Variation in Performance of *Eucalyptus tereticornis* Provenances at Michafutene, Mozambique

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Summary

Variation in performance of 13 *Eucalyptus tereticornis* and one *E. camaldulensis* provenances was evaluated in a 14 year-old trial planted at Michafutene, Mozambique.

At the age of 14 years, data was collected on survival, breast height diameter, height, stem form and wood basic density.

Significant differences in survival and stem form were found between provenances. Overall, performance of provenances from northern parts of Australia was found to be superior to that of sources from southern parts and those from outside Australia (land races).

The following outstanding provenances are recommended for small scale planting at Michafutene and other areas with similar soil and climatic conditions: *E. tereticornis* ex South of Helenvale, ex North west of Mareeba, ex Kennedy River, ex North of Lakeland and ex Cooktown.

Key words: Eucalyptus tereticornis, E. camaldulensis, provenance, survival, growth, yield, wood basic density.

Introduction

Eucalyptus tereticornis SM. commonly known as forest red gum is native to Papua New Guinea and Victoria, New South Wales and Queensland territories of Australia. The species ranks among the most extensively planted *Eucalyptus* in the tropics and subtropics (ZOBEL *et al.,* 1987; EVANS, 1992). The species has been introduced to produce wood for fuel, poles, construction and pulp. Its popularity, as that of other widely planted eucalypts is attributed to its rapid growth and production of desirable wood when grown in a wide range of environmental and soil conditions (ZOBEL *et al.,* 1987; LAMPRECHT, 1989).

Eucalyptus tereticornis and other eucalypts and pines were introduced to Mozambique in the early 1950's and planted in plantations (COSTA, 1983). Seeds from these plantations whose origin is unknown were used since 1975 when the Government of Mozambique embarked on an ambitious afforestation programme covering all provinces and three big cities (Maputo, Beira and Nampula) to meet the increasing demand for fuelwood and other uses of wood products as well as reducing exploitation pressure on indigenous forests (CEZERRILO, 1985). Three years after establishment, these plantations showed very poor performance. The mortality rate was very high and individuals which survived showed great variability in height and diameter growth (FUENTES *et al.,* 1983). The variable growth rates were not quantified. However, in high potential areas in Monica Province, annual volume growth rates (under bark) were found to range from 12 m^3 to 16 m^3 per ha for pines (*Pinus patula, P. elliottii, P. taeda, P. caribaea* and *P. kesiya*) and from 30 m^3 to 36 m^3 per ha for eucalypts (*Eucalyptus saligna, E. paniculata, E. maculata* and *E. tereticornis*).

The total area of plantation at the end of 1985 was 42,273 ha. The area planted with pines was 22,339 ha, eucalypts 18,120 ha and other species 1,813 ha. Most of the planting was done in Monica Province (23,727 ha) and the rest in Maputo, Gaza, Sofala, Zambezia, Niassa, In'hambane and Nampula provinces.

Following the poor performance of the early *Eucalyptus* plantations, the Mozambique Forestry Department decided to establish species and provenance trials in three representative parts of the country (Michafutene, Dondo and Nampula) so that the best sources of seeds could be identified and used in large scale afforestation programme.

This paper describes variation in performance of 13 *E. tereticornis* provenances and one *E. camaldulensis* provenance (control) at Michafutene near Maputo, 14 years after establishment.

Materials and Methods

Study site

The trial is located at Michafutene near Maputo, Southern Mozambique (24°44'S, 34°41'E, 26 m asl).

The average annual rainfall is 730 mm, most of it falling between October and March. The annual total potential evapotranspiration averages 1392 mm. The highest and lowest air temperatures are 26°C and 20°C respectively. The annual average temperature is 23°C. Topography is characterized by low undulating hills. The soil of this area is a Psamitic Grey Cambic Soil. Selected soil properties of pedons sampled to 70 cm depth in the study area have been described by WATE *et al.* (1999) as sandy in texture, electrical conductivity ranges between 1.96 dS m^{-1} to 3.83 dS m^{-1}, pH 5.3 to pH 6.0, organic carbon 1% to 2%, total nitrogen 0.03% to 0.06%, and available phosphorus 1.01 µg g^{-1} to 2.51 µg g^{-1}.

Source of seed and nursery techniques

Seed sources of 13 *Eucalyptus tereticornis* provenances and one *Eucalyptus camaldulensis* provenance are shown in *table 2.* Seed sources of provenances from Australia are plotted in the Australian map (*Fig. 1*). Seedlings were raised using standard cultural techniques. Seedlings were top pruned to 30 cm, 10 days before field planting.

Experimental design and treatments

The trial was laid out using a randomized complete block design with three replications and 14 treatments (13 *Eucalyptus tereticornis* provenances and one *E. camaldulensis* provenance).

Field procedures

The site was prepared by complete clearing of all vegetation and disc ploughing followed by staking and pitting. Planting was carried out in March 1982. Each treatment plot had 5 x 5

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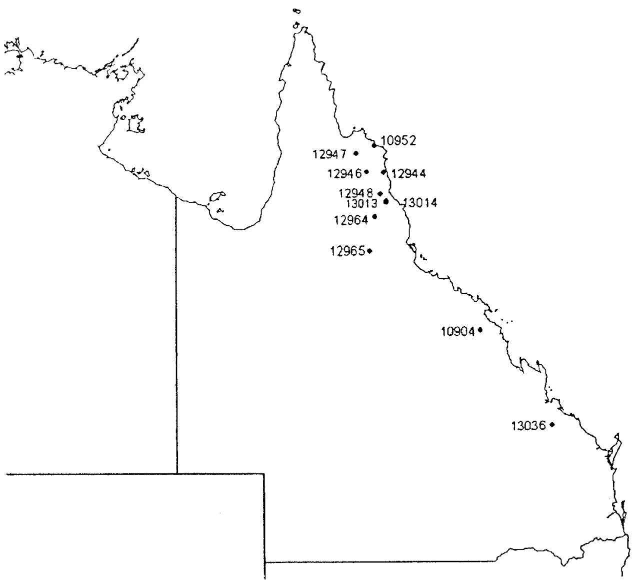

Figure 1. – The map of Australia showing the source of provenances.

trees planted at a spacing of 2.5 m x 2.5 m. The inner plot consisted of 4 x 4 inner rows. Due to very limited rainfall at planting out, seedlings were irrigated 3 times during the first week with 5 litres to 6 litres of water per plant. During the first two years after planting, two weedings per year were carried out. Thereafter, the trial was subjected to slashing of weeds whenever necessary. No thinning has been carried out.

Data collection

Measurements included tree survival, breast height diameter, height, stem form and wood basic density at 14 years. All surviving inner trees in a plot were measured for breast height diameter (DBH) using a calliper to the nearest 0.1 cm. The DBH tally also gave tree survival data. For height, the three largest trees per plot and four other trees of different diameter classes were measured to the nearest 0.1 m using Suunto hypsometer. Stem form was assessed using a point scoring system as follows:

1	–	Straight
2	–	Slightly crooked
3	–	Crooked stem

For the determination of wood basic density, four defect-free trees with straight boles and representative of the diameter ranges of each plot were sampled. Wood cores were then taken at DBH point from selected trees using an increment borer (6 mm internal diameter). The cores were stored in pieces of Khaki corrugated hard paper and sealed with cellotape.

In the laboratory, the cores were saturated in distilled water for at least 24 hours in order to regain green condition after which their volumes were measured by water displacement. The cores were then oven-dried at 103 °C ± 2 °C to constant weight and cooled in desiccators before determining oven dry weight. Basic density for each core was calculated as its oven dry weight divided by green volume.

Data analysis

For all statistical analysis a fixed effect model was fitted (Equation 1) and a Type III SS analysis was carried out.

Y = replication + provenance + error .... (1)

where Y is the measurement.

Statistical analyses were carried out using the General Linear Model (GLM) of SAS-PC (SAS Inc., 1987). Individual tree data for survival (%), height (m), DBH (cm), wood basic density (kg m^{-3}), stem form and basal area (m^2 ha^{-1}) were subjected to analysis of variance (ANOVA). Prior to ANOVA, score and count data were transformed to induce normality and equal variance. Survival percentages were transformed to arcsine values and stem form categories were square root transformed before statistical analysis (SOKAL and ROHLF, 1969). Significant

Table 1. – Sources of *Eucalyptus tereticornis* provenances grown at Michafutene, Marracuene, Mozambique.

Provenance/ Location	Seed lot No.	No. of parent trees	Lat. S	Long. E	Altitude masl	Annual rainfall (mm)
South of Callope,QLD[x]	13036	10	24° 23’	151° 00’	860	650-1200
North of Lakeland D., QLD	12946	6	15° 45’	144° 41’	170	650-1200
North West of Mareeba, QLD	12948	44	16° 50’	145° 18’	400	650-1200
Little Mitchel R., QLD	13014	5	16° 47’	145° 18’	380	650-1200
South West of Mt. Garnet, QLD	12965	25	18° 30’	144° 45’	800	650-1200
Mt. Carbine, QLD	13013	15	16° 32’	145° 07’	330	650-1200
South of Helenvale, QLD	12944	25	15° 46’	145° 14’	120	650-1200
Cooktown	10952	–	14° 49’	144° 58’	20	
Em. Petford, QLD	12964	25	17° 20’	144° 58’	460	<250
Mackay, QLD	10904	–	21° 11’	148° 33’	150	>1200
Kennedy R. QLD	12947	10	15° 05’	144° 19’	90	650-1200
Mysore, India	–	–	–	–	–	–
Sao Paulo, Brazil	–	–	–	–	–	–
Zimbabwe	–	–	–	–	–	–

*) QLD – Queensland; Em. – *Eucalyptus camaldulensis*.

Table 2. – Transformed (arcsine) and untransformed survival percentage and mean and dominant height (m) of 14 year old of *Eucalyptus tereticornis* provenances grown at Michafutene, Marracuene, Mozambique.

	Survival (%)		Height (m)	
Provenance[v]	Transformed	Untransformed	Mean	Dominant
South of Callope, QLD	52.7ef[w] (5.42)	62.7	15.40abc (0.58)	16.84 (0.33)
North of Lakeland D., QLD	72.3ab (2.53)	92.0	15.25abc (0.55)	16.39 (1.36)
North West of Mareeba, QLD	71.5ab (3.59)	89.3	15.97ab (0.53)	17.78 (1.50)
Little Mitchel R., QLD	71.0abc (1.28)	90.7	16.09ab (0.56)	18.00 (0.53)
South West of Mt. Garnet, QLD	70.4abc (4.01)	88.0	11.25d (1.50)	16.67 (0.92)
Mt. Carbine, QLD	60.9bcde (3.14)	76.0	15.69ab (0.34)	16.61 (1.50)
South of Helenvale, QLD	79.0a (5.48)	94.7	16.21ab (0.80)	18.39 (1.26)
Cooktown	70.5abc (4.36)	88.0	16.15ab (0.66)	17.21 (1.15)
Em. Petford, QLD	72.8ab (3.50)	90.7	13.69c (0.49)	15.89 (1.25)
Mackay, QLD	57.6cdef (5.19)	72.0	14.48bc (0.57)	17.06 (0.58)
Kennedy R. QLD	77.8a (6.23)	93.3	16.00ab (0.36)	18.00 (0.73)
Mysore, India	63.7abcd (1.82)	76.0	16.28a (0.51)	17.22 (0.68)
Sao Paulo, Brazil	53.7def (4.61)	65.3	14.40bc (0.57)	16.17 (0.35)
Zimbabwe	46.4f (7.28)	52.0	14.93abc (0.44)	16.58 (0.88)
Pr>F-ratio[x]	****	–	****	–
RMSE[y]	6.20	–	14.9	–
CV[z]	10.96	–	2.28	–

[v]) Em. – *Eucalyptus camaldulensis;* QLD – Queensland; [w]) Mean of 3 observations with standard error in parentheses; Values with the same letter(s) within the same column do not differ significantly (P>0.05); [x]) Pr> F-ratio (Probability of greater F-ratio) = 0.0001 – ****; [y]) RMSE – root mean square error; [z]) CV – coefficient of variation (%).

provenance means were separated by DUNCAN's Multiple Range Test (STEEL and TORRIE, 1980).

To identify the best and the worst overall provenance at 14 years, ordinal ranking was developed. This was done as follows. For each variable evaluated, provenances were assigned ranks from the best (assigned 1 point) to the worst (assigned 14 points) performing provenance. Thereafter, ranks were added, then averaged and the overall score was taken as a basis of the overall provenance ranking.

Results

Survival

Provenances differed significantly ($P<0.0001$) in survival (*Table 2*). At the age of 14 years, untransformed survival ranged from 52.0% (Zimbabwe provenance) to 93.3% (Kennedy R provenance). Only three provenances had survivals less than 70% (Zimbabwe, Sao Paulo, and South of Callope, QLD). A regression of provenance survival at 14 years on seed source latitude showed a significant ($P = 0.0017$, $R^2 = 0.73$) negative relationship. Survival showed a decreasing trend with increasing latitude of seed origin.

Mean and dominant height

Dominant heights was not significantly ($P>0.05$) different between provenances (*Table 2*). Provenances only differed significantly ($P<0.0001$) in mean height (*Table 2*). At age 14 years, mean height ranged between 16.28 m (Mysore, India provenance) and 11.25 m (South West of Mt. Garnet, QLD).

Table 3. – Diameter at breast height (DBH cm) and basal area (m^2 ha^{-1}) of 14 year old *Eucalyptus tereticornis* provenances planted at Michafutene, Marracuene, Mozambique.

Provenance[v]	Mean DBH (cm)	Basal area (m^2 ha^{-1})
South of Callope, QLD	11.03dc[w] (1.23)	11.69 (3.87)
North of Lakeland D., QLD	15.85a (0.57)	29.14 (5.85)
North West of Mareeba, QLD	15.91a (0.57)	29.85 (2.12)
Little Mitchel R., QLD	14.34ab (0.66)	24.40 (5.14)
South West of Mt. Garnet, QLD	10.10d (1.48)	18.64 (3.71)
Mt. Carbine, QLD	13.57abc (0.66)	17.00 (4.19)
South of Helenvale, QLD	14.50ab (1.10)	24.96 (2.34)
Cooktown	14.58ab (0.73)	22.09 (5.41)
Em. Petford, QLD	13.84ab (0.73)	17.12 (2.40)
Mackay, QLD	12.46bcd (0.65)	20.26 (1.84)
Kennedy R. QLD	14.56ab (0.82)	22.09 (2.78)
Mysore, India	14.21ab (0.64)	17.91 (6.97)
Sao Paulo, Brazil	11.76bcd (0.78)	14.90 (2.53)
Zimbabwe	12.50 bcd (1.18)	11.45 (2.99)
Pr>F-ratio[x]	***	ns
RMSE[y]	4.91	7.03
CV[z]	35.8	34.7

[v]) Em. – *Eucalyptus camaldulensis;* QLD – Queensland; [w]) Mean of 3 observations with standard error in parentheses; [x]) Pr> F-ratio (Probability of greater F-ratio) > 0.05 – ns. i.e. not significant; *** – Pr> F-ratio = 0.001. [c]) RMSE – root mean square error; [z]) CV – coefficient of variation (%).

Diameter at breast height (DBH) and basal area

Provenances were not significantly (P>0.05) different in basal areas, but were significantly different in breast diameter (*Table 3*). At 14 years of age, the DBH ranged from 10.10 cm (South-west of Mt. Garnet) to 15.91 cm (North-west of Mareeba provenance). At this age, basal area ranged between 11.45 m^2 ha^{-1} (Zimbabwe provenance) and 29.85 m^2 ha^{-1} (North-west of Mareeba provenance).

Wood basic density and stem form

Provenances differed markedly for wood density although they were not significantly (P>0.05) different in wood basic density (*Table 4*). The South of Helenvale provenance had the highest basic density (613 kg m^{-3}) while Zimbabwe provenance had the lowest basic density (456 kg m^{-3}) (*Table 4*).

At 14 years of age stem form was not significantly (P>0.05) different between provenances (*Table 4*).

Ordinal ranking of tree variables

When the ranking of provenances in six tree variables (survival, mean height, DBH, basal area, stem form and wood basic density) was computed, provenances were ranked as shown in *table 5*. The best five provenances were South of Helenvale, North-west of Mareeba, Kennedy River, North of Lakeland and Cooktown. The four worst provenances were Zimbabwe, Sao Paulo, South of Callope and South-west of Mt. Garnet. A regression of provenance mean score on seed source latitude showed a significant (P = 0.02, R^2 = 0.52) relationship. Provenance performance decreased with increasing latitude.

Discussion

The results of this study show that provenances were in most cases not significantly different in growth variables and that highly significant differences were detected mainly in sur-

Table 4. – Transformed (square root) stem form and untransformed wood basic density (kg m^{-3}) of *Eucalyptus tereticornis* provenances planted at Michafutene, Marracuene, Mozambique.

Provenance[v]	Stem form	Wood basic density (kg m^{-3})
South of Callope,QLD	1.39 (0.12)	537 (9)
North of Lakeland D., QLD	1.14 (0.08)	533 (18.4)
North West of Mareeba, QLD	1.06 (0.04)	600 (32)
Little Mitchel R., QLD	1.20 (0.06)	511 (27.4)
South West of Mt. Garnet, QLD	1.26 (0.05)	517 (19)
Mt. Carbine, QLD	1.24 (0.12)	581 (7.4)
South of Helenvale, QLD	1.17 (0.07)	613 (31)
Cooktown	1.23 (0.09)	564 (5)
Em. Petford, QLD	1.37 (0.04)	577 (17)
Mackay, QLD	1.32 (0.09)	557 (32)
Kennedy R. QLD	1.12 (0.08)	586 (18)
Mysore, India	1.27 (0.11)	477 (57)
Sao Paulo, Brazil	1.41 (0.17)	535 (8)
Zimbabwe	1.36 (0.06)	456 (-)
Pr>F-ratio[x]	ns	ns
RMSE[y]	0.148	38.8
CV[z]	11.8	7.05

[v]) Em. – *Eucalyptus camaldulensis;* [w]) Mean of 3 observations with standard error in parentheses; [x]) Pr> F-ratio (Probability of greater F-ratio) > 0.05 – ns. (not significant); [c]) RMSE – root mean square error; [z]) CV – coefficient of variation (%).

vival. The survival data showed a trend of increasing survival with decreasing latitude of seed origin. While this trend was not noticeable for the growth variables, it was when the mean score of all studied variables (in ordinal ranking) was regressed on latitude of seed origin. The superiority of provenances from the northern parts of Australia when planted in tropical exotic environments compared to those from the southern parts of the country has been reported in other *E. tereticornis* and *E. camaldulensis* trials (OTEGBEYE, 1985; CHAPOLA and NGULUBE, 1991; KAARAKKA and JOHANSSON, 1993). This has been explained to be due to climatic differences among the two groups, the northern parts having a predominantely summer rainfall as the tropical exotic environments while the southern parts have a winter rainfall pattern.

The *E. tereticornis* "land races" in the present study (i.e. Mysore, Sao Paulo and Zimbabwe) ranked low in ordinal ranking (*Table 5*). Usually when land races are developed in one region, they often will also be useful in other similar regions (NIKLES and BURLEY, 1977, in: ZOBEL and TALBERT, 1991). Also, seed from plantations (as a land race) of wide genetic base could be 10% more productive than seed of natural forests because of increased outcrossing in plantations (SEDGLEY and GRIFFIN, 1989, in: PINYOPSARERK *et al.,* 1996a). The poor performance of the „land races“ in this study is an indication that the soil and environmental conditions at Michafutene are not favourable and/or that the sources were from plantations of inferior or narrow genetic base. It has for example been shown that if outstanding, closely related individuals are brought together in a land race, growth of their progeny may be poor, seed not viable or seed may not be produced due to relatedness (ZOBEL *et al.,* 1987).

The growth and yield of the outstanding *E. tereticornis* provenances in the present study compare favourably with results reported in trials of the species elsewhere (OTEGBEYE, 1990;

Table 5. – Ordinal ranking of tree variables showing differences between *Eucalyptus tereticornis* provenances fourteen years after planting at Michafutene, Marracuene, Mozambique.

	Parameter and ordinal raking score[x]							
Provenance[y]	1	2	3	4	5	6	Mean score	Overall Score
South of Helenvale, QLD	1	2	5	3	4	1	2.7	1
North West of Mareeba, QLD	8	6	1	1	1	2	3.2	2
Kennedy R. QLD	2	5	4	5	2	3	3.3	3
North of Lakeland D., QLD	3	9	2	2	3	9	4.7	4
Cooktown	6	3	3	5	6	6	4.8	5
Little Mitchel R., QLD	4	4	6	4	5	12	5.8	6
Mt. Carbine, QLD	9	7	9	11	7	4	7.8	7
Mysore, India	9	1	7	9	9	13	8.0	8
Em. Petford, QLD	4	13	8	10	12	5	8.7	9
Mackay, QLD	11	11	11	7	10	7	9.5	10
South West of Mt. Garnet, QLD	6	14	14	8	8	11	10.2	11
South of Callope,QLD	13	8	13	13	13	8	11.3	12
Sao Paulo, Brazil	12	12	12	12	14	10	12.0	13
Zimbabwe	14	10	10	14	11	14	12.2	14

[x]) 1 – Survival; 2 – Mean height; 3 – Breast height diameter (DBH); 4 – Basal area; 5 – Stem form; 6 – Wood basic density; [y]) QLD – Queensland; Em. – *Eucalyptus camaldulensis.*

CHAPOLA and NGULUBE, 1991; SUNDARARAJU *et al.,* 1995) and *E. camaldulensis* in the same location (WATE et al., 1997). Of the five outstanding provenances (South of Helenvale, NW of Mareeba, Kennedy River, North of Lakeland and Cooktown) in this trial (*Table 5*), two provenances namely South of Helenvale and Kennedy River have also been found to perform well in several other trials e.g. Bangladesh (DAVIDSON and DAS, 1985, in: PINYOPUSARERK *et al.,* 1996b), Kenya (KAARAKKA and JOHANSSON, 1993), Nigeria (OTEGBEYE, 1990) and Thailand (PINYOPUSARERK *et al.,* 1996b). The Kennedy River provenance of *E. tereticornis* is now recognized as *E. camaldulensis* because of its *camaldulensis*-like floral bud traits and seed and progeny morphology (DORAN and BURGESS, 1993).

All provenances except two had wood basic density values above 500 kg m^{-3}. These results are not unexpected as *E. tereticornis* belongs to the category of eucalypts with dense wood (ZOBEL *et al.,* 1987).

Conclusions and Recommendations

The results obtained from this trial indicate that genetic differences exist among the provenances of *E. tereticornis.* The following five provenances which ranked high in survival and growth are recommended for small scale planting at Michafutene and similar sites: South of Helenvale, North-west of Mareeba, Kennedy River, North of Lakeland and Cooktown. The generally straight form and dense wood of these provenances, make them outstanding for both poles and fuelwood, the two main objectives of the afforestation programme of the Government of Mozambique.

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