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WHICH EUCALYPT GROWS BEST IN ETHIOPIAN HIGHLANDS?

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Abstract—Based on four, 5 to 32 years old species trials, the growth potential of *Eucalyptus globulus* Labill., *Eucalyptus saligna* Sm., *Eucalyptus grandis* W. Hill ex Maid. and *Eucalyptus citriodora* Hook. was studied in the Ethiopian highlands. Volume production of *E. globulus*, *E. saligna* and *E. grandis* was comparable over a wide zone (altitude 2200–2600 m above sea level, rainfall 1000–1200 mm a^{-1}) in Ethiopia's central plateau whereas *E. citriodora* was less productive. *E. grandis* produced most in the moister and lower southern and western areas; the highest mean annual increment measured for it was 60 m^3 ha^{-1} a^{-1} at the age of 9.1 years. In a thinned trial all four species developed a two-storey structure after harvest. Combined production of fuelwood (under storey) and transmission poles (upper storey) seems feasible for *E. grandis* and *E. saligna* in suitable growing sites. *E. citriodora* is a potential plantation species for the essential oils industry in the country.

Keywords—Exotic forests, *Eucalyptus grandis*, *Eucalyptus saligna*, *Eucalyptus globulus*, *Eucalyptus citriodora*, adaptation, species selection.

1. INTRODUCTION

Eucalypts are the most common plantation trees in Ethiopia. They were introduced at the turn of the century in response to the deepening fuelwood shortage.[2] During a prolonged period of private forestry, starting at the beginning of the 1900s and lasting until the revolution of 1974–75, about 90,000 ha of eucalypts were planted in the surroundings of Addis Ababa and the other Ethiopian highland cities and towns.[4,5]

The revolution interrupted the plantation establishment for a few years. Planting of eucalypts was resumed in the 1980s when peri-urban fuelwood plantation schemes were initiated by the African Development Bank, the United Nations Sudano-Sahelian Office and the World Bank. At the end of the 1980s the additional area under post-revolution *Eucalyptus* plantations totalled about 20,000 hectares.[8]

Eucalypts have been planted over the Ethiopian central plateau, at altitudes ranging from 1400 to 3500 m a.s.l., and in rainfall zones of 700–2000 mm a^{-1}. The most widely planted species is *Eucalyptus globulus* Labill.,[10] which is popular in climatic zones similar to that of Addis Ababa (altitude 2400 m, rainfall 1100 mm a^{-1}).

The rural population favors *E. globulus* as an excellent fuel. It is also desired in small and medium scale construction.[1] At the peak of the Ethiopian *Eucalyptus* husbandry around the 1960s to the 1970s, small-sized *E. globulus* construction poles were exported to neighboring Arab countries. Although the production of construction poles was at that time the main target of production, the tree tops, branches, and even leaves were used for fuel.

The second most common eucalypt is *Eucalyptus camaldulensis* Dehnh., which is planted in the drier and lower edges of the central plateau. The closely related *Eucalyptus tereticornis* Sm. has also been planted in the same zone. Growth results[7,15] of neither *E. camaldulensis* nor *E. tereticornis* have been in accordance with the expectations or popularity of these species.

Eucalyptus saligna Sm. and to some extent *Eucalyptus grandis* W. Hill ex Maid. were the preferred species in the plantings of the late 1960s and early 1970s in fertile areas, especially along the eastern escarpment of the Rift Valley.[11] *Eucalyptus viminalis* Labill. has been planted at the highest possible plantation altitudes, around 3000 m because of its frost resistance.[7] A later introduction in Ethiopia is *Eucalyptus citriodora* Hook., the lemon scented eucalypt, a possible and planned raw material for the factory extracting essential oils in Wondo Genet.

The growth potential of various eucalypts in the Ethiopian highlands can be reflected back to the requirements in their home country,

Australia. *E. globulus* is a southern species growing mainly on the island of Tasmania. It tolerates some frost days but not a severe dry season. *E. saligna* belongs to the eastern bluegum group of mainland Australia. Its typical environments are moister slopes and cooler mountains. *E. grandis* is by its natural habitat very similar to *E. saligna*; its optimal growing sites, however, are somewhat warmer than those of *E. saligna*. *E. citriodora* occurs in the central and northern areas of eastern Queensland; the main occurrence is higher and rather dry country some distance from the coast.[3]

The purpose of this study was, based on local Ethiopian forest research since 1975, to investigate the growth of the main fuelwood and pole plantation species *Eucalyptus globulus* in comparison with other promising fast growing eucalypts in the zone: *E. saligna*, *E. grandis* and *E. citriodora*. The aim was to establish the yield and the optimal growing sites for these main species.

2. SPECIES TRIALS

Comparative species trials of eucalypts in Ethiopia are rather few. The oldest trial was established in 1956 in Holetta (2400 m a.s.l.) 50 km west of Addis Ababa. It has two *Eucalyptus* species: *E. globulus* and *E. saligna*. Both eucalypts have grown reasonably well in this trial and clearly better than any other exotic or indigenous species.[15]

An important set of species elimination trials, with a number of different eucalypts, was established by the Forest Research Center in 1975: in Menagesha (altitude 2400 m a.s.l., rainfall 1100 mm a^{-1}, 20 km west of Addis Ababa), Hamulo (2200 m, 1200 mm a^{-1}, 250 km south of Addis Ababa) and Bellete (1600 m, 1600 mm a^{-1}, 300 km southwest of Addis Ababa). These trials have been measured at the age of 5[7] and 10 years.[15] Based on these measurements, planting of *E. globulus* was recommended in the central highlands and of *E. saligna*, *E. grandis* and *E. viminalis* in the moister western and south-western parts of the country.[14,15]

The third and most thoroughly planned *Eucalyptus* trial was established in the Wondo Genet Forest Resources Institute in 1980 (1800 m, 1200 mm a^{-1}, 270 km south of Addis Ababa).[13] By then, based on earlier information, it was obvious that *E. globulus*, *E. saligna* and *E. grandis* were worthy of more careful growth studies.

3. MATERIAL

The Wondo Genet trial was the main source of growth data for this study. Additional data on *E. saligna*, *E. globulus* and *E. grandis* were collected from temporary sample plots in the species trials of Holetta, Bellete, Menagesha and Hamulo.

The Wondo Genet trial used a latin square design with four replicates and a spacing of 2 × 2 m (100 trees per plot). The trial has been measured 3 times: at ages 5.0, 7.8 and 9.1 years (Table 1). The volume calculations in the first assessment[13] were based on stand basal area, mean height and a form factor of 0.45. In the later measurements stem volumes were computed by diameter classes using models of Örlander[15] and Pukkala and Pohjonen.[9]

After the yield assessment at 5.0 years the plots were thinned in November 1984 removing 17–22% of the stand basal area. The following average volumes were removed: *E. grandis*

Table 1. Characteristics of the Eucalyptus stands in Wondo Genet at measurement points of 5.0, 7.8 and 9.1 years

Stand	Age (years)	*DomH* (m)	*DgM* (cm)	*G* (m^2 ha^{-1})	*V* (m^3 ha^{-1})	*MAI* (m^3 ha^{-1} a^{-1})
E. saligna	5.0	18.5	nm	nm	160	32.0
E. saligna	7.8	26.5	18.6	26.1	252	32.3
E. saligna	9.1	26.7	19.7	28.4	274	30.1
E. globulus	5.0	19.8	nm	nm	165	33.0
E. globulus	7.8	25.7	17.2	21.9	215	27.6
E. globulus	9.1	26.2	18.1	23.1	228	25.1
E. grandis	5.0	22.8	nm	nm	263	52.6
E. grandis	7.8	32.1	20.4	38.6	442	56.7
E. grandis	9.1	33.0	22.2	44.4	521	57.3
E. citriod.	5.0	16.0	nm	nm	117	23.4
E. citriod.	7.8	23.4	16.6	24.7	223	28.6
E. citriod.	9.1	24.3	17.4	28.1	258	28.4

DomH = dominant height, *DgM* = basal area median diameter, *G* = basal area, *V* = volume, *MAI* = Mean Annual Increment, nm = not measured.

Table 2. Significant differences ($p > 0.01$, analysis of variance) between species in some stand characteristics in Wondo Genet eucalypt trial. ESA = *E. saligna*, EGL = *E. globulus*, EGR = *E. grandis*, ECI = *E. citriodora*. For other abbreviations, see Table 1

Characteristics	Age (Years)	Significant differences
Volume	7.8	EGR > others
Volume	9.1	EGR > others
DomH	7.8	EGR > others, ESA > ECI, EGL > ECI
DomH	9.1	EGR > others, ESA > ECI, EGL > ECI
DgM	7.8	EGR > others, ESA > ECI
DgM	9.1	EGR > others, ESA > ECI
G	7.8	EGR > others
G	9.1	EGR > others

44 $m^3 ha^{-1}$, *E. saligna* 26 $m^3 ha^{-1}$, *E. globulus* 20 $m^3 ha^{-1}$, *E. citriodora* 13 $m^3 ha^{-1}$.

4. RESULTS

In Wondo Genet there were clear differences between the species in stand volume and other characteristics (Table 2). Generally, *E. grandis* was superior to the other species. There were only a few significant differences in the stand characteristics between the other three species.

The total volume production increased almost linearly from 5.0 to 9.1 years for all species (Fig. 1). *E. grandis* produced most, about 570 $m^3 ha^{-1}$ during the first 9.1 years.

The mean annual increment (MAI) for *E. grandis* was almost twice that of the other species (Fig. 2). There is an indication of the maximum of the mean annual increment for all species at the age of about 8 years, but especially for *E. saligna*, *E. globulus* and *E. citriodora*.

All the tested species developed a two-storey structure after the harvest (Fig. 3). Coppicing was the strongest in *E. grandis*. The volume of the coppices in 1989, 4.3 years after thinning, were as follows:

E. grandis 23.3 $m^3 ha^{-1}$
E. saligna 13.8 $m^3 ha^{-1}$
E. citriodora 11.8 $m^3 ha^{-1}$
E. globulus 3.3 $m^3 ha^{-1}$.

Additional comparisons between *E. grandis*, *E. saligna* and *E. globulus* were made using the available data from Menagesha, Hamulo, Bellete and Holetta (Fig. 4). In Menagesha, *E. globulus* produced most at time points of 10, 12 and 14 years. At Hamulo *E. globulus* was more productive than *E. saligna* at the age of 12 years, but the opposite result was obtained, based on a different set of temporary plots, at the age of 14 years. In Bellete, both *E. grandis* and *E. saligna* produced more than *E. globulus* at age 10 years, but at the age 14 years all the species produced about the same volume. In Holetta, *E. globulus* and *E. saligna* were equally productive at the age of 31 years.

5. DISCUSSION

The growth results of this study follow rather consistently the prevailing climatic conditions in the Ethiopian highlands and climatic

Fig. 1. Total volume production of eucalypts in Wondo Genet trial. At age 5.0 years the total volume equals the standing volume. At age 7.8 and 9.1 years the total production is the sum of the standing volume and that removed in November 1984.

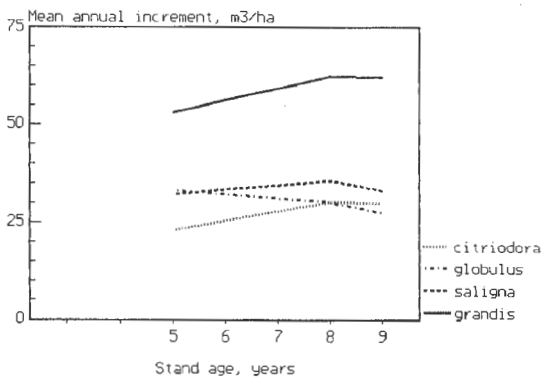

Fig. 2. Mean annual increment of eucalypts in Wondo Genet trial.

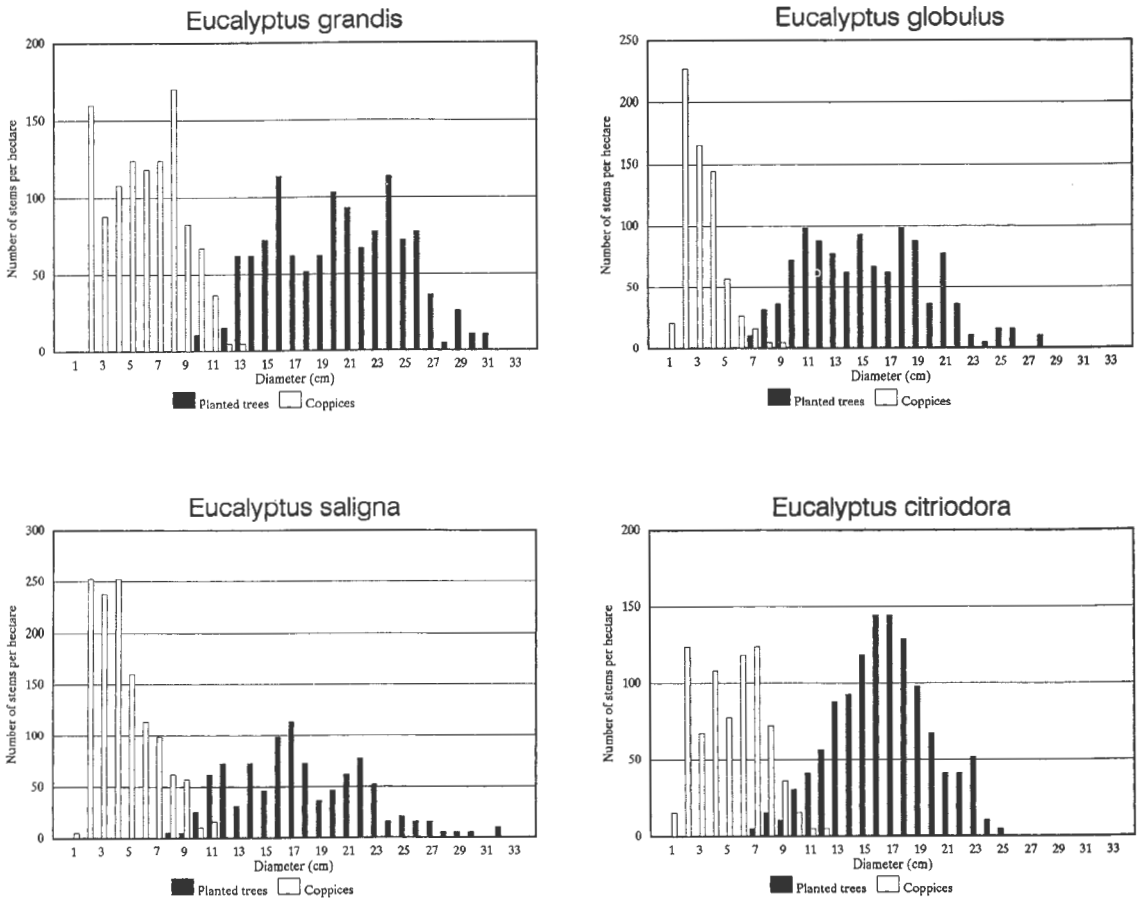

Fig. 3. Diameter distribution of different species in Wondo Genet trial at 9.1 years of age. The coppice storey has developed from stumps harvested at the age of 5.0 years.

requirements of the four species in their home country. In general the Ethiopian highlands are cool, as they are for the most part over 2000 m above sea level. It is expected that the Tasmanian blue gum, *E. globulus* grows well at these heights. Similar climatic adaptation explains the popularity of *E. globulus* in mediterranean conditions, in Portugal and Spain.[3] The Ethiopian species trial results from the 1970s and onwards justify the selection of *E. globulus* for wide areas in Ethiopia as a fast growing plantation species for fuelwood and poles.

As the climatic requirements for *E. saligna* and especially for *E. grandis* include more warmth and rainfall than for *E. globulus*, it is not surprising that they also produced better in Wondo Genet, Hamulo and Bellete. All these sites are original Ethiopian mountain

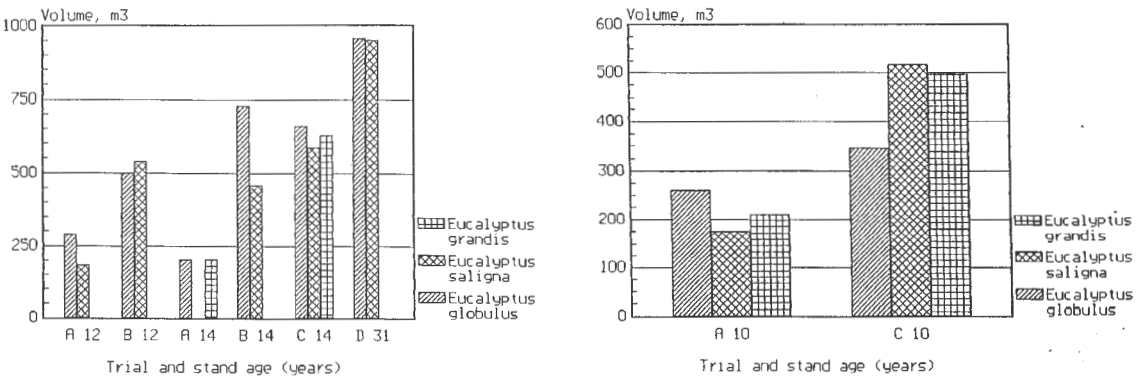

Fig. 4. Comparison of volume production of three eucalypts in Menagesha (A), Hamulo (B), Bellete (C) and Holetta (D) species trials at the ages of 10, 12, 14 and 31 years.

rainforests, now for the most part cleared for agriculture and grazing. If such areas were to be converted into forests again, *E. grandis* and *E. saligna* are valid choices. Another choice, which in the future seems more obvious, is to manage through natural regeneration the remnant rainforests in these areas, to convert surplus areas back into East African rainforests. In light of the present results, land type suitability and availability, the expectations for *E. grandis* and *E. saligna* as high yielding plantation species for Ethiopian highlands are not as promising for practical forestry.

The growth of *E. citriodora* is not comparable with the other three species. However, due to its possible use for essential oils, plantation forestry with *E. citriodora* is fully feasible in the moist Ethiopian highlands, such as conditions prevailing in Wondo Genet where the first essential oils factory has been located.

Compared to many other African and Asian countries the species selection trials in the Forest Research Service of Ethiopia are rather good, although they are few in number. Data is available from 5 trials from various geographical parts of the central plateau. In all trials the plot size has been adequate: at least 400 m^2. The Holetta trial, which was already planted in 1956, gives valuable information of the growth potential of *Eucalyptus globulus* and *Eucalyptus saligna* (over 30 years of age).

However, only the latin square design in Wondo Genet fulfills the criteria of a conventional species trial. There are no proper replicates in the Holetta, Menagesha, Hamulo, and Bellete trials. Only the Holetta trial is on even land. The others are located on uneven hillsides where the placement of a single plot on the slope may greatly affect the growth. The growth data of Holetta, Menagesha, Hamulo and Bellete trials can therefore be regarded only as indicative.

The results from the earlier trials are quite consistent. The results have also been regarded sufficient for species recommendation at the practical level.[14,15] The selection of *E. globulus* as the main species, which apparently was originally done rather intuitively, is supported by these trials.

The growth results in the replicated Wondo Genet trial are very clear: *E. grandis* grew fastest by far. The mean annual increment of about 60 $m^3\,ha^{-1}\,a^{-1}$ at 9.1 years, is the highest recorded of any plantation species in Ethiopia.

The Wondo Genet trial is located at the eastern edge of the Rift Valley, at an altitude of 1850 m. The average annual rainfall is 1200 mm. The trial plots are located on a deep and fertile soil, on the foothills of the surrounding mountains, where the ground water conditions are also favorable.[3,6] This trial, being a demonstration site in a training institute, was established more carefully than usual. Therefore, direct application of the growth results to other sites and similar rainfall environments should be done with caution.

The growth results provide some direction for the selection of *Eucalyptus* species for different sites. In the central highlands with a typical altitude of 2400 m (as in Addis Ababa) *E. globulus* should be the choice. At lower altitudes and higher rainfall areas, *E. saligna* should take over. In the best sites, with deep soils and enough rainfall, *E. grandis* may be chosen. Whenever *E. grandis* is selected it needs careful tending for maximum production since it is the most sensitive to the environment. In general, the triple *E. globulus*, *E. saligna* and *E. grandis* is the immediate choice for short rotation plantations in the Ethiopian highlands. The final choice between them is more a site specific decision to be made based on microclimatic and soil fertility conditions.

The good growth of *E. grandis* in favorable conditions makes it suitable for intensively managed special-purpose plantations. The first of these is already in practice in Ethiopia: the growing of long, straight stems for transmission line poles.

E. camaldulensis is more suitable to the lower and drier edges of the plateau, whereas *E. viminalis* is adapted to the coolest and wettest mountain slopes. The species selection along the ecological gradients is further illustrated in Fig. 5. This gradient based species selection follows rather well the older recommendations.[14,15]

The growing of *E. camaldulensis* in Ethiopia is justified by results and recommendations from similar ecological conditions elsewhere, not necessarily only by local growth results.[7,11,14,15] New selection trials of *E. camaldulensis* and *E. tereticornis*, with comparison to *E. globulus*, are still needed at altitudes less than 2400 m and at rainfall zones less than 1000 mm a^{-1}.

The growth results achieved in this study, are generally comparable or somewhat higher than reported with the same species elsewhere in

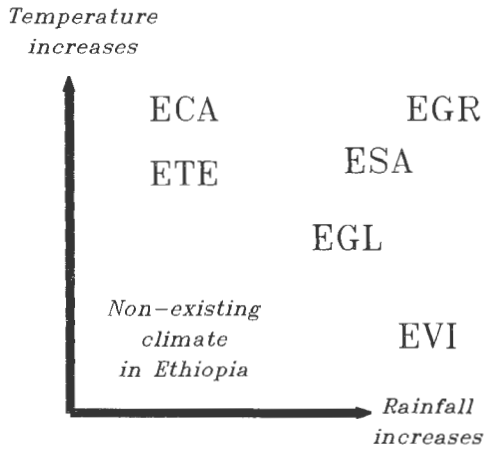

Fig. 5. Species recommendation for eucalypts in the Ethiopian highlands based on gradients in temperature and humidity conditions. Symbols: ECA = *E. camaldulensis*, EGR = *E. grandis*, ESA = *E. saligna*, ETE = *E. tereticornis*, EGL = *E. globulus*, EVI = *E. viminalis*.

the world. *E. globulus*, for instance, has been reported to produce 25 $m^3\ ha^{-1}\ a^{-1}$ in Uruguay, *E. saligna* 42 $m^3\ ha^{-1}\ a^{-1}$ in Hawaii, and *E. grandis* 50 $m^3\ ha^{-1}\ a^{-1}$ in Argentina,[3] all planted as exotics, outside Australia. In the light of the growth potential, Ethiopia is well comparable with any other tropical country where fast growing eucalypt plantations are feasible.

All the species coppiced well after thinning and produced a clear lower storey. The ranking of the species, however, was rather surprising. One might have expected, based on the reputation of *E. globulus* as a vigorously coppicing species, that it might coppice most and *E. saligna* and *E. grandis* least. *E. grandis*, however, produced the most vigorous coppice, and *E. globulus* was the poorest. The favorable soil conditions might have favored the coppicing of the more demanding *E. grandis*.

In Ethiopia the most important products of *Eucalyptus* plantations are fuelwood and poles. Even if the plantation is established for pole production, it always produces small amounts of fuelwood. Because fuelwood is regularly harvested by manual methods, the small size of trees removed is an advantage. One way to manage *Eucalyptus* stands for combined production of poles and fuelwood is to create two distinct storeys in the stand: the upper storey trees are grown for large poles using long rotations, whereas the under storey comprises coppices which are harvested at few year intervals. The obvious time point to establish the lower storey is the first thinning of the plantation.

The Wondo Genet trial gives some indication as to how suitable the four *Eucalyptus* species are for this kind of management. Each species allows the lower-storey trees to survive and grow, but there are clear differences between the species.

The establishment of eucalypt plantations has been criticized somewhat in Ethiopia, as well as in other tropical countries. However, at least one purely ecological reason justifies the planting: under Ethiopian conditions, eucalypts are the most efficient converters of solar energy into biomass.[1] As there is an acute scarcity of fuelwood and construction timber in the highlands, *Eucalyptus* plantations can most effectively alleviate this problem and decrease the pressure on natural forests.

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