

Growth and form of *Eucalyptus grandis* provenances at Wondo Genet, southern Ethiopia

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Summary

Twelve provenances of *Eucalyptus grandis* from a wide range of localities in Australia, and one from a planted stand in Zambia, were established in 1991 in a trial at Wondo Genet, southern Ethiopia. A randomized complete block design with three replications and 49 trees per plot was used. To compare the provenances, stem diameter at breast height over bark (DBH), height, form, branching characteristics and survival of trees were assessed for the inner 25 trees in each plot at 8 y of age. Stem diameter showed very significant variation ($P < 0.001$), the seedlot from Mt George, Taree, NSW, having the greatest diameter (18.4 cm) and that from Cherry Tree State Forest, NSW, having the smallest (13.8 cm). Branch diameter was the only other attribute to exhibit significant variation. The excellent growth in this trial (average height 22 m at 8 y) makes these comparisons of particular interest. The overall volume production (mean annual increment 25–41 m³ ha⁻¹) was well above the minimum acceptable growth observed on good sites elsewhere. Differences between provenances were small and mostly not statistically significant, and no pattern of geographic variation was detected. No single provenance stood out as being much superior to the others. Hence all provenances should be maintained for further selection and breeding and to maximize genetic diversity of the species in Ethiopia.

Keywords: provenance trials; growth; stem form; habit; *Eucalyptus grandis*; Ethiopia

Introduction

Eucalyptus grandis W.Hill ex Maiden, commonly known as flooded gum or rose gum, is a rapidly growing tree up to 75 m high in natural stands, with smooth white bark above a short rough basal stocking (Eldridge *et al.* 1994). It belongs to the sub-genus *Symphyomyrtus* (Pryor and Johnson 1971) and is closely related to *E. saligna* Smith, with which it was included until its valid description as a separate species in 1918 (Burgess 1983; Eldridge *et al.* 1994).

The natural range of *E. grandis* is a narrow band within 100 km of the eastern Australian coast, extending from latitude 17°S near Atherton, Queensland, to 33°S near Newcastle, New South Wales (NSW) (Eldridge *et al.* 1994; Arnold *et al.* 1996). *Eucalyptus grandis* is probably the most widely planted of all eucalypts for

industrial wood production, with a global plantation area estimated to be about 2 M ha in 1987 (Burgess 1988; Eldridge *et al.* 1994). Most of this area is in Brazil (>1 M ha) and South Africa (300 000 ha), but there are also large plantations in Argentina, Australia, India, Uruguay, Zambia, Zimbabwe and other countries (Eldridge *et al.* 1994; Turnbull 1999).

Eucalyptus grandis is generally the best eucalypt in volume production and stem form among those tested when planted on suitable sites (Zobel *et al.* 1987), and Eldridge *et al.* (1994) considered it to be among the most productive eucalypts in the world. In nature it generally occupies moderately fertile, lower valley slopes, often adjacent to rainforests. It grows on a wide range of soil types in plantations. Given a favourable environment and good silviculture, *E. grandis* plantations commonly yield timber volumes >25 m³ ha⁻¹ y⁻¹ (Eldridge *et al.* 1994).

Since their introduction to Ethiopia about 108 y ago, eucalypts have played an important role in day-to-day life of both rural and urban societies. The chronology of eucalypt introduction to Ethiopia, and the habit, ecology, socio-economic aspects, uses, taxonomy and genetics, site matching, management, farming and impact of eucalypts have been critically reviewed (Demel Teketay 2000; Dechasa Jiru 2001; Tsegaye Bekele 2001). Many Ethiopians are absolutely dependent on eucalypts as a source of fuelwood, wood for house construction and income (Davidson 1995; Turnbull 1999).

While initial public interest in Ethiopia was concentrated on *E. globulus* and *E. camaldulensis* because of their ease of propagation and rapid growth, other eucalypts were more or less neglected. With the beginning of modern development and industrialization, however, the potential importance of other eucalypts was realised — particularly those yielding timber more suitable for building and industrial purposes. Hence a number of species unknown in Ethiopia up to that time (*E. grandis*, *E. saligna*, *E. sideroxylon* and *E. viminalis*) were introduced by Australian, French, British and Ethiopian foresters (von Breitenbach 1961).

Eucalyptus grandis is among 10 of the 70 eucalypt species introduced to Ethiopia which have been reasonably well tested in suitable ecological zones (Davidson 1995). Overall, 62 species represented by 178 provenances, 124 of known origin and 54 of unknown origin, have been tried in Ethiopia (Amare Getahun *et al.* 1990). The first comprehensive research results came from

Table 1. Climatic conditions of the experimental site at Wondo Genet and climatic requirements for viable plantations of *E. grandis*

Parameter	Wondo Genet ^a	Requirements for viable production ^b
Mean annual rainfall (mm)	1200	700–2500
Mean annual temperature (°C)	19	14–25
Mean maximum temperature (°C)	28	25–34
Mean minimum temperature (°C)	8	3–16
Annual potential evapo-transpiration (mm)	1392	Unspecified

Sources: ^aAnonymous (1988) and Corbett (2001); ^bBooth and Pryor (1991)

species elimination trials at Menagesha (central Ethiopia), Hamulo (southern Ethiopia) and Bellete (south-western Ethiopia) forest areas. In the first two places *E. grandis* has grown slightly better than *E. saligna*, while at Bellete it has done comparatively well (Örlander 1986a; Davidson 1995).

Despite the widespread planting of eucalypts in Ethiopia, early introductions were of unknown origin and there has not been systematic selection and use of best-performing provenances. The genetic base is suspected to have been narrow (EFAP 1994; Davidson 1995). To make more effective use of the genetic resources of eucalypts in general and of *E. grandis* in particular, a key research requirement has been to identify provenances most compatible with the Ethiopian climate, soil factors and social needs. The early trials with *E. grandis* were species elimination and growth trials (Pohjonen 1989; Davidson 1995; Negash Mamo *et al.* 1995).

This paper reports one of the earliest *E. grandis* provenance trials at Wondo Genet, southern Ethiopia. The objective of the trial was to assess the variation in growth and morphological characteristics among provenances of the species, and to select the most suitable provenances for plantation establishment.

Materials and methods

Study site

The experiment was established in the compound of Wondo Genet College of Forestry, southern Ethiopia. This site is located at 7°13'N and 38°37'E, about 273 km south of Addis Ababa, at an altitude of 1800 m. The site is in dry Afromontane forest which stretches along the escarpment of the Great Rift Valley. The soils are characterized by layers of homogenous materials with various textural sizes (gravel, coarse sand, silt and clay) and shapes (smooth, round and rectangular). These soils are common on colluvial foot and alluvial toe slopes, and are classified as Eutric Fluvisols (Anonymous 1988). Soil pH ranges between 3.9 at natural forest sites and 7.3 at pasture sites, with an average value of 5.7 (Zewdu and Högberg 2000). The area has an average annual rainfall of 1200 mm with a bimodal distribution in two rainy seasons: a minor rainy period from February to April and a more extensive period from July to September. There is a four-month dry season from October to February. Other climatic conditions at the site are shown in Table 1.

The natural vegetation of the study site is dominated by *Albizia gummifera*, *Celtis africana*, *Cordia africana*, *Croton macrostachyus*, *Ficus sur*, *Ficus thonningii*, *Milletia ferruginea*,

Olea capensis ssp. *hochstetteri* and *Syzygium guineense*. Shrubs and very small trees include *Allophylus abyssinicus* and *Vernonia amygdalina*. Species in plantations include *Cupressus lusitanica*, *E. citriodora*, *E. grandis*, *Grevillea robusta*, *Juniperus procera*, *Pinus patula* and others. There is also a *Coffea arabica* plantation with shade trees of *Acacia abyssinica* and *Albizia gummifera*, *Cordia africana*, etc. Nomenclature of plants follows Friis (1992, 1995).

Seed sources and nursery techniques

In February 1991, 13 provenances of *E. grandis* (Table 2) were introduced from the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Forest Research. All were from New South Wales and Queensland (Fig. 1) except one, a landrace from a plantation in Zambia.

To protect the seeds from damaging agents they were fumigated with carbon dioxide and/or carbon disulfide. The seedlings were raised in a soil mixture with two parts of forest soil and one part of sand, potted in polyethylene tubes and planted at the age of 6 mo.

Experimental design and site management

The experimental design used was a randomized complete block design with three replications for each provenance. Plots contained 49 trees (7 x 7 trees) at a spacing of 2.0 m x 2.0 m (2500 stems

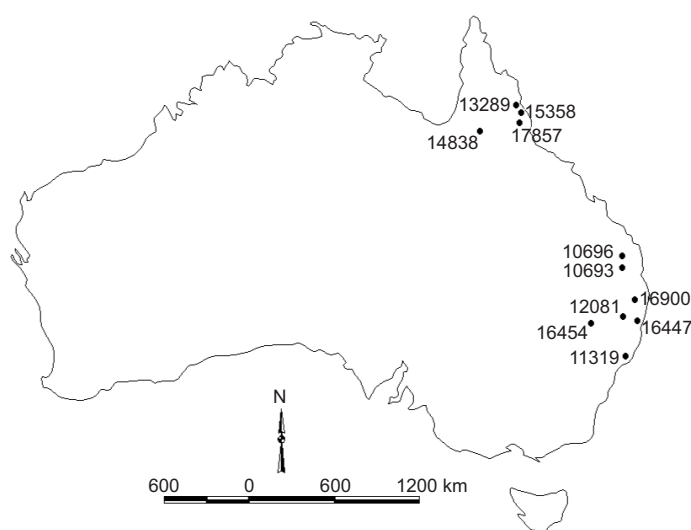


Figure 1. Seed sources of *Eucalyptus grandis* in Australia used in the provenance trial at Wondo Genet, southern Ethiopia

Table 2. Geographic origin of seed lots of *E. grandis* used in the 1991 provenance trial at Wondo Genet, South Ethiopia

CSIRO number	Number of parent trees	Locality of origin	Latitude (S)	Longitude (E)	Altitude (m)
10630	Unknown	Chati, Zambia	12°50'	127°50'	1250
10693	3	Veteran Logging Area, NE Gympie, Qld	26°07'	152°42'	76
10696	4	Bellthorpe SF, Qld	26°52'	152°42'	460
11319	Unknown	Bulahdelah, NSW	32°30'	152°13'	3
12081	Unknown	Coffs Harbour district, NSW	30°00'	152°02'	950
13289	17	Mt Lewis, Timber Reserve 66, Qld	16°36'	145°16'	1000
14519	25	Mt George, Taree, NSW	31°50'	152°01'	230
14838	7	WNW Cardwell, Qld	18°14'	143°00'	620
15358	22	24 km NE Atherton, Qld	17°06'	145°36'	1050
16447	10	Near Coffs Harbour, NSW	30°13'	152°56'	630
16454	15	Near Coffs Harbour, NSW	30°24'	153°0'	150
16900	8	Cherry Tree SF, NSW	28°54'	152°49'	480
17857	11	10 km S Ravenshoe, Qld	17°42'	145°29'	925

NSW = New South Wales; Qld = Queensland; SF = State Forest

ha⁻¹). The spacing between blocks and plots was 4 m and 3 m respectively, so that the trial occupied a total area of about 1.1 ha.

The site was flat and appeared to be fairly uniform. It was prepared by complete clearing of natural vegetation, destumping, digging and pitting. Planting was done at the beginning of the main rainy season in July 1991. Spot weeding was carried out once a year in the first two years, followed by irregular weeding until canopy closure.

Assessment

Eight years after planting, the inner 25 trees per plot were assessed for survival, height and stem diameter at breast height (DBH) over bark. The following attributes (Otegbeye and Samarawira 1991) were also assessed: (1) number of forks — the number of times forking had occurred along the tree bole; (2) height of first fork — the distance from the ground to the point on the bole where the first fork appeared; (3) stem form — a score ranging from 1 (best) to 6 (worst); (4) branch diameter — the mean diameter, near the bole, of five branches chosen at random along the crown of each tree; (5) branch angle — a score ranging from 1 (near horizontal) to 4 (near vertical); and (6) number of branches — total number of living branches along the tree bole.

Statistical analyses

Data for percentage survival were arcsine transformed to approximate normality (Snedecor and Cochran 1989). Volume was calculated using the model (Örlander 1986b):

$$\ln(V) = -3.3670 + 1.7527 \ln(DBH) + 1.2132 \ln(H),$$

where V = volume (dm³ tree⁻¹); DBH = diameter at breast height (cm) and H = height (m).

Plot means for the assessed parameters were subjected to analyses of variance (ANOVA) using Statistical Analysis Systems (SAS 1999–2001). When provenances' means differed significantly, the differences were tested with Duncan's Multiple Range Test (DMRT).

Results and discussion

The provenances differed significantly ($P < 0.001$) in their DBH, but height, survival and volume did not show statistically significant variation ($P > 0.05$) (Table 3). Taree was taller (23.2 m) than any other provenance and Ravenshoe the shortest (21.5 m). Similarly, the Taree seedlot showed the greatest volume (326 m³ ha⁻¹), while the material from Zambia had the least volume (202 m³ ha⁻¹) (Table 3).

Significant differences ($P < 0.05$) were found among provenances for branch diameter; but there were no significant differences among provenances in the number of forks, height to first fork, stem form, branch angle and number of branches (Table 4). The greatest branch diameter (3.10 cm) was scored by the provenance from Atherton and the smallest (2.22 cm) by the Gympie provenance. The best stem form (2.06) was achieved by Taree, while the Cardwell provenance had the poorest (3.26), though differences were not significant.

The Taree provenance of *E. grandis* had the greatest mean DBH (18.4 cm) and Cherry Tree the least (13.8 cm). The Cherry Tree provenance, however, showed the greater survival of these two provenances (70% cf. 51%), and this might have contributed to the lower DBH, as trees in denser stands experience heightened competition. The Taree provenance also showed slightly greater mean height than other provenances (Table 3) and exhibited the best stem form (Table 4). The superiority of Taree in volume production can be attributed to its advantages in DBH and height.

The Taree provenance, from a more southerly location and lower altitude than most other provenances (Table 2), grew best in this trial. This is contrary to a previously-reported result (Arnold *et al.* 1996) that *E. grandis* from low-altitude sites of New South Wales had poor survival and growth in tropical and sub-tropical environments. The performance of the Taree provenance at Wondo Genet might be ascribed to the favourable climatic conditions, especially the high rainfall, at the trial site (Table 1). The seedlot that ranked second-best for diameter growth was

Table 3. Means of survival, height, diameter, volume and volume increment for *E. grandis* provenance trial at age 8 y in Wondo Genet, southern Ethiopia

Provenance	Survival (%)	Height (m)	DBH (cm)	Volume (m ³ ha ⁻¹)	MAI (m ³ ha ⁻¹)
10630, Zambia	44	22.3	15.9cbd	202	25.3
10693, Gympie	52	21.5	14.9cde	219	27.7
10696, Bellthorpe	58	23.1	15.2bcde	258	32.0
11319, Bulahdelah	51	21.9	15.6cde	223	28.0
12081, Coffs Harbour A	49	22.4	15.1cde	221	27.7
13289, Mt Lewis	66	21.9	15.1cde	274	34.0
14519, Mt George	51	23.2	18.4a	326	40.7
14838, Cardwell	58	22.0	16.9b	290	36.3
15358, Atherton	52	22.9	16.6bc	280	35.0
16447, Coffs Harbour B	59	22.7	15.7bcd	286	36.0
16454, Coffs Harbour C	53	22.3	14.7de	220	27.7
16900, Cherry Tree	70	21.7	13.8e	248	31.0
17857, Ravenshoe	63	21.6	15.2bcde	262	33.0
ANOVA Provenance <i>P</i>	0.195 ^{ns}	0.741	0.0004 ^{***}	0.476 ^{ns}	0.475 ^{ns}

Means followed by the same letter are not significantly different ($P < 0.001$)

*** = Very highly significant ($P < 0.001$)

^{ns} = Not significant ($P < 0.05$)

Table 4. Means of number of forks, height to first fork, stem form, branch diameter, branch angle and number of branches for *E. grandis* provenance trial at age 8 y in Wondo Genet, southern Ethiopia

Provenance	Number of forks	Height to first fork (m)	Stem form (score 1–6)	Branch diameter (cm)	Branch angle (score 1–4)	Number of branches
10630, Zambia	0.10	13.8	2.2	2.45c	2.9	8.7
10693, Gympie	0.00	15.7	2.2	2.22c	3.1	6.2
10696, Bellthorpe	0.30	15.1	2.4	2.36c	2.7	8.3
11319, Bulahdelah	0.18	13.4	2.3	2.38bc	3.9	6.1
12081, Coffs Harbour A	0.04	14.6	3.1	2.45bc	2.6	7.6
13289, Mt Lewis	0.00	12.1	3.1	2.61abc	2.9	7.5
14519, Mt George	0.13	14.5	2.1	2.89ab	2.8	8.5
14838, Cardwell	0.04	13.1	3.2	2.65abc	2.6	7.5
15358, Atherton	0.00	13.6	2.5	3.10a	2.2	7.9
16447, Coffs Harbour B	0.05	15.2	2.4	2.54bc	2.5	7.9
16454, Coffs Harbour C	0.09	14.5	2.2	2.40bc	2.8	6.4
16900, Cherry Tree	0.15	15.5	2.5	2.53c	2.9	6.8
17857, Ravenshoe	0.04	14.92	2.2	2.23c	2.6	7.8
ANOVA Provenance <i>P</i>	0.051 ^{ns}	0.7595 ^{ns}	0.1205 ^{ns}	0.0227*	0.3531 ^{ns}	0.5001 ^{ns}

Means followed by the same letter are not significantly different

* = Significant ($P < 0.05$)

^{ns} = Not significant ($P > 0.05$)

from Cardwell. This also exhibited the second-greatest volume (although only slightly better than provenances ranked below it), but ranked eighth in height and had the poorest stem form. This is consistent with results of a similar provenance trial at Loxton, Australia, where the Cardwell provenance also had the poorest stem form (Arnold *et al.* 1996).

Though differences in survival were not significant at age 8 y, the Cherry Tree provenance had the highest survival followed by Mount Lewis. The survival ranged from 70% (Cherry Tree) to 44% (Zambia). The latter result may reflect inferior adaptability arising from a narrow genetic base.

Generally, mortality was subjectively attributable to abiotic factors such as drought and debarking, although biotic problems like disease were also experienced during the assessment period. In particular, *Botryosphaeria* species (fungi causing stem and branch canker) have been isolated from the trial plantation (Alemu Gezahegn *pers. comm.*). Elsewhere, Evans (1996) has reported that 40% of *E. grandis* from Coffs Harbour, NSW, in the main part of the species' natural range (26–31°S), suffered canker damage when grown in tropical lowlands. In contrast, a seedlot of *E. grandis* from near Atherton (17°S) achieved a growth rate of 35–40 m³ ha⁻¹ y⁻¹ and was significantly less susceptible to canker (Zobel *et*

al. 1987; Evans 1996). At Wondo Genet this provenance ranked third in diameter and height, though significant variation was not detected for height (Table 3), and fourth for volume production (MAI 35 m³ ha⁻¹), and it had a survival of 52% (Table 3).

Eucalyptus grandis provenance trials in other parts of the world (for example, Hawaii, Zimbabwe and Australia) have often, but not always, revealed large significant differences in performance between provenances (Zobel *et al.* 1987; Eldridge *et al.* 1994; Arnold *et al.* 1996). In south-eastern China, significant variation for volume was found (Wang *et al.* 1993). In the present study the climate of the site lies within the range of conditions favorable for cultivation of *E. grandis*; significant differences between provenances were detected for only two of the parameters investigated, i.e. stem diameter and branch diameter.

The MAI of this trial ranged between 25 m³ ha⁻¹ (Zambia) and 41 m³ ha⁻¹ (Taree), exceeding the MAI of 25 m³ ha⁻¹ reported on best sites elsewhere (Eldridge *et al.* 1994).

It has been suggested that significant genetic diversity in plantations helps to counter severe outbreaks of pests and diseases (Wingfield *et al.* 1991). It is therefore wise to keep all the provenances of the species at the study site to maintain the diversity of the gene pool for establishing good quality, large-scale plantations of *E. grandis* in the future. Seed parents can be selected in this trial regardless of provenance.

Conclusions

Stem and branch diameters varied significantly between provenances, with the greatest diameter growth being shown by a provenance from Taree, NSW. Volume production by all provenances in this trial was equal to or better than that obtained on fertile sites elsewhere. This trial has shown that *E. grandis* has high potential for future plantation establishment in Ethiopia.

Since Ethiopia is located in an area of Africa climatically suitable for *E. grandis*, further trials in different agro-ecological zones of the country are needed to fully examine variability between the provenances. All the provenances studied in the trial reported should be maintained for further selection and breeding, and to maintain genetic diversity of the species in the country.

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