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Evaluation of an *Acacia aneura* provenance trial at Phaltan, India

Trial no. 19 in the arid zone series

by

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The *Acacia aneura* trial at Phaltan, India. Provenance Vaughan Springs, Nt (Australia).
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Danida Forest Seed Centre (DFSC) is a Danish non-profit institute which has been working with development and transfer of know-how in management of tree genetic resources since 1969. The development objective of DFSC is to contribute to improve the benefits of growing trees for the well-being of people in developing countries. DFSC's programme is financed by the Danish International Development Assistance (Danida).

Preface

This report belongs to a series of analysis reports published by the Danida Forest Seed Centre. It is the intention that the series should serve as a place for publication of trial results for the Centre itself as well as for our collaborators. The reports will be made available from the DFSC publication service and online from the web-site www.dfsc.dk. The scope of the series is in particular the large number of trials from which results have not been made available to the public, and which are not appropriate for publication in scientific journals. We believe that the results from these trials will contribute considerably to the knowledge on genetic variation of tree species in the tropics. Also, the analysis report will allow a more detailed documentation than is possible in scientific journals.

The report presents results within the framework of the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species', initiated by FAO. Following collection and distribution of seed between 1983-87, a large number of trials were established by national institutions during 1984-1989. An international assessment of 26 trials took place from 1990 to1994. DFSC is responsible for the reporting of this assessment.

This trial was established and maintained by the Nimbkar Agricultural Research Institute (NARI) Maharashtra in collaboration with Forest Research Institute & Colleges (FRI), Dehra Dun, U.P. India. The assessment team consisted of N. Nimbkar (NARI), Vinod Kumar (FRI), Anders Pedersen (DFSC), and 5 locally employed labourers (Garpat Bhonsale, Sawita Pawar, Vandara Pawar, Gharwat S. J., Vani S.L.).

The authors wish to acknowledge the help of the personnel at NARI with the establishment, maintenance and assessment of the trials, and thank the personnel of DFSC for their help with the data management and preliminary analyses. Drafts of the manuscript were commented on by Marcus Robbins, consultant to FAO, and Nandini Nimbkar, (NARI).

Abstract

This report describes results from a trial with nine provenances of the Australian tree *Acacia aneura*. Three provenances of *Acacia holosericea* (Australia) *Acacia nilotica* (India), *Albizia lebbeck* (India) were included as well. The trial was established with a spacing of 3 x 3 metres at Phaltan, India, in 1987 and tended intensively. It was assessed 5 years later in 1992, and different growth parameters were measured and subjected to analyses of variance and multivariate analyses.

Even though survival was high for some provenances of *Acacia aneura*, the growth of this species was clearly inferior to the local *Acacia nilotica* and *Albizia lebbeck*. The local species were superior in all variables except number of stems, where *Acacia aneura* had the largest values.

Albizia lebbeck had the fastest growth, corresponding to an increment in basal area of 1.6 m^2 ha^{-1} y^{-1}, followed by *Acacia nilotica* with 1.2 m^2 ha^{-1} y^{-1}. The dry weight of *Acacia nilotica* was estimated to 3.9 t ha^{-1} y^{-1}. The basal area of the fastest growing provenance of *Acacia aneura* was less than one tenth of the basal area of *Albizia lebbeck*. Too few trees of *Acacia holosericea* were included in the trial to say anything decisive on the performance of this species.

Even though there was a considerable variation between the provenances of *Acacia aneura*, the trial did not give firm statistical evidence of significant differences. The best provenances were found among the provenances from the Northern Territory in Australia.

Contents

1. Introduction

This report describes the results from trial no. 19 in a large series of provenance trials within the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species'. The main goals of the series were to contribute to the knowledge on the genetic variation of woody species, their adaptability and productivity and to give recommendations for the use of the species. The species included in this series of trials are mainly of the genera *Acacia* and *Prosopis*. A detailed introduction to the series is given by DFSC (Graudal *et al.* 2003).

This trial includes provenances of the species *Acacia aneura*, *Acacia holosericea*, *Acacia nilotica* and *Albizia lebbeck*. The main species is *Acacia aneura* with nine provenances, whereas the other species are represented with only one provenance each. *A. aneura* and *A. holosericea* are both exotic species (from Australia), but the provenances of *A. nilotica* and *A. lebbeck* are local and most likely intended as controls in the trial.

A. aneura has a wide distribution in the central and southern of the Australian continent (Hall *et al.* 1979). The species is restricted to the arid and semi-arid zone with annual precipitation in the range of 100 to 500 mm, and the provenances in this trial cover most of the range geographically. Seed of the species are used for food by the aboriginal people in Australia (John Larmour, pers. com.) and could be an alternative food crop. Besides this it is an important fodder species in Australia, and is believed to have a potential for erosion control and shelter (Hall *et al.* 1979).

2. Materials and methods

2.1 Site and establishment of the trial

The trial is placed at Lundy Farm in Village Rajale, Phaltan (17°55′N, 74°25′W) in India at an altitude of 560 m. The mean annual temperature is approximately 25°C, and the annual rainfall around 500 mm with a dry period of eight to eleven months. The trial was established in October 1987. The date of sowing is not known, but for calculations of annual increments it is assumed that the seed was sown in May 1987. Beating up took place in February 1988, and 50 NPK (19:19:19) was applied to each plant. The trial was irrigated by flooding 14 times from 1987 to 1991, most intensively during the first years. It was weeded nine times during the first two years and bullock cultivated in 1990. Further information is given in the assessment report (DFSC 1994) and summarised in annex 1.

2.2 Species and provenances

The trial includes 11 provenances whose identities are given in Table 1. As mentioned in the introduction there are eight provenances of *Acacia aneura* and one provenance of each of the species *Acacia holosericea*, *Acacia nilotica* and *Albizia lebbeck*. The provenances are given identification numbers relating to their geographical origin (name of province or country followed by a number), and the original seedlot numbers are provided in annex 2. The provenances India3 and India4 are local provenances, but information on their exact origin is not available.

2.3 The experimental design

The experimental design is a randomised block design with three blocks. Most provenances were represented in all three blocks, but the provenances NS Wales1, Queensland5 and W Australia2 of *A. aneura* and N Territory7 of *A. holosericea* were present in only one of the blocks. Within each block, the provenances were represented by 16 trees in a plot, planted in a square of 4×4 trees. For *A. holosericea* the plot consisted of only eight trees. The trees are placed with a spacing of 3×3m. The layout of the trial is shown in annex 3, and further details are given in DFSC (1994).

2.4 Assessment of the trial

In May 1992 NARI, FRI and DFSC undertook a joint assessment. The assessment included the following characters (DFSC 1994):

- Survival
- Health status
- Stem length
- Vertical height
- Diameter of the three largest stems at 0.3 m
- Number of stems at 0.3 m
- Crown diameter

Raw data from the assessment is documented in DFSC (1994). The plot data set on which the statistical analyses in this report are performed is shown in annex 4. This data set includes directly observed values as well as derived variable values.

Table 1. Species and provenances of *Acacia* tested in trial no. 19 at Phaltan, India.

Provenance	Species	Seed collection site	Country of origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
N Territory1	*Acacia aneura*	Alice Springs, Nt	Australia	23° 28' S	133° 17' E	650	264	10
N Territory2	*Acacia aneura*	Vaughan Springs, Nt	Australia	22° 12' S	130° 55' E	600	264	10
N Territory3	*Acacia aneura*	Floodout, Nt	Australia	21° 47' S	131° 09' E	580	264	10
N Territory4	*Acacia aneura*	Glen Helen, Nt	Australia	23° 47' S	132° 27' E	650	264	10
NS Wales1	*Acacia aneura*	Cobar, Nsw	Australia	31° 31' S	145° 45' E	180	355	10
Queensland5	*Acacia aneura*	Eromanga, Qld	Australia	26° 22' S	143° 09' E	180	291	10
W Australia1	*Acacia aneura*	Kalgoorlie, Wa	Australia	30° 45' S	121° 30' E	400	247	
W Australia2	*Acacia aneura*	Jameson, Wa	Australia	25° 54' S	126° 31' E	440	213	10
N Territory7	*Acacia holosericea*	Vaughan Springs, Nt	Australia	22° 12' S	130° 55' E	600	264	
India4	*Acacia nilotica*		India					
India3	*Albizia lebbeck*		India					

3. Statistical analyses

3.1 Variables

In this report the following variables are analysed:

- Survival
- Vertical height
- Crown area
- Number of stems at 0.3 m
- Basal area of the mean tree at 0.3 m
- Total basal area at 0.3 m
- Dry weight of the mean tree
- Total dry weight
- Damage score

The values were analysed on a plot basis, i.e. ratio, mean or sum as appropriate. Survival was analysed as the rate of surviving trees to the total number of trees per plot. Height, crown area, number of stems and damage score were analysed as the mean of surviving trees on a plot, as were the basal area and the dry weight of the mean tree. The total basal area and the total dry weight represent the sum of all trees in a plot, expressed on an area basis. Note that the calculations of basal area are based on measurements of the three largest stems per tree.

For 84 of the small or intermediate sized trees, no assessment of diameter, number of stems and crown diameter was made. Considering that the number of surviving trees was only 228, this represents a significant part of the data. Since omission of these trees will produce biased results and lead to an over-estimation of the provenances in question, the values for crown area, basal area and dry weight for these observations have been set to zero. There is no reasonable way to estimate the number of stems of such trees, and no default value has been set for this variable. After the correction the estimates of the variables will still be biased, but hopefully to a lesser extent than when ignoring them.

The dry weight values were calculated from regressions between biomass and basal area, established in another part of this study (Graudal *et al.* in prep.). For *A. nilotica* the regression used was

$$TreeDW = e^{(a \times \ln(basalarea) - b)}$$

where *TreeDW* expresses the dry weight of the tree in kg tree^{-1}, and *basalarea* expresses the basal area of the tree in cm^{-2}. Unfortunately no regressions were available for the other species.

3.2 Statistical model and estimates

The statistical analysis of the trial was based on a two-step approach. The first step involved a test of differences between all provenances, whereas the second step was a test of differences between provenances of *A. aneura*. Both tests were based on the model:

$$X_{jk} = \mu + provenance_j + block_k + \varepsilon_{jk}$$

where X_{jk} is the value of the trait in plot *jk*, μ is the grand mean, $provenance_j$ is the fixed effect of provenance number *j*, $block_k$ is the fixed effect of block *k*, and ε_{jk} is the residual of plot *jk* and is assumed to follow a normal distribution $N(0, \sigma_e^2)$.

To complement blocks in adjusting for uneven environments, co-variates related to the plot position were included in the initial model. In the initial models, the co-variates were distance along the axis of the trial, ploty, and the squared value of this distances, ploty2. The co-variates were excluded successively if they were not significant at the 10% level.

Standard graphical methods and calculated standard statistics were applied to test model assumptions of independence, normality and variance homogeneity (Snedecor & Cochran 1980, Draper & Smith 1981, Ræbild *et al.* 2002). Where appropriate, transformations or weighting of data as well as excerption of outliers were performed to fulfil basic model assumptions (ibid., Afifi & Clark 1996). Weighting of data with the inverse of the variance for the seedlots was used to obtain normality of the residuals where the seedlots appeared to have different variances.

The P-values from the tests of provenance differences were corrected for the effect of multiple comparisons by the sequential table-wide Bonferroni method (Holm 1979). The tests were ranked according to their P values, and the test corresponding to the smallest P value (P_1) was considered significant on a 'table-wide' significance level of α if $P_1<\alpha/n$, where n is the number of tests. The second smallest P value (P_2) was declared significant if $P_2<\alpha/(n-1)$, and so on (c.f. Kjær & Siegismund 1996). In this case the number of tests was set to nine, thus equalling the number of variables analysed. The significance levels are indicated by (*) (10%), * (5%), ** (1%), *** (1 ‰) and n.s. (not significant).

Finally the model was used to provide estimates for the provenance values. Two sets of estimates are presented: The least square means (LS-means) and the Best Linear Unbiased Predictors (BLUPs) (White & Hodge 1989). In brief, the LS-means give the best estimates of the performance of the chosen provenances at the trial site, whereas the BLUPs give the best indication of the range of variation within the species. As it is assumed in the calculation of BLUPs that the provenances represent a random selection, they are usually presented for the species separately. In this case we present BLUP estimates for *A. aneura*, since this is the only species with more than one provenance. Note that in some cases the ranking of provenances between the LS-mean values and the BLUP values may be different. Special problems arise for NS Wales1, Queensland5 and W Australia2, because they are present in only one of the blocks. In weighted models, provenances with only one replicate will have a BLUP value that equals the average – they do not deviate from the mean value. Therefore BLUPs are not presented for these provenances in weighted models.

A multivariate analysis providing canonical variates, and Wilk's lambda and Pillai's trace statistics, complemented the univariate analyses (Chatfield & Collins 1980, Afifi & Clark 1996, Skovgaard & Brockhoff 1998).

A more detailed description of the methods used for the analyses of variance is given in Ræbild *et al.* (2002), and a short description of the analysis of each variable is included in the result section. The statistical software package used was Statistical Analysis System (SAS 1988a, 1988b, 1991, Littell *et al.* 1996).

4. Results

4.1 Survival

Survival is regarded as one of the key variables when analysing tree provenance trials, since it indicates the adaptability of the provenance to the environment at the trial site. It should be noted that survival reflects only the conditions experienced during the growth of the first few years of the trial and not necessarily the climatic extremes and conditions that may be experienced during the life-span of a tree in the field.

Statistical analysis

Analysis of survival was simple since there was no need for transformation or weights. The co-variate ploty2 was significant in both analyses.

Results

Survival was highly variable ranging from almost zero to almost 100 % (Fig. 1). There were significant differences between the provenances when all provenances were included, but within *Acacia aneura* the provenances were not significantly different (Table 2). The highest survival was found in the local provenances (India3 and India4 of *Albizia lebbeck* and *Acacia nilotica*, respectively). Three out of eight trees for the provenance of *Acacia holosericea* had survived, corresponding to 38 %.

For *Acacia aneura* survival was highly variable. The provenance NS Wales1 had only two surviving trees, but for N Territory1, N Territory3 and W Australia1 the survival was approximately 70 %. The corresponding BLUP values ranged from −20 to +20 % (Fig. 2).

Table 2. Results from analysis of variance of provenance differences of survival in trial 19.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances					
Provenance	10; 11	1630	4.2	0.01	*
Block	2; 11	65.5	0.2	0.85	
Ploty	1; 11	2774	7.1	0.02	
Error	11	389			
A. aneura					
Provenance	7; 7	1131	2.4	0.13	n.s.
Block	2; 7	4.68	0.01	0.99	
Ploty2	1; 7	3263	7.0	0.03	
Error	7	468			

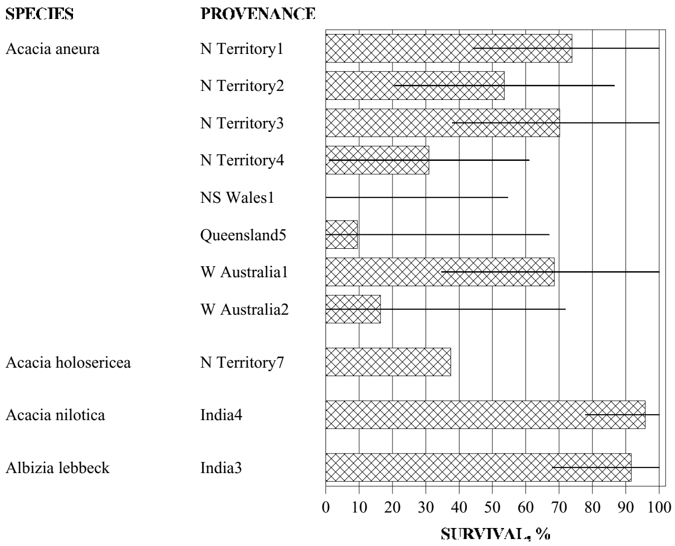

Figure 1. Survival in the *Acacia* species and provenance trial at Phaltan, India (Trial no. 19 in the arid zone series). Values presented are least square means with 95 % confidence limits. The provenance of *A. holosericea* has no confidence limits because the value is estimated from only one observation.

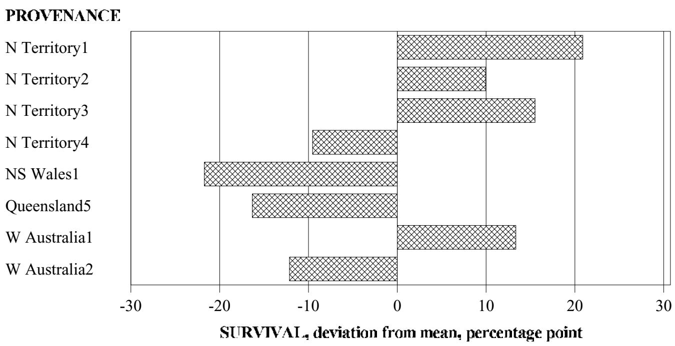

Figure 2. Best linear unbiased predictors (BLUP's) for survival in the *A. aneura* provenances in the trial at Phaltan, India (Trial no. 19 in the arid zone series). Values presented are deviations from the mean value in percentage point.

4.2 Height

Height is usually considered an important variable in the evaluation of species and provenances, though this depends on the main uses of the trees. Apart from indicating productivity, height may also be seen as a measure of the adaptability of trees to the environment, tall provenances/trees usually being better adapted to the site than short provenances/trees. This interpretation need not always be true, as there have been cases where the tallest provenances are suddenly affected by stress and subsequent die-off.

Statistical analysis

In both analyses there were signs that the provenances had different variances, and the data was weighted. No co-variates were significant.

Results

The differences between provenances was highly significant when all provenances were included (Table 3). When only *Acacia aneura* was considered, the differences were significant at the 5 % level, but significance disappeared when the correction for multiple comparisons was made, indicating that the differences should be interpreted cautiously.

Acacia holosericea, *Acacia nilotica* and *Albizia lebbeck* were the highest with heights in the range of 3 to 4 m (Fig. 3). In *Acacia aneura*, height was much smaller, ranging from 80 cm to 2.2 m. Here N Territory1 and N Territory2 were the highest. BLUP values were in the range of ±35 % (Fig. 4).

Table 3. Results from analysis of variance of provenance differences of vertical height in trial 19.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances					
Provenance	6; 12	130.5		<0.0001	***
Block	2; 12	0.8	0.8	0.47	
Error	12	1.1			
A. aneura					
Provenance	4; 8	6.58	6.0	0.02	n.s.
Block	2; 8	3.63	3.3	0.09	
Error	8	1.10			

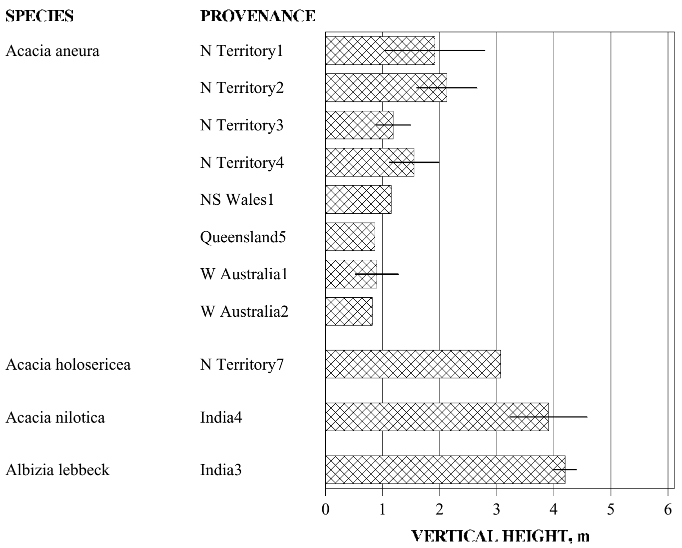

Figure 3. Vertical height in the *Acacia* species and provenance trial at Phaltan, India (Trial no. 19 in the arid zone series). Values presented are least square means with 95 % confidence limits. The provenance of *A. holosericea* has no confidence limits because the value is estimated from only one observation.

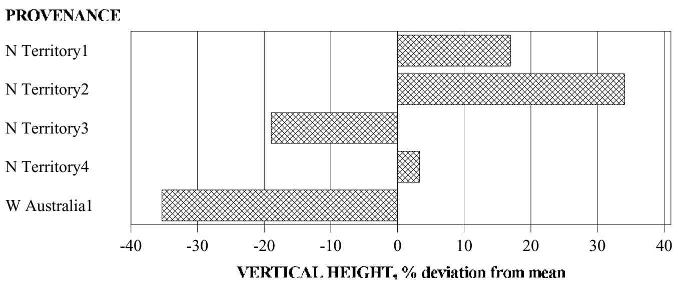

Figure 4. Best linear unbiased predictors (BLUP's) for vertical height in the *A. aneura* provenances in the trial at Phaltan, India (Trial no. 19 in the arid zone series). Values are presented as deviations in percent of the mean value. Due to the weight statement there are no estimates for the provenances NS Wales1, Queensland5 and W Australia2. These provenances are represented by only one observation and hence automatically get a BLUP value equalling the average value (deviation equals zero).

4.3 Crown area

The crown area variable gives the ability of the trees to cover the ground. The character is important because of shading for agricultural crops, in evaluations of the production of fodder and in protection of the soil against erosion.

Statistical analysis

There was variance heterogeneity between the provenances, and in both analyses the data was weighted. No co-variates were significant. Note that for a large number of small trees, crown area was not assessed, and that the values for these trees have been set to a default value of zero instead. This may introduce a bias in the tests and estimates (section 3.1). For example the provenances Queensland5 and W Australia2 did not have trees above 1 m, which means that the average values for these provenances are zero.

Results

Differences between provenances were again highly significant (Table 4). However, when only provenances of *Acacia aneura* were considered, the differences were on the limit of significance, and the correction for multiple comparisons made significance disappear completely.

The largest crown area was found in *Albizia lebbeck* with 15 m^2 $tree^{-1}$ (Fig. 5). *Acacia nilotica* and *Acacia holosericea* had crown areas of 8 and 6 m^2 $tree^{-1}$, respectively. For *Acacia aneura*, the average crown areas were varying between practically zero for Queensland5 and W Australia2, and almost 2 m^2 $tree^{-1}$ for N Territory1. Despite the lack of significant provenance differences, the BLUP values indicated that there are substantial gains by choosing the best provenances: Values varied between –70 and +40 % (Fig. 6).

Table 4. Results from analysis of variance of provenance differences of crown area in trial 19.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances					
Provenance	6; 12	92.8	80.1	<0.0001	***
Block	2; 12	3.3	2.8	0.10	
Error	12	1.2			
A. aneura					
Provenance	4; 8	3.5	3.4	0.07	n.s.
Block	2; 8	8.5	8.3	0.01	
Error	8	1.0			

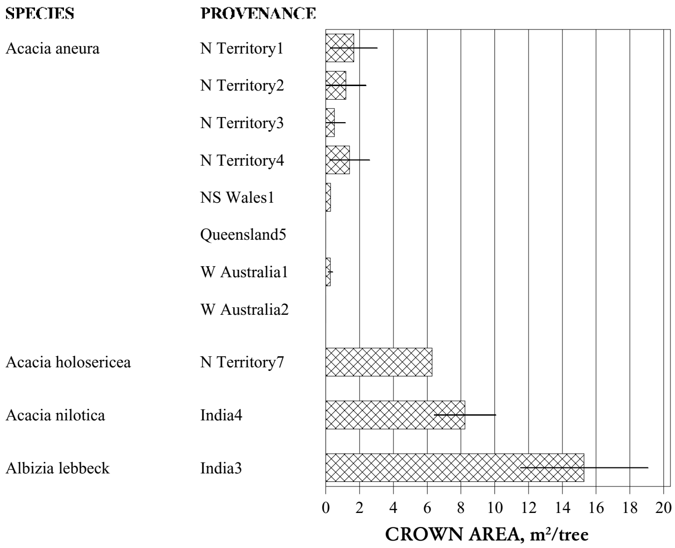

Figure 5. Crown area in the *Acacia* species and provenance trial at Phaltan, India (Trial no. 19 in the arid zone series). Values presented are least square means with 95 % confidence limits. The provenance of *A. holosericea* has no confidence limits because the value is estimated from only one observation.

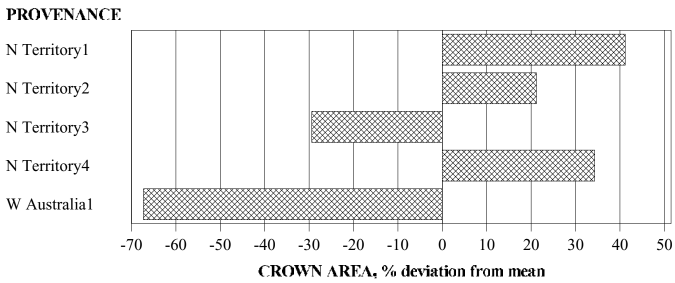

Figure 6. Best linear unbiased predictors (BLUP's) for crown area in the *A. aneura* provenances in the trial at Phaltan, India (Trial no. 19 in the arid zone series). Values are presented as deviations in percent of the mean value. Due to the weight statement there are no estimates for the provenances NS Wales1, Queensland5 and W Australia2. These provenances are represented by only one observation and hence automatically get a BLUP value equalling the average value (deviation equals zero).

4.4 Number of stems

The number of stems gives an indication of the growth habit of the provenances. Trees with a large number of stems are bushy, whereas trees with only one stem have a tree-like growth.

Statistical analysis

As there was variance heterogeneity in the data, data was weighted in both models. No co-variates were significant. For a large number of small trees the number of stems was not assessed, which introduces a bias in the analysis (section 3.1). Values should therefore be interpreted with caution. Since Queensland5 and W Australia2 had no trees larger than 1 m height, there are no estimates for these provenances.

Results

The analyses of variance demonstrated that there were significant differences between the provenances, but that the significance disappeared when *Acacia aneura* was considered alone (Table 5). It seemed that the provenances of *Acacia aneura* had much larger number of stems than the other species, having average values of between 4 and 6 stems tree^{-1}. For the three other species, the number of stems was between 1 and 2 (Fig. 7). In *Acacia aneura* the BLUP values were between −13 and +9%, indicating modest gains by provenance selection for this character (Fig. 8).

Table 5. Results from analysis of variance of provenance differences of number of stems in trial 19.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances					
Provenance	6; 11	5.65	5.6	0.007	*
Block	2; 11	9.09	9.1	0.005	
Error	11	1.00			
A. aneura					
Provenance	4; 7	2.02	2.7	0.12	n.s.
Block	2; 7	97.3	128.6	<0.0001	
Error	7	0.756			

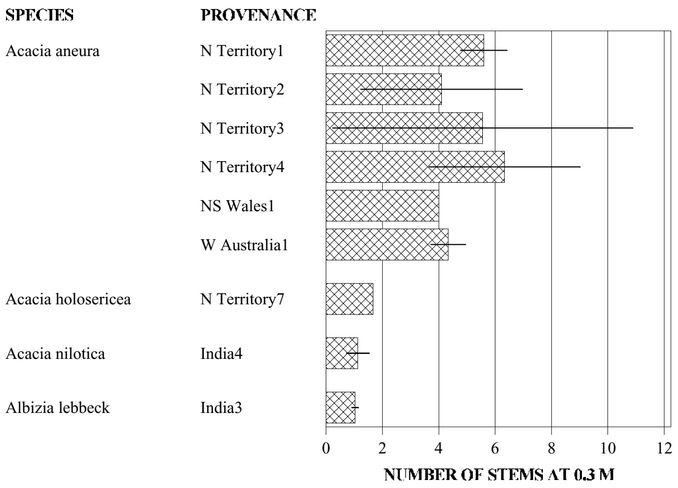

Figure 7. Number of stems in the *Acacia* species and provenance trial at Phaltan, India (Trial no. 19 in the arid zone series). Values presented are least square means with 95 % confidence limits. The provenance of *A. holosericea* has no confidence limits because the value is estimated from only one observation.

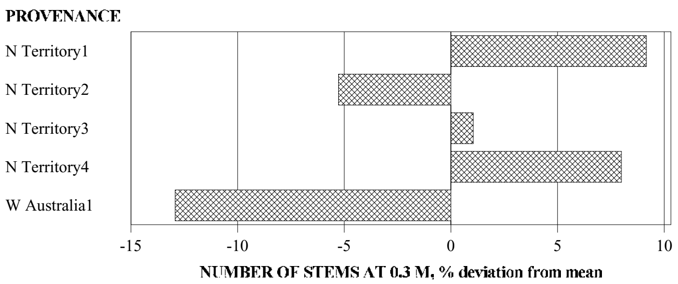

Figure 8. Best linear unbiased predictors (BLUP's) for number of stems in the *A. aneura* provenances in the trial at Phaltan, India (Trial no. 19 in the arid zone series). Values are presented as deviations in percent of the mean value. Due to the weight statement there are no estimates for the provenances NS Wales1, Queensland5 and W Australia2. These provenances are represented by only one observation and hence automatically get a BLUP value equalling the average value (deviation equals zero).

4.5 Basal area of the mean tree

The basal area is often used as a measure of the productivity of stands, since it is correlated with the production of wood. The basal area of the mean tree is calculated on the live trees only and gives an estimate of the potential basal area production of the provenance under the condition that all trees survive.

Statistical analysis

There was variance heterogeneity between the provenances in both analyses, and the data was weighted to fulfil the assumptions of the models. No co-variates were significant. Note that as in the analyses crown area the basal area has been set to zero for trees where the assessment was missing (section 3.1). This may introduce a bias in tests and estimates.

Results

There was a very large variation between the basal area of the mean tree for the different provenances, which resulted in the provenance effect being highly significant (Table6). For *Acacia aneura* considered alone, the difference between provenances was almost significant, but this disappeared when the correction for multiple comparisons was made.

Albizia lebbeck had the largest basal area of the mean tree with 73 cm^2 $tree^{-1}$, followed by *Acacia nilotica* with 56 cm^2 $tree^{-1}$ and *Acacia holosericea* with 18 cm^2 $tree^{-1}$ (Fig. 9). The provenances of *A. aneura* varied between almost nothing and 7 cm^2 $tree^{-1}$. In this species, N Territory1, N Territory2 and N Territory4 had the fastest growth, and the BLUP values predicted gains between 65 and 30 % by provenance selection (Fig. 10).

Table 6. Results from analysis of variance of provenance differences of basal area of the mean tree in trial 19.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances					
Provenance	6; 12	66.4	67.8	<0.0001	***
Block	2; 12	0.14	0.15	0.86	
Error	12	0.98			
A. aneura					
Provenance	4; 8	3.7	3.3	0.07	n.s.
Block	2; 8	5.7	5.2	0.04	
Error	8	1.1			

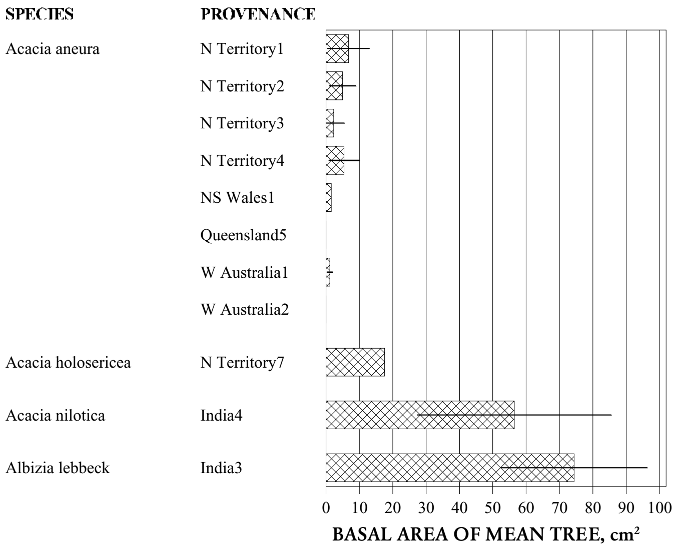

Figure 9. The basal area of the mean tree in the *Acacia* species and provenance trial at Phaltan, India (Trial no. 19 in the arid zone series). Values presented are least square means with 95 % confidence limits. The provenance of *A. holosericea* has no confidence limits because the value is estimated from only one observation.

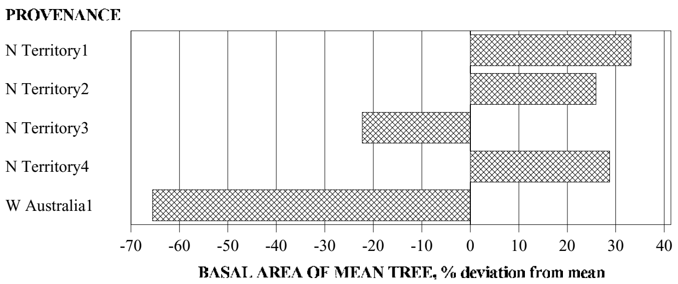

Figure 10. Best linear unbiased predictors (BLUP's) for the basal area of the mean tree of the *A. aneura* provenances in the trial at Phaltan, India (Trial no. 19 in the arid zone series). Values are presented as deviations in percent of the mean value. Due to the weight statement there are no estimates for the provenances NS Wales1, Queensland5 and W Australia2. These provenances are represented by only one observation and hence automatically get a BLUP value equalling the average value (deviation equals zero).

4.6 Total basal area

In comparison to the basal area of the mean tree, the total basal area accounts for missing trees and is thus a better measure of the actual production on the site.

Statistical analysis

There was variance heterogeneity in both models, and the data was weighted before analyses. In the analysis of all provenances the co-variate ploty was significant.

Results

The differences between provenances were highly significant when all provenances were included, but within the provenances of *Acacia aneura* the differences between provenances were not significant (Table 7).

Albizia lebbeck had the largest total basal area with 7.6 m^2 ha^{-1}, followed by *Acacia nilotica* with 6.1 m^2 ha^{-1}. *Acacia holosericea* had a basal area of 0.7 m^2 ha^{-1}. For the provenances of *Acacia aneura*, total basal area varied between 0 and 0.6 m^2 ha^{-1}, with N Territory1 as the fastest growing.

As the differences between provenances of *A. aneura* were far from significant, it was not possible to calculate BLUP estimates. Therefore no figure with predicted deviations from the mean value is presented.

Table 7. Results from analysis of variance of provenance differences of total basal area in trial 19.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances					
Provenance	6; 11	51.7	47.4	<0.0001	***
Block	2; 11	9.1	8.4	0.006	
Ploty	1; 11	10.5	9.6	0.01	
Error	11	1.1			
A. aneura					
Provenance	4; 8	1.60	1.8	0.22	n.s.
Block	2; 8	1.90	2.2	0.18	
Error	8	0.883			

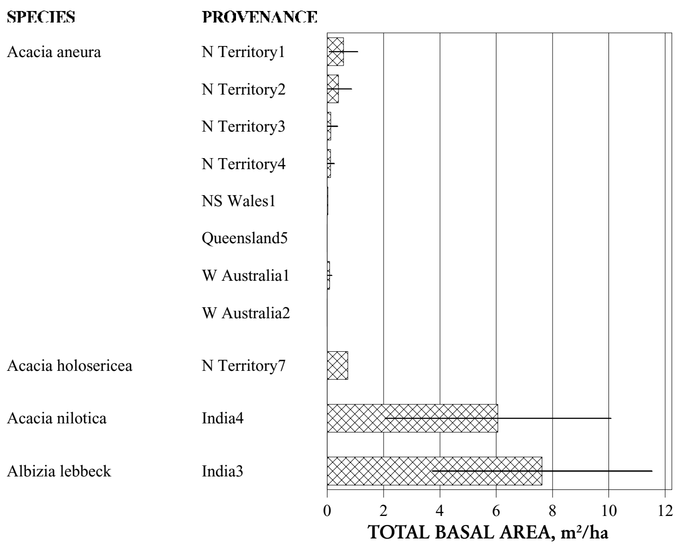

Figure 11. Total basal area in the *Acacia* species and provenance trial at Phaltan, India (Trial no. 19 in the arid zone series). Values presented are least square means with 95 % confidence limits. The provenance of *A. holosericea* has no confidence limits because the value is estimated from only one observation.

4.7 Dry weight of the mean tree and total dry weight

The average dry weight is comparable to the average basal area in that they both are calculated on the live trees only and thus serve as a measure of the potential production at the site, provided that all trees survive. Furthermore, the two variables are linked, as the basis for estimation of the dry weight is the basal area. However, an important difference is that the dry weight includes a cubic term (in comparison to basal area having only a square term), meaning that large trees with a large dry mass are weighted heavily in this variable. The dry weight of the mean tree is thus the best estimate for the potential production of biomass at the site, provided that all trees survive. Similarly, the total dry weight gives the best estimate for the actual production of biomass at the site. Since the dry weight could only be calculated for India4, the provenance of *A. nilotica*, no statistical analyses of the two variables were made.

The dry weight of the mean tree for India4 was 16 kg $tree^{-1}$, and the total dry weight was 17.5 t ha^{-1}. This corresponds to an average annual growth of 3.5 t ha^{-1}. Since there is a close connection between basal area and dry weight, it can be assumed that *Albizia lebbeck* must have a dry weight in the same range as for India4, whereas the other provenances have dry weights that are substantially smaller, perhaps less than a tenth of India4 (*cf.* the graphs of basal area, Fig. 9 and 11).

4.8 Damage score

The damage score was determined on a scale from 0 to 3, where 0 means no damage, 1 - light damage, 2 - moderate damage and 3 - severe damage. About half of the damaged trees were damaged by drought, whereas the other half was described as damaged by physical stress.

Statistical analysis

In the analysis of all provenances there were differences in variance between the provenances, and the data was weighted. This was not necessary in the analysis of provenance differences within *A. aneura*. No co-variates were significant.

Two problems with the scale should be borne in mind when interpreting the results. First, the scores are subjective and do not necessarily reflect the real damage level of the trees. It may be difficult to give the proper scores to different species or to trees of different sizes, because the damage affects the trees differently. Second, the scores are not necessarily equidistant. For the growth of a tree it may mean less going from a damage score of 0 to 1 than going from a score of 1 to 2. There are ways of taking this into account, but this has not been attempted in the current analyses.

Results

The differences in damage score were highly significant different. In the analysis of *Acacia aneura* provenances alone, the provenance effect was also significant, but disappeared after the correction for multiple comparisons (Table 8).

The average damage scores varied a lot, ranging from 0.5 in *Albizia lebbeck* to 3 in Queensland5 of *Acacia aneura* (Fig. 12). Many provenances of *Acacia aneura* were heavily damaged, but N Territory4 had a value below 1, corresponding to light damage. The trees of *Acacia holosericea* were also moderately to severely damaged, whereas *Acacia nilotica* had only light damage.

In *Acacia aneura* the BLUP values indicated that there could be substantial gains by choosing the best provenances. N Territory had a damage score almost 1 score below the average (corresponding to a superior health), whereas the most damaged provenances had scores 0.5 higher than the average (Fig. 13).

Table 8. Results from analysis of variance of provenance differences of damage score in trial 19.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances					
Provenance	6; 12	22.6	20.8	<0.0001	***
Block	2; 12	2.8	2.6	0.12	
Error	12	1.1			
A. aneura					
Provenance	7; 8	1.5	3.9	0.04	n.s.
Block	2; 8	0.9	2.3	0.16	
Error	8	0.4			

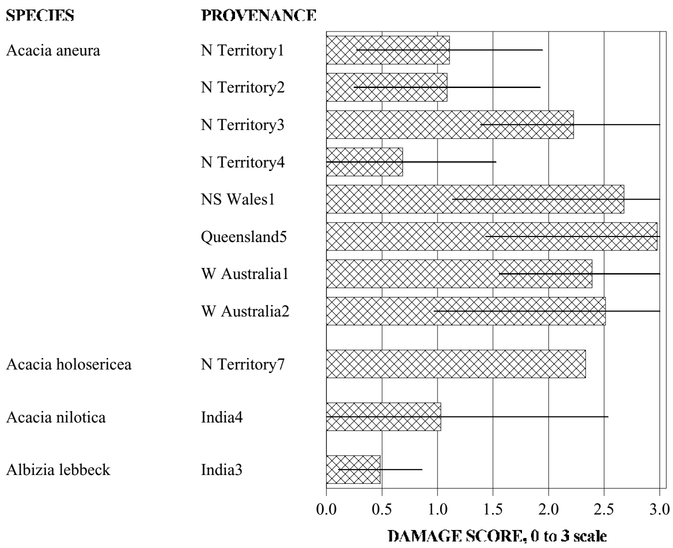

Figure 12. Damage score in the *Acacia* species and provenance trial at Phaltan, India (Trial no. 19 in the arid zone series). Values presented are least square means with 95 % confidence limits. The provenance of *A. holosericea* has no confidence limits because the value is estimated from only one observation.

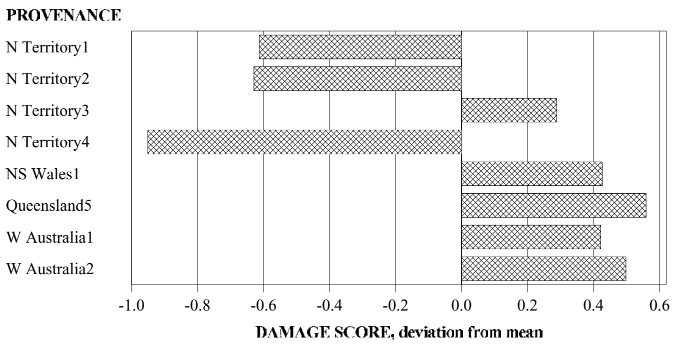

Figure 13 Best linear unbiased predictors (BLUP's) for number of stems in the *A. aneura* provenances in the trial at Phaltan, India (Trial no. 19 in the arid zone series). Values are presented as deviations from the mean value in the units of the damage score. Note that negative deviations from the mean correspond to a better health status.

4.9 Multivariate analysis

The multivariate analysis included the all the variables subjected to a statistical analysis in the univariate analyses, i.e. excluding dry weight of the mean tree and total dry weight. The variance heterogeneity that was observed in many of the univariate analyses was not accounted for.

The first two canonical variates were significant, in total accounting for 98 % of the variation (Table 9). Differences between the provenances were highly significant (P-value for Wilk's lambda<0.0001, P-value for Pillai's trace=0.002).

Fig. 14 gives the plot of scores for the two first canonical variates. Apart from the scores, the mean values for the provenances are given together with their approximate 95 % confidence regions. In the diagram, provenances that are far apart are interpreted as being different, and if the confidence regions do not overlap, it is likely that the provenances have different properties. It should be noted that the confidence regions are calculated on the assumption that there are three replicates. This means that they are not valid for the provenances with only one replicate.

The clustering of the provenances in Fig. 14 confirms the impression obtained from the univariate analyses. The provenances of *Acacia aneura* are all in the same group, whereas the provenances of the other species are located far away from this group, thus indicating the differences between *Acacia aneura* and the rest of the species.

A second analysis, only with the provenances of *Acacia aneura*, was made with the same variables as for the analysis of all provenances. However, as even the first canonical variate was far from being significant, there were no indications of differences between the provenances, and the analysis was not continued.

Table 9. Results from the canonical variate analyses for the first two canonical variates in trial 19.

Canonical variate no.	**1**	**2**
Proportion of variation accounted for	0.93	0.05
Significance, P-value	<0.0001	0.007

	Raw canonical coefficients		**Standardised canonical coefficients**		**Canonical directions**	
Canonical variate no.	**1**	**2**	**1**	**2**	**1**	**2**
Survival	0.019	-0.056	0.6	-1.6	12.0	11.4
Height	1.2	8.2	1.5	10.4	0.9	0.6
Crown area	0.81	-1.3	4.3	-6.9	4.1	-3.1
Number of stems	0.078	0.32	0.2	1.0	-1.4	-1.8
Basal area of the mean tree	0.77	-0.39	22.0	-11.1	21.6	-3.8
Total basal area	-4.1	3.5	-12.7	10.9	2.3	-0.3
Damage score	4.2	3.1	3.7	2.7	-0.2	0.8

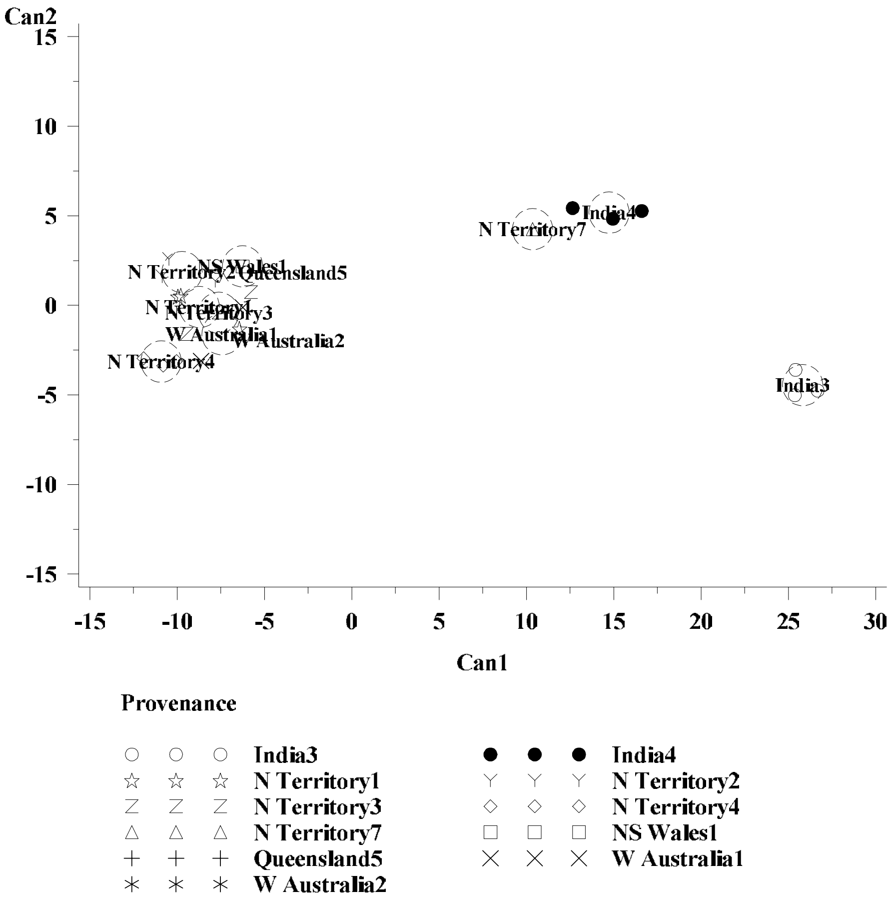

Figure 14. Score plot of the first and the second canonical variate from the canonical variate analysis for the provenances in the trial at Phaltan, India (Trial no. 17 in the arid zone series). The variables survival, height, crown area, number of stems, basal area of the mean tree, total basal area and damage score were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.

5. Discussion and conclusions

Productivity

Whereas the provenances of *Acacia aneura* had a very modest production, *Albizia lebbeck* and *Acacia nilotica* had an increase in the basal area of 1.5 and 1.2 m^2 ha^{-1} y^{-1}. For the provenance of *Acacia nilotica*, this corresponded to an average production of 3.5 t ha^{-1} y^{-1}. At Phaltan there is another trial included in this series (Trial no. 20), and the maximum production in the other trial corresponds much to what is found in the current trial. Comparison to the rest of the trials in the arid zone series is difficult, however, as tending has been very intensive in the trials at Phaltan. Irrigation has taken place on several occasions, meaning that survival and growth could be influenced heavily compared to situations where tending has been more extensive.

Species and provenance differences

It was clear from the trial that the provenances of *Acacia aneura* had a very poor performance in the trial. As provenances from a large proportion of the natural distribution have been included, it seems that possibilities for finding provenances that have a more convincing growth are limited. Of the three other species included, the two local species, *Acacia nilotica* and *Albizia lebbeck* were relatively fast growing and were the most productive in all characters. The exception was number of stems, where the two species had less than *Acacia aneura*. For *Acacia holosericea* it is difficult to draw conclusions, since there was only one replicate with few trees. The surviving trees had a performance better than *Acacia aneura*, but inferior to the two other species.

Within *Acacia aneura* there were signs of significant differences between provenances in the variables height, crown area, basal area of the mean tree and damage score. The correction for multiple comparison always made significance disappear, and the multivariate analysis gave no signs of significant differences. This indicates that the interpretation of provenance differences should be cautious – also because some of the provenances are represented only in one block. However, if the species should be explored in more detail, it seems that some of the provenances from the Northern Territory and the provenance W Australia1 have an acceptable survival. Since the Queensland and New South Wales provenances are represented by only one provenance each it is difficult to draw conclusions for this group.

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Annex 1. Description of the trial site

Name of site:	Village Rajale (Lundy Farm), Phaltan Latitude: 1755°N Longitude: 74°25'E Altitude: 560 m
Meteorological stations:	Tambmal (Phaltan) Lundy Farm (Rajale)
Rainfall (Rajale):	Annual mean (period): 499 mm/year (1987-1992) Yearly registrations: 1987/88: 587.3 1988/89: 530.4 1989/90: 603.5 1990/91: 467.1 1991/92: 305.9 Month of establishment (October 1987): 113.2
Rainy season:	6-10 (June-October) Length (days): 32
Dry months/year:	No. of dry months (< 50 mm): 8-11 No. of dry periods: 1
Temperature (Tambmal):	Annual mean: 25 Coldest month: 11 Hottest month: 41
Topography:	Flat/gentle.
Soil:	Type: Vertisols with stone substrate Depth: Shallow/medium
Climatic/agroecological zone:	Semi-arid
Koeppen classification:	BSh

Annex 2. Seedlots tested in trial no. 19 at Phaltan, India

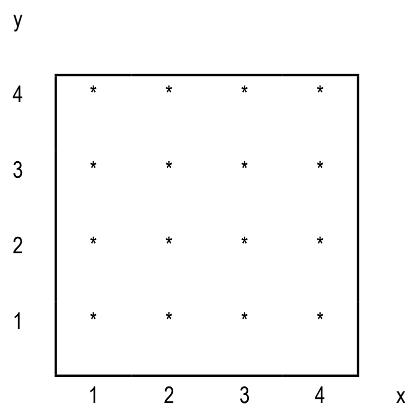
Seedlot numbers				Provenance information							
Provenance	**DFSC**	**Country of origin**	**Plot**	**Species**	**Origin**	**Country of origin**	**Latitude**	**Longitude**	**Altitude (m)**	**Rainfall (mm)**	**No. of mother trees**
N Territory1		13716	2	*Acacia aneura*	Alice Springs, Nt	Australia	23 28 S	133 17 E	650	264	10
N Territory2		13719	3	*Acacia aneura*	Vaughan Springs, Nt	Australia	22 12 S	130 55 E	600	264	10
N Territory3		13720	1	*Acacia aneura*	Floodout, Nt	Australia	21 47 S	131 09 E	580	264	10
N Territory4		13722	4	*Acacia aneura*	Glen Helen, Nt	Australia	23 47 S	132 27 E	650	264	10
NS Wales1		12791	9	*Acacia aneura*	Cobar, Nsw	Australia	31 31 S	145 45 E	180	355	10
Queensland5		13490	8	*Acacia aneura*	Eromanga, Qld	Australia	26 22 S	143 09 E	180	291	10
W Australia1		12838	5	*Acacia aneura*	Kalgoorlie, Wa	Australia	30 45 S	121 30 E	400	247	
W Australia2		14079	10	*Acacia aneura*	Jameson, Wa	Australia	25 54 S	126 31 E	440	213	10
N Territory7		13771	11	*Acacia holosericea*	Vaughan Springs, Nt	Australia	22 12 S	130 55 E	600	264	
India4		Phaltan2	7	*Acacia nilotica*							
India3		Phaltan1	6	*Albizia lebbeck*							

Annex 3. Layout of the trial

Layout of blocks and plots in the field: N

y	Block 1	Block 2	Block 3
9	11		
8	8	9	10
7	2	7	1
6	4	1	5
5	1	5	6
4	5	6	2
3	7	4	3
2	3	2	7
1	6	3	4
x	1	2	3

Individual tree positions in each plot (except plot (1,9)):



Annex 4. Plot data set

The plot numbers correspond to the seedlots in the layout of the trial, see annex 3.

Provenance	Species	Block	Plot	Plotx	Ploty	Survival	Height	Crown area	Number of stems	Basal area of mean tree	Total basal area	Dry weight of mean tree	Total dry weight	Damage score
						%	m	m^2 tree^{-1}	no. tree^{-1}	cm^2 tree^{-1}	m^2 ha^{-1}	kg tree^{-1}	t ha^{-1}	0-3 scale
N Territory1	*Acacia aneura*	1	2	1	7	50	1.57	0.78	3.00	2.9	0.14			1.43
N Territory2	*Acacia aneura*	1	3	1	2	83	2.17	0.70	3.80	3.9	0.27			0.90
N Territory3	*Acacia aneura*	1	1	1	5	47	1.49	1.03	1.67	4.7	0.23			1.29
N Territory4	*Acacia aneura*	1	4	1	6	13	1.95	2.41	3.00	9.1	0.13			0.00
Queensland5	*Acacia aneura*	1	8	1	8	23	0.87	0.00		0.0	0.00			2.67
W Australia1	*Acacia aneura*	1	5	1	4	56	0.76	0.25	2.00	0.7	0.04			2.33
N Territory7	*Acacia holosericea*	1	11	1	9	38	3.07	6.29	1.67	17.5	0.73			2.33
India3	*Albizia lebbeck*	1	6	1	1	100	4.12	17.02	1.00	77.4	8.60			0.31
India4	*Acacia nilotica*	1	7	1	3	100	3.76	7.85	1.07	55.4	6.16	16.2	18.0	0.81
N Territory1	*Acacia aneura*	2	2	2	2	75	1.72	1.79	7.43	6.8	0.56			1.25
N Territory2	*Acacia aneura*	2	3	2	1	93	2.64	2.55	5.50	9.1	0.89			0.36
N Territory3	*Acacia aneura*	2	1	2	6	47	1.20	0.41	3.00	1.0	0.05			2.57
N Territory4	*Acacia aneura*	2	4	2	3	20	1.43	1.47	10.00	5.7	0.12			0.33
NS Wales1	*Acacia aneura*	2	9	2	8	13	1.15	0.28	4.00	1.6	0.02			2.50
W Australia1	*Acacia aneura*	2	5	2	5	69	1.34	0.54	6.00	2.6	0.20			2.09
India3	*Albizia lebbeck*	2	6	2	4	81	4.28	14.63	1.08	64.5	5.82			0.54
India4	*Acacia nilotica*	2	7	2	7	88	3.74	7.78	1.00	45.3	4.40	12.4	12.0	1.71
N Territory1	*Acacia aneura*	3	2	3	4	88	2.46	2.40	6.36	10.4	1.02			0.64
N Territory2	*Acacia aneura*	3	3	3	3	33	1.57	0.32	3.00	1.9	0.04			2.00
N Territory3	*Acacia aneura*	3	1	3	7	73	0.87	0.10	12.00	1.2	0.09			2.82
N Territory4	*Acacia aneura*	3	4	3	1	79	1.26	0.33	6.00	1.4	0.10			1.73
W Australia1	*Acacia aneura*	3	5	3	6	25	0.60	0.00		0.0	0.00			2.75
W Australia2	*Acacia aneura*	3	10	3	8	31	0.82	0.00		0.0	0.00			3.00
India3	*Albizia lebbeck*	3	6	3	5	94	4.20	14.21	1.00	81.3	8.46			0.60
India4	*Acacia nilotica*	3	7	3	2	100	4.22	9.08	1.31	68.6	7.62	20.3	22.5	0.56