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Trial no. 3 in the arid zone series

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Evaluation of a species trial of *Prosopis* at Petrolina, Brazil

Trial no. 3 in the arid zone series

by

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A plot of *Prosopis alba* in the trial. Phot: Lars Graudal 1992.

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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.

At the same time, the report presents results within the framework of the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Specie', 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 to1994. 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 thank the personnel at Embrapa/CPATSA for help with the establishment, maintenance and assessment of the trial, and thank the personnel of DFSC for their help with 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-Árido.

Abstract

This report describes results from a trial with nine provenances of *Prosopis*. There was one provenance of each of the species *P. affinis*, *P. alba* var. *panta*, *P. flexuosa*, *P. glandulosa*, *P. kuntsei*, *P. nigra*, *P. pallida* and two of *P. juliflora*. The trial was established with a spacing of 2.5 x 3 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 provenance had an increment rate in basal area of 0.65 m2 ha^{-1} y^{-1}, corresponding to a dry weight production of approximately 1.7 t ha^{-1} y^{-1}. Survival in the trial was high for most provenances. The provenances with the fastest growth in basal area were of *P. affinis*, *P. juliflora* and *P. pallida*, whereas provenances of *P. alba* and *P. glandulosa* were intermediate. Provenances/species with slow growth were of *P. flexuosa*, *P. kuntsei* and *P. nigra*. The differences between the provenances were highly significant for most of the analysed variables.

Contents

1. Introduction

This report describes the results from trial no. 3 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 nine provenances of the genus *Prosopis*, all of neotropical origin but with two landraces from Pakistan. Eight species are represented. It should be noted that the taxonomy of *Prosopis* is difficult and still a matter of debate (cf. Ffolliott & Thames 1983).

An almost parallel trial is trial no. 2 in this series, established at the same site and including seven of the provenances in this trial. Results from the two trials 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 °C, and the mean annual rainfall is 553 mm (DFSC 1994). Soils at the site are shallow latosols with low water-holding capacity, low organic content and deficiency in Phosphorous (Lima 1998). The dry period is approximately 7 months. Further information is given in the assessment report (DFSC 1994) and summarised in annex 1.

The date for sowing of seed is uncertain but could be December 1988. This is assumed for the calculation of annual increments. The trial was established in November 1989.

2.2 Species and provenances

The trial includes 9 provenances, one each of the species *P. affinis*, *P. alba* var. *panta*, *P. flexuosa*, *P. glandulosa*, *P. kuntsei*, *P. nigra*, *P. pallida* and two of *P. juliflora* (Table 1). The provenances have been 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.

Originally it was believed that only 8 provenances were planted, but when looking closer at a provenance from Pakistan, it turned out that there were two species on the plots. The two species are therefore treated separately in the analyses (Punjab9a and Punjab9b). It should be noted that these provenances, although from Pakistan, are landraces of material from Latin America.

2.3 The experimental design

The experimental design is a randomised complete block design with three blocks. Within each block, each provenance is represented by 25 trees in a plot, planted in a square of 5×5 trees. The trees are placed with a spacing of 2.5×3 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. The assessment included 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 1993 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. Provenances of *Prosopis* species tested in trial no. 3 at Petrolina - PE, Brazil.

Provenance identification	Species	Seed collection site	Country of origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
Peru03	*P. affinis*		Peru	5°12'S	80°38'W			
Argentina2	*P. alba* var. *panta*		Argentina	27°30'S	64°55'W			16
Argentina5	*P. flexuosa*		Argentina	29°30'S	67°00'W			19
Punjab9a	*P. glandulosa*	Fazal Abad Rice Mill, D.I.Khan	Pakistan	31°15'N	70°45'W	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
Paraguay2	*P. kuntsei*		Paraguay					
Argentina6	*P. nigra*		Argentina	29°30'S	67°00'W			11
Peru05	*P. pallida*	Piura	Peru	5°12'S	80°30'W			4

3. Statistical analyses

3.1 Variables

In this report the following nine 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 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 only.

A problem with the assessment data is that for trees with heights below 1 m, no assessments of diameter and number of stems were made. Out of the total 600 observations (trees), this occurred for 157 trees or more than a quarter of the population. For crown diameter, the same problem occurred in 31 observations. Since exclusion these data will produce biased results and provide an over-estimation of the provenances in question, the values for crown area and basal area 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 these variables will be biased.

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.

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

$$TreeDW = e^{(2.814 \times \ln(basalarea) - 2.765)}$$

For the other species, such regressions were not available.

3.2 Statistical model and estimates

The statistical analysis of the trial was based on the model:

$$X_{ij} = \mu + provenance_i + block_j + \varepsilon_{ij}$$

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

Two analyses were made. In the first analysis, the mixed provenance was considered as two separate provenances, and all provenances were included. Since this strictly speaking violates the assumption of independence, a second analysis was performed to investigate the difference between the seedlots when the mixed provenance was excluded.

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). Where appropriate, weighting of data and exemption 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. Kjaer & 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 least square means. 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 survival reflects only the conditions experienced during the first years of the trial and not necessarily the climatic extremes and conditions that may be experienced during the life span of a tree.

Statistical analysis

There were clear signs of variance heterogeneity in the data, and in both analyses the data were weighted. No co-variates were significant. In the plots containing the mixed seedlot, the species identity of the dead trees is unknown. Therefore the survivals for the two provenances coming from the mixed seedlot were set to the average of the total survival for the plot, meaning that the estimates for survival of these provenances are possibly biased.

Results

The differences between the provenances were highly significant both with and without the mixed seedlot (Table 2). Overall, the survival was high, being 100 % or close to 100 % for most provenances (Fig. 1). Only Paraguay2 (*P. kuntsei*) had a survival departing seriously, the least square mean being 78 %. Note that for this variable, the values for the provenances Punjab9a and Punjab9b should be interpreted cautiously (see above).

Table 2. Results from analysis of variance of provenance differences of survival in trial 3.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
All provenances					
Provenance	8; 16	6.55	6.1	0.001	**
Block	2; 16	0.796	0.7	0.49	
Error	16	1.08			
Without mixed provenance					
Provenance	6; 12	3.82	6.0	0.004	*
Block	2; 12	0.107	0.2	0.85	
Error	12	0.632			

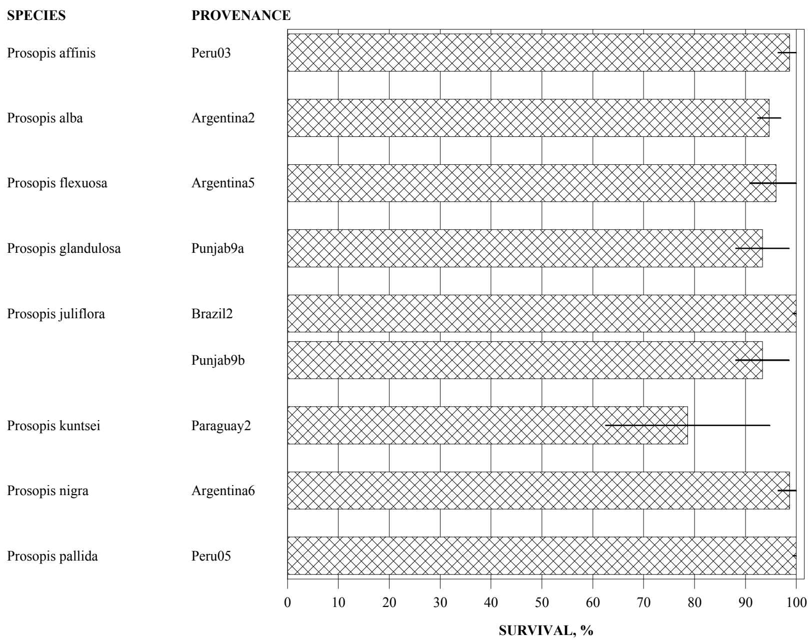

Figure 1. Survival in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Values presented are least square means with 95 % confidence limits. Before analysis the data were weighted with the inverse of the variance for the provenances, and the confidence intervals are therefore of different length.

4.2 Height

Height is usually considered an important variable in the evaluation of species and provenances. The importance will depend 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 need not always be true, as there have been cases where trees in the tallest provenances are suddenly affected by stress and die-off.

Statistical analysis

The first analysis demonstrated that the provenance Brazil2 in block 3 had an outlier tendency, the standardised residual being clearly larger (negative) than the rest. However, since there was no obvious explanation for this, it was decided to present the data with the value included. This is also justified by the fact that the significance only increased when the observation was removed.

In none of the models there were significant co-variates.

Results

There was a large and highly significant variation in the height of the different provenances, also without the mixed seedlot (Table 3). The absolute leaders were Peru03 of *P. affinis* and Brazil2 of *P. juliflora*, which both attained mean heights of approximately 2.6 m (Fig. 2). Paraguay2 (*P. kuntsei*) and Argentina6 (*P. nigra*) had heights of only 0.4 and 0.9 m respectively, while the rest of the provenances were intermediate. It is noteworthy that the two provenances of *P. juliflora* were highly different, the provenance from Punjab being only half the height of the Brazilian landrace.

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

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
All provenances					
Provenance	8; 16	1.74	34.3	<0.0001	***
Block	2; 16	0.139	2.7	0.10	
Error	16	0.0507			
Without mixed provenance					
Provenance	6; 12	2.24	39.7	<0.0001	***
Block	2; 12	0.141	2.5	0.12	
Error	12	0.0564			

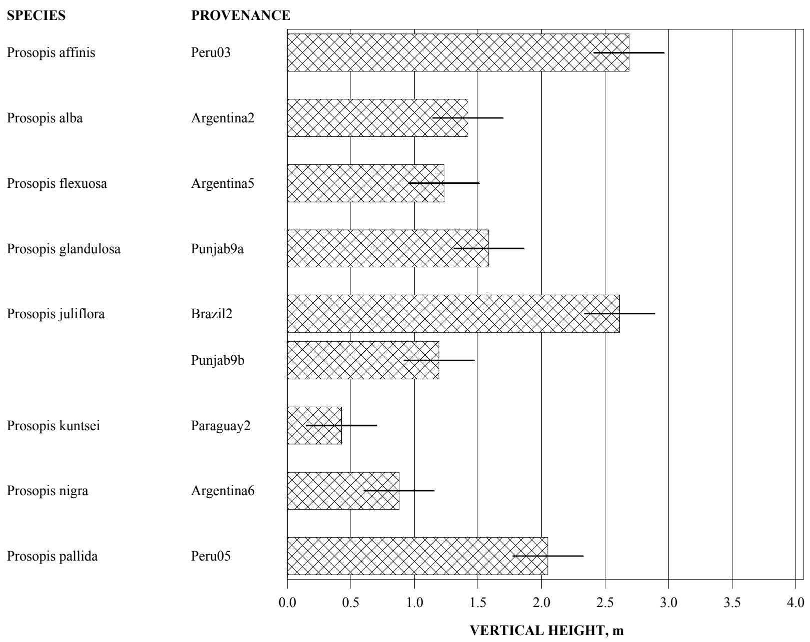

Figure 2. Vertical height in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.3 Crown area

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

Statistical analysis

Crown area for the provenance Punjab9b (*P. juliflora*) in block 1 departed strongly from the crown area of the provenance in the other blocks, which was also reflected in the standardised residuals where the observation showed outlier tendency. The trees of this plot also had in particular many flowers and fruits compared to the rest, but there was no obvious explanation why the crown areas should be bigger than crown areas of trees in the other blocks. Since the outlier had only limited influence on the level of significance, the observation was kept in the model.

Note also that for 30 of the smallest trees (corresponding to 5 % of the observations), no measurement of crown area was made. The crown areas for these trees have therefore been set to 0, which may introduce a small bias in the analyses and estimates.

Results

The average crown area for the provenances varied between 0.4 and 9.4 m^2 $tree^{-1}$. As the trees were planted with a distance of 2.5×3 m, trees in the largest provenances were thus starting to cover the area. Differences between the provenances were highly significant, also after the mixed provenance had been removed (Table 4).

The three largest provenances were Peru03 (*P. affinis*), Brazil2 (*P. juliflora*) and Peru05 (*P. pallida*) (Fig. 3). Note again that the second provenance of *P. juliflora*, Punjab9b, had only half the crown area of the Brazilian provenance. The provenance of *P. kuntsei*, Paraguay2, was the smallest, whereas the rest of the provenances were intermediate.

Table 4. Results from analysis of variance of provenance differences of crown area in trial 3.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
All provenances					
Provenance	8; 16	29.3	30.8	<0.0001	***
Block	2; 16	1.05	1.1	0.35	
Error	16	0.95			
Without mixed provenance					
Provenance	6; 12	37.9	64.0	<0.0001	***
Block	2; 12	0.75	1.3	0.32	
Error	12	0.59			

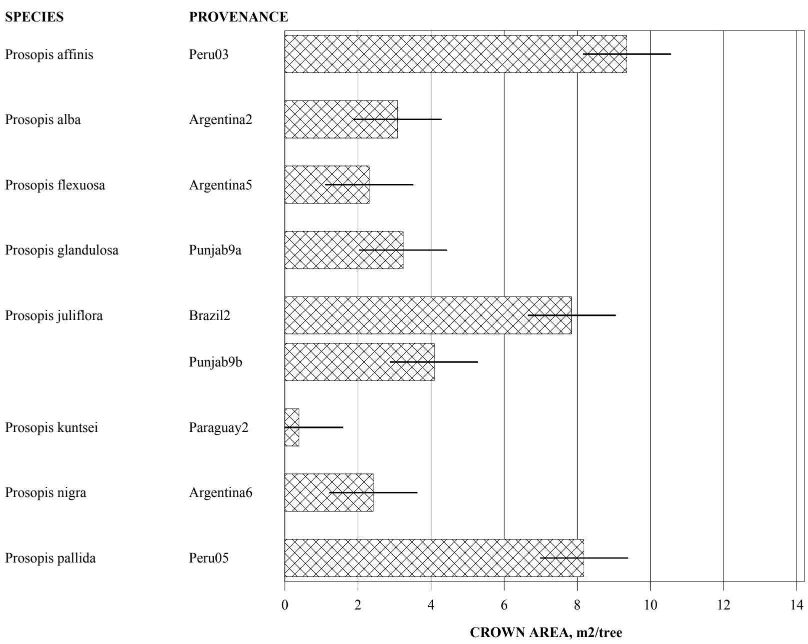

Figure 3. Crown area in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Values presented are least square means with 95 % confidence limits.

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

The analysis was straightforward in both analyses, and no co-variates were significant. Note that for the smallest trees (>25% of the data) no record of stem number was made, which may bias results from the analyses as well as the estimates. The results are therefore valid only for trees above 1 m height.

Results

The average number of stems varied between 1.1 and 3.6. Again the differences between provenances were highly significant, also without the mixed seedlot (Table 5). The provenances Peru03 (*P. affinis*), Argentina2 (*P. alba* var. *panta*), Punjab9a (*P. glandulosa*), Punjab9b and Brazil2 (both *P. juliflora*) all had numbers of stems larger than 2 (Fig. 4). The rest of the provenances had smaller numbers of stems, with Paraguay2 (*P. kuntsei*) as the extreme with an average number of stems of only 1.1.

Table 5. Results from analysis of variance of provenance differences of number of stems in trial 3.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
All provenances					
Provenance	8; 15	2.28	19.7	<0.0001	***
Block	2; 15	0.397	3.4	0.06	
Error	15	0.116			
Without mixed provenance					
Provenance	6; 11	1.88	22.9	<0.0001	***
Block	2; 11	0.192	2.3	0.14	
Error	11	0.0820			

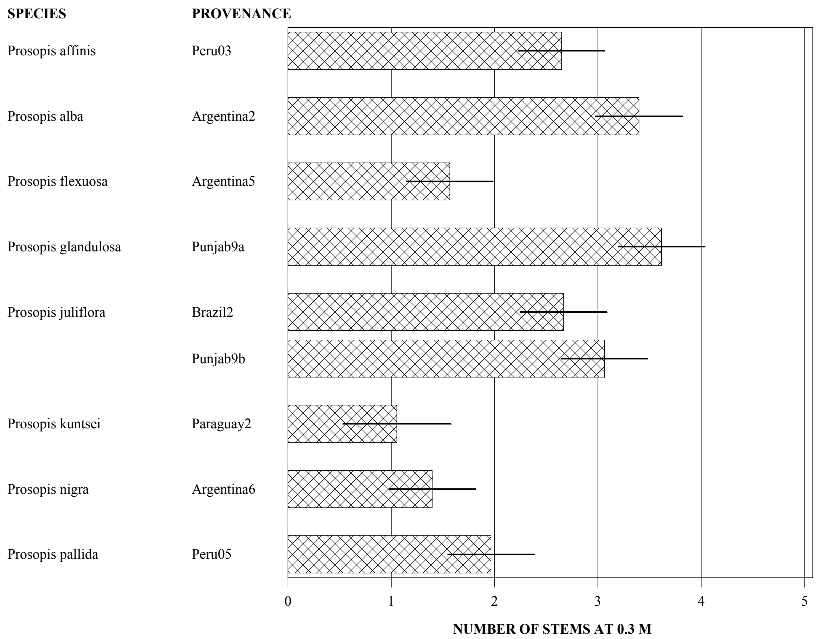

Figure 4. Number of stems in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Values presented are least square means with 95 % confidence limits.

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 to 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

In both models there were signs of variance heterogeneity, and the data were weighted to solve the problem. No co-variates were significant.

For more than 25 % of the observations, diameter was not measured, and basal areas are therefore not available. Since this was only the case for the smallest trees, the basal area for such trees was set to zero. Notice that this is bound to introduce a bias in the analyses and estimates.

Results

The analyses of variance demonstrated that there were highly significant differences between the provenances (Table 6). Removing the mixed seedlot only increased the significance. The range in basal area was very variable (Fig. 5). The top three provenances were Peru03 (*P. affinis*), Brazil2 (*P. juliflora*) and Peru5 (*P. pallida*), having basal areas of 19, 17 and 14 cm^2 $tree^{-1}$, respectively. The other provenances had smaller basal areas, with Paraguay2 (*P. kuntsei*) as the smallest, having a basal area of only 0.3 cm^2 $tree^{-1}$. The two provenances of *P. juliflora* were significantly different from each other, with the local provenance being the fastest growing.

Table 6. Results from analysis of variance of provenance differences of basal area of the mean tree in trial 3.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
All provenances					
Provenance	8; 15	66.5	94.2	<0.0001	***
Block	2; 15	0.86	1.2	0.31	
Error	15	0.71			
Without mixed provenance					
Provenance	6; 11	83.5	139.8	<0.0001	***
Block	2; 11	0.39	0.65	0.54	
Error	11	0.60			

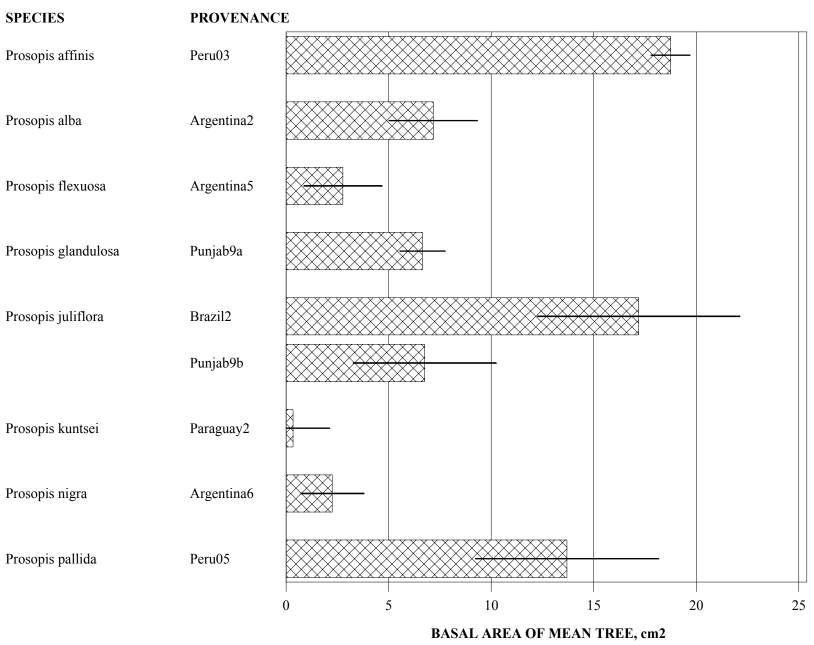

Figure 5. The basal area of the mean tree in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Values presented are least square means with 95 % confidence limits. Before analysis the data were weighted with the inverse of the variance for the provenances, and the confidence limits are therefore of different length.

4.6 Total basal area

In comparison to the basal area of the mean tree, the total basal area is expressed per unit area (land surface) and is thus a better measure of the total production on the site (rather than the potential production given by the basal area of the mean tree).

Statistical analysis

There was clear variance heterogeneity in the data, and a weight statement was used to solve the problem in both models. No co-variates were significant. Note that the analysis of all provenances rely on the assumption that the mortality in the mixed seedlot was the same for the two species.

Results

There was a large and highly significant variation in the total basal areas, both with and without the mixed seedlots (Table 7). The three largest provenances were again Peru03 (*P. affinis*), Brazil2 (*P. juliflora*) and Peru05 (*P. pallida*), having total basal areas of 2.5, 2.3 and 1.8 $m^2\ ha^{-1}$, respectively (Fig. 6). This corresponds to a maximum growth of 0.65 $m^2\ ha^{-1}\ y^{-1}$. Paraguay2 (*P. kuntsei*) again formed the bottom end with only 0.04 $m^2\ ha^{-1}$, but also Argentina5 (*P. flexuosa*) and Argentina6 (*P. nigra*) had a quite low production. The two provenances of *P. juliflora* seemed to differ significantly from each other.

Table 7. Results from analysis of variance of provenance differences of total basal area in trial 3.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
All provenances					
Provenance	8; 16	95.6	123.5	<0.0001	***
Block	2; 16	2.8	3.6	0.05	
Error	16	0.8			
Without mixed provenance					
Provenance	6; 12	96.1	113.2	<0.0001	***
Block	2; 12	6.1	7.2	0.009	
Error	12	0.8			

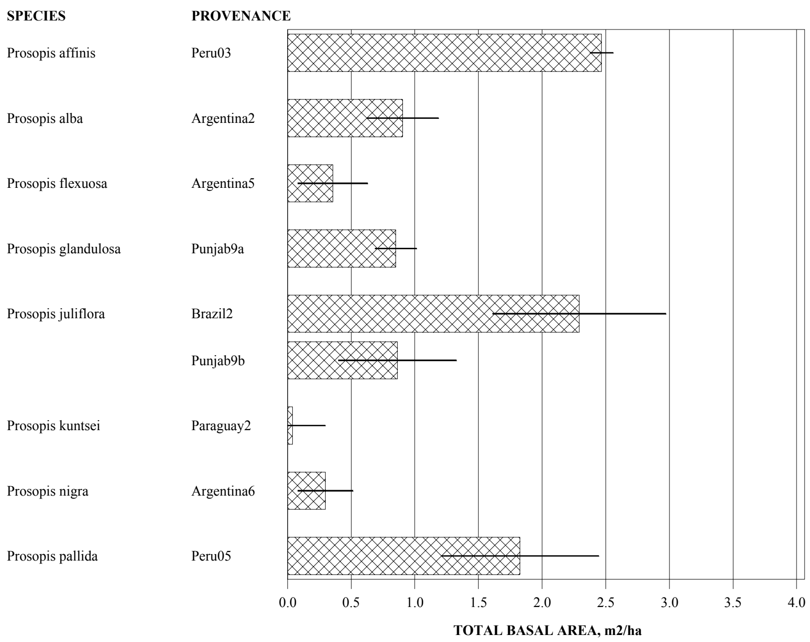

Figure 6. Total basal area in the *Prosopis* species and provenances trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Values presented are least square means with 95 % confidence limits. Before analysis the data were weighted with the inverse of the variance for the provenances, and the error bars are therefore of different length.

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 includes a cubic term (in comparison to basal area having only a square term), meaning that large trees with a large dry mass weight heavily in this variable. The dry weight is thus the best estimate for the production potential of biomass at the site.

Statistical analysis

Since no regressions were available for most of the species, the dry weight of the mean tree was analysed for only three provenances. The analysis was straightforward, and the co-variate ploty was significant in the model analysing all three provenances (but not when the mixed provenance was removed).

Results

The dry weights of mean trees varied from 2 to 5 kg tree^{-1}, corresponding to a growth of just about one kg annually for a tree in the largest provenance, which was Brazil2 (*P. juliflora*). The mean trees of Punjab9b (*P. juliflora*) and Peru05 (*P. pallida*) had dry weights of approximately 2 kg tree^{-1} for both provenances (Fig. 7). When the three provenances were analysed together, the provenance effect was significant at the 5 % level (Table 8). However, when the provenance of the mixed seedlot was deleted from the data set, the provenance effect was no longer significant. This was despite the fact that the estimates and confidence limits of the model with all three provenances indicated that there were differences between Brazil2 and Peru05. The reason for this lack of coherence must be that in the small model, the number of error degrees of freedom was too small to yield any discrimination between the provenances.

Table 8. Results from analysis of variance of provenance differences of dry weight of the mean tree in trial 3.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of species differences					
Provenance	2; 3	6.6	19.4	0.02	(*)
Block	2; 3	4.5	13.3	0.03	
Ploty	1; 3	3.8	11.3	0.04	
Error	3	0.3			
Without mixed provenance					
Provenance	1; 2	4.8	4.8	0.16	n.s.
Block	2; 2	4.4	4.4	0.18	
Error	2	1.0			

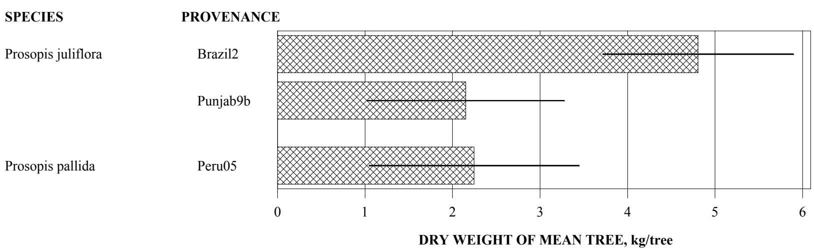

Figure 7. Dry weight of the mean tree in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.8 Total dry weight

In parallel with the total basal area, the total dry weight is expressed per area and gives the best measure of the total production of biomass on the site.

Statistical analysis

As for the total basal area, the analysis of all provenances relies on the assumption that the mortality in the mixed seedlot was the same for the two species. The analyses were straightforward, and ploty was significant in the analysis where all three provenances were included.

Results

The differences between the three provenances were significant, but again the significance disappeared when the provenance Punjab9b was excluded (Table 9, *cf.* section 4.7). Of the analysed provenances, Brazil2 (*P. juliflora*) had the largest production with 6.4 t ha^{-1}, corresponding to an annual growth of approximately 1.7 t ha^{-1}. The other provenances, Punjab9b (*P. juliflora*) and Peru05 (*P. pallida*), had accumulated only half as much dry weight, approximately 3 t ha^{-1} (Fig. 8).

Table 9. Results from analysis of variance of provenance differences of total dry weight in trial 3.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of species differences					
Provenance	2; 3	12.1	20.8	0.02	(*)
Block	2; 3	7.9	13.6	0.03	
Ploty	1; 3	6.7	11.5	0.04	
Error	3	0.6			
Without mixed provenance					
Provenance	1; 2	8.5	4.8	0.16	n.s.
Block	2; 2	7.9	4.5	0.18	
Error	2	1.8			

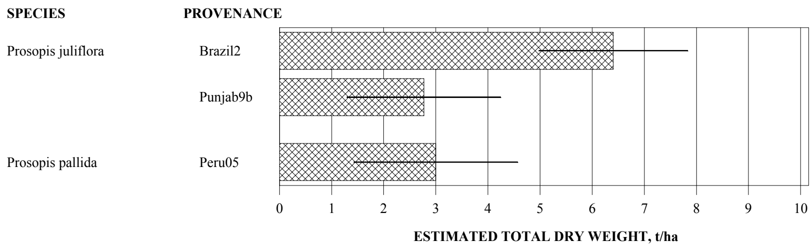

Figure 8. Total dry weight in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.9 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.

Statistical analyses

There were clear signs that the provenance Paraguay2 had a larger variance than the rest of the provenances, and in both analyses the data were weighted to ensure that the model assumptions were fulfilled.

There are two methodological problems with the applied scale. First, the scores are subjective and may be expressed and evaluated differently at different species. Second, the scores are not necessarily equidistant. For example, 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. This should be borne in mind when interpreting the results.

Results

Most of the trees were not damaged at all, and if some were damaged, the assessors usually considered it as only light damage. The provenance Paraguay2 seemed to be considerably more damaged than the others (Fig. 9), almost all trees in block 1 and 2 being lightly or moderately damaged. However, since none of the trees in block 3 were marked as damaged, the differences were not significant (Table 10). Although the statistics allow for no such conclusion, it seems improbable that Paraguay2 should not be more prone to damage than the others, also recalling that there is a poorer survival and growth in this provenance than in any of the other.

Table 10. Results from analysis of variance of provenance differences of damage score in trial 3.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential table-wide correction
Test of species differences					
Provenance	8; 16	0.96	1.9	0.14	n.s.
Block	2; 16	0.38	0.7	0.50	
Error	16	0.52			
Without mixed provenance					
Provenance	6; 12	0.97	2.2	0.12	n.s.
Block	2; 12	0.40	0.9	0.43	
Error	12	0.44			

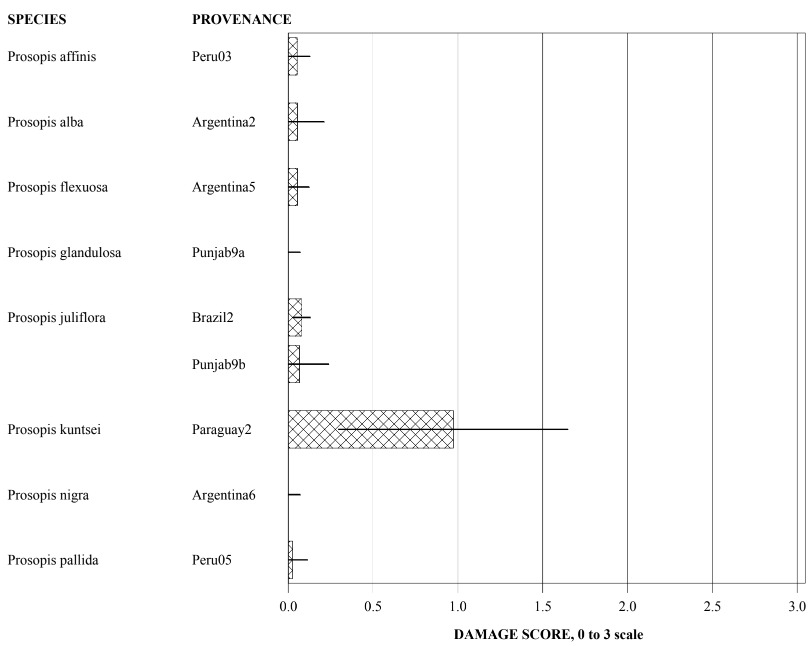

Figure 9. Damage score in the *Prosopis* species and provenances trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). Damage was scored on a scale from 0 to 3, where 0 denotes a healthy tree and 3 a severely damaged tree. Note that large values mean that the provenance is severely damaged. Values presented are least square means with 95 % confidence limits. Before analysis the data were weighted with the inverse of the variance for the provenances, and the confidence intervals are therefore of different length.

4.10 Multivariate analysis

The multivariate analysis included all variables analysed in the univariate analyses except for the dry weight of the mean tree and the total dry weight, meaning that in total seven variables were included. The dry weight variables were excluded because they were calculated only for *P. juliflora* and *P. pallida*. An important reservation with the analysis is that it does not account for the variance heterogeneity that was observed in some of the univariate analyses.

The first three canonical variates were highly significant, whereas the fourth was only marginally significant (Table 11). In total, the first three variates accounted for 94 % of the variation, with the fourth variate adding another 3 %. Thus the variation between provenances should be described in three or possibly four dimensions. The differences between the provenances were highly significant (P-value for Wilk's lambda and Pillai's trace both below 0.0001).

The scores for the second and third canonical variates plotted against the scores for the first canonical variate are shown in Fig. 10. Because the plots of the fourth canonical variate did not add much new information, these data are not presented. In the figure, the mean values for the provenances are given together with their approximate 95 % confidence regions. Provenances that are far apart in any of the diagrams are interpreted as being different, and if the confidence regions of two provenances do not overlap, it is likely that the two provenances have different properties.

At least three groups of provenances could be separated. The three best-performing provenances, Peru03, Peru05 and Brazil2, formed a group of their own (Fig. 10 lower diagram), whereas a second group was formed by the provenances Punjab9a, Punjab9b and Argentina2 (Fig. 10 upper diagram). Finally the three provenances Paraguay2, Argentina5 and Argentina6 were located together in the three dimensional space spanned by the three canonical variates. However, even within the groups there was dispersion among the provenances. For example, the confidence regions of Paraguay2, Argentina5 and Argentina6 were not overlapping, indicating that the provenances have different growth patterns.

Table 11. Results from the canonical variate analyses for the first four canonical variates in trial 3.

Canonical variate no.	1	2	3	4
Proportion of variation accounted for	0.65	0.20	0.10	0.03
Significance, P-value	<0.0001	<0.0001	0.002	0.07

	Canonical variate no.			
Raw canonical coefficients	1	2	3	4
Survival	0.01	-0.03	0.17	0.38
Height	12.3	0.26	-9.8	-1.3
Crown area	0.66	0.29	0.88	-1.5
Number of stems	-1.9	3.2	1.7	0.81
Basal area of mean tree	1.8	0.23	-4.2	-2.5
Total basal area	-20.5	-3.2	36.1	23.8
Damage score	-0.43	-0.28	4.7	9.3

Standardised canonical coefficients	1	2	3	4
Survival	0.1	-0.2	1.1	2.6
Height	8.9	0.2	-7.2	-1.0
Crown area	2.0	0.9	2.7	-4.5
Number of stems	-1.7	2.9	1.5	0.8
Basal area of mean tree	12.6	1.6	-28.4	-16.9
Total basal area	-18.7	-2.9	32.8	21.6
Damage score	-0.1	-0.1	1.3	2.6

Canonical directions	1	2	3	4
Survival	12.1	2.3	1.1	-14.7
Height	2.1	1.1	0.89	1.2
Crown area	8.3	2.2	10.3	-1.4
Number of stems	0.24	4.9	0.20	0.81
Basal area of mean tree	17.4	8.8	18.9	12.8
Total basal area	2.3	1.1	2.5	1.7
Damage score	-0.25	-0.46	0.23	1.1

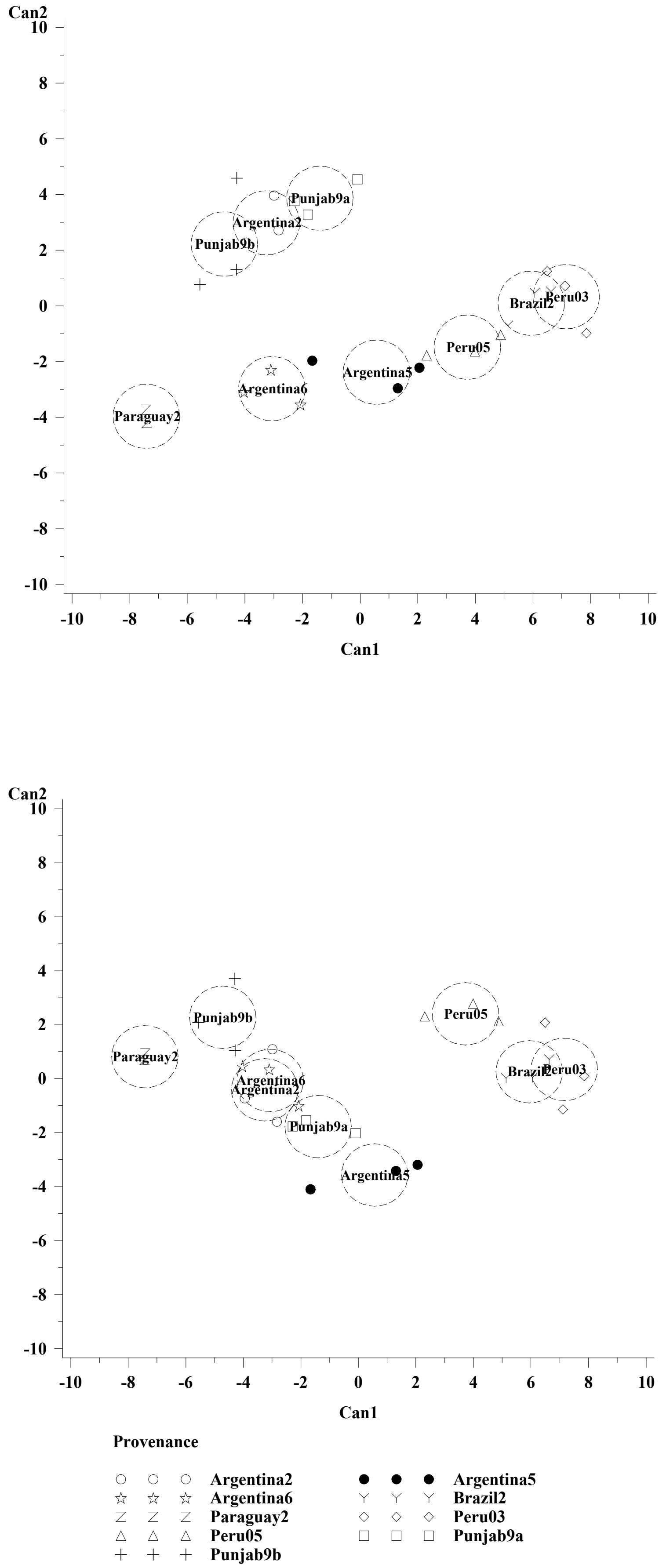

Figure 10. Score plot of the first and the second (upper figure) and of the first and the third canonical variates (lower figure) from the canonical variate analysis for the 9 provenances in the *Prosopis* species and provenance trial at Petrolina - PE, Brazil (Trial no. 3 in the arid zone series). The 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

The experimental station at Petrolina - PE holds other trials, including *Prosopis* and *Acacia* (trial numbers 1,2 and 4 in the arid zone series). A trial with provenances of *P. juliflora* (trial no. 4) was established a year earlier than this trial. Survival was only 45-80 %, even for the provenance Brazil2. Height growth was slightly higher, the trees having attained heights of 4 m in comparison to the 2.6 m in the present trial. However, the lower survival meant that the production of biomass in trial no. 4 was only approx. 1 t ha^{-1} y^{-1}, compared to the 1.5 t ha^{-1} y^{-1} attained in this trial.

On the other hand, in trial no. 2, which has almost the same provenances as this trial, the productivity was somewhat higher, amounting to 2.1 t ha^{-1} y^{-1} and with a annual height growth of approximately 1 m. In these terms the productivity of the current trial seems to be intermediate.

Species and provenance differences

In general, survival was quite good in the trial, indicating that most of the species have the ability to survive at the site. However, there were large differences in the growth potential of the species. The provenances having the best height growth, crown areas and increase in basal area were Peru03 of *P. affinis* and Brazil2 of *P. juliflora*. Unfortunately regressions between basal area and dry weight were only available for two of the species, meaning that the biomass production of *P. affinis* (Peru03) could not be calculated. Peru05 (*P. pallida*) also appeared to have fast height, crown area and diameter growth, but since the wood is lighter than the wood of *P. juliflora*, the dry weight production was only half the dry weight of Brazil2. In the parallel trial (no. 2) the best provenances were also Brazil2 and Peru05. Peru03 was not represented, but Punjab9b had a better growth than in this trial.

Most of the other provenances had an inferior growth and will probably be of limited value at the site, unless they produce products high in demand, such as fruits. In the intermediate group were the species *P. alba*, *P. glandulosa* and the provenance of *P. juliflora* from Pakistan (Punjab9b). *P. flexuosa* and *P. nigra* from Argentina had a poor growth, whereas the absolutely poorest provenance was *P. kuntsei* from Paraguay.

The two provenances from Pakistan were originally part of the same seedlot. During the assessment it was observed that the seedlot was a mixture of two different species (*P. glandulosa* and *P. juliflora*). However, in the univariate analyses there were no signs that the provenances were different, and only in the multivariate analysis the two species could be separated. With regard to growth potential, it therefore seems that the two provenances can be considered alike.

On the other hand, the two provenances of *P. juliflora* (Brazil2 and Punjab9b) were clearly different in most variables. Brazil2 seemed to be the best adapted to the site. In trial no. 2 the trend was opposite: Here Punjab9b had a larger dry weight than Brazil2, even though the difference was not significant. One possible explanation is that the two trials were established in different years, with subsequent different growth conditions during the establishment phase. In trial no. 4, Brazil2 was the most productive together with a provenance from Senegal. Punjab9b was not present in the latter trial, but taken all together the data indicate that Brazil2 has a rather good performance at the site, even if it may not always be the best. As mentioned earlier, it is a major concern that the local provenance may have a narrow genetic base, but so far this has not been manifested in the trials.

The trial was designed to test a number of exotic *Prosopis* species for their ability to grow in the dry climate at Petrolina - PE. Looking at the geographical origin, it seems that the species coming from close to the equator have the best performance. Both the two species from Peru (*P. affinis* and *P. pallida*) are only 5° from the equator, whereas the local land race (Brazil2) of *P. juliflora* are 10° from the equator. In contrast, the other provenances, including the species *P. alba*, *P. flexuosa*, *P. glandulosa*, *P. juliflora*, *P. kuntsei* and *P. nigra*, were all 20-30° to the north or the south of the equator (Table 1).

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Annex 1. Description of the trial site

Name of site:	Bebedouro, Petrolina 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. 3 at Petrolina - PE, Brazil. The plot number refers to the seedlot in the map of the trial, see Annex 3. Species codes: paf: *P. affinis*, palpa: *P. alba* var. *panta*, pfl: *P. flexuosa*, pgl: *P. glandulosa*, pju: *P. juliflora*, pku: *P. kuntsei*, pni: *P. nigra*, ppa: *P. pallida*.

Seedlot numbers					**Provenance information**						
Provenance	**DFSC No.**	**Country of origin**	**Plot**	**Species code**	**Origin**	**Country**	**Latitude**	**Longitude**	**Altitude (m)**	**Rainfall (mm)**	**No. of mother trees**
Peru3		SF02/89	2	paf		Peru	5°12'S	80°38'W			
Argentina2		SF03/85	7	palpa		Argentina	27°30'S	64°55'W			16
Argentina5		SF04/85	8	pfl		Argentina	29°30'S	67°00'W			19
Punjab9a	1235/84		4	pgl	Fazal Abad Rice Mill, D.I.Khan	Pakistan	31°15'N	70°45'W	330	300	25
Brazil2			3	pju	Bebedouro	Brazil	9°9'S	40°22'W	365	553	15
Punjab9b	1235/84		4	pju	Fazal Abad Rice Mill, D.I.Khan	Pakistan	31°15'N	70°45'E	330	300	25
Paraguay2		SF03/87	1	pku		Paraguay					
Argentina6		SF05/85	6	pni		Argentina	29°30'S	67°00'W			11
Peru5		SF43-46/82	5	ppa	Piura	Peru	5°12'S	80°30'W			4

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	Block 3	
8	1	6	8	
7	2	5	7	
6	3	2	6	
5	4	7	5	
4	5	1	4	
3	6	8	3	
2	7	3	2	
1	8	4	1	
	1	2	3	x

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

y						
5	1	2	3	4	5	
4	10	9	8	7	6	
3	11	12	13	14	15	
2	20	19	18	17	16	
1	21	22	23	24	25	
	1	2	3	4	5	x

Annex 4. Plot data set

Species codes: paf: *P. affinis*, palpa: *P. alba* var. *panta*, pfl: *P. flexuosa*, pgl: *P. glandulosa*, pju: *P. juliflora*, pku: *P. kuntsei*, 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	Damage score
					Proportion	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
1	1	7	Peru03	paf	1.00	2.72	9.4	2.4	18.8	2.5			0.12
1	1	2	Argentina2	palpa	0.96	1.33	2.9	3.4	6.9	0.9			0.00
1	1	1	Argentina5	pfl	0.96	1.07	1.6	1.9	2.5	0.3			0.17
1	1	5	Punjab9a	pgl	1.00	1.58	3.1	3.8	7.8	1.0			0.00
1	1	6	Brazil2	pju	1.00	2.92	8.5	3.1	21.4	2.9	5.9	7.87	0.08
1	1	5	Punjab9b	pju	0.92	1.35	6.4	3.0	11.6	1.5	3.2	4.14	0.00
1	1	8	Paraguay2	pku	0.76	0.29	0.3		0.0	0.0			1.47
1	1	3	Argentina6	pni	1.00	0.79	2.6	1.5	2.5	0.3			0.00
1	1	4	Peru05	ppa	1.00	1.82	8.0	2.0	12.5	1.7	2.5	3.33	0.00
2	2	6	Peru03	paf	1.00	2.78	10.1	3.0	19.5	2.6			0.00
2	2	5	Argentina2	palpa	0.96	1.50	2.5	3.4	6.7	0.9			0.00
2	2	3	Argentina5	pfl	1.00	1.29	2.6	1.4	2.6	0.3			0.00
2	2	1	Punjab9a	pgl	1.00	1.54	3.1	3.5	6.2	0.8			0.00
2	2	2	Brazil2	pju	1.00	2.90	8.8	2.9	20.1	2.7	5.4	7.23	0.12
2	2	1	Punjab9b	pju	0.93	1.32	3.4	3.9	5.3	0.7	1.3	1.64	0.00
2	2	4	Paraguay2	pku	0.72	0.52	0.5	1.0	0.4	0.0			1.44
2	2	8	Argentina6	pni	1.00	0.96	2.4	1.3	2.0	0.3			0.00
2	2	7	Peru05	ppa	1.00	2.50	9.1	2.2	19.4	2.6	4.3	5.80	0.04
3	3	2	Peru03	paf	0.96	2.56	8.6	2.5	18.0	2.3			0.04
3	3	7	Argentina2	palpa	0.96	1.43	3.8	3.4	7.9	1.0			0.17
3	3	8	Argentina5	pfl	0.96	1.35	2.7	1.4	3.2	0.4			0.00
3	3	4	Punjab9a	pgl	1.00	1.63	3.5	3.5	5.9	0.8			0.00
3	3	3	Brazil2	pju	1.00	2.02	6.2	2.0	10.0	1.3	2.5	3.29	0.04
3	3	4	Punjab9b	pju	0.91	0.91	2.5	2.3	3.3	0.4	0.9	1.09	0.20
3	3	1	Paraguay2	pku	0.92	0.47	0.4	1.0	0.6	0.1			0.00
3	3	6	Argentina6	pni	0.96	0.90	2.2	1.4	2.3	0.3			0.00
3	3	5	Peru05	ppa	1.00	1.83	7.5	1.7	9.2	1.2	1.6	2.12	0.04