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

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Summary

A trial testing 10 provenances from across the natural range of *Eucalyptus saligna* and a local land race was established at Wondo Genet, southern Ethiopia. Eight years after planting, survival, tree height, diameter at breast height over bark, stem form, number of forks, height to the first fork, number of branches, branch diameter and branch angle were assessed. Volume per hectare was also calculated. Survival ranged between 36% (a provenance from 87 km north of Windsor, NSW) and 79% (Consuelo Tableland, Queensland), and differences were significant ($P < 0.05$). Among morphological characteristics, only the number of branches showed significant variation ($P < 0.05$), with the greatest number (12.4) being recorded for the Bulahdelah, NSW, provenance and the least (8.5) for the Clyde River, NSW, provenance. Major growth and morphological parameters (tree height, diameter, volume and stem form) did not differ significantly. The overall volume production (mean annual increment 26.4 m^3 ha^{-1}) was well above the minimum acceptable growth observed on good sites elsewhere. Differences between provenances were small and mostly not significant, and no pattern of geographic variation was detected. Given the acceptable mean annual increment, those provenances represented by an adequate number of parent trees could be maintained for further selection and breeding, and to maintain genetic diversity of the species in Ethiopia.

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

Introduction

Sydney blue gum, *Eucalyptus saligna* Smith, is a straight evergreen tree up to 55 m in height in its natural habitat (FAO 1981; Pohjonen 1989). It belongs to sub-genus *Symphyomyrtus* (Eldridge *et al.* 1994) and is closely related to *E. grandis*. It occurs naturally between latitudes 28°S and 35°S in catchments of coastal and tableland rivers flowing into the Pacific Ocean in southern Queensland and most of New South Wales. Within its natural range the mean annual rainfall is 700–1800 mm (uniform or bimodal distribution), mean maximum temperature is 22–32°C, mean minimum temperature is 1–14°C and mean annual temperature is 14–23°C with a dry season of 0–6 months (Booth and Pryor 1991). It usually grows on moderately fertile loams which are moist but not waterlogged. The parent rock may be shale, sandstone, conglomerate or basalt (Turnbull and Pryor 1984).

It is estimated that outside Australia there are at least 500 000 ha of successful *E. saligna* plantations (Pohjonen 1989). *Eucalyptus saligna* is planted commercially in the North Island of New Zealand and in many other countries including Angola, Brazil and Hawaii (Eldridge *et al*. 1994). It has also been planted on an operational scale in Munnesa forest, Ethiopia (Pohjonen 1989). The species is an important multi-purpose hardwood which is used for firewood, charcoal, timber, furniture, veneer, bee forage and flooring. It is usually straight and its extremely good stem form suits it to transmission-line poles (Pohjonen 1989); it is also greatly valued for construction purposes in mid-altitude areas of Ethiopia. During the last five years of the National Tree Seed Project (Addis Ababa), *E. saligna* seed has been among the most-requested eucalypt species, following *E. globulus* and *E. camaldulensis*.

Eucalypts were introduced to Ethiopia in 1895 to solve an acute shortage of construction timber and fuelwood (Teferi 1961; von Breitenbach 1961). *Eucalyptus globulus* and *E. camaldulensis* became part of the landscape within a very short time, while *E. saligna* was introduced more recently in recognition of the need to capitalize on the potential of other eucalypts for development and industrialization (von Breitenbach 1961; Davidson 1995).

The first *E. saligna* trial in Ethiopia, consisting of only one plot and subjected to uncontrolled cutting, was reported in 1956 by Holota Agricultural Research Center. The growth rate was comparable to that of *E. grandis* (Pohjonen 1989). Plots of *E. grandis* and *E. saligna* planted near Addis Ababa in the late 1950s showed better growth than *E. globulus* when fenced and protected from cattle and sheep (FAO 1981). In addition, in species elimination trials conducted in the Bellete forest area (south-western Ethiopia), and in Hamulo and Menagesha (central Ethiopia), *E. saligna* has performed very well with remarkable mean annual increment (Örlander 1986a; Davidson 1995). These results, however, were based on limited material. Systematic collections from a wide range of natural provenances did not become available in Ethiopia until 1991 when the present trial was established.

This paper reports growth and form of an *E. saligna* provenance trial at Wondo Genet, southern Ethiopia. Assessments of provenance growth and form are presented.

Table 1. *Eucalyptus saligna* provenances used in the trial at Wondo Genet

CSIRO number	No. of parents	Origin: Locality	Origin: Latitude (S)	Origin: Longitude (E)	Origin: Altitude (m)
7786	12	87 km N of Windsor, NSW	32°22'	150°33'	300
13029	1	NE of Bulahdelah, NSW	32°22'	152°28'	80
13263	11	Consuelo Tablelands, Qld	24°57'	148°03'	1090
13327	9	NW of Kyogle, NSW	28°32'	152°46'	350
13336	11	E of Guyra, NSW	30°06'	152°08'	1100
13339	4	W of Urbenville, NSW	32°0'	152°24'	680
13340	3	NE of Warwick, Qld	27°58'	152°12'	850
13341	10	Kenilworth, Qld	26°41'	152°37'	470
14435	3	Kenilworth State Forest, Qld	26°38'	152°33'	600
16620	5	Clyde River, Yadboro, NSW	35°20'	150°12'	60
*	Bulk	Ethiopia			

* = Bulked seed collected from the local land race of *E. saligna* of unknown origin at several sites
NSW = New South Wales; Qld = Queensland

Materials and methods

Seed source

Seed of ten provenances of *E. saligna* was supplied by the Forestry and Forest Products Division of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia. One local land race from Ethiopia was also included in the trial (Table 1 and Fig. 1).

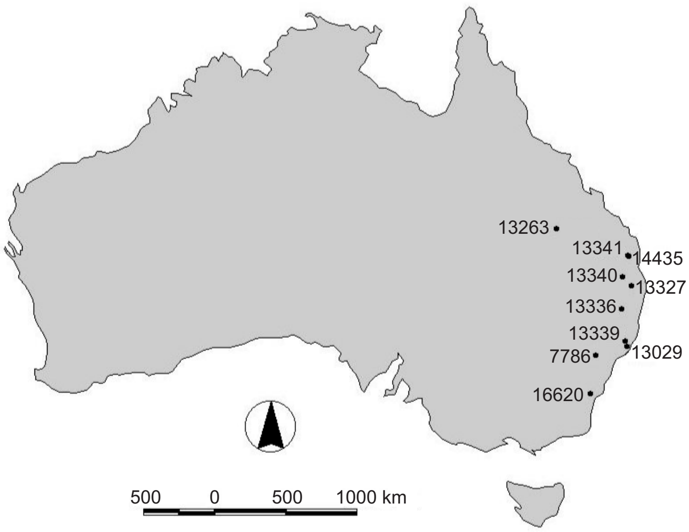

Figure 1. Seed sources of *Eucalyptus saligna* in Australia used in the provenance trial at Wondo Genet, southern Ethiopia

Trial site

The trial site is located in the compound of Wondo Genet College of Forestry (7°06'N, 38°37'E) on the eastern slope of the Rift Valley escarpment about 1800 m asl. The climate is characterised by two rainy seasons. The short rainy season, from February to April, is followed by a short dry season in May and then by a long rainy season from July to September. The long dry season lasts from October to February. Average annual rainfall of the area is 1244 mm; the mean annual temperature is 19°C, mean minimum temperature 8°C and mean maximum temperature 27.8°C. Soils are characterised by layers of homogenous materials with various textural sizes (gravel, silt, clay) and classified as Eutric Fluvisols; pH is 5.7 (Zewdu Eshetu and Högberg 2000). The site includes both natural and planted forests. The natural forest consists of *Celtis africana*, *Albizia gummifera*, *Podocarpus falcatus* and *Millettia ferruginea.* Plantations are mainly of *Eucalyptus* species, *Pinus patula*, *Grevillea robusta* and *Juniperus procera.*

Experimental design and establishment techniques

The experimental design was randomised complete blocks with three replications for each provenance. Forty-nine seedlings per plot were planted at a spacing of 2 m x 2 m. The distance between plots was 3 m, and between blocks 4 m. The trial site had a total area of about 0.8 ha. The site is flat and appeared to be fairly uniform.

Seedlings were raised in polythene tubes in the nursery of the Forestry Research Center, Addis Ababa, using a potting mix of two parts forest soil and one part sandy soil. The planting site was prepared by complete clearing of secondary forest. Pits were dug and seedlings planted in July 1991, the beginning of the main rainy season. Weed control was carried out twice a year in the first two years and subsequently annually when necessary.

Assessment

The inner 25 trees per plot were used for assessment to avoid border effects. At the age of 8 y, tree height (m), diameter at breast height (DBH) over bark (cm) and tree survival (%) were measured. The following parameters (Otegbeye and Samarawira 1991) were also assessed: (1) stem form — a score ranging from 1 (best) to 6 (worst); (2) number of forks — the number of times forking had

Table 2. Mean survival, height, diameter, volume growth and morphological characteristics of *Eucalyptus saligna* provenances at Wondo Genet at age 8 y

Provenance	Survival (%)	Height (m)	DBH (cm)	Volume ($m^3 ha^{-1}$)	MAI ($m^3 ha^{-1}$)	No. of forks	Height to first fork (m)	Stem form (score 1–6)	Branch diameter (cm)	Branch angle (score 1–4)	No. of branches
7786, Windsor	36 c	19.3	16.3	181	22.6	1.1	9.5	3.9	3.2	2.9	10.1abc
13029, Bulahdelah	39 bc	21.6	16.9	204	25.5	0.2	12.6	2.4	2.9	2.6	12.4a
13263, Consuelo Tablelands	79 a	18.0	14.3	249	31.1	0.4	9.6	3.8	3.2	2.6	9.2c
13327, Kyogle	52 bc	19.4	15.2	205	25.7	0.1	12.1	2.4	2.8	2.7	10.4abc
13336 Guyra	47 bc	19.4	15.5	191	23.8	0.2	10.0	2.8	3.0	2.6	9.1c
13339, Urbenville	52 bc	18.9	14.7	185	23.2	0.0	11.9	3.1	3.1	2.6	9.6bc
13340, Warwick	51 bc	19.8	15.4	199	24.9	0.1	11.4	3.6	2.8	2.6	8.6c
13341, Kenilworth	55 bc	19.5	15.1	209	26.1	0.2	10.5	3.1	3.3	2.4	9.1c
14435, Kenilworth SF	60 ab	20.4	15.0	238	29.8	0.7	12.9	2.9	2.6	2.8	9.7bc
16620, Clyde River	51 bc	18.8	15.3	188	23.6	0.2	9.9	3.9	2.5	2.8	8.5c
Local land race	47 bc	22.2	17.2	275	34.4	0.1	13.7	2.9	2.8	2.6	11.9ab
Mean	51	19.8	15.6	211	26.4	0.3	11.3	3.2	2.9	2.6	9.9
ANOVA											
Provenance *P*	0.024*	0.16^{ns}	0.38^{ns}	0.74^{ns}	0.74^{ns}	0.72^{ns}	0.24^{ns}	0.11^{ns}	0.10^{ns}	0.78^{ns}	0.04*

Means with the same letter are not significant. * = significant ($P < 0.05$); ^{ns} = not significant ($P > 0.05$).

occurred along the tree bole; (3) height of first fork — the distance from the ground to the point on the bole where the first fork appeared; (4) number of branches — total number of living branches along the tree bole; (5) branch diameter — the mean diameter, near the bole, of five branches chosen at random along the crown of each tree; and (6) branch angle — a score ranging from 1 (near horizontal) to 4 (near vertical).

Statistical analyses

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

$$\ln(V) = -3.3228 + 1.7527 \times \ln(DBH) + 1.2132 \times \ln(H),$$

where V = volume ($dm^3\ tree^{-1}$), 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 explored with Duncan's Multiple Range Test (DMRT) (Snedecor and Cochran 1989).

Results and discussion

Significant differences ($P < 0.05$) among provenances were detected for percentage survival (Table 2). The highest mean survival (79%) was for the Consuelo Tablelands provenance followed by the Kenilworth State Forest provenance (60%). The provenance from Windsor had the lowest survival (36%).

Although height and DBH did not show significant variation ($P > 0.05$), the local land race grew best (22.2 m and 17.2 cm DBH). The Consuelo Tablelands provenance was poorest (18.0 m and 14.3 cm DBH) (Table 2). No significant differences ($P > 0.05$) were detected among provenances in volume per hectare (Table 2). The overall provenance mean volume was 211 $m^3 ha^{-1}$.

Eucalyptus saligna provenances planted in 1982 at Peachester (south-eastern Queensland) at age 4 y and at Coffs Harbour at age 3 y demonstrated significant variation in tree height and diameter (Eldridge *et al*. 1994). In the present trial, however, differences in height, DBH and volume per hectare were small and not significant among provenances. The local land race showed slightly better growth. It is well established that local provenances may outperform any other provenance of the same species that is planted directly in the exotic environment (Zobel and Talbert 1984). This could be because the newly introduced provenances may have retained the effects of inbreeding in natural stands, and/or because the local land race may have passed through a series of generations and become better adapted to the new environment.

Seedlots from the local land race showed the greatest volume production (275 m^3 ha^{-1}, equivalent to 34 m^3 ha^{-1} y^{-1}), while the least volume was produced by the provenance from Windsor (181 m^3 ha^{-1}, equivalent to 23 m^3 ha^{-1} y^{-1}). The poorer performance of the Windsor provenance might be attributed to the low survival of the provenance. Overall mean annual increment (MAI) for the trial site was 26.4 m^3 ha^{-1}, whereas on more fertile soils in Brazil the species has produced 35 m^3 ha^{-1} y^{-1}. A more usual figure, however, might be 15–18 m^3 ha^{-1} y^{-1} (Turnbull and Pryor 1984). Previous observations in Ethiopia have also recorded a MAI of 20–25 m^3 ha^{-1} (Pohjonen 1989). The climatic parameters of the trial site are within the natural range of *E. saligna* and would have been conducive to the high volume production.

Among morphological characteristics, the mean number of branches showed significant variation ($P < 0.05$) among the provenances tested (Table 2). Differences in branch angle, branch diameter, form, number of forks and height to first fork, however, were not significant (Table 2).

Fewest branches (8.5) were recorded for the provenance from Clyde River and the greatest number (12.4) for the provenance from Bulahdelah (Table 2). This provenance and some others, however, were represented by few parent trees (Table 1).

Poorly represented provenances may exhibit the genetic worth of the chosen trees rather than the provenance's potential. If selection and large-scale plantation establishment is based on provenances of narrow genetic base, the opportunity for further genetic improvement will be smaller (Zobel and Talbert 1984; Davidson 1995).

In general, the provenance variation in some morphological characteristics of *E. saligna*, as shown at Wondo Genet, may not be worth considering in further selection programs, as the differences were not statistically significant.

Conclusions

Significant variation between provenances was not evident in growth and form parameters in the *E. saligna* trial at Wondo Genet. It can be concluded, therefore, that further selection and breeding for faster early growth and better tree form in the region can be based on the best trees from those provenances represented by adequate numbers of parent trees.

The trial stand could be developed into a seedling seed orchard by selective thinning, as the provenances provide a diverse genetic base for future breeding and afforestation programs. It should be augmented by trials of additional provenances from the natural range of the species, planted in diverse climatic conditions within this country.

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