Evaluation of a species and provenance trial of Prosopis at Petrolina - PE, Brazil

Trial no. 2 in the arid zone series

Ræbild, Anders; Graudal, Lars Ole Visti; Lima, Paulo C.F.

Publication date:
2003

Document version
Publisher's PDF, also known as Version of record

Evaluation of a species and provenance trial of *Prosopis* at Petrolina - PE, Brazil

Trial no. 2 in the arid zone series

by

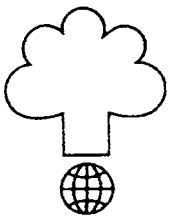
Anders Ræbild[1], Lars Graudal[1] and Paulo Cesar Fernandes Lima[2]

Empresa Brasileira de Pesquisa Agropecuaria[2], Brazil

Centro de Pesquisa Agropecuária do Trópico Semi-Arido, Brazil

Food and Agriculture Organization, Rome

Danida Forest Seed Centre[1], Denmark



Results and documentation no. 13

Danida Forest Seed Centre

July 2003

Citation:
A. Ræbild, Lars Graudal and Paulo Cesar Fernandes Lima. Evaluation of a species and provenance trial of *Prosopis* at Petrolina - PE, Brazil. Trial no 2 in the arid zone series. Results and Documentation No. 13. Danida Forest Seed Centre, Humlebaek, Denmark.

ISSN 0902-3224

Cover photo:
A plot of *Prosopis pallida* in the trial. Phot: Lars Graudal 1992.

This publication can be requested from:

Danida Forest Seed Centre
Krogerupvej 21. DK-3050 Humlebaek, Denmark
Phone: +45-49190500
Fax: +45-49190258
Email: dfsc@sns.dk
Web Site: www.dfsc.dk

and/or be downloaded from the DFSC homepage:
www.dfsc.dk/publications/

Technical Editor: Melita Jørgensen

Print:
Toptryk A/S, Graasten

Results and documentations are publications of analyses of e.g. provenance trials, carried out between DFSC and other institutions. DFSC publications are distributed free of charge.

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.

At the same time, the report presents results within the framework of the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species', initiated by the 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 to 1994. DFSC is responsible for the reporting of this assessment.

This trial was established and maintained by the Empresa Brasileira de Pesquisa Agropecuaria (Embrapa) / Centro de Pesquisa Agropecuária do Trópico Semi-Arido (CPATSA), Petrolina, Pernambuca, in Brazil. The assessment team consisted of Paulo César Fernandes Lima, João Claro de Souza, Pedro José Alves, José de Assis Amaral de Lima (Embrapa/CPATSA), Agnete Thomsen (FAO) and Lars Graudal (DFSC).

The authors wish to acknowledge the help of the personnel at Embrapa/CPATSA 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 Luiz Balbino Morgado, researcher at Embrapa Semi-Àrido.

Abstract

This report describes results from a trial with 13 provenances of *Prosopis*. The species were *P. alba*, *P. chilensis*, *P. flexuosa*, *P. glandulosa*, *P. juliflora*, *P. nigra* and *P. pallida*, represented with two provenances each except for *P. nigra* with only one. The trial was established with a spacing of 6 x 6 metres at Petrolina - PE, Brazil in 1988, and assessed after 5 years in 1992. Different growth parameters were measured and subjected to analyses of variance and multivariate analyses.

The fastest growing provenances had an increment rate in basal area of 0.5 m^2 ha^{-1} y^{-1}, corresponding to a dry weight production of approximately 2.1 t ha^{-1} y^{-1}. The provenances with the fastest growth in basal area were of *P. juliflora* and *P. pallida*, whereas provenances of *P. chilensis*, *P. flexuosa*, *P. glandulosa* and *P. nigra* had slower growth. *P. alba* was intermediate. The differences between provenances were highly significant, but species differences were less conspicuous. There was evidence of differences between the provenances within *P. juliflora*, *P. flexuosa* and *P. alba*.

Contents

1. Introduction

This report describes the results from trial no. 2 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 more detailed introduction to the series is given by DFSC (Graudal *et al*. 2003).

Many species of the genus *Prosopis* occur naturally in extremely hot and highly arid environments. Only four *Prosopis* species are native to the Old World, and the largest diversity of species is found in South and Central America (Ffolliott & Thames 1983). The current trial includes thirteen provenances of the genus *Prosopis*, all of neotropical origin but with two landraces from Pakistan. The provenances represent a selection of not less than seven species. It should be noted that the taxonomy of *Prosopis* is difficult and still a matter of debate (cf. Ffolliott & Thames 1983).

Results from this trial have also been analysed by Lima (1998).

2. Materials and methods

2.1 Site and establishment of the trial

The trial is located at Bebedouro, Petrolina (9°9′S, 40°22′W) in Pernambuco state, Brazil, at an altitude of 366 m. The mean annual temperature is 27 ºC, and the mean annual rainfall is 553 mm (DFSC 1994). The dry period is approximately 7 months. The soils in the area are shallow latosols with low water holding capacity, low content of organic matter and phosphorous deficiency (Lima 1998). Further information is given in the assessment report (DFSC 1994) and summarised in annex 1.

The seed were sown in January 1988, and the trial was established in March the same year.

2.2 Species and provenances

The trial includes thirteen provenances of seven species of the genus *Prosopis* (Table 1). The provenances have been given identification numbers relating to their geographical origin (name of province or country followed by a number). The original seedlot numbers are provided in annex 2.

The species *P. alba*, *P. chilensis*, *P. flexuosa*, *P. glandulosa*, *P. juliflora* and *P. pallida* are represented by two provenances each, whereas the species *P. nigra* is represented by one provenance. During the assessment it was discovered that the seedlot from Punjab was in fact a mixture of two species, which are therefore treated as two separate provenances in the analyses. The two seedlots of *P. alba* were collected at the same place and the same time, but the one collection is made on the variety *panta*, and the trial therefore allows for a test of differences between the two provenances. It should also be noted that the provenances Argentina4, Argentina5 and Argentina6, although of different species, were collected at the same site.

Geographically, the provenances represent the countries Argentina, Brazil, Chile, Mexico and Peru, with the provenances from Punjab, India, as the only one coming from outside Latin America. These provenances are landraces of species introduced from Latin America. The provenance from Brazil is a local landrace of *P. juliflora* and may serve as a control in the trial.

2.3 The experimental design

The experimental design is a lattice design with four replicates of each provenance and 16 sub-blocks with 3 provenances each. An alternative interpretation of the design is a randomised complete block design with four blocks. Irrespective of the interpretation, there is a small error in the design, violating the assumption of independence: The sub-blocks have not been randomised as can be seen from the fact that the western-most provenance in each block is always the provenance Brazil2. This is ignored in the current analyses.

Within each block, each provenance is represented by 36 trees in a plot, planted in a square of 6×6 trees. The trees are placed with a spacing of 6×6 m. The layout of the trial is shown in annex 3. Further details are given in DFSC (1994).

2.4 Assessment of the trial

In October 1992 Embrapa/CPATSA, FAO and DFSC undertook a joint assessment, including the following characters:

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

A detailed account of the assessment methods is given by DFSC (Graudal *et al.* 2003), and raw data from the 1992 assessment are 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 *Prosopis* tested in trial no. 2 at Petrolina - PE, Brazil.

Provenance identification	Species	Seed collection site	Country of origin	Latitude	Longitude	Altitude (m)	Ann. rainfall (mm)	No. of mother trees
Argentina2	*P. alba* var *panta*	Catamarca	Argentina	27°30'S	64°55'W			16
Argentina3	P. alba	Catamarca	Argentina	27°30'S	64°55'W			14
Argentina4	*P. chilensis*	La Rioja	Argentina	29°30'S	67°00'W			13
Chile05	*P. chilensis*	Lampa	Chile	33°17'S	70°53'W	500	306	5
Argentina5	*P. flexuosa*	La Rioja	Argentina	29°30'S	67°00'W			19
Chile09	*P. flexuosa*	Copiado	Chile	27°18'S	70°45'W	300	15	
Mexico03	*P. glandulosa* var. *torreyana*	Concepcion Del Oro	Mexico	24°49'N	101°25'W	1650		
Punjab9a	*P. glandulosa*	Fazal Abad Rice Mill, D.I.Khan	Pakistan	31°15'N	70°45'E	330	300	25
Brazil2	*P. juliflora*	Bebedouro	Brazil	9°9'S	40°22'W	365.5	553	15
Punjab9b	*P. juliflora*	Fazal Abad Rice Mill, D.I.Khan	Pakistan	31°15'N	70°45'E	330	300	25
Argentina6	*P. nigra*	La Rioja	Argentina	29°30'S	67°00'W			11
Peru05	*P. pallida*	Piura	Peru	5°12'S	80°38'W			4
Peru13	*P. pallida*	Ocucaje (Ica), Zona: Tres Esquinas	Peru	14°20'S	75°40'W	420		

3. Statistical analyses

3.1 Variables

In this report the following eight 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

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 and number of stems were analysed as the mean of surviving trees on a plot, as was 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 remaining 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. A number of health characters were also assessed, but since the trees were generally in good health and there was little apparent difference between the provenances, no analyses is made. Instead a graphic presentation of the health data is given in Annex 5.

A special problem with the assessment data is that for a few small trees, no assessment of diameter and/or number of stems were made. For diameter, four observations were missing, whereas three trees had no observations of number of stems. Since exclusion of these data will produce biased results and result in over-estimation of the provenances in question, the values for 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 values have been set for this variable. In any case, the estimates of the variables will be slightly biased, but considering that there are a total of 765 trees in the trial, this has probably only limited importance.

Another problem is posed by the mixed seedlot. Estimation of survival, total basal area and total biomass will have to be based on assumptions of the identity of the missing trees. In the analyses of these three variables it was assumed that the ratio of missing trees of the two provenances was the same as the ratio of live trees for the two provenances. In other words, it is assumed that the mortality for the two species is the same. Since mortality was low, it is believed that this introduces only a minor error in the calculations. However, in block 4, only two trees of the Punjab provenance were *P. juliflora*, which means that there is a considerable uncertainty related to the plot means and sums of variables from this plot. This is amongst others accounted for by weighting of the data (see below).

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 *P. juliflora* the regression used was

$$TreeDW = e^{(2.466 \times \ln(basalarea) - 2.036)}$$

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}. For *P. pallida* the regression was

$$TreeDW = e^{(2.813 \times \ln(basalarea) - 2.765)}$$

No regressions were available for the other species.

3.2 Statistical model and estimates

As mentioned above the design can be interpreted both as a lattice design and as a randomised complete block design. In a similar trial of *Acacia* species, also at Petrolina - PE, Brazil, a comparison between analysis by the normal block design and by the lattice design showed that the lattice design did not give better estimates than the randomised complete block design (Trial no. 1 in this series, Ræbild et al. 2003a). On the basis of this comparison it was decided to make the analyses of this trial according to the randomised complete block design.

Several tests were performed to analyse the variation between provenances in the trial. The first step was a test of differences between all provenances, based on the model

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

where X_{jk} is the value of the trait (e.g. height) 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 $N(0, \sigma_\varepsilon^2)$.

The second test was performed to clarify whether there were differences between the species of the trial. In this test the following model was used:

$$X_{ijk} = \mu + species_i + provenance(species)_{ij} + block_k + \varepsilon_{ijk}$$

where X_{ijk} is the value of the trait in plot *ijk*, μ is the grand mean, $species_i$ is the fixed effect of species number *i*, $provenance(species)_{ij}$ is the effect of provenance number *j* nested within species *i*, assumed to be a random effect with an expected value of zero and variance σ_{pr}^2, $block_j$ is the effect of block (replication) *k* in the trial, assumed to be a random effect (or, in the case of calculating least square means, a fixed effect), and ε_{ijk} is the residual of plot *ijk*, and is assumed to follow the normal distribution $N(0, \sigma_e^2)$. In this test, the Satterthwaite's approximation was used for calculating degrees of freedom (SAS 1988a).

Both tests were performed with and without the mixed seedlot (Punjab9a and Punjab9b) because of the apparent uncertainty related to it. Finally a series of tests were performed to analyse differences between the provenances of each species separately. These tests were performed according to the model (3).

To complement blocks in adjusting for uneven environments, co-variates related to the plot position were included. In the initial models, the co-variates were distances along the two axes of the trial, plotx and ploty, and squared values of these, plotx2 and 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). 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 (*ibid.*; Afifi & Clark 1996).

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. Kjaer & Siegismund 1996). In this trial, the number of tests was usually set to eight, thus equalling the number of variables analysed. However, the number was six for some of the tests of differences within species, as no dry weight estimation was possible for these species (all species except for *P. juliflora* and *P. pallida*). The significance levels are indicated by (*) (10%), * (5%), ** (1%), *** (1 ‰) and n.s. (not significant).

Finally the model was used to provide least square means (LS-means) estimates for the provenances, and 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, Skovgård & Brockdorf 1998).

The statistical software package used was Statistical Analysis System (SAS 1988a, 1988b, 1991, Littell *et al.* 1996). 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 given in the result section.

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 the survival reflects only the conditions experienced during the first few years of the trial and not necessarily the climatic extremes and conditions that may be experienced during the whole life-span of a tree.

Statistical analysis

The analyses proceeded without problems, and no transformations or weights were used. No covariates were significant.

Results

The survival was highly variable, ranging from below 10 % for the provenance Chile09 to almost 90 % for others. Correspondingly, the differences between provenances were highly significant, irrespective of whether the mixed provenance from Punjab was included or not (Table 2). However, the differences between species were not significant (Table 2). Within the species, differences between the provenances were not significant with the single exception of *P. flexuosa*, which was however not significant after the correction for multiple comparisons was made (Table 3). Thus, the significant differences between provenances must be primarily due to differences between provenances of different species.

The provenances of *P. glandulosa*, *P. juliflora* and *P. pallida* had the highest survivals, whereas the provenances Argentina4, Chile05 (both *P. chilensis*) and Chile09 (*P. flexuosa*) had survivals below 50 % (Fig. 1). The rest of the provenances were intermediate.

Table 2. Results from tests of differences in survival between all provenances in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of differences between all provenances					
Provenance	12; 36	0.264	14.7	<0.0001	***
Block	3; 36	0.052	2.9	0.05	
Error	36	0.018			
Test of differences between all provenances except provenances from Punjab					
Provenance	10; 30	0.269	14.5	<0.0001	***
Block	3; 30	0.053	2.9	0.05	
Error	30	0.019			
Test of differences between species, including all provenances					
Species	6; 6	0.393	2.9	0.11	n.s.
Provenance(species)	6; 36	0.134	7.5	<0.0001	
Block	3; 36	0.052	2.9	0.05	
Error	36	0.018			
Test of differences between species, excluding provenances from Punjab					
Species	6; 4	0.317	1.6	0.33	n.s.
Provenance(species)	4; 30	0.197	10.6	<0.0001	
Block	3; 30	0.053	2.9	0.05	
Error	30	0.019			

Table 3. Results from tests of provenance differences in survival within species in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
P. alba					
Provenance	1; 3	0.0176	1.6	0.30	n.s.
Block	3; 3	0.0221	2.0	0.29	
Error	3	0.0111			
P. chilensis					
Provenance	1; 3	0.0488	4.4	0.13	n.s.
Block	3; 3	0.000651	0.06	0.98	
Error	3	0.0111			
P. flexuosa					
Provenance	1; 3	0.705	19.0	0.02	n.s.
Block	3; 3	0.0404	1.1	0.47	
Error	3	0.0371			
P. glandulosa					
Provenance	1; 3	0.0122	0.8	0.45	n.s.
Block	3; 3	0.0278	1.7	0.33	
Error	3	0.0161			
P. juliflora					
Provenance	1; 3	0.00195	0.1	0.77	n.s.
Block	3; 3	0.00326	0.2	0.91	
Error	3	0.0189			
P. pallida					
Provenance	1; 3	0.0176	5.4	0.10	n.s.
Block	3; 3	0.0560	17.2	0.02	
Error	3	0.00326			

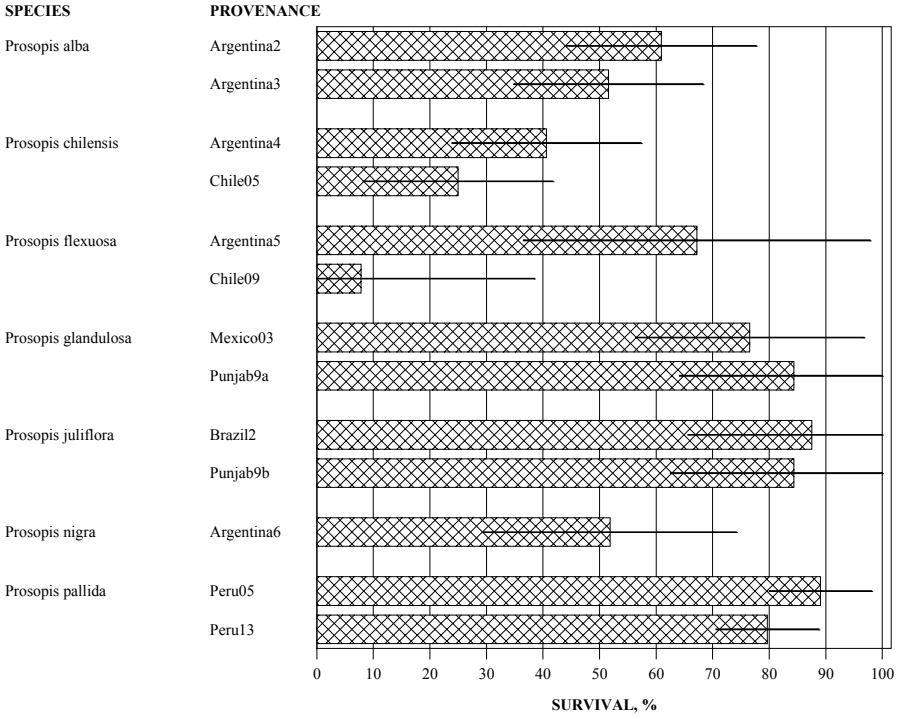


Figure 1. Survival in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.2 Height

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

Statistical analysis

In the full model with all provenances included, the data were weighted in order to fulfil the assumptions of variance homogeneity. When the mixed provenance was excluded this was not necessary, and the weight statements were omitted in this analysis as well as in the tests of differences within species. No co-variates were significant.

Results

Again the differences between all provenances were highly significant, both with and without the mixed provenances (Table 4). The analyses also demonstrated that there were significant differences between the species in the trial. On the other hand there were no significant differences between provenances within the species (Table 5).

The species with the tallest trees was *P. pallida*, where the average heights were between 4 and 4.5 m (Fig. 2). For *P. juliflora* the provenance Brazil2 (the local landrace) had a height of 4.2 m whereas the provenance Punjab9b was 3.1 m high. The species *P. alba*, *P. chilensis*, *P. flexuosa* and *P. glandulosa* all had heights between 2 and 3 m, whereas the provenance of *P. nigra* had a height of only 1.9 m.

Table 4. Results from tests of differences in height between all provenances in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of differences between all provenances					
Provenance	12; 35	46.3	41.0	<0.0001	***
Block	3; 35	5.4	4.8	0.007	
Error	35	1.1			
Test of differences between all provenances except provenances from Punjab					
Provenance	10; 29	2.93	14.5	<0.0001	***
Block	3; 29	0.10	0.51	0.68	
Error	29	0.20			
Test of differences between species, including all provenances					
Species	6; 4.2	40.1	18.9	0.005	*
Provenance(species)	6; 35	1.9	1.6	0.16	
Block	3; 35	5.4	4.8	0.007	
Error	35				
Test of differences between species, excluding provenances from Punjab					
Species	6; 3.8	4.78	27.6	0.004	*
Provenance(species)	4; 29	0.17	0.9	0.50	
Block	3; 29	0.10	0.5	0.68	
Error	29	0.20			

Table 5. Results from tests of provenance differences in height within species in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
P. alba					
Provenance	1; 3	0.327	0.7	0.45	n.s.
Block	3; 3	0.117	0.3	0.85	
Error	3	0.438			
P. chilensis					
Provenance	1; 3	0.153	0.4	0.58	n.s.
Block	3; 3	0.224	0.6	0.67	
Error	3	0.395			
P. flexuosa					
Provenance	1; 2	0.0303	2.2	0.27	n.s.
Block	3; 2	0.140	10.3	0.09	
Error	2	0.0135			
P. glandulosa					
Provenance	1; 3	0.00651	0.03	0.88	n.s.
Block	3; 3	0.0264	0.1	0.95	
Error	3	0.255			
P. juliflora					
Provenance	1; 3	2.58	5.9	0.09	n.s.
Block	3; 3	1.54	3.5	0.16	
Error	3	0.437			
P. pallida					
Provenance	1; 3	0.192	2.0	0.25	n.s.
Block	3; 3	0.318	3.3	0.18	
Error	3	0.0962			

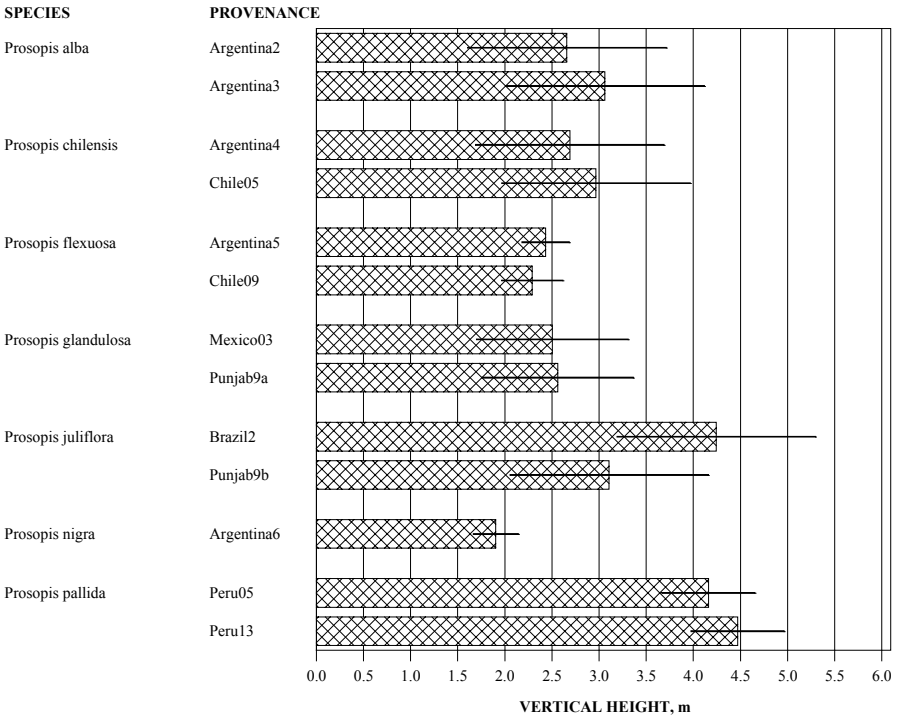


Figure 2. Vertical height in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.3 Crown area

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

Statistical analysis

There was variance heterogeneity in the data, and a weight statement was applied to solve the problem. Apparently the mixed seedlot was responsible for this, because when the seedlot was removed from the analyses, the weights were not necessary. The same was the case for the analyses of differences within species. The co-variates plotx2 and ploty2 were both significant when all provenances were included, but in the tests of differences within species, the co-variates were not significant.

Results

The average crown area for the provenances varied between 5 and 33 m^2 $tree^{-1}$. As the trees were planted at a distance of 6 × 6 m, the trees in the largest provenances were just about to cover the area. The differences between all provenances were highly significant, with and without the mixed seedlot (Table 6). Part of this significance could be explained by significant differences between the species, although the correction for multiple comparisons calls for a cautious interpretation (Table 6). Only within *P. alba* were the differences between provenances significant and did not disappear when correcting for multiple comparisons (Table 7).

The species with the largest crown areas were *P. juliflora* and *P. pallida* (Fig. 3). Provenances in these species had crown areas of 20 m^2 $tree^{-1}$ or more. Within *P. alba* the provenance Argentina3 had the largest crown area, reaching 15 m^2 $tree^{-1}$. In the other provenances the average crown areas were at or below 10 m^2 $tree^{-1}$.

Table 6. Results from tests of differences in crown area between all provenances in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of differences between all provenances					
Provenance	12; 33	33.2	36.7	<0.0001	***
Block	3; 33	1.6	1.8	0.17	
Plotx2	1; 33	12.7	14.0	0.0007	
Ploty2	1; 33	10.9	12.0	0.002	
Error	33	0.9			
Test of differences between all provenances except provenances from Punjab					
Provenance	10; 27	220	24.2	<0.0001	***
Block	3; 27	8	0.9	0.46	
Plotx2	1; 27	37	4.1	0.05	
Ploty2	1; 27	75	8.2	0.008	
Error	27	9			
Test of differences between species, including all provenances					
Species	6; 5.0	36.5	6.7	0.03	n.s.
Provenance(species)	6; 33	3.8	4.2	0.003	
Block	3; 33	1.6	1.8	0.17	
Plotx2	1; 33	12.7	14.0	0.0007	
Ploty2	1; 33	10.9	12.0	0.002	
Error	35	0.9			
Test of differences between species, excluding provenances from Punjab					
Species	6; 3.9	331	6.9	0.04	n.s.
Provenance(species)	4; 27	46	5.1	0.004	
Block	3; 27	8	0.9	0.46	
Plotx2	1; 27	37	4.1	0.05	
Ploty2	1; 27	75	8.2	0.008	
Error	27	9			

Table 7. Results from tests of provenance differences in crown area within species in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
P. alba					
Provenance	1; 3	130	35.6	0.009	*
Block	3; 3	5.86	1.6	0.35	
Error	3	3.65			
P. chilensis					
Provenance	1; 3	8.17	0.5	0.54	n.s.
Block	3; 3	21.0	1.2	0.44	
Error	3	17.2			
P. flexuosa					
Provenance	1; 2	0.166	0.2	0.72	n.s.
Block	3; 2	0.129	1.3	0.47	
Error	2	1.01			
P. glandulosa					
Provenance	1; 2	20.8	9.9	0.09	n.s.
Block	3; 2	7.0	3.3	0.24	
Error	2	2.1			
P. juliflora					
Provenance	1; 3	178	1.2	0.36	n.s.
Block	3; 3	192	1.3	0.42	
Error	3	149			
P. pallida					
Provenance	1; 3	136	5.1	0.11	n.s.
Block	3; 3	21.5	0.8	0.57	
Error	3	26.6			

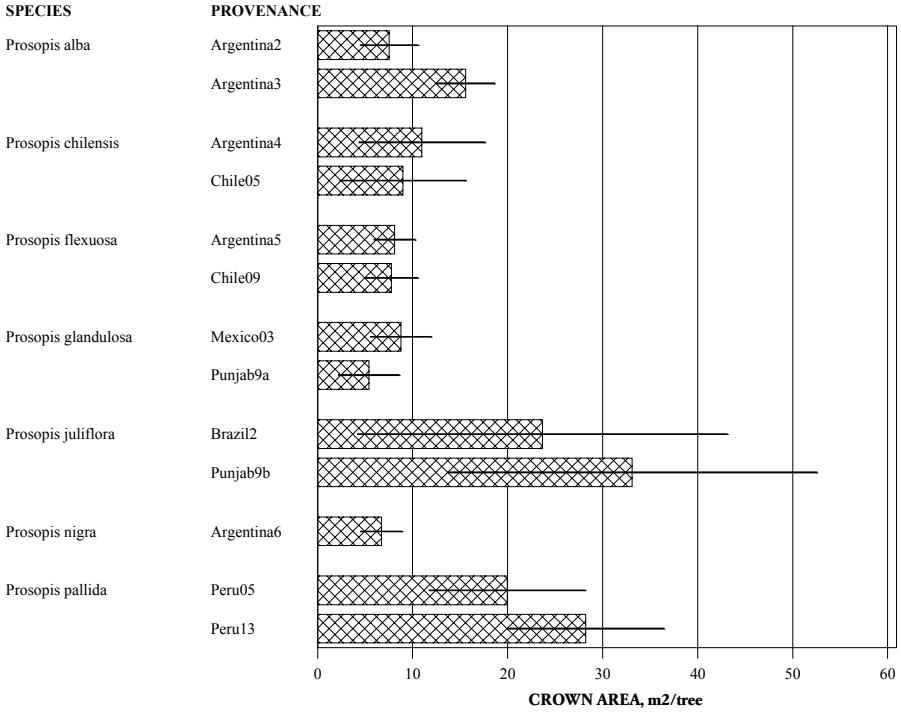


Figure 3. Crown area in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.4 Number of stems

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

Statistical analysis

There was variance heterogeneity between the provenances, and the data were weighted (both with and without the mixed seedlot). The weighting was not necessary in the tests of differences between provenances within the species. No covariates were significant.

It should be noted that three small trees were not assessed, which introduces a bias in the analysis. As the number of trees planted in the trial is 765, this is believed to be of minor importance.

Results

There was a large difference between the average number of stems for the provenances, ranging from 2 to more than 5 stems per tree. These differences were highly significant as seen from the tests of differences between all provenances in Table 8. Removing the provenances from Punjab had no effect on this.

The differences between species were at the border of significance, and when the Punjab provenances were removed, the significance disappeared (Table 8). Within the species there were only small signs of differences between the provenances, the two provenances of *P. juliflora* being close to being significantly different (Table 9). This near significance disappeared when accounting for the effect of multiple comparisons.

The hierarchy between the provenances was different from what was seen in the earlier variables (Fig. 4). The provenances of *P. nigra* and *P. pallida* had the smallest number of stems, whereas provenances from *P. chilensis* and *P. glandulosa* together with the provenance Punjab9b of *P. juliflora* had the largest number of stems. All the provenances must be considered having a quite bushy growth habit as none of them have numbers of stems close to 1.

Table 8. Results from tests of differences in number of stems between all provenances in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of differences between all provenances					
Provenance	12; 35	13.5	12.7	<0.0001	***
Block	3; 35	9.9	9.3	<0.0001	
Error	35	1.1			
Test of differences between all provenances except provenances from Punjab					
Provenance	10; 29	15.1	13.5	<0.0001	***
Block	3; 29	10.4	9.3	0.0002	
Error	29	1.1			
Test of differences between species, including all provenances					
Species	6; 2.7	20.1	14.8	0.03	n.s.
Provenance(species)	6; 35	1.2	1.2	0.34	
Block	3; 35	9.9	9.3	<0.0001	
Error	35	1.1			
Test of differences between species, excluding provenances from Punjab					
Species	6; 0.58	15.4	34.0	0.27	n.s.
Provenance(species)	4; 29	0.7	0.6	0.64	
Block	3; 29	10.4	9.3	0.0002	
Error	29	1.1			

Table 9. Results from tests of provenance differences in number of stems within species in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
P. alba					
Provenance	1; 3	0.886	1.0	0.39	n.s.
Block	3; 3	0.693	0.8	0.57	
Error	3	0.861			
P. chilensis					
Provenance	1; 3	0.998	0.8	0.43	n.s.
Block	3; 3	2.60	2.2	0.27	
Error	3	1.20			
P. flexuosa					
Provenance	1; 2	0.418	0.2	0.69	n.s.
Block	3; 2	1.50	0.7	0.62	
Error	2	2.02			
P. glandulosa					
Provenance	1; 3	0.00822	0.004	0.95	n.s.
Block	3; 3	0.905	0.5	0.71	
Error	3	1.85			
P. juliflora					
Provenance	1; 3	3.76	8.4	0.06	n.s.
Block	3; 3	0.897	2.0	0.29	
Error	3	0.448			
P. pallida					
Provenance	1; 3	0.110	0.5	0.54	n.s.
Block	3; 3	0.319	1.4	0.40	
Error	3	0.234			

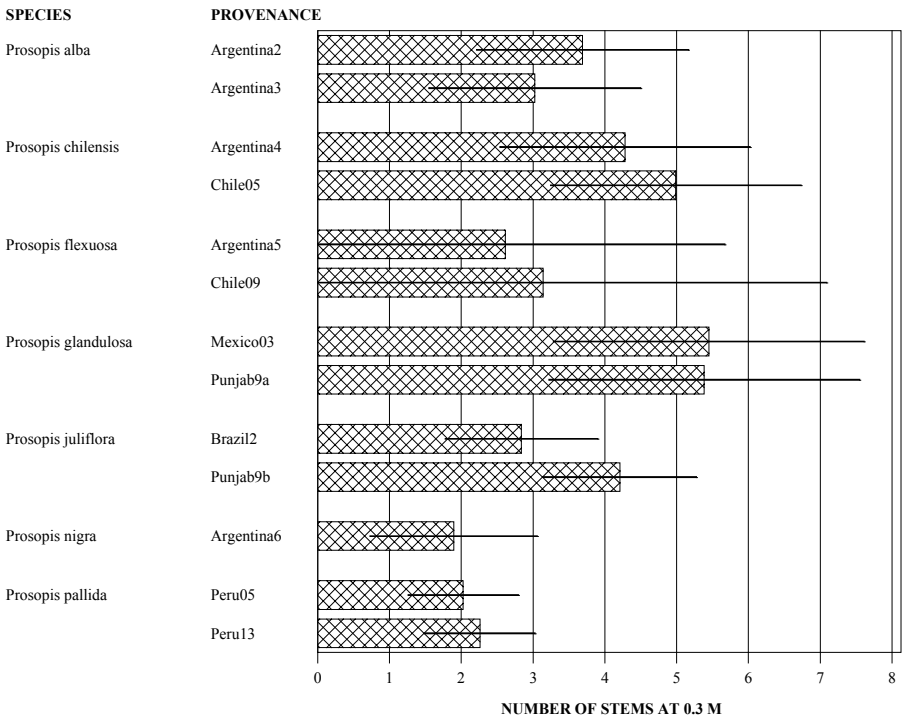


Figure 4. Number of stems in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). Values presented are least square means with 95 % confidence limits.

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 account of the potential basal area production of the provenance provided that all trees survive.

Statistical analysis

Since there was variance heterogeneity in the data, weight statements were applied with all analyses except for the analyses of differences within species. The co-variate ploty2 was highly significant.

For four of the smallest trees, no assessment of diameter was made. Instead, the values for basal area for these trees have been set to 0. Considering that the total number of trees planted in the trial was 765, the implications of this are believed to be small.

Results

Also in this variable there was a large variation, the mean values ranging from 17 to 115 cm^2 $tree^{-1}$. For trees in the largest provenance this corresponds to a mean annual growth of 35 cm^2 $tree^{-1}$ - a quite considerable growth. The analysis of all provenances demonstrated that there were highly significant differences both with and without the seedlot from Punjab (Table 10). The differences between species were significant, but the significance disappeared when correcting for multiple comparisons, and without the mixed provenance disappeared completely. Within the species there were faint signs of differences between the provenances of both *P. alba* and *P. pallida*, even though the Bonferroni table-wide tests suggested that this should be interpreted cautiously (Table 11).

The largest basal areas of the mean tree were found in the provenances of *P. juliflora* and *P. pallida*, and in the provenance Argentina3 of *P. alba* (Fig. 5). The smallest trees in this respect were found within the species *P. nigra*, *P. glandulosa* and *P. flexuosa*.

Table 10. Results from tests of differences in basal area of the mean tree between all provenances in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of differences between all provenances					
Provenance	12; 34	34.3	35.1	<0.0001	***
Block	3; 34	14.5	14.8	<0.0001	
Ploty2	1; 34	76.5	78.3	<0.0001	
Error	34	1.0			
Test of differences between all provenances except provenances from Punjab					
Provenance	10; 28	49.1	47.6	<0.0001	***
Block	3; 28	11.3	11.0	<0.0001	
Ploty2	1; 28	49.5	48.1	<0.0001	
Error	28	1.0			
Test of differences between species, including all provenances					
Species	6; 5.6	32.6	5.6	0.03	n.s.
Provenance(species)	6; 34	4.9	5.0	0.0009	
Block	3; 34	14.5	14.8	<0.0001	
Ploty2	1; 34	76.5	78.3	<0.0001	
Error	34				
Test of differences between species, excluding provenances from Punjab					
Species	6; 3.5	50.7	2.7	0.20	n.s.
Provenance(species)	4; 28	8.6	8.3	<0.0001	
Block	3; 28	11.3	11.0	<0.0001	
Ploty2	1; 28	49.6	48.1	<0.0001	
Error	28	1.0			

Table 11. Results from tests of provenance differences in basal area of the mean tree within species in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
P. alba					
Provenance	1; 3	8404	17.7	0.02	(*)
Block	3; 3	146	0.3	0.82	
Error	3	475			
P. chilensis					
Provenance	1; 3	21.1	0.03	0.87	n.s.
Block	3; 3	488	0.8	0.59	
Error	3	650			
P. flexuosa					
Provenance	1; 2	28	0.37	0.60	n.s.
Block	3; 2	127	1.7	0.39	
Error	2	75			
P. glandulosa					
Provenance	1; 3	22	0.3	0.62	n.s.
Block	3; 3	64	0.9	0.54	
Error	3	74			
P. juliflora					
Provenance	1; 3	1881	0.96	0.40	n.s.
Block	3; 3	3571	1.8	0.32	
Error	3	1959			
P. pallida					
Provenance	1; 3	2043	8.4	0.06	n.s.
Block	3; 3	417	1.7	0.34	
Error	3	244			

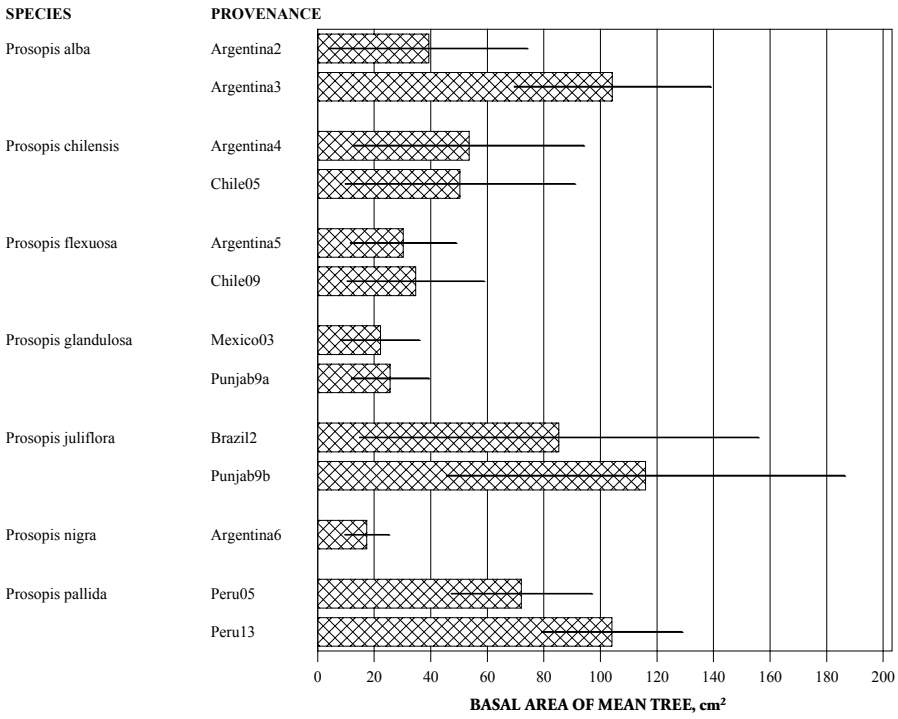


Figure 5. The basal area of the mean tree in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.6 Total basal area

In comparison to the basal area of the mean tree, the total basal area is expressed on an area basis (per ha) and is thus a better measure of the actual production on the site.

Statistical analysis

In the data there were clear signs of variance heterogeneity, and the data were weighted to fulfil the assumptions of the models. This was done in all analyses except the analyses of differences within species. No co-variates were significant in this variable.

For the mixed seedlot (Punjab9a and Punjab9b), the estimates should be used with caution, since the proportion of the area covered by the two species is uncertain (see section 3.1), and since competition between the two species may have affected the results.

Results

The average total basal areas varied from below 0.1 to 2.6 m^2 ha^{-1}, corresponding to an average annual increment of approximately 0.5 to 0.55 m^2 ha^{-1} for the largest provenances. The differences between all provenances analysed together were highly significant, also when the mixed seedlot was excluded (Table 12). Similarly, the differences between species were significant, though the correction for multiple comparisons suggested that this could be due to random variation (Table 12). This was irrespective of whether the mixed seedlot was included or not.

Within the species, there were significant differences in *P. alba* and *P. chilensis*, and in *P. flexuosa* and *P. pallida* the differences were close to significance (Table 13). The correction for multiple comparisons suggested that the significance could be due to random variation in at least *P. flexuosa* and *P. pallida*. The hypothesis of differences between provenances within species are supported by the overall significance for the provenance(species) effect tested in Table 12.

The provenances of *P. juliflora* and *P. pallida* had the largest total basal areas in the trial (Fig. 6). Except for the provenance Argentina3 of *P. alba* which was intermediate, the other provenances had low basal areas compared to these provenances. Within *P. chilensis*, the largest provenance was Argentina4. In *P. flexuosa* the largest provenance was Argentina6, and in *P. pallida*, the last species with indications of significant provenance differences, the largest provenance was Peru13.

Table 12. Results from tests of differences in total basal area between all provenances in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of differences between all provenances					
Provenance	12; 36	25.3	28.7	<0.0001	***
Block	3; 36	1.4	1.6	0.21	
Error	36	0.9			
Test of differences between all provenances except provenances from Punjab					
Provenance	10; 30	29.5	34.3	<0.0001	***
Block	3; 30	0.9	1.0	0.39	
Error	30	0.9			
Test of differences between species, including all provenances					
Species	6; 6.2	22.1	5.6	0.03	n.s.
Provenance(species)	6; 36	4.1	4.7	0.001	
Block	3; 36	1.4	1.6	0.21	
Error	36	0.8			
Test of differences between species, excluding provenances from Punjab					
Species	6; 4.2	32.7	6.3	0.04	n.s.
Provenance(species)	4; 30	6.0	7.0	0.0004	
Block	3; 30	0.9	1.0	0.39	
Error	30	0.9			

Table 13. Results from tests of provenance differences in total basal area within species in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
P. alba					
Provenance	1; 3	1.36	20.2	0.02	(*)
Block	3; 3	0.11	1.6	0.35	
Error	3	0.07			
P. chilensis					
Provenance	1; 3	0.150	32.4	0.01	(*)
Block	3; 3	0.049	10.5	0.04	
Error	3	0.005			
P. flexuosa					
Provenance	1; 3	0.52	8.6	0.06	n.s.
Block	3; 3	0.09	1.4	0.38	
Error	3	0.06			
P. glandulosa					
Provenance	1; 3	0.028	0.5	0.52	n.s.
Block	3; 3	0.014	0.3	0.85	
Error	3	0.052			
P. juliflora					
Provenance	1; 3	0.6	0.5	0.52	n.s.
Block	3; 3	2.1	1.7	0.33	
Error	3	1.2			
P. pallida					
Provenance	1; 3	0.43	7.8	0.07	n.s.
Block	3; 3	0.46	8.4	0.06	
Error	3	0.05			

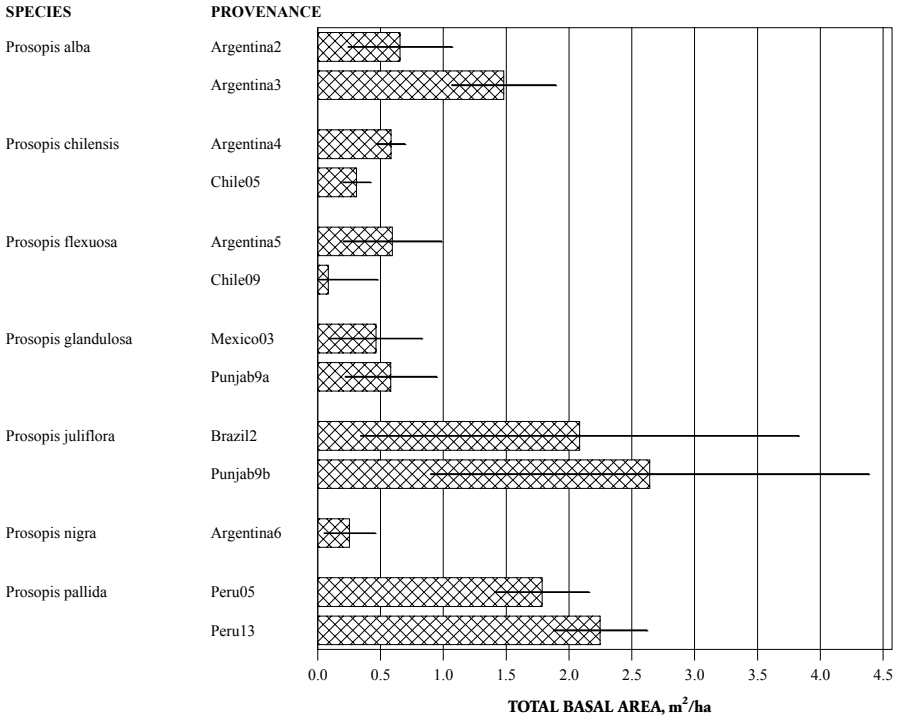


Figure 6. Total basal area in the *Prosopis* species and provenances trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.7 Dry weight of the mean tree

The dry weight of the mean tree is comparable to the basal area of the mean tree 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 closely, as the basis for estimation of the dry weight is the basal area. However, an important difference is that the dry weight include a cubic term (in comparison to basal area having only a square term), meaning that trees with large diameters are weighted heavily in this variable. The dry weight is thus the best estimate for the production of biomass at the site.

Statistical analysis

The plots of residuals did not indicate variance heterogeneity in the data, and no weight statements were applied. Note that estimates exist only for the species *P. juliflora* and *P. pallida*. This means that there is no test for species differences when the only provenance from the mixed seedlot is excluded. There was an unusual result in the analyses: No co-variates were significant when all four provenances were included, but when the provenance from Punjab was excluded, the covariate plotx became significant.

Results

In the provenances for which the estimates of dry weight were available, the dry weights of the mean tree varied from 28 to 50 kg tree^{-1}. This corresponds to a growth of just about 13 kg annually for trees in the largest provenances.

The tests of provenance differences for all provenances gave some results that are difficult to interpret (Table 14). When all provenances were included, the differences between provenances were not significant, but when the provenance from Punjab was excluded, the provenance effect became significant. It is difficult to say whether it is correct to exclude Punjab9b or not. As this provenance is growing mixed with another species with shorter height growth, this gives the trees a competitive advantage, but may also introduce a larger variation between trees in the provenance. Irrespective of these considerations, the differences between species were far from significant, and the tests within species demonstrated that only the provenances of *P. pallida* were approaching significant differences.

The provenances with the largest dry weights were Punjab9b of *P. juliflora* and Peru13 of *P. pallida*, but note the above considerations on the estimates for Punjab9b.

Table 14. Results from tests of differences in dry weight of the mean tree between all provenances in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of differences between all provenances					
Provenance	3; 9	460	2.1	0.17	n.s.
Block	3; 9	802	3.6	0.06	
Error	9	220			
Test of differences between all provenances except provenance from Punjab					
Provenance	2; 5	482	21.3	0.004	**
Block	3; 5	135	6.0	0.04	
Plotx	1; 5	195	8.6	0.03	
Error	1; 5	22			
Test of differences between species, including all provenances					
Species	1; 2	59	0.09	0.79	n.s.
Provenance(species)	2; 9	661	3.0	0.10	
Block	3; 9	802	3.6	0.06	
Error	9	220			

Table 15. Results from tests of provenance differences in dry weight of the mean tree within species in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
P. juliflora					
Provenance	1; 3	600	1.4	0.33	n.s.
Block	3; 3	778	1.8	0.32	
Error	3	436			
P. pallida					
Provenance	1; 3	723	7.8	0.07	n.s.
Block	3; 3	156	1.7	0.34	
Error	3	93			

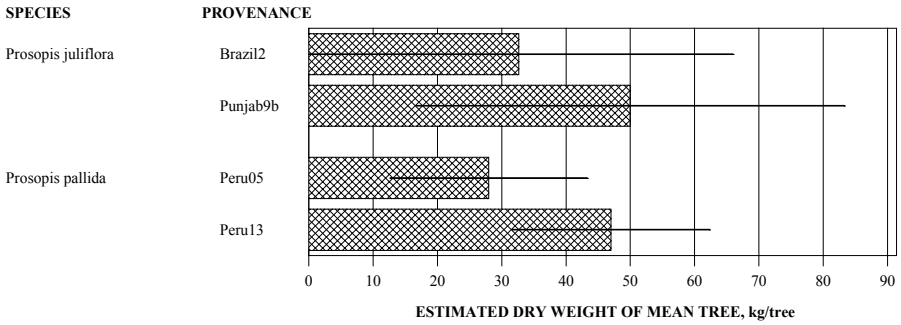


Figure 7. Dry weight of the mean tree in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.8 Total dry weight

In parallel with the total basal area, the total dry weight is calculated on an area basis and gives the best measure of the actual production on the site.

Statistical analysis

Since the provenances appeared to have different variance it was necessary to weight the data. No co-variates were significant. The estimates are available only for *P. juliflora* and *P. pallida*.

Results

For the two species total dry weight ranged between 7 and 11.3 t ha^{-1}, corresponding to 1.5 to 2.4 t ha^{-1} y^{-1}. Again the analyses of variance gave some not easily comprehensible results (see section 4.7). The differences between provenances were not significant when all provenances were included, but when the provenance Punjab9b was excluded, the differences were significant (Table 18). The differences between species were not significant.

Within the species, the differences between provenances were just below the 5% significance level in *P. pallida*, but in *P. juliflora* the differences were not significant (Table 19). The correction for multiple comparisons took away the significance in *P. pallida*.

Overall the largest production was found in Punjab9b and Peru13, while the provenances Brazil2 and Peru05 had smaller dry weights (Fig. 8).

Table 18. Results from tests of differences in total dry weight between all provenances in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of differences between all provenances					
Provenance	3; 9	1.58	2.3	0.14	n.s.
Block	3; 9	3.83	5.6	0.02	
Error	9	0.68			
Test of differences between all provenances except provenance from Punjab					
Provenance	2; 6	9.8	9.9	0.01	*
Block	3; 6	15.5	15.7	0.003	
Error	1; 6	1.0			
Test of differences between species, including all provenances					
Species	1; 2.5	0.43	0.2	0.66	n.s.
Provenance(species)	2; 9	2.21	3.3	0.08	
Block	3; 9	3.83	5.7	0.02	
Error	9	0.68			

Table 19. Results from tests of provenance differences in total dry weight within species in trial 2.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
P. juliflora					
Provenance	1; 3	22	0.78	0.44	n.s.
Block	3; 3	46	1.64	0.35	
Error	3	28			
P. pallida					
Provenance	1; 3	18.9	13.1	0.04	n.s.
Block	3; 3	12.1	8.4	0.06	
Error	3	1.4			

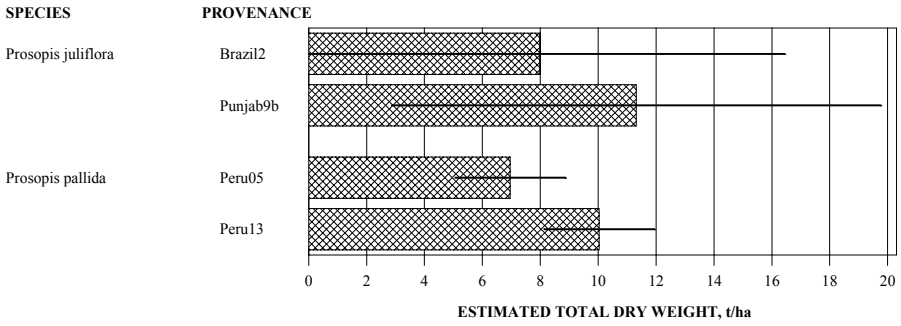


Figure 8. Total dry weight in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.9 Multivariate analysis

The multivariate analysis included the variables survival, height, crown area, number of stems, basal area of the mean tree and total basal area. Since observations with missing values are deleted from the multivariate analysis, the dry weight variables, which were available for two species only, were not included. In the analysis no account was made for the variance heterogeneity observed in the univariate analysis.

In the analysis, the first five canonical variates were significant or highly significant, pointing to the multidimensional variation in the trial (Table 20). In total, the five variates accounted for 99.8 % of the variation. Only results for the first three canonical variates are shown. They accounted for 90 % of the variation. According to the analysis, the differences between the provenances were highly significant (P-value for Wilk's lambda and for Pillai's trace both below 0.0001).

Fig. 9 gives the plot of scores for the first three canonical variates together with the mean values for the provenances and 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 two provenances have different properties. The combinations of all plots of canonical variates give the real distances between the provenances, and ideally the plots of scores for the fourth and the fifth canonical variates should be included. However, since these variates accounted for only a small amount of variation and the additional information was limited, only three canonical variates are presented.

Within the provenances there were two major clusters. The first comprised the three provenances Peru05 and Peru13 (both *P. pallida*), and Brazil2 of *P. juliflora*. These provenances did not separate in any of the dimensions. The second cluster contained most of the other provenances. Only the provenances Argentina3 (*P. albida*) and Punjab9b (*P. juliflora*) did not fit into this pattern, being separated from the rest.

Assuming that the multivariate analysis can be used as final proof of differences between provenances of the individual species, it seems that there are quite solid evidence for differences between the provenances Punjab9b and Brazil2 of *P. juliflora* (Fig. 9). The provenances Argentina2 and Argentina3 of *P. alba*, which were collected at the same site and represent different varieties of the same species, are also clearly different. The distance between the provenances Chile09 and Argentina5 of *P. flexuosa* is smaller, but still large enough to be significant. For the provenances of *P. chilensis*, *P. glandulosa* and *P. pallida* there were no convincing differences within the species.

Table 20. Results from the canonical variate analyses in trial 2. The table gives the proportion of the variation aacounted for by the canonical variates and the significance values for the 6 canonical variates in the analysis, together with the canonical coefficients and the canonical directions for the three first canonical variates.

Canonical variate no.	**1**	**2**	**3**	**4**	**5**	**6**
Proportion of variation	0.50	0.27	0.13	0.07	0.04	0.002
Significance, P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.05	0.94

	Raw canonical coefficients			**Standardised canonical coefficients**			**Canonical directions**		
Canonical variate no.	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Survival	5.2	3.4	5.8	1.4	0.9	1.6	2.1	0.8	2.7
Height	2.8	-2.7	-1.5	2.6	-2.5	-1.3	6.8	3.2	-5.0
Crown area	0.34	-0.048	0.11	3.5	-0.5	1.2	59.4	96.5	4.7
Number of stems	-0.49	-0.64	0.72	-0.7	-1.0	1.1	-5.7	-7.3	18.8
Basal area of the mean tree	-0.089	0.10	0.0067	-3.6	4.0	0.3	115.4	421.4	-104.9
Total basal area	-1.3	-0.13	-0.93	-1.2	-0.1	-0.9	6.0	9.4	1.3

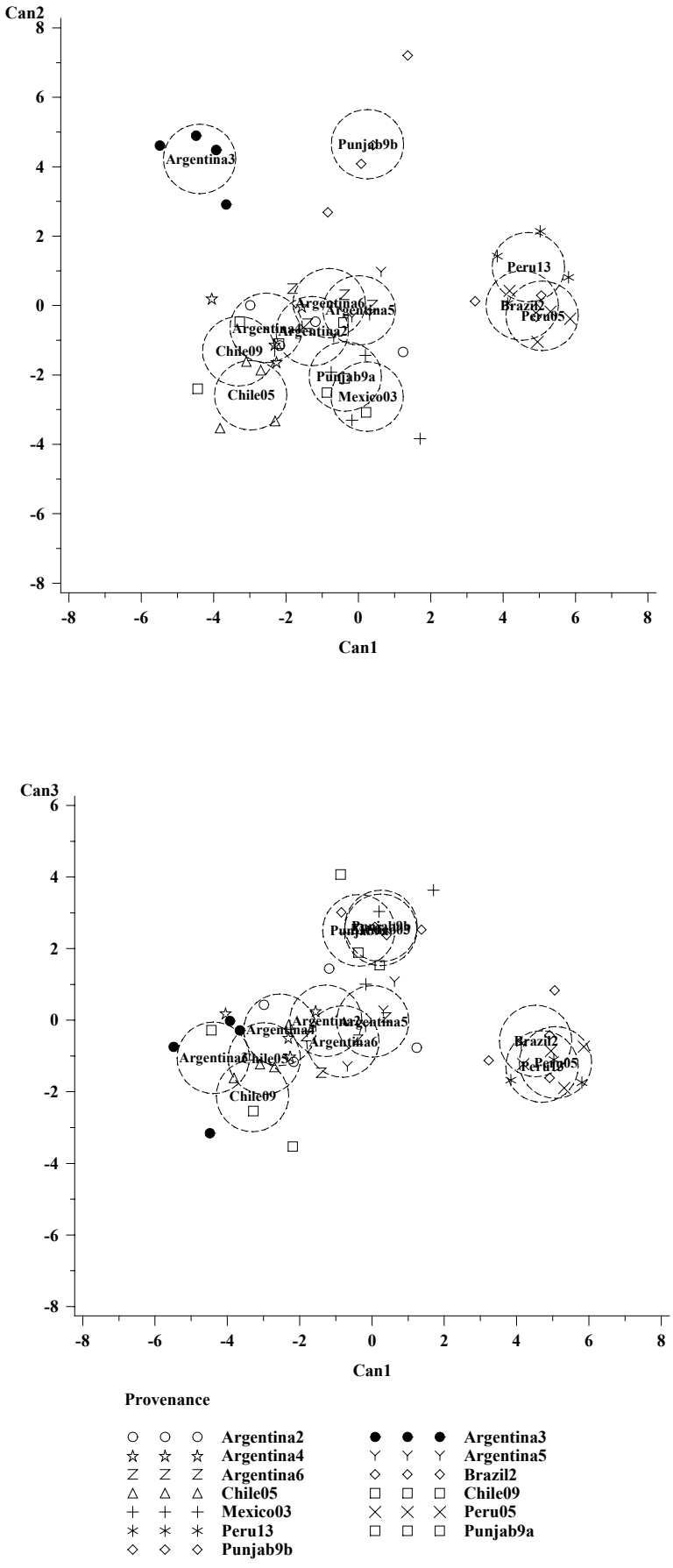


Figure 9. Score plot of the first and the second canonical variate (upper figure) and of the first and the third canonical variate (lower figure) from the canonical variate analysis of the provenances in the *Prosopis* trial at Petrolina - PE, Brazil (Trial no. 2 in the arid zone series). The variables survival, height, crown area, number of stems, basal area of the mean tree and total basal area were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.

5. Discussion and conclusions

Productivity

Dry weight could only be assessed for *P. juliflora* and *P. pallida*, but the total basal areas indicate that these species were also the most productive species.

Compared to other trials at Petrolina the best provenances in this trial had a relatively large production of biomass (Ræbild et al. 2003a, b, c). If we ignore Punjab9b of *P. juliflora*, which could be biased due to the mix with another species, the provenance Peru13 of *P. pallida* had the largest growth with almost 2.1 t dry weight ha^{-1} y^{-1}. In two other *Prosopis* trials at Petrolina (Trial nos. 3 and 4 in this series), the best provenances of *P. juliflora* attained dry weight productions of 1.6 and 1.1 t ha^{-1} y^{-1}. In a trial of *Acacia* species (Trial no. 1), the best provenance of *A. nilotica* had a production of 2.0 t ha^{-1} y^{-1}.

At the same time, height growth was impressive, being approximately 1 m per year for Peru13 - larger than in any of the trials mentioned above.

It appears that part of the reason for the large production in the current trial is that there are favourable micro-site conditions compared to the other trials mentioned. Brazil2 is present in all the *Prosopis* trials, and the growth is clearly larger in this trial than in the others.

Differences between species

Interpretation of species differences based on trials with few provenances of each species may be dangerous unless there is certainty that the provenances represent the best provenances for the site. It is in this light that the considerations below should be seen, and there is reason to be cautious with the conclusions.

In many variables the differences between species were at the border of significance. For the variables height, crown area, basal area of the mean tree and total basal area there were signs that *P. juliflora* and *P. pallida* were the best. The multivariate analysis confirmed that these species were separated from the other species, even though the provenance Punjab9b was different from the other provenances of the two species.

The potential of the species *P. alba* may warrant more investigation, as one of the provenances had basal areas that were if not as high then at least comparable with the basal areas in the two best species.

Differences between provenances

In the univariate analyses there were only few signs of differences between provenances. For *P. alba*, the analyses indicated that there were provenance differences in crown area, basal area of the mean tree and total basal area. The provenance Argentina3 was generally more productive compared to the provenance Argentina2, which is of the variety *panta*. In *P. chilensis* there were signs of differences in total basal area.

However, the multivariate analysis showed a somewhat different picture. First, the two provenances of *P. juliflora*, Punjab9b and Brazil2, were far from each other although they were hard to separate in the univariate tests. Second, Argentina4 and Chile05, the provenances of *P. chilensis*, could not be separated in the multivariate test. Third, the data indicated that there were differences between the provenances Chile09 and Argentina5 of *P. flexuosa*, a fact that was not detected in the univariate analyses. Even though one should be careful not reading too much into the multivariate test because it does not take variance heterogeneity into account, at least the first two conclusions mentioned here seem rather robust.

Finally the multivariate test confirmed that the two provenances of *P. alba* were separated, thus acknowledging the fact that there are differences between the two provenances. This is interesting, not only because they represent different varieties, but also because they were collected at the same site.

Giving provenance recommendations it appears that the best provenances are found in *P. juliflora* and *P. pallida*. Even though the average growth of the provenance Punjab9b of *P. juliflora* appeared to be larger than the other provenances, there is so much uncertainty linked to this provenance that it should be avoided before further testing has taken place. In the trial number 3, Punjab9b had a much inferior growth than the local landrace, Brazil2.

Thus, for purposes of wood production, it appears that there are three, possibly four, provenances to be recommended: Brazil2 (*P. juliflora*), Peru05 and Peru13 (both *P. pallida*). The provenance Argentina3 of *P. alba* may also be considered, even though not as fast growing as the provenances just mentioned.

6. References

Afifi, A.A. and V. Clark. 1996 Computer-aided multivariate analysis. Chapman & Hall, London, 3rd ed., 455 pp.

Chatfield, C. and A.J. Collins, 1980. Introduction to multivariate analysis. Chapman and Hall, London.

DFSC 1994. Preliminary assessment report – trial no. 2. Prosopis species/provenance trial, Bebedouro, Brazil, joint assessment, October 1992 by EMBRAPA/CPATSA, FAO and DFSC. Unpublished working document, Danida Forest Seed Centre, Humlebaek, Denmark.

Draper, N. and H. Smith. 1981. Applied regression analysis, second edition. John Wiley & Sons, New York, 709 pp.

Ffolliott, P.F. and J.L. Thames. 1983. Handbook on taxonomy of *Prosopis* in Mexico, Peru and Chile. Food and Agriculture Organization of the United Nations, Rome, 31 pp.

Graudal *et al.* (2003). Introduction to the international arid zone series of species and provenance trials. Danida Forest Seed Centre, Humlebæk, Denmark.

Graudal, L. *et al.* (in prep.). Biomass regressions for some species of *Acacia* and *Prosopis*.

Holm, S. 1979. A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6: 65-70.

Kjaer, E.D. and H.R. Siegismund. 1996. Allozyme diversity in two tanzanian and two nicaraguan landraces of teak (*Tectona grandis* L.). Forest Genetics 3: 45-52.

Lima, P.C.F. 1998. Genetic improvement program of *Prosopis* in Northeastern Brazil. *In:* Puri, S. (ed.): Tree Improvement: Applied Research and Technology Transfer. Science Publishers Inc., Enfield, New Hampshire, pp. 141-154.

Littell, R.C., G.A. Milliken, W.W. Stroup and R.D. Wolfinger. 1996. SAS® System for mixed models. SAS Institute Inc., Cary, NC, 633 pp.

Ræbild, A., L. Graudal and P.C.F. Lima. 2003a. Trial no. 1, Bebedouro, Brazil - *Acacia* species/provenance trial. Results and Documentation No.12. Danida Forest Seed Centre, Humlebaek, Denmark.

Ræbild, A., Graudal, L. and Lima, P.C.F. 2003b. Analysis Report, Trial no. 3, Bebedouro, Brazil - *Prosopis* species trial. Results and Documentation No.14. Danida Forest Seed Centre, Humlebaek, Denmark.

Ræbild, A., Graudal, L. and Lima, P.C.F. (2003c. Analysis Report, Trial no. 4, Bebedouro, Brazil - *Prosopis juliflora* provenance trial. Results and Documentation No.15. Danida Forest Seed Centre, Humlebaek, Denmark.

Ræbild, A., C.P. Hansen and E.D.Kjaer. 2002 Statistical analysis of provenance trials. Guidelines and Technical notes no.63. Danida Forest Seed Centre, Humlebaek, Denmark.

SAS (1988a): SAS® Procedures Guide, Release 6.03 Edition. SAS Institute Inc., Cary, NC, 441 pp.

SAS (1988b): SAS/STAT® Users Guide, Release 6.03 Edition. SAS Institute Inc., Cary, NC, 1028 pp.

SAS (1991): SAS® System for Statistical Graphics, First Edition. SAS Institute Inc., Cary, NC, 697 pp.

Skovgaard, I.M. and P. Brockhoff. 1998. Multivariate analysis and variance components. Lecture notes, Dept. of Mathematics and Physics, The Royal Veterinary and Agricultural University, Copenhagen, 41 pp.

Snedecor, G.W. & Cochran, W.G. (1980): Statistical methods. Iowa State University Press, 7th ed., 507 pp.

Annex 1. Description of the trial site

Name of site:	Bebedouro, Petrolina - PE Latitude: 9°9'S Longitude: 40°22'W Altitude: 365.5 m
Meteorological stations:	Local (5 km (Establishment Report 1988)) Petrolina (9°23'S, 40°29'W, 370 m (FAO 1985))
Rainfall:	Annual mean (period): 553 (11 years - period not given (Establishment Report 1988))
Rainy season:	November-April (Establishment Report 1988) Type: Intermediate (FAO 1985) Length (days): 60 (FAO 1985)
Dry months/year	(Establishment Report 1988): No. of dry months (<50 mm): 7 No. of dry periods: 1
Temperature (°C)	(Establishment Report 1988): Annual mean: 27 Coldest month: 18 (minimum) Hottest month: 40 (maximum)
Wind:	Speed: 1.4 (FAO 1985)
Topography:	Flat/gentle
Soil:	Type: Latosols, low water holding capacity, low organic matter (Lima 1986) and stony Depth: Shallow (Lima 1986)
Climatic/agroecological zone:	Semi-arid
Dominant natural vegetation:	'Caatinga', deciduous woodland
Koeppen classification:	BSh

Annex 2. Seedlot numbers

Species and provenances of *Prosopis* tested in trial no. 2 at Petrolina - PE, Brazil. The plot number refers to the seedlot in the map of the trial, see Annex 3.

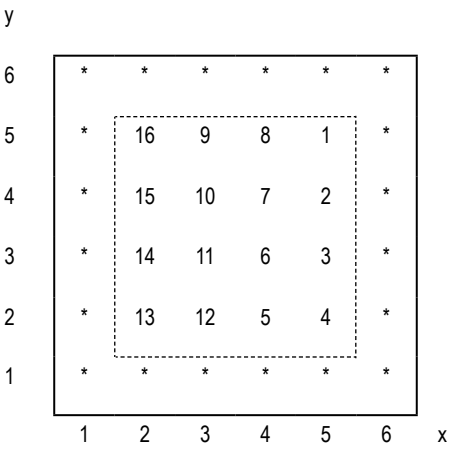
Seedlot numbers					**Provenance information**						
Provenance	**DFSC**	**Country of origin**	**Plot**	**Species**	**Origin**	**Country of origin**	**Latitude**	**Longitude**	**Altitude (m)**	**Rainfall (mm)**	**No. of mother trees**
Argentina2		SF 03/85	2	*P. alba* var. *panta*	Catamarca	Argentina	27°30'S	64°55'W			16
Argentina3		SF 02/85	9	P. alba	Catamarca	Argentina	27°30'S	64°55'W			14
Argentina4		SF 07/85	4	*P. chilensis*	La Rioja	Argentina	29°30'S	67°00'W			13
Chile05	1161/83		5	*P. chilensis*	Lampa	Chile	33°17'S	70°53'W	500	306	5
Argentina5		SF 04/85	6	*P. flexuosa*	La Rioja	Argentina	29°30'S	67°00'W			19
Chile09	1457/84		12	*P. flexuosa*	Copiado	Chile	27°18'S	70°45'W	300	15	
Mexico03	1211/83		8	*P. glandulosa* var.. *torreyana*	Concepcion Del Oro	Mexico	24°49'N	101°25'W	1650		
Punjab9a	1235/84		3	*P. glandulosa*	Fazal Abad Rice Mill, D.I.Khan	Pakistan	31°15'N	70°45'E	330	300	25
Brazil2			1	P. juliflora	Bebedouro	Brazil	9°9'S	40°22'W	365.5	553	15
Punjab9b	1235/84		3	*P. juliflora*	Fazal Abad Rice Mill, D.I.Khan	Pakistan	31°15'N	70°45'E	330	300	25
Argentina6		SF 05/85	10	*P. nigra*	La Rioja	Argentina	29°30'S	67°00'W			11
Peru05		SF 4346/ 82	7	*P. pallida*	Piura	Peru	5°12'S	80°38'W			4
Peru13	1156/83	15.7.83	11	*P. pallida*	Ocucaje (Ica), Zona: Tres Esquinas	Peru	14°20'S	75°40'W	420		

Annex 3. Layout of the trial

Layout of blocks and plots in the field. The numbers correspond to the seedlots given in Annex 2.

y	BLOCK 1			BLOCK 2			
8	1	5	9	1	6	11	
7	2	6	10	5	2	12	
6	3	7	11	9	3	8	
5	4	8	12	10	7	4	
4	1	7	12	1	10	8	
3	2	11	8	9	2	7	
2	5	10	3	6	3	12	
1	9	6	4	5	11	4	
	1	2	3	4	5	6	x
	BLOCK 3			BLOCK 4			

Individual tree positions in each plot (each plot core tree indicated by its local tree number):



* : Plot border trees

Annex 4. Plot data set

Species codes: pal: *P. alba*, palpa: *P. alba* var. *panta*, pch: *P. chilensis*, pfl: *P. flexuosa*, pgl: *P. glandulosa*, pglto: *P. glandulosa* var. *torreyana*, pju: *P. juliflora*, pni: *P. nigra*, ppa: *P. pallida*.

Block	Plotx	Ploty	Provenance	Species	Survival	Height	Crown area	Number of stems	Basal area of mean tree	Total basal area	Dry weight of mean tree	Total dry weight
					Proportion	m	m^2 $tree^{-1}$	no. $tree^{-1}$	cm^2 $tree^{-1}$	m^2 ha^{-1}	kg $tree^{-1}$	t ha^{-1}
1	1	5	Argentina4	pch	0.50	2.28	8.4	4.6	30.5	0.42		
1	1	6	Punjab9a	pgl	1.00	2.00	3.9	5.0	12.2	0.34		
1	1	6	Punjab9b	pju	1.00	1.54	11.3	4.0	29.1	0.81	11	2.70
1	1	7	Argentina2	palpa	0.63	2.43	10.1	5.3	47.5	0.83		
1	1	8	Brazil2	pju	0.81	3.78	21.7	3.4	73.7	1.66	27	6.17
1	2	5	Mexico03	pglto	0.94	2.86	13.0	7.7	26.5	0.69		
1	2	6	Peru05	ppa	1.00	3.53	15.2	2.1	51.7	1.44	17	4.74
1	2	7	Argentina5	pfl	0.81	2.31	7.4	3.5	21.6	0.49		
1	2	8	Chile05	pch	0.13	3.75	14.4	7.5	81.1	0.28		
1	3	5	Chile09	pfl	0.00					0.00		
1	3	6	Peru13	ppa	0.94	4.35	27.9	2.4	89.4	2.33	36	9.34
1	3	7	Argentina6	pni	0.69	2.08	7.6	2.8	21.0	0.40		
1	3	8	Argentina3	pal	0.44	3.37	17.4	2.7	116.5	1.42		
2	4	5	Argentina6	pni	0.36	1.74	5.3	1.4	10.5	0.09		
2	4	6	Argentina3	pal	0.50	3.36	17.2	3.8	124.7	1.73		
2	4	7	Chile05	pch	0.31	2.02	3.3	3.0	18.3	0.16		
2	4	8	Brazil2	pju	1.00	4.37	28.7	3.6	97.8	2.72	38	10.63
2	5	5	Peru05	ppa	1.00	4.94	21.5	2.1	95.2	2.64	42	11.57
2	5	6	Punjab9a	pgl	1.00	2.84	5.7	5.0	25.6	0.53		
2	5	6	Punjab9b	pju	0.64	3.66	37.6	5.1	139.3	2.90	59	12.23
2	5	7	Argentina2	palpa	0.69	1.95	5.4	3.5	19.0	0.36		
2	5	8	Argentina5	pfl	0.94	2.69	8.5	2.7	42.5	1.11		
2	6	5	Argentina4	pch	0.38	2.68	7.1	3.7	40.7	0.42		
2	6	6	Mexico03	pglto	0.88	2.06	4.9	4.4	11.8	0.29		
2	6	7	Chile09	pfl	0.13	2.50	7.0	1.5	35.2	0.12		
2	6	8	Peru13	ppa	1.00	4.75	23.5	3.3	101.1	2.81	46	12.72
3	1	1	Argentina3	pal	0.63	2.88	15.5	3.2	97.7	1.70		
3	1	2	Chile05	pch	0.25	2.88	8.5	4.3	48.4	0.34		
3	1	3	Argentina2	palpa	0.75	3.49	7.7	3.2	46.8	0.97		
3	1	4	Brazil2	pju	0.88	4.07	21.2	2.5	74.4	1.81	28	6.75
3	2	1	Argentina5	pfl	0.31	2.18	9.5	2.3	24.1	0.21		
3	2	2	Argentina6	pni	0.47	1.83	5.8	2.1	20.7	0.25		
3	2	3	Peru13	ppa	0.69	4.15	24.5	1.7	94.8	1.81	42	8.08
3	2	4	Peru05	ppa	0.81	4.02	22.4	2.0	69.2	1.56	26	5.92
3	3	1	Argentina4	pch	0.38	2.82	16.4	4.3	65.8	0.69		
3	3	2	Punjab9a	pgl	1.00	2.79	7.0	5.3	32.7	0.68		
3	3	2	Punjab9b	pju	0.56	2.58	28.7	3.2	93.2	1.94	38	7.86
3	3	3	Mexico03	pglto	0.69	2.36	8.0	5.4	25.8	0.49		

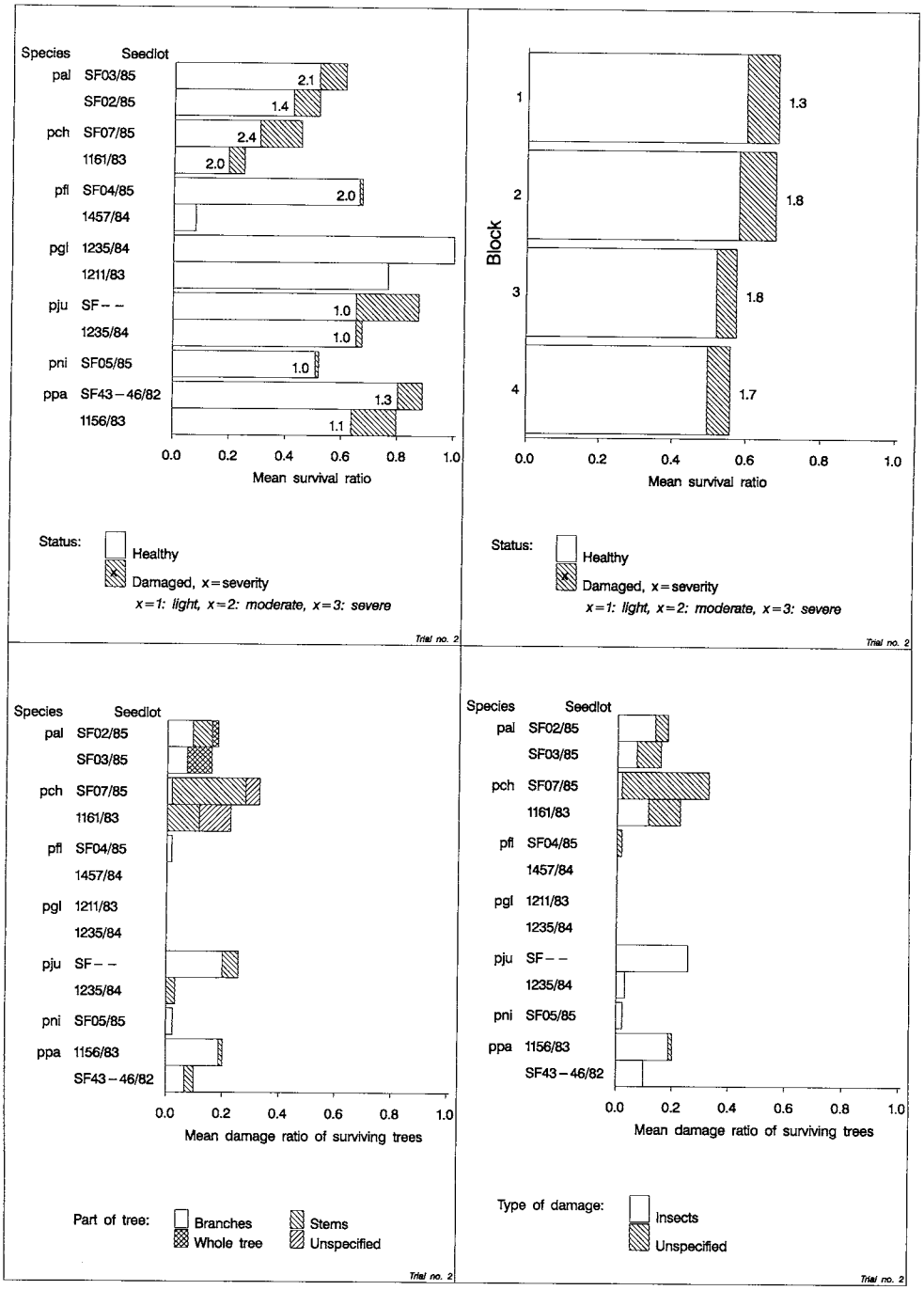
Block	Plotx	Ploty	Provenance	Species	Survival	Height	Crown area	Number of stems	Basal area of mean tree	Total basal area	Dry weight of mean tree	Total dry weight
					Proportion	m	m^2 $tree^{-1}$	no. $tree^{-1}$	cm^2 $tree^{-1}$	m^2 ha^{-1}	kg $tree^{-1}$	t ha^{-1}
3	3	4	Chile09	pfl	0.06	1.90	8.8	5.0	27.4	0.05		
4	4	1	Chile05	pch	0.31	3.22	9.7	5.2	53.7	0.47		
4	4	2	Argentina5	pfl	0.63	2.56	6.9	2.0	32.9	0.57		
4	4	3	Argentina3	pal	0.50	2.64	12.3	2.4	77.9	1.08		
4	4	4	Brazil2	pju	0.81	4.75	23.1	1.8	95.4	2.15	37	8.42
4	5	1	Peru13	ppa	0.56	4.62	37.0	1.7	130.8	2.04	64	10.00
4	5	2	Punjab9a	pgl	1.00	2.62	7.1	6.3	31.9	0.77		
4	5	2	Punjab9b	pju	0.50	4.65	54.8	4.5	202.4	4.92	92	22.47
4	5	3	Argentina2	palpa	0.38	2.77	6.9	2.8	44.2	0.46		
4	5	4	Argentina6	pni	0.56	1.97	8.1	1.2	17.4	0.27		
4	6	1	Argentina4	pch	0.46	2.98	12.0	4.5	77.5	0.81		
4	6	2	Chile09	pfl	0.13	2.60	8.1	2.0	50.0	0.17		
4	6	3	Peru05	ppa	0.75	4.14	20.7	1.9	72.2	1.50	27	5.61
4	6	4	Mexico03	pglto	0.56	2.73	7.0	4.3	24.9	0.39		

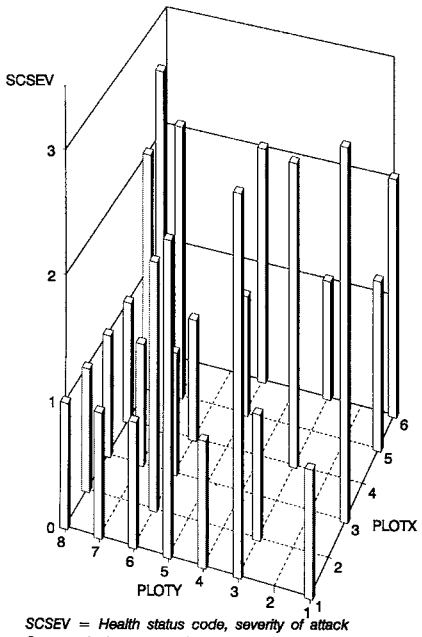
Annex 5. Graphical presentation of health data

The health status of the trees were evaluated on a scale from 0 to 3, where 0 indicates no damage, and 1, 2 and 3 indicates light, moderate and severe damage, respectively. The health status code is named SCSEV in the diagrams on the following pages.

The diagrams present the mean survival ratios, the damage ratios of the surviving trees and the average damage scores for the damaged trees. They also indicate the distribution of the damage on the trees and the cause of the damage. The damage scores are presented according to plots, blocks and seedlots.

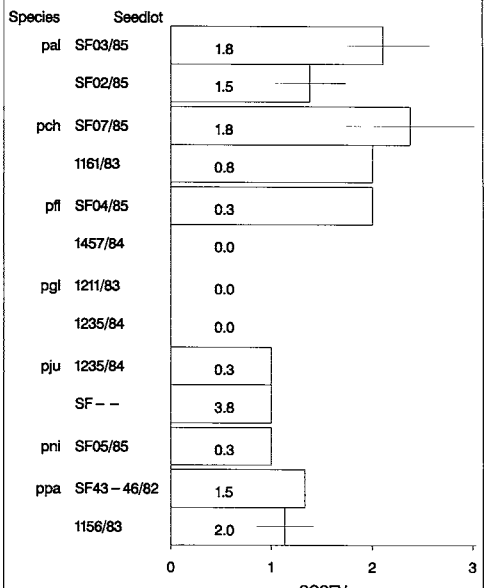
Please note that the seedlot codes correspond to the numbers given in annex 2.





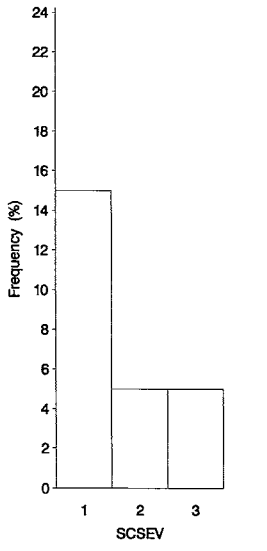
SCSEV = Health status code, severity of attack
Scatter of plot mean values

Trial no. 2



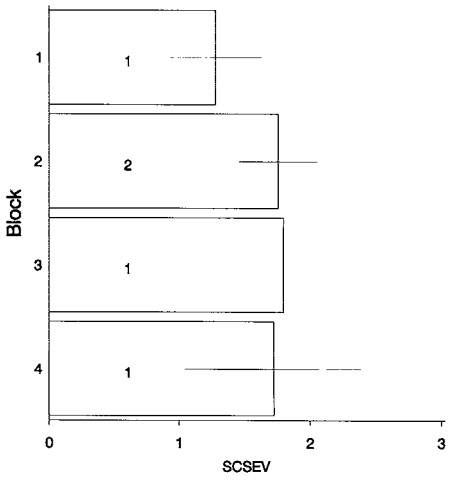
Mean SCSEV of seedlot with error bar line (+/- standard deviation of the mean) and the average number of assessed (living) trees per plot for each seedlot.

Trial no. 2



Frequency distribution of plot mean values

Trial no. 2



Mean SCSEV of block with error bar line (+/- standard deviation of the mean) and the average number of assessed (living) trees per plot in each block.

Trial no. 2