was *E. grandis>E. globulus>E. saligna,* with mean DBH values of 4.55 cm, 3.17 cm and 2.77 cm, respectively. The species ranked as *E. grandis>E. saligna>E. globulus* with mean DBH values of 4.69 cm, 4.08 cm and 3.01 cm and 4.77 cm, 3.71 cm and 3.24 cm for Hoboken and Mapoff, respectively.

Breast height diameter comparisons by planting density within sites showed significant differences (P < 0.05) with inconsistent rankings across the sites. At Excelsior, the planting densities ranked as 1515 >1333 >1190 stems/ha with DBH means of 3.77 cm, 4.07 cm and 2.66 cm, respectively. At Hoboken, the ranking was 1333 >1190 >1515 stems/ha with mean DBH values of 4.40 cm, 3.70 cm and 3.68 cm, respectively. A ranking of 1515 >1190 >1333 stems /ha was significant (P < 0.05) at Mapoff with DBH means of 4.05 cm, 3.97 cm and 3.40 cm, respectively.

**Height performance**

A significant difference (P < 0.05) in species mean height was observed within sites. At Excelsior, the species ranked as *E. grandis>E. globulus>E. saligna* with mean height values of 4.96 cm, 4.08 cm and 3.45 cm, respectively. At Hoboken and Mapoff the species ranked as *E. grandis>E. saligna>E. globulus* with mean heights of 5.48 m, 4.80 m and 4.35 m at Hoboken and 5.34 m, 4.35 m and 3.96 m at Mapoff.

Mean height comparisons within sites by planting densities showed marked differences (P < 0.05) which were, however, not consistent across the sites. At Excelsior and Hoboken, the planting densities ranked as 1333 >1515 /ha>1190 stems/ha with mean heights of 4.76 m, 4.33 m and 3.41 m at Excelsior and 5.36 m, 4.64 m and 4.62 m at Hoboken. At Mapoff, the ranking was 1515 >1190 >1333 stems/ha with mean heights of 4.69 m, 4.27 m and 4.68 m, respectively.

**Growth characteristics of the species at four years after establishment.**

Survival, DBH and height performance of the species across sites is summarised in Table 2.

**Survival**

Mean survival for species within sites were significantly (P < 0.05) different at the three sites invariably ranking as *E. saligna>E. grandis>E. globulus* with survival means of 85.96 %, 82.91 % and 65.95 % at Excelsior and 85.43 %, 83.01 % and 36.85 % at Hoboken and finally 88.01 %, 85.79 % and 61.95 % at Mapoff.

Survival based on planting density within sites was significantly different (P < 0.05) for Excelsior with 1333 >1515 >1190 stems/ha with means of 88.18 %, 74.14 % and 72.25 %, respectively. At Hoboken, the trend was 1333 >1190 >1515 stems/ha with 70.99 %, 67.73 % and 66.62 %, respectively. At Mapoff, the planting densities ranked as 1190 >1515 >1333 stems/ha with mean survival percentages of 79.02, 78.92 and 77.83, respectively.

Within species, mean survival based on planting density was significant (P < 0.05) in all cases ranking as 1333 >1515 =1190 stems/ha with means of 85.40 %, 83.94 % and 83.28 %, respectively, for *E. grandis* and 89.95 %, 87.95 % and 82.35 % for *E. saligna* and finally 62.45 %, 54.53 % and 47.76 % for *E. globulus.*

**DBH performance**

At the rotation age, DBH comparisons by species showed consistent and significant variations (P < 0.05) ranking as *E. grandis>E. saligna>E. globulus.* Mean DBH values for Excelsior were 14.26 cm, 13.09 cm and 5.77 cm in respect of species ranking, for Hoboken 14.07 cm, 14.14 cm and 5.18 cm and for Mapoff, 13.02 cm, 10.95 cm and 6.17 cm. In terms of planting density the only significant (P < 0.05) DBH variation was observed at Excelsior with 1515 <1333 stems/ha with means of 10.35 cm and 11.62 cm.

**Height performance**

Rotation age height comparisons within sites indicated significant (P < 0.05) differences and consistent rankings across the sites. The species ranked as *E. grandis>E. saligna>E. globulus* with mean heights of 16.43 m, 15.90 m and 7.83 m at Excelsior, 16.80 m, 16.65 m, 5.88 m at Hoboken and at Mapoff 15.44 m, 14.53 m and 6.80 m. Mean height comparisons at 4 years by planting density were only significant at Excelsior where the planting density of 1515 stems/ha (mean height 12.60 m) had shorter trees (P < 0.05) than 1333 stems/ha with a mean height of 14.09 m.

**Table 2:** Mean height, DBH and survival four years after establishment.

| Site | Species | Planting density (stems/ha) | Survival (%) ±SE | Mean DBH (cm)±SE | Mean Height (m)±SE |
|---|---|---|---|---|---|
| Excelsior | *E.grandis* | 1515 | 78.91±2.41 | 13.98±4.24 | 15.79±3.64 |
| | | 1333 | 82.84±0.89 | 15.34±4.05 | 17.44±3.36 |
| | | 1190 | 86.98±1.18 | 13.47±4.27 | 16.04±3.65 |
| | *E.globulus* | 1515 | 67.15±0.93 | 4.97±2.66 | 7.06±3.07 |
| | | 1333 | 91.11±1.37 | 5.67±1.68 | 8.31±2.65 |
| | | 1190 | 39.58±1.98 | 6.69±3.54 | 8.11±3.61 |
| | *E.saligna* | 1515 | 77.09±1.16 | 12.12±3.35 | 14.96±3.14 |
| | | 1333 | 90.59±1.69 | 13.84±4.35 | 16.53±4.03 |
| | | 1190 | 90.19±2.09 | 13.31±3.80 | 16.20±3.51 |
| Hoboken | *E.grandis* | 1515 | 83.32±1.99 | 13.97±3.39 | 16.62±2.00 |
| | | 1333 | 92.86±1.23 | 13.66±3.45 | 16.80±2.25 |
| | | 1190 | 72.86±1.08 | 14.57±2.94 | 16.97±1.95 |
| | *E.globulus* | 1515 | 33.70±2.99 | 4.96±1.48 | 5.97±1.87 |
| | | 1333 | 33.30±0.82 | 5.48±1.85 | 6.13±1.92 |
| | | 1190 | 43.54±1.33 | 5.08±2.18 | 5.55±2.16 |
| | *E.saligna* | 1515 | 82.84±1.21 | 14.32±3.47 | 17.12±2.28 |
| | | 1333 | 86.83±0.89 | 13.77±4.82 | 15.93±3.59 |
| | | 1190 | 86.78±1.54 | 14.33±4.26 | 16.90±3.27 |
| Mapoff | *E.grandis* | 1515 | 86.88±1.17 | 14.47±2.88 | 16.21±2.78 |
| | | 1333 | 80.50±2.26 | 10.79±3.27 | 13.49±3.59 |
| | | 1190 | 90.00±1.44 | 13.80±2.94 | 16.61±1.98 |
| | *E.globulus* | 1515 | 62.74±1.28 | 6.30±2.47 | 7.09±2.77 |
| | | 1333 | 62.95±1.18 | 6.94±2.26 | 7.71±2.53 |
| | | 1190 | 60.17±1.83 | 5.26±1.44 | 5.62±1.51 |
| | *E.saligna* | 1515 | 87.12±1.03 | 10.78±2.67 | 14.64±3.19 |
| | | 1333 | 90.04±1.22 | 10.70±2.87 | 13.98±3.01 |
| | | 1190 | 86.88±1.18 | 11.37±3.58 | 14.53±3.02 |
| Significance | Site | | *** | ** | *** |
| | Species | | *** | *** | *** |
| | Planting density | | *** | Ns | ns |
| | Site x Species | | *** | *** | ** |
| | Site x Planting density | | *** | Ns | * |
| | Species x Planting density | | *** | Ns | ns |

Means within the same column are significantly different at * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$, ns = not significant

**Discussion**

Of the three species tried at Vumba, *E. grandis* performed best at all the sites in terms of height and DBH after one and four years of age. This is in line with previous experiences where *E. grandis* performed better than other eucalyptus species in many conditions. A comparison of the three species in the Ethiopian highlands showed that *E. grandis* performs best in moist, warm lowlands (below 1600 m a.s.l) followed by *E. saligna* and lastly *E. globulus* (Pohjonen, 1989). In this case, at an altitude of 1850 m a.s.l and annual precipitation of 1200 mm, *E. grandis,* with a Mean Annual Increment (MAI) of 56 $m^3$/ha/annum and heights exceeding 16 m outgrew *E. saligna* (35.4 $m^3$/ha/annum) and *E. globulus* (27.5 $m^3$/ha/annum) at heights of 14 m and 13 m respectively. Under similar rainfall conditions, but lower altitude, the same trend was observed at Vumba highlands. Similar field trials with Australian eucalyptus established in semi-arid to humid areas in Kenya showed that *E. saligna* and *E. grandis* had the best growth and survival in humid areas (Milimo, 1989). Evans (1992) reported *E. grandis* (of the Coffs Harbour origin) to be a fast grower and well adapted to Zimbabwe, yielding about 40 $m^3$/ha/annum and 35 $m^3$/ha/annum (NAS, 1980) in Zimbabwe and South Africa respectively. Barrett et al (1975), reported *E. grandis* as the fastest growing exotic species in Zimbabwe, which is planted over a wide range of sites with a MAI exceeding 40 $m^3$/ha/annum in good sites and marginal sites producing no more than 7 $m^3$/ha/annum. *E. saligna* prefers higher altitudes (1800 m.a.s.l) and much cooler conditions than *E. grandis* (Pohjonen, 1989).

Like the Vumba experience, *E. globulus* has been difficult to establish in the Ethiopian highlands requiring repeated blanking (Pohjonen, 1989). However, contrary to the Ethiopian highlands where the saplings died during the first dry season, Vumba highlands experienced significant *E. globulus* mortality in all sites during the second to the fourth year of establishment. This mortality was highest at Hoboken as a result of low altitude since *E. globulus* has a preference for higher altitudes (Pohjonen, 1989).

During the first year of growth, planting density of 1333 compared to 1190 and 1515 stems/ha achieved the best mean DBH and height. This indicates faster growth at 1333 stems/ha before canopy closure with individual trees growing independently whereas at 1190 stems/ha canopy closure is attained much later with reduced competition as trees continue to be independent of each other.

In general, total volume production decreases with an increase in spacing (Lohani, 1980). Wider spacings usually lead to some loss in total volume production per hectare but individual trees grow larger because a stand of trees planted far apart will have a lower photosynthetic surface area per hectare to intercept light in the early years and consequently reduce yield. However, a wide spacing enables individual trees to develop and maintain large crowns and their root systems to occupy a large volume of soil before competition starts, both of which enhance growth (Evans, 1992).

With low densities adopted for planting eucalyptus in India, the effect of density on survival was observed to decline when it was increased from 1111 stems/ha (91 %) to 10 000 stems/ha (56 %) (Lohani, 1980). Diameter growth strongly correlated with planting density, as density decreased, average DBH increased (e.g. at age 6 from 9.32 cm at 10 000 stems/ha to 14.25 cm at 1001 stems/ha or 14.56 cm at 1000 stems/ha). Bhatia (1980) reported that a planting density of 1111 stems/ha resulted in taller and thicker trees than 4444 stems/ha in a eucalyptus hybrid plantation. Average yield per tree increased from low to high planting densities (Vacharangkura, 1988). Spacing trials with *E. camaldulensis, E. deglupta,* and *E. tereticornis* conducted at Takuapa, Phang Nga Province in Thailand, demonstrated that each species of eucalyptus growing under densities of 2500 stems/ha produced more biomass than 1111 and 625 stems/ha (Sahunalu, 1984). Contrary to these observations, the lack of this direct relationship between growth parameters (height and DBH) and planting density noted in the trials at Vumba highlands, must have resulted from the narrow range of the planting densities used that is from 1190 to 1515 stems/ha or the effect of species-planting density interaction.

Growth in eucalyptus species varies according to climate, soils and altitude (Jacobs, 1979). Significant variations in growth and survival observed by site after one and four years of establishment show Hoboken to have the best trees mainly resulting from the lower altitude, a site requirement for both *E. grandis* and *E. saligna.* The lower altitude, however, increased mortality for *E. globulus*, which prefers higher altitudes. The three species are generally not demanding in terms of soil fertility and are mostly influenced by rainfall and altitude and are thus adaptable to changing environmental conditions (Jacobs, 1979). The other significant variations in growth characteristics and survival emanated from interactions of site and species, site and planting density, planting density and species, which overshadowed the effects of site on growth parameters and survival. Survival of *E. globulus* was lowest at Hoboken compared to the other sites resulting from site-species interaction. Site-planting density interactions manifested in the 1515 and 1190 stems/ha significantly impacted on survival, which was generally lower for the highest planting density, both after one and four years of age.

## Conclusion

In conclusion this research recommends that for afforestation purposes *E. grandis* and *E. saligna* be planted at a density of 1333 stems/ha in Vumba.

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