Growth and quality of G*revillea robusta* provenances in Ruhande Arboretum, Butare, Rwanda

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Abstract

Exotic hardwood tree species are very important in Rwandan plantation forestry. They are the primary source of energy, which makes about 97% of total national energy consumption. They are used as sawn timber for furniture industry, for construction and packaging. They are essential components of agroforestry systems where they play a significant role in conservation, species and product diversification to mention but a few. A trial on Grevillea robusta seed sources comprising of seven Queensland (Australia) provenances and one land race on an oxisol at Ruhande Arboretum, Butare, Rwanda was carried out. The species is the commonest on farm tree species in Rwandan agroecosystems and serves many functions. Wood productivity has been observed to decline when tree germplasm used is collected from landrace populations of exotic species. This study intends to evaluate the performance of seven provenances and one landrace of G. robusta in terms of wood yield and quality. Although the outstanding provenances reported elsewhere are not represented in the Rwandan trial which is very small and with a design that is not very well designed, useful results were obtained. Significant differences were observed in tree height and branching pattern at 13 years. All traits indicated strong juvenile-mature correlations. Trait-trait phenotypic correlation was also found to be strong in all traits. The correlations were observed to increase consistently with age, indicating the possibility of predicting yield at maturity by using early tree dimensions. High value germplasm may be produced from seed production areas using the best provenances from the species' natural range. Conservation stands are suggested for further breeding and for seed production using seed from natural Australian sources.

Key words: Grevillea robusta, *land race, provenance, agroecosystems, germplasm, conservation, seed production areas*

Résumé

Les essences ligneuses exotiques jouent un rôle important dans les plantations forestières du Rwanda. Elles constituent la première source d'énergie et couvrent 97% des besoins en énergie. Elles sont utilisées comme bois d'œuvre, bois de construction et pour autres fins. Elles sont une composante importante des systèmes agroforestières où il jouent un rôle de conservation et de diversification des produits. Un essai de 7 provenances a été installé en utilisant des semences de Queensland (Australie) et une espèce naturalisée (land race). L'essai a été installé sur un oxisol à l'arboretum de Ruhande, Butare, Rwanda. Grevillea est une espèce à usage multiple communément planté dans les system agricole au Rwanda. Le rendement en bois a été observé de tomber quand les semences étaient collectées des espèces naturalisées (land race). La présente étude a pour objet d'évaluer 7 provenances et une espèce naturalisée (land race) en matière de rendement et de qualité en bois. De bons résultats ont été obtenus malgré les dimensions petites de l'essai. Il y avait une différence significative quant à la hauteur des arbres et leur embranchement à la fin de 13 ans. Tous les traits ont indiqué une forte corrélation jeune-adulte. Les corrélations phénotypiques trait-trait étaient aussi fortes à travers tous les paramètres. Les corrélations avaient une tendance d'augmenter avec l'âge, indiquant une possibilité de prévoir le rendement à la maturité en utilisant les dimensions des jeunes arbres. Le germoplasm de qualité peut être obtenu des peuplements semenciers établis à base des semences sélectionnées. Les peuplements de conservation sont proposés pour l'amélioration génétique et pour la production des semences de haute qualité en provenance des semences des peuplements naturels d'Australia.

Mots clés : Grevillea robusta*, espèce naturalisée, provenance, agroecosystems, germpolasm, conservation, zone des semences*

Introduction

Grevillea robusta A. Cunn. ex R. Br. commonly known as 'Silky Oak' is a member of the Proteaceae, subfamily Grevilleoideae in the tribe Grevilleeae (McGillivray 1993). The species has a restricted natural range on the east coast of Australia from latitude 22° 50' S to 30° 10' S (Harwood & Booth, 1992). *G. robusta* was introduced to Rwanda in the early 20th century mainly for ornamental purposes and for shade in tea plantations (Kalinganire & Hall, 1993). It is one of the most widely planted upper storey tree species in agroforestry systems in Rwanda having proved its adaptability under a range of conditions and it contributes to more than 10% of the total man-made forests of the country including the trees on farms (Kalinganire, 1996).

G. robusta has been introduced to many countries in South and Central America, South Asia, and in the highlands of eastern and central Africa where it is very common and popular for farm plantings (Kalinganire *et al.*, 2000). In Rwanda, *G. robusta* is a multipurpose tree species mainly grown by farmers as a boundary tree, windbreak or shelterbelt and among crops on small farms. It is grown as a shade tree for tea and coffee plantations, in agroforestry plantings mainly for timber, firewood and poles, with leaves used for mulch. It also stabilises soils when planted along contours in combination with other species such as C*alliandra calothyrsus* and *Leucaena diversifolia*. The golden flowers are attractive to bees making the species an important honey provider. It has conspicuous proteoid roots which are often concentrated near the soil surface during the active growing period and which enhance water and nutrient uptake. The roots help it to grow in low-fertility soils (Skene *et al.,* 1996). They penetrate deep into soil layers far below the zone utilised by agricultural crops, recycling nutrients from these levels back into the soil surface through decomposition of leaf litter (Harwood & Booth, 1992).

In Rwanda growth commonly achieved in routine plantings using locally produced seed averages about 2 m and 2 cm per year for height and diameter at breast height respectively during the first 5-10 years (Kalinganire, 1996); however higher production is being obtained in other countries with some Australian provenances (Kalinganire & Hall, 1993).

This paper reports growth, stem form and branching pattern of a *G. robusta* provenance trial at Ruhande Arboretum, Butare, Rwanda. Assessments of tree growth, stem straightness; branching pattern and phenotypic correlations are presented. Wood basic density was not measured at all assessment occasions (assessed only at 2.5 and 8 years) and therefore not reported here.

MATERIALS AND METHODS

Trial site, seed sources and experimental design

The experiment is located in Ruhande Arboretum (latitude 2° 33' S, longitude 29° 46' E, elevation 1700 m asl) on a moderate gradient (about 20%) oxisol, with an easterly aspect. The rainfall is bimodal (February-May and September-December). The mean annual rainfall is about 1200 mm. Monthly means of daily temperature maxima range from 28.5 °C (April) to 32 °C (September) and corresponding minima from 10 °C (April) to 9 °C (September). The humic ferrallitic soils on the site are generally shallow (20-30cm) and of light texture, with a sandy-clay character at the surface (Gasana, 1973).

The trial comprises seven provenances from Queensland, Australia of which five were from natural forest and two from plantations of unknown origin, and one Rwandan land race. The seed was supplied by the Queensland Forest Research Institute (QFRI). Details of the provenances are given in Table 1.

Experimental design

A randomised complete block design was used, with four replicates, ten-tree line plots and spacing of 2.5 m x 2.5 m between trees. The site was manually cleared and land tilled by hand before planting. No fertilizer was applied. Complete weeding has been done manually each year for the first four years, then bush clearing every year in May (just after the long rains). Thinning was effected only once in August 1997 with a thinning intensity of 30%. Some silvicultural treatments such as early thinning and pruning could not be executed due to problems of war and genocide in 1994.

Assessment procedures

Earlier measurements were conducted when the trial was 2.5, 5, 8 and 13 years old. Results from previous data were reported by Kalinganire (1992), Kalinganire and Hall (1993), and Mugunga (2002). Data for all ages were analysed for phenotypic correlations.

Growth traits

All surviving trees in each plot were measured for tree height (Ht) using a Haga altimeter and recorded to the nearest 0.1 m. Stem diameter at breast height (DBH) was assessed for all surviving trees with measurements taken at 1.3 m above the ground using a calliper and values recorded to the nearest 0.1 cm.

Form and crown traits

Stem form or straightness was visually scored subjectively for all trees in a plot. A scale of 1 to 8 was used in the assessment, with 1 for very crooked or least straight trees, and eight representing the straightest and almost cylindrical trees. Branching coarseness was assessed on a similar scale as that of stem form, 1 representing individuals with dense, large and vertical (close to 0°) branches and 8 representing trees with sparse, small and horizontal (close to 90°) branches.

Statistical analyses

Statistical analyses were carried out using Statistical Analysis Systems (SAS, 1982). Prior to analysis of variance, square root transformation was applied to stem form data so as to force normality (Ott, 1993). The data for each characteristic were subjected to analyses of variance. The following linear model was covered:

$$Y_{ij} = \mu + B_i + P_j + e_{ij}$$

Where Y_{ij} = plot mean of the j^{th} provenance in the i^{th} block, μ = overall mean, B_i = effect of the i^{th} block, P_j = effect of the j^{th} provenance, and e_{ij} = residual error of the ij^{th} plot mean.

Significantly different means were separated using Student's Newman-Keuls test (Ott, 1993). Correlation analyses were carried out to determine juvenile-mature as well as trait-trait relationships for DBH and Ht, stem straightness, branching pattern and wood basic density. Phenotypic correlations were computed by using Pearson correlation method (Snedecor and Cochran, 1989).

RESULTS AND DISCUSSION

Provenance means and overall trial mean are also given in Table 2. There were significant differences between provenances for height (trial mean 19.2 m, P<0.05, Table 2) at 18 years. The highest height growth was obtained by Benarkin (49), Imbil (41) and Pechey (42) with respective mean values of 20.6 m, 20.1 m and 20.0 m. These were significantly different from the least producing provenances, Brooyar (46) and Gallangowan (48) with values of 17.2 m for both.

Table 1. Seed sources of *Grevillea robusta* provenances in the study at Ruhande Arboretum, Butare

Serial No.	QFRI Provenance No.	Parent stand	Provenance name (all Australians but no.52)	No. of parent trees	Latitude (S)	Longitude (E)	Altitude (m)	Rainfall (mm)
1	41	Natural	Imbil	10	26° 10'	152° 40'	100	100
2	42	Plantation	Pechey	10	27° 17'	152° 04'	600	100
3	44	Plantation	Coominglan	4	24° 47'	150° 49'	500	780
4	46	Natural	Glastonbury Ren. Area, Brooyar	3	26° 10'	152° 30'	100	950
5	48	Natural	Gallangowan	6	26° 23'	152° 20'	400	850
6	49	Natural	Bernakin	10	26° 47'	152° 11'	280	990
7	NA	Plantation	Shyanda	>20	2° 33'	29° 36'	1700	1200
8	52	Natural	S.F. Parish of Glenbar	5	25° 50'	152° 20'	200	1040

NA: not applicable

Table 2 shows stem straightness and crown density results at 18 years for the provenances tested. Although stem straightness did not show significant variation (mean 4.6, P>0.05), Benarkin (49) and Shyanda (Rwandan land race) indicated the straightest stems with a score of 5, and Gallangowan (48) and Brooyar (46) had the least straight stems with scores of 4.2 and 4.3 respectively. Differences among *G. robusta* provenances for branching pattern were highly significant (mean score: 3.7, P<0.01). Glenbar (52) has the densest crown individuals with a score of 3.2 and Coominglan (44) show trees with open crowns with a score of 4.5. There are strong age-age and trait-trait correlations even at very young age and this increase consistently with age (Table 3).

The overall mean tree size attained in the Ruhande trial, height 19.2 m and DBH 18.2 cm at age 18 years is clearly higher than the general plantation growth of *G. robusta* reported under similar site conditions. In a 12-year old plantation, Kalinganire (1996) reported tree size of 15.6 m and 12.9 cm respectively for tree height and DBH, i.e. about 25% more overall height growth than in normal plantation. The results are comparable to growth obtained in the highlands of Kenya (Kamweti, 1992) and Uganda (Okorio and Peden, 1992) with better soil conditions than the study site. Higher yields can be further obtained using the best provenances such as Benarkin, Imbil and Pechey with tree height growth of 20.6 m, 20.1 and 20 m respectively. The study shows growth differences between some Australian sources and the local land race. Some Australian provenances were observed to be superior in various trials in the tropical and sub-tropical conditions, for example in three different trials in northern Argentina (Lopez *et al.,* 1999), in two trials in western Kenya (Kalinganire and Esegu, 1995), in two trials in Tanzania (Maliondo *et al.*, 1998), and in three trials in north Queensland, Australia (Sun *et al.*, 1995 and Harwood *et al.*, 2002). Unfortunately a number of provenances are not represented in the current experiment and the trial is very small, making it difficult to compare provenance results amongst studies.

Table 2: Provenance means for tree height, dbh, stem straightness and branch pattern at 18 years in the trial at Ruhande Arboretum, Butare, Rwanda

QFRI Provenance **No.**	**Provenance** Name	Height (m)	Dbh (cm)	Stem Straightness	Branching Pattern	Volume
42	Imbil, Australia	20.1a	19.1	4.8	4.0a	0.217
42	Pechey, Australia	20.0a	19.5	4.7	4.0a	0.209
44	SF 82 Coominglan, Australia	19.2a	17.3	4.7	4.5a	0.206
46	Glastobury, Brooyar, Austrlia	17.2b	17.2	4.3	3.4ab	0.194
48	Gallangowan, Australia	17.4b	18.0	4.2	3.5ab	0.184
49	Benarkin, Australia	20.6a	16.8	5.0	3.8ab	0.172
NA	Shyanda, Butare, Rwanda	19.6a	18.4	5.0	3.5ab	0.169
52	Glenbar, Australia	19.1b	19.0	4.6	3.2b	0.163
Overall means		19.2	18.2	4.6	3.7	0.189
Standard error of difference of means		0.4	0.4	0.11	0.15	0.008
Significance of difference between provenances		*	NS	NS	*	NS

Means with the same letter are not statistically different; * and ** indicate significant differences at p<0.05 and p<0.01 respectively; ns denotes non significant differences

Table 3: Phenotypic [age-age] correlation matrix for growth traits of *Grevillea robusta* provenance trial in Ruhande Arboretum, Butare, Rwanda

	Ht 2 years	Ht 5 years	Ht 8 years	Ht 18 years	DBH 2 years	DBH 5 years	DBH 8 years	DBH18 years	VOL 18 (kgha^{-1})
Ht 2 years	1								
Ht 5 years	0.87*	1							
Ht 8 years	0.75*	0.88**	1						
Ht 18 years	0.67	0.91**	0.27	1					
DBH 2 years	0.89**	0.70	0.77*	0.84*	1				
DBH 5 years	0.63	0.65	0.79*	0.89**	0.97***	1			
DBH 8 years	0.25	0.15	0.63	0.76*	0.82*	0.92***	1		
DBH18 years	0.04	0.68	0.62	0.74	0.87**	0.90**	0.96***	1	
VOL18 years	0.20	0.33	0.30	0.56	0.50	0.78*	0.89**	0.95***	1

*, ** and *** indicate significant differences at p<0.05, p<0.01 and p<0.001 respectively

Seed of *G. robusta* used for local planting is mainly collected from on farm trees found on farmers` fields. Such trees have undergone selective thinning over generations during harvesting as farmers usually select best trees to cut for sawing, leaving poor quality ones to grow. The process goes on every time trees are cut. Such tendency may lead to genetic erosion since planting material is continually collected from poorer residual trees remaining on farms after selective cuttings. Use of appropriates germplasm may alleviate this problems resulting from planting trees using seed collected from land races of narrow genetic base with high proportions of inbreeding (Griffin, 1989). In many exotic tree species, heterozygous individuals indicate faster growths compared to homozygous ones (Nei, 1987). Seed collected from land races have been observed to show substantially lower levels of heterozygosity in *G. robusta* landraces than in natural populations and attribute this to be a result of very small founder populations in some cases (Harwood *et al.,* 1992). Similar observations have been reported in Kenya, where a considerable inbreeding depression of up to 10% for height and up to 9% for diameter leading to substantial loss of production by using the Kenyan land races (Kalinganire, 1999). This may explain better the superior height growth rate obtained in some Australian provenances (Benarkin, Imbil and Pechey). In an isozyme study, Harwood *et al.* (1997) reported lower genetic variability in the East and Central African land races (including Shyanda) than in the Australian provenances.

The performance of the land race (Shyanda) does not indicate that poor performance in this study. As the species is an obligate out crosser (Kalinganire *et al.,* 2000), this may help to explain why in general, land race performance has not deteriorated greatly despite the species having descended through several land race generations with no genetic management (Harwood, 2002). Even the little diameter variation observed may be due to delayed thinning that was done at 10 years. As reported by Kalinganire (1996), wider spacing favours diameter growth and hence individual tree volume, but has no significant effect on height growth and overall volume production per unit area. There was no significant variation between provenances for stem straightness. The observed good form of the trees confirms results obtained by Kalinganire (1992) for the same trial at 2.5 months. Generally *G. robusta* has a reputation of producing straight stems, unless other environmental factors such as prevailing strong winds affect the stand. However, Harwood *et al.* (2002) reported significant genetic gains in stem straightness in a one year old provenance trial in Queensland showing some potential for genetic improvement in that trait.
It is evident that provenances with best height growth except Benarkin had also significantly denser crowns (coarser branching pattern) than slow growing sources. Although Benarkin had light crown, individual stem volume production was significantly higher than that of most other provenances (Mugunga, 2002). As discussed by Kalinganire and Hall (1993) provenances producing higher stem volume than leaf and branch biomass should be favoured for plantations, whereas higher biomass producing ones would be more appropriate for other purposes like litter (mulch) and fuelwood production.

Strong juvenile - mature and trait - trait phenotypic correlations through all ages in all traits (Mugunga, 2002) are consistent with findings in other studies. Harwood *et al.* (2002) found high genetic and phenotypic correlations (at least 0.7) between height and DBH, and age-age correlations for both height and DBH for *G. robusta* in Queensland, Australia.

CONCLUSION

The trial at Ruhande does not test the whole natural range of the *G. robusta*, and some sources originated from plantations in Australia, likely with low genetic diversity. Moreover, the outstanding provenances reported elsewhere are not represented in the Rwandan trial which is very small and with a design that is not most appropriate. However, the study revealed significant variation between provenances in height growth and branching pattern (crown characteristics). The study confirms that *G. robusta* develops straight stems in Rwanda, and may not require selection for that trait, or at least, selection for stem form may be ignored when resources do not allow with high probabilities of getting good stem quality. Furthermore, early growth performance can be relied upon and based on when selecting for wood yields.

The results of this study indicate that substantial gains in tree growth could be achieved through the use of the best provenances. Although the Rwandan landrace showed performance that compares favourably with some Australian natural sources, it is advised that more sources be introduced so as to broaden the genetic base. The best performing provenances from the species' natural range reported in other places but not tested in this trial are suggested for this purpose. These could then be used to design provenance/progeny trials that can be managed as open-pollinated seed production areas. Such stands would be located where flowering is expected to be prolific at sites where bird pollinators (sunbirds and white eyes) are abundant. For a long-term breeding strategy, breeding populations and conservation stands should be established from outstanding Australian provenance-identified individuals.

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