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Evaluation of a *Prosopis cineraria* provenance trial at Dagar Kotli, Pakistan

Trial no. 23 in the arid zone series

by

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The *Prosopis* species and provenance trial at Dagar Kotli, Pakistan. Plot of *Prosopis cineraria*. Assessment of biomass production by destructive sampling. 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 is among the first in a new 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 represents the first 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 Pakistan Forest Institute (PFI).

The assessment team in April/May 1992 consisted of M. Noor, M.S. Mughal (PFI), Agnete Thomsen (FAO), and Lars Graudal (DFSC), assisted by M.I. Shah, Mushlaq and Ram Zahn (PFI) and 3 villagers at the trial site.

The authors wish to acknowledge the help of the personnel at PFI 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.

Abstract

This report describes results from a trial with 12 provenances of *Prosopis cineraria* from India, Pakistan and Yemen (3, 8 and 1 provenances respectively) and one provenance of *P. chilensis* from Chile. The trial was established at Dagar Kotli, Pakistan in 1984 with a spacing of 3x3 metres, and assessed after eight years in 1992. Different growth parameters were measured and subjected to analyses of variance and multivariate analyses.

Survival of the different provenances was variable, and there were significant provenance differences in survival, height, crown area, number of stems, basal area of the mean tree and dry weight of the mean tree. When basal area and dry weight were analysed on a per-ha basis, differences were only at the limit of significance or not significant. Both Pakistan and Indian provenances were quite variable, and there were no signs of general differences between the two groups of provenances. The fastest growing provenance had a basal area increment rate of 1.3 m^2 ha^{-1} y^{-1}, corresponding to a dry weight production of approximately 3.5 t ha^{-1} y^{-1}.

Contents

1. Introduction

This report describes the results from trial no. 23 in a large series of provenance trials within the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species'. The main goals of the series were to contribute to the knowledge on the genetic variation of woody species, their adaptability and productivity and to give recommendations for the use of the species. The species included in this series of trials are mainly of the genera *Acacia* and *Prosopis*. A detailed introduction to the series is given by DFSC (Graudal *et al.* 2003).

The current trial includes twelve provenances of *P. cineraria* and one provenance of *P. chilensis*. Furthermore a provenance of *P. tamarugo* was planted in the trial, but because none of the plants survived, it was replaced by a local provenance of *P. cineraria*.

P. cineraria is a species native to the arid zones of the Arabian Gulf, Pakistan and parts of India (Pedersen 1980, Brown no date). Despite its many potentials as producer of wood and fodder and use in soil amelioration and cultivation of saline soils, little is known on the genetic variation within the species (Leakey & Last 1978). In this trial a range of provenances from Pakistan, India and Yemen are tested.

2. Materials and methods

2.1 Site and establishment of the trial

The trial is placed at Dagar Kotli (31°33′N, 71°07′E) in the Thal desert of Pakistan, at an altitude of 200 m. The mean annual temperature is approximately 25°C, but the site experiences temperatures up to 48°C. Precipitation is variable, ranging from below 200 to 300 mm (DFSC 1994, Hussain no date). The sparse rainfall is scattered around the year, and the number of dry months (with rainfall below 50 mm) is high, ten - eleven months. There are occasional frosts at the site.

The site is characterised by moderately calcareous, clayey loam soils, overlaid in part by sand dunes. The terrain is essentially flat. Further information is summarised in annex 1.

Seed were sown in March 1984, and the trial was established in August the same year. After planting hand watering was at weekly intervals in summer, and every two weeks during winter, in total for one year. At each watering, the quantity of water was 4 l $plant^{-1}$ (Hussain, no date).

2.2 Species and provenances

The thirteen provenances in the trial are shown in table 1. The provenances have been given identification numbers relating to their geographical origin (name of province or country followed by a number). *P. cineraria* is represented by eight provenances from Pakistan, three provenances from India and one provenance from Yemen. The last provenance is *P. chilensis* from Chile.

During the assessment it was discovered that there was a lack of correspondence between the establishment report and some early assessments of the trial, in that the seedlot numbers were not always the same. The assessment team tried to attach the proper seedlot numbers to each plot, but there is some uncertainty as regards the provenances Chile02, Pakistan1, Pakistan2, Punjab07, Punjab08, Sind10 and Punjab10. Pakistan1 and Pakistan2 are assumed to be local provenances from Dagar Kotli. Until a final identification of the seedlots has been obtained, no recommendations on the use of the provenances mentioned above should be made. The problems are described in detail in annex 2, together with the original seedlot numbers.

2.3 The experimental design

The experimental design is a randomised complete block design with four blocks. In each replicate 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 3×3 m, and only the 16 central trees were assessed. Three of the blocks are line blocks, whereas the fourth is a square block. The layout of the design is shown in annex 3, and further details are given in DFSC (1994).

2.4 Assessment of the trial

In April/May 1992 PFI, FAO and DFSC undertook a joint assessment. The assessment included the following characters (DFSC 1994):

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

Raw data from the assessment 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* tested in trial no.23 at Dagar Kotli, Pakistan. All provenances are *P. cineraria*, except for Chile02 (*P. chilensis*).

Provenance	See Collection SiteOrigin	Country of origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
Chile02	Rio Pama	Chile	31° 09' S	71° 04' W		250	26
Pakistan1							
Pakistan2							
Punjab07	Greater Cholistan, Toofan, Bahawalpur	Pakistan	29° – N	72° -- E	160	125	32
Punjab08	Lesser Cholistan, Bhodan, Bahawalpur	Pakistan	29° – N	72° -- E	160	125	30
Punjab10	Gadani	Pakistan	31° 42' N	71° 36' E	200	200	
Punjab11	Darya Khan, Bhakkar	Pakistan	31° 47' N	71° 10' N	200	200	30
Rajasthan08	Sidhari-Guda, Barmer	India	25° 45' N	71° 23' E	194	310	20
Rajasthan09	Jhunjhunu	India	28° 10' N	75° 15' E	338	648	27
Sind09	Islam-Kot, Tharparkar, Registan (Loonio)	Pakistan	24° 40' N	70° 17' E	50	150	25
Sind10	Saeed-Abad, Hyderabad	Pakistan	25° 25' N	68° 24' E	30	157	25
Uttar Pradesh3	Yamuna/ Chambal, Etawah	India	27° 14' N	79° 03' E	157	762	30
Yemen4	Khanfar (Aden)	Yemen	13° 00' N	45° 10' E	15	50	20

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 were the basal area and the dry weight of the mean tree. The total basal area and the total dry weight represent the sum of all trees in a plot, expressed on an area basis. Note that the calculations of basal area are based on measurements of the three largest stems per tree. The trees almost all appeared to be healthy, and no analysis of the health data is made. In stead a graphical presentation of the health scores is given in annex 5.

It appeared that for some small trees, no assessment of diameter, number of stems and crown diameter was made. This was the case for 46-48 trees of the 317 surviving trees. The omission of these data will produce biased results and lead to an over-estimation of the provenances in question. Therefore the values for crown area, basal area and dry weight for these observations have been set to zero. There is no reasonable way to estimate the number of stems of such trees, and no default value has been set for this variable. In any case, the estimates of the variables will be slightly biased even after correction, but this is hopefully less important than without correction.

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. cineraria* the regression used was

$$TreeDW = e^{(2.395 \times \ln(basalarea) - 2.436)}$$

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}. No regression was available for *P. chilensis*.

3.2 Statistical model and estimates

The tests of provenance differences were 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 $N(0, \sigma e2)$.

The first test included all provenances, but a second test was performed in which the provenance of *P. chilensis* was excluded in order to test whether there were differences within the provenances of *P. cineraria*.

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, Afifi & Clark 1996). Only for survival, analysis was without complications. For all other variables, plots of the residuals indicated that there was variance heterogeneity between the different provenances. Therefore, for these variables data were weighted with the inverse of the variance for the seedlots in order to obtain normality of the residuals.

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 (P1) was considered significant on a 'table-wide' significance level of α if $P1<\alpha/n$, where n is the number of tests. The second smallest P value (P2) was declared significant if $P2<\alpha/(n-1)$, and so on (c.f. Kjaer & Siegismund 1996). In this case the number of tests was six where *P. chilensis* was included. In tests of only *P. cineraria*, the number of was eight, equalling the number of variables analysed. The significance levels are indicated by (*) (10%), * (5%), ** (1%), *** (1 ‰) and n.s. (not significant).

Finally the model was used to provide estimates for the provenance values. Two sets of estimates are presented: The least square means (LS-means) and the Best Linear Unbiased Predictors (BLUPs) (White & Hodge 1989). In brief, the LS-means give the best estimates of the performance of the chosen provenances at the trial site, whereas the BLUPs give the best indication of the range of variation within the species. Since it is assumed in the calculation of BLUPs that the provenances represent a random selection, they are usually presented for the species separately. In this case we only present BLUP estimates for *P. cineraria*.

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). This analysis was made with all provenances included as well as with the *P. cineraria* provenances alone.

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).

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 year's growth of the trial and not necessarily the climatic extremes and conditions that may be experienced during the life span of a tree in the field.

Survival varied from below 5% in Pakistan2 to almost 70% in Sind09 (Fig. 1). Differences between provenances were significant in both analyses, and also the co-variates plotx and ploty were significant (Table 2). The four best provenances were Rajasthan08, Rajasthan09, Sind09 and Sind10, and there were no signs of general differences between the provenances from India and Pakistan. The provenance from Yemen was intermediate, as was the provenance of *P. chilensis*. There was apparently no correlation between survival and rainfall at the site of origin for the provenances.

For *P. cineraria*, the BLUP-values indicated that there were considerable gains in survival by choosing the best provenances. The deviation from the average value ranged from −20 to +20 percentage point (Fig. 2).

Table 2. Results from analysis of variance of provenance differences of survival in trial 23.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	12	1069	2.7	0.01	*
Block	3	449	1.2	0.34	
Plotx	1	5685	14.6	0.0005	
Ploty	1	1485	3.8	0.06	
Error	34	390			
P. cineraria					
Provenance	11	1060	2.7	0.01	*
Block	3	477	1.2	0.32	
Plotx	1	5599	14.3	0.0007	
Ploty	1	1547	3.9	0.06	
Error	31	392			

Figure 1. Survival in the *Prosopis* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are least square means with 95 % confidence limits.

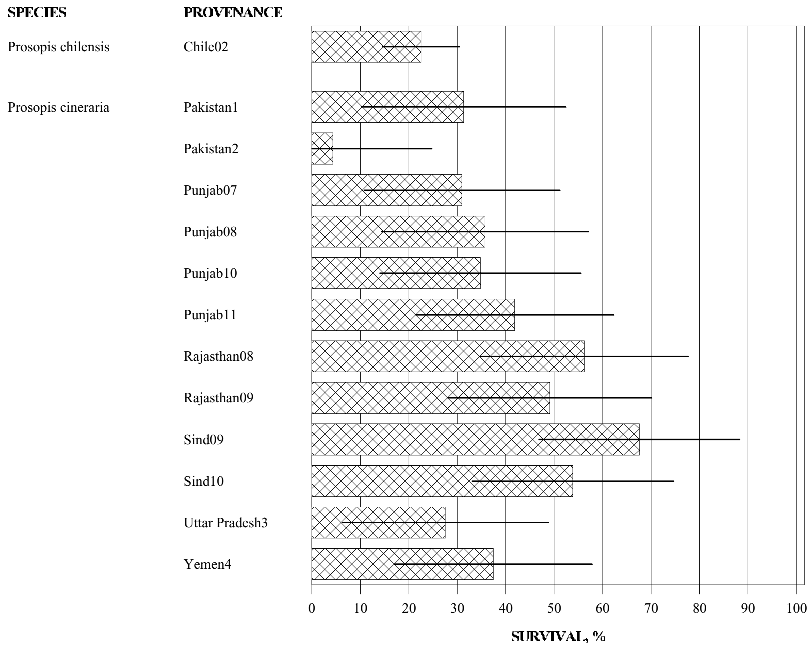
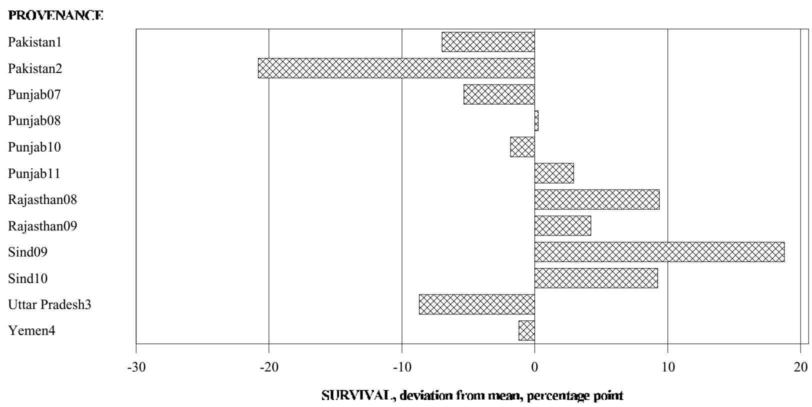


Figure 2. Best linear unbiased predictors (BLUP's) for survival in the *P. cineraria* provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are deviations from the mean value in percentage point.



4.2 Height

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

The differences between the height of the provenances were highly significant (Table 3). The provenance of *P. chilensis* had the tallest trees with an average of 5.2 m, closely followed by Rajasthan08 with 5.0 m (Fig. 3). The rest of the provenances were varying between 1.7 m and 3.2 m, with Punjab10 as the smallest. It was difficult to find connections between geographical patterns, rainfall and height growth of the provenances.

According to the BLUP values in fig. 4, the predicted gains by choosing Rajasthan08 was almost 60% of the average value. At the other end, choosing Punjab10 would give a loss of 30%.

The Pakistan2 provenance had surviving trees in only one plot. This is why neither confidence intervals in the LSMEANS graphs and BLUP values for the provenance are presented. The problem is the same for the rest of the variables in this report.

Table 3. Results from analysis of variance of provenance differences of height in trial 23.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	11	4.9	4.6	0.0005	**
Block	3	36.0	34.0	<0.0001	
Error	28				
P. cineraria					
Provenance	10	5.1	4.7	0.0008	**
Block	3	33.5	30.8	<0.0001	
Error	25				

Figure 3. Vertical height in the *Prosopis* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are least square means with 95 % confidence limits.

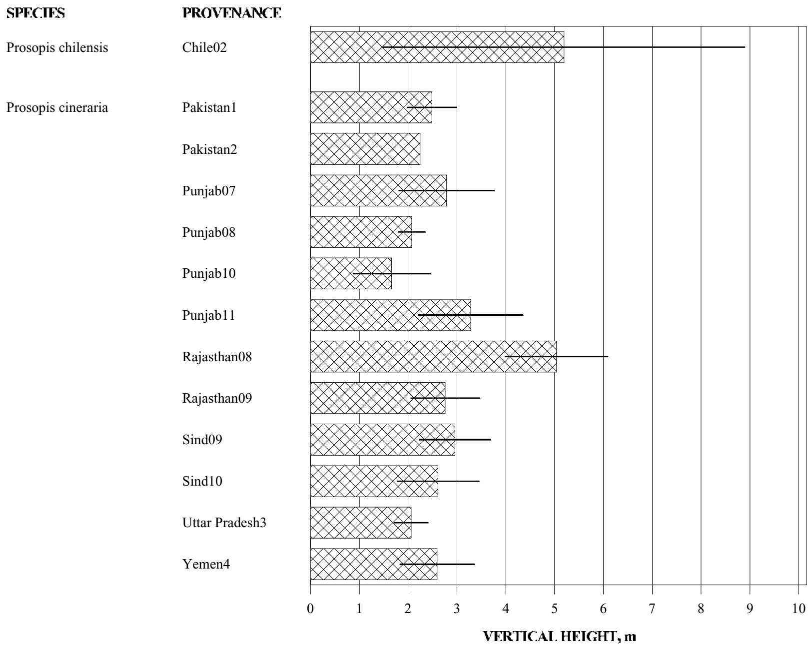
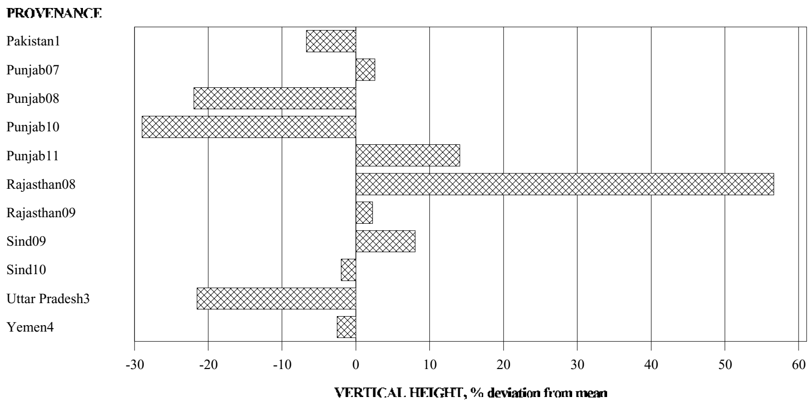


Figure 4. Best linear unbiased predictors (BLUP's) for vertical height in the *P. cineraria* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values are presented as deviations in percent of the mean value.



4.3 Crown area

The crown area variable gives 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. Since crown area was not measured for a number of small trees, the values for these valuables were set to zero (section 3.1). This may introduce a bias in the analyses.

Again there were significant differences between the provenances, and the significance level increased when only *P. cineraria* provenances were analysed (Table 4). The trees of *P. chilensis* had by far the largest crown areas, the average value amounting to 19 m^2 $tree^{-1}$ (Fig. 5). Note however that there was also a large variation within the provenance as indicated by the large error bars in fig. 5. For the provenances of *P. cineraria* the crown areas were much more modest, varying between 1.6 (in Punjab10) and 6.3 m^2 $tree^{-1}$ (Rajasthan08).

Despite the small crowns when compared to *P. chilensis*, the BLUP values for *P. cineraria* were ranging from −50 to +60%, indicating that the are substantial gains by selection of provenances (Fig. 6). The best provenance was Rajasthan08, with no apparent geographical trends in the performance of the provenances.

Table 4. Results from analysis of variance of provenance differences of crown area in trial 23.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	11	3.6	3.5	0.003	*
Block	3	76.4	74.2	<0.0001	
Error	28	1.0			
P. cineraria					
Provenance	10	6.4	6.4	<0.0001	***
Block	3	31.3	30.9	<0.0001	
Error	25				

Figure 5. Crown area in the *Prosopis* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are least square means with 95 % confidence limits.

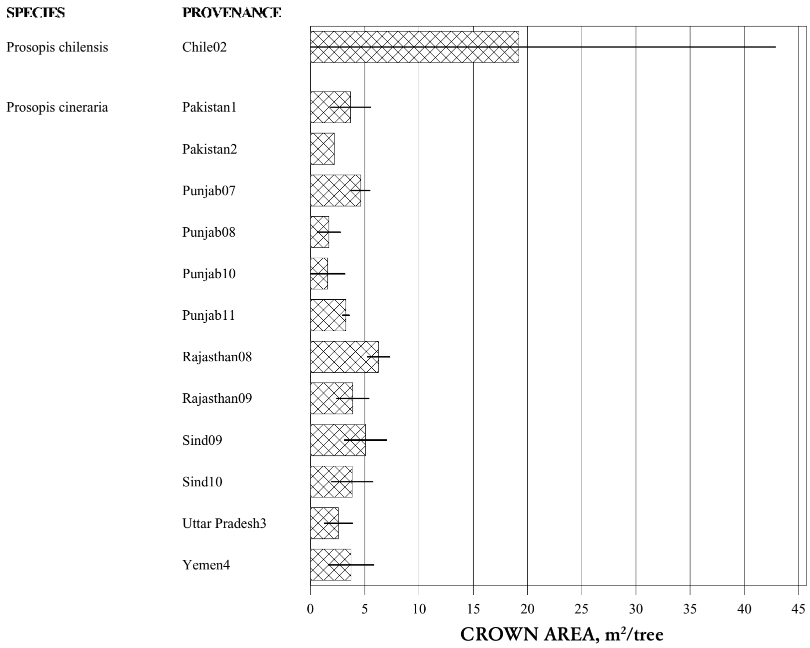
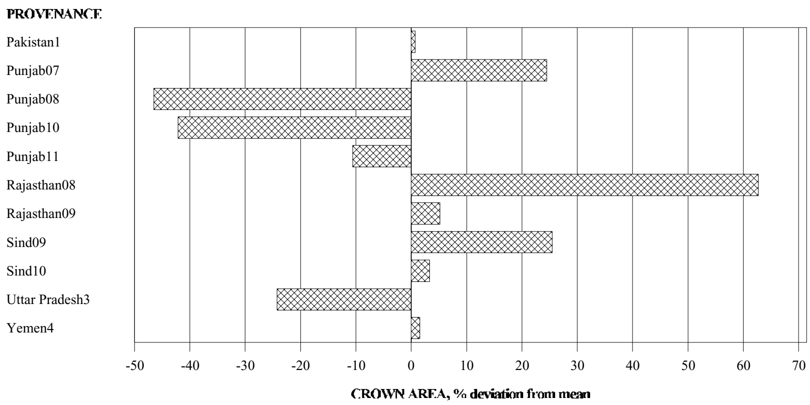


Figure 6. Best linear unbiased predictors (BLUP's) for crown area in the *P. cineraria* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values are presented as deviations in percent of the mean value.



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 more tree-like growth. Note that a number of small trees were not included in the analysis, as the number of stems for these trees were not registered (section 3.1). This introduces a bias in the analysis, being valid only for larger trees.

The provenances had significantly different numbers of stems in both analyses, but less so in the analysis where *P. chilensis* was excluded than in the analysis with all provenances (Table 5). This is because the provenance of *P. chilensis* had a larger number of stems than the other provenances, the average value for this provenance being more than 3 stems $tree^{-1}$. The *P. cineraria* provenances had values ranging from 1 to 1.8 stems $tree^{-1}$. Uttar Pradesh3 had the highest values and Pakistan2 the smallest (Fig. 7).

The BLUP values predict modest gains by selection of provenances, ranging from −7 to +10 percent (Fig. 8). Note that the ranks of the provenances have changed in comparison to the least square means values in fig. 7. The use of weights in the analysis makes the BLUP values larger for provenances that are determined with high precision in contrast to values that are determined with small precision. Compare e.g. the values for the provenances Sind10 and Uttar Pradesh3.

Table 5. Results from analysis of variance of provenance differences of number of stems in trial 23.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	11	4.6	4.4	0.0008	**
Block	3	2.0	1.9	0.16	
Error	27	1.0			
P. cineraria					
Provenance	10	3.1	3.5	0.006	*
Block	3	5.9	6.7	0.002	
Error	24				

Figure 7. Number of stems in the *Prosopis* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are least square means with 95% confidence limits.

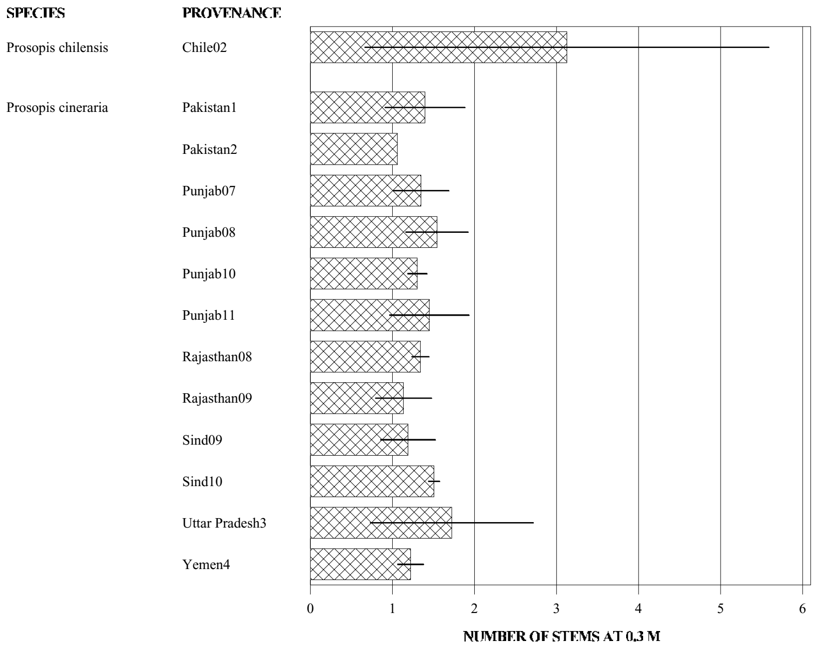
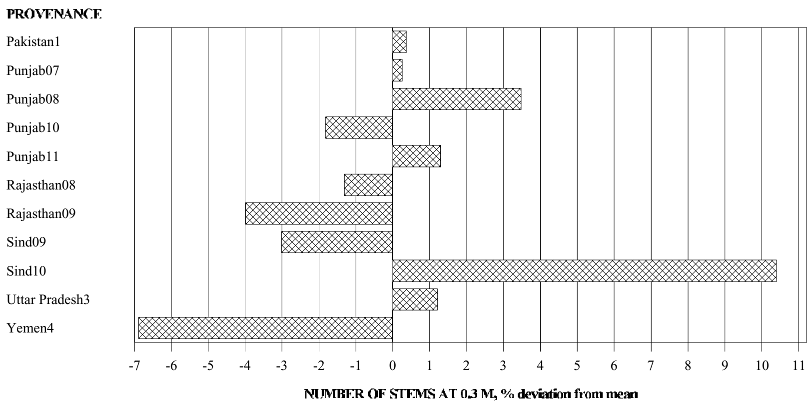


Figure 8. Best linear unbiased predictors (BLUP's) for number of stems in the *P. cineraria* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values are presented as deviations in percent of the mean value.



4.6 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 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. For a number of small trees, the diameters were not measured (section 3.1). Therefore the basal areas for these trees have been set to zero, which may introduce a bias in the analyses.

The differences between provenances were significant in both analyses (Table 6). *P. chilensis* took the lead again with a basal area of 200 cm^2 $tree^{-1}$ (Fig. 9). Among the provenances of *P. cineraria*, Rajasthan08 was the largest with basal areas of 150 cm^2 $tree^{-1}$. The rest of the provenances were considerably smaller, with values ranging from only 10 to 55 cm^2 $tree^{-1}$. This was also reflected in the BLUP values, where the predicted gains varied between −50 and +50%, with the highest values for Rajasthan08 (Fig. 10).

Table 6. Results from analysis of variance of provenance differences of basal area of the mean tree in trial 23.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	11	3.2	3.1	0.007	*
Block	3	284.4	276.9	<0.0001	
Error	28	1.0			
P. cineraria					
Provenance	10	4.4	4.2	0.002	*
Block	3	21.7	20.8	<0.0001	
Error	25				

Figure 9. The basal area of the mean tree in the *Prosopis* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are least square means with 95% confidence limits.

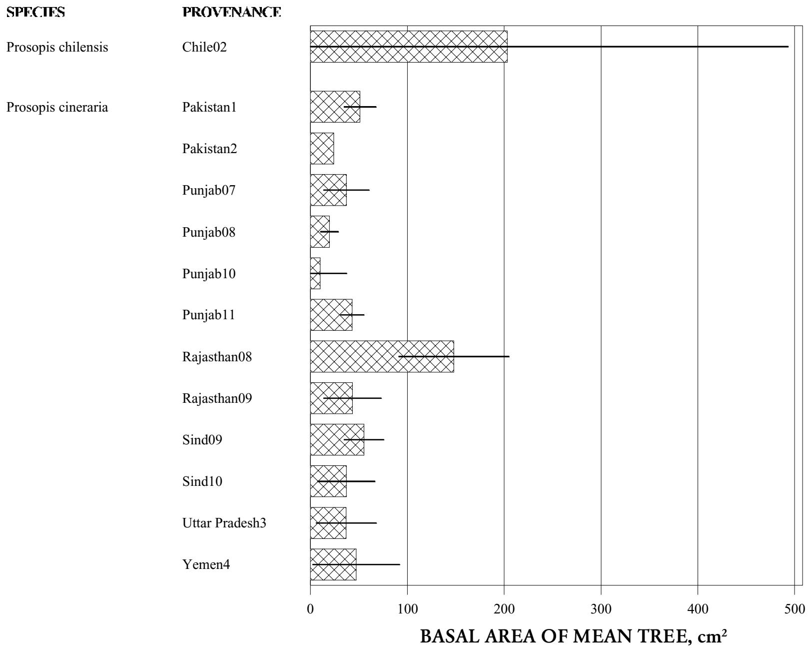
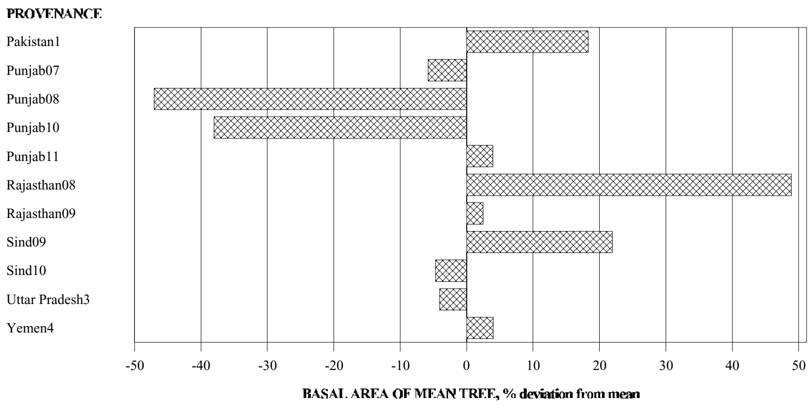


Figure 10. Best linear unbiased predictors (BLUP's) for the basal area of the mean tree in the *P. cineraria* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values are presented as deviations in percent of the mean value.



4.6 Total basal area

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

In the analysis of all provenances, the differences between provenances were significant. Excluding the provenances of *P. chilensis* meant that the effect of provenances was only significant at the 10 % level, and the correction for multiple comparisons indicated that the differences were not significant at all (Table 7). The co-variate plotx was significant in the analysis of all provenances, but not in the analysis of differences within *P. cineraria*.

The largest value for total basal area was found in Rajasthan08, which had a value of 10.4 m^2 ha^{-1}. This corresponds to an average annual increment of 1.3 m^2 ha^{-1}. Note however, that there is a large uncertainty on the estimate for Rajasthan08 as indicated by the long error bars in fig. 11. Chile02 of *P. chilensis* and Sind09 of *P. cineraria* had basal areas of approximately 5 m^2 ha^{-1}., whereas the rest of the provenances had values below 3 m^2 ha^{-1}.

The large variation between the plots of Rajasthan08 had consequences for the ranking according to the BLUP values (Fig. 12). Here the provenances Sind09 and Punjab11 were ranking highest with predicted values of 10-20 % above the average. In comparison, the poorest provenance (Punjab08) had a predicted value below –15 %.

Table 7. Results from analysis of variance of provenance differences of total basal area in trial 23.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	12	3.1	3.0	0.006	*
Block	3	17.8	17.2	<0.0001	
Plotx	1	5.4	5.2	0.03	
Error	35	1.0			
P. cineraria					
Provenance	11	1.9	2.0	0.07	n.s.
Block	3	14.6	14.7	<0.0001	
Error	32	1.0			

Figure 11. Total basal area in the *Prosopis* species and provenances trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are least square means with 95% confidence limits.

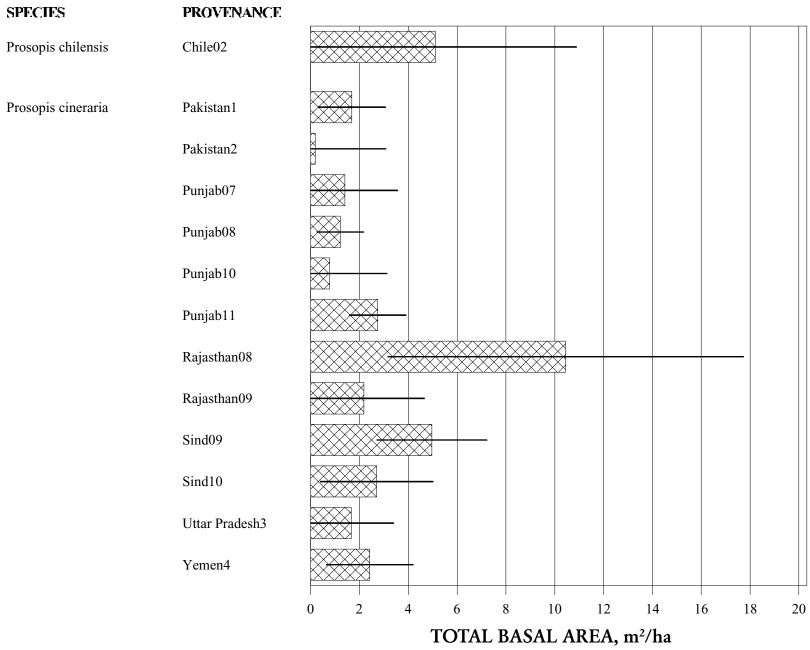
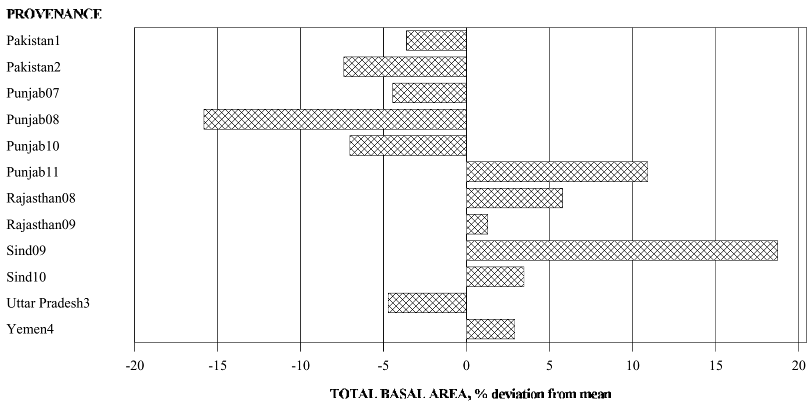


Figure 12. Best linear unbiased predictors (BLUP's) for total basal area in the *P. cineraria* provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values are presented as deviations in percent of the mean value.



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 together as the basis for calculation 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 are weighted heavily in this variable. The dry weight of the mean tree is thus the best estimate for the production of biomass at the site. As the dry weight was not determined for *P. chilensis*, this species was excluded from the analysis.

The differences between provenances were significant, also after the Bonferroni correction for multiple comparisons (Table 8). Rajasthan08 was again the largest with the average dry weight attaining 38 kg tree^{-1}. The other provenances had much smaller dry weights of 12 kg tree^{-1} or below (Fig. 13). However, the large variation within Rajasthan08 again meant that it was less dominating in the BLUP values (Fig. 14). Rajasthan08, Pakistan01 and Sind09 had the largest predicted values of approximately 20-30% above the average, whereas Punjab08 as the poorest provenance had values of –46%.

Table 8. Results from analysis of variance of provenance differences of dry weight of the mean tree in trial 23.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
P. cineraria					
Provenance	10	3.5	3.4	0.007	*
Block	3	17.5	17.0	<0.0001	
Error	25	1.0			

Figure 13. Dry weight of the mean tree in the *Prosopis* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are least square means with 95% confidence limits.

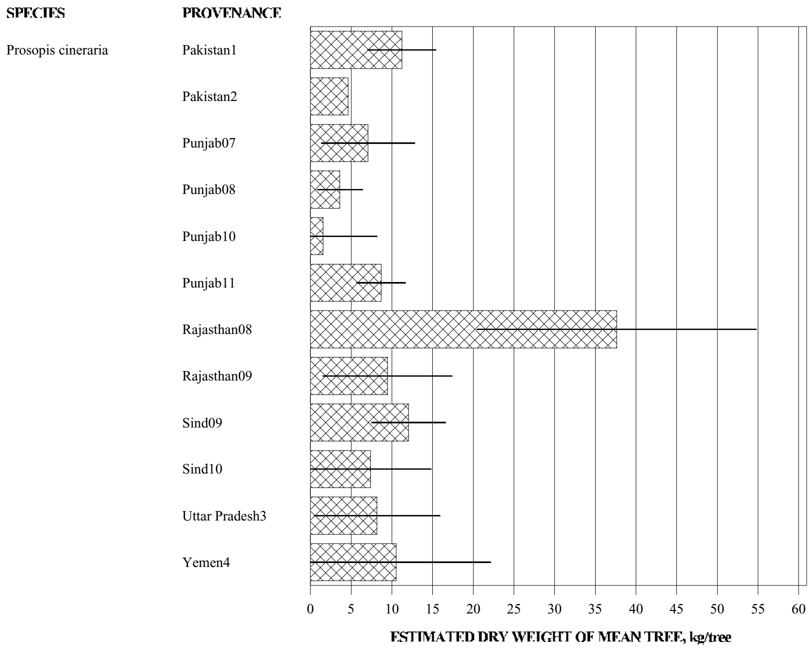
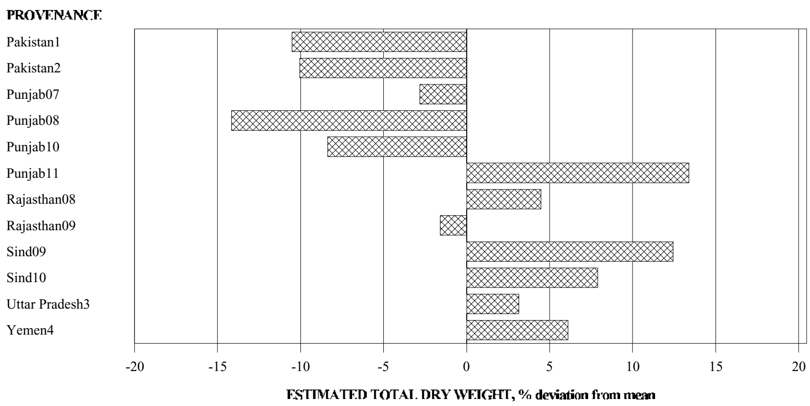


Figure 14. Best linear unbiased predictors (BLUP's) for dry weight of the mean tree in the *P. cineraria* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values are presented as deviations in percent of the mean value.



4.8 Total dry weight

In parallel with the total basal area, the total dry weight includes missing trees and gives the best measure of the actual production on the site. Again *P. chilensis* was not included in this analysis, as dry weight could not be estimated for this species.

The differences between provenances were only at the limit of significance, and when the correction for multiple comparisons was made, significance disappeared completely (Table 9). Therefore differences between provenances should be interpreted cautiously. Rajasthan08 had the largest average production of dry weight, amounting to 28 t ha^{-1}. This corresponds to an average annual production of 3.5 t ha^{-1}. The other provenances had dry weights of 10 t ha^{-1} or less (Fig. 15).

In accordance with the weak signs of significant differences, the BLUP values also indicated that the gains by provenance selection were modest, ranging from −14 to +13 % compared to the mean (Fig. 16). Note that Rajasthan08 is ranked only as the fifth best producer of dry weight – primarily because the variation within the provenance is so big.

Table 9. Results from analysis of variance of provenance differences of total dry weight in trial 23.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
P. cineraria					
Provenance	11	1.9	1.8	0.09	n.s.
Block	3	17.6	17.3	<0.0001	
Error	33				

Figure 15. Total dry weight in the *Prosopis* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values presented are least square means with 95% confidence limits.

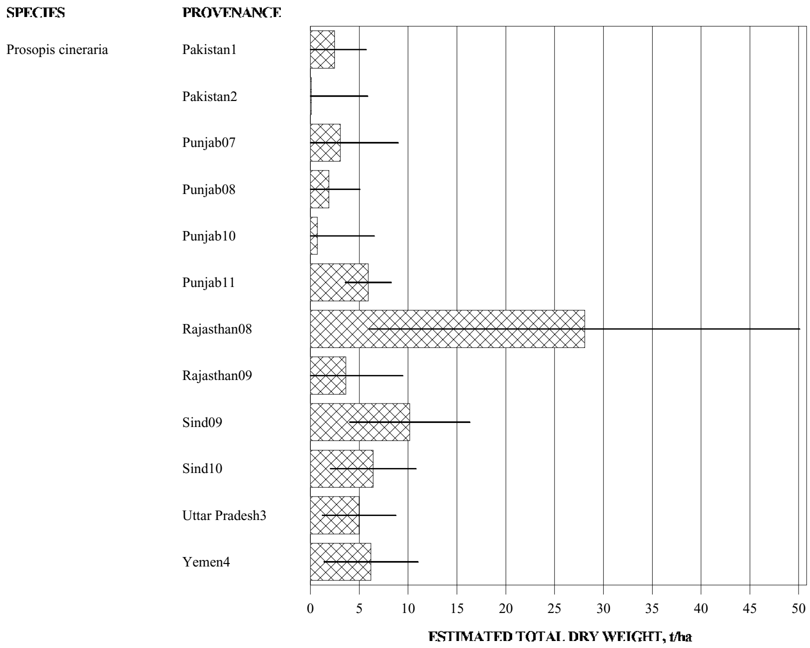
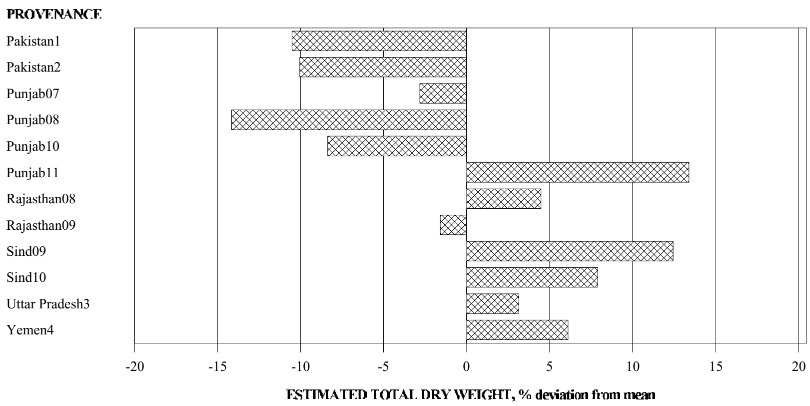


Figure 16. Best linear unbiased predictors (BLUP's) for total dry weight in the *P. cineraria* provenance trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). Values are presented as deviations in percent of the mean value.



4.9 Multivariate analysis

Two multivariate analyses were performed. The first included all provenances, whereas the second included only the provenances of *P. cineraria*.

Analysis of all provenances

This 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 excluded from this analysis, 9 observations where the survival was zero were excluded. The multivariate analysis does not account for the variance inhomogeneity observed in the univariate analyses, and the results should be interpreted cautiously.

The first canonical variate was highly significant, whereas the second was at the border of significance (Table 10). In total, the two variates accounted for 78 % of the variation. Differences between the provenances were highly significant (P-value for Wilk's lambda=0.0005, P-value for Pillai's trace=0.003).

Fig. 17 gives the plot of scores for the two first canonical variates. Apart from the scores, the mean values for the provenances are presented together with their approximate 95% confidence regions. In the diagram, provenances that are far apart are interpreted as being different, and if the confidence regions do not overlap, it is likely that the two provenances have different properties.

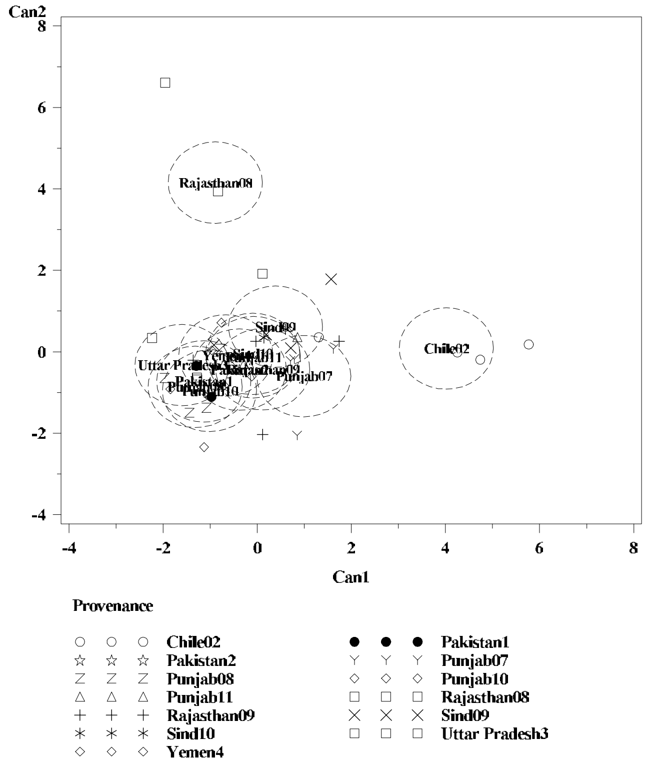
From the diagram it appears that the provenance Chile02 of *P. chilensis* is separated from the rest of the provenances, as would also have been expected from the univariate analyses. Within the provenances of *P. cineraria*, Rajahsthan08 is separated from the other provenances, which are situated more or less in a cluster. Still it should be kept in mind that the variance inhomogeneity is not accounted for.

Table 10. Results from the canonical variate analyses for the first two canonical variates in trial 23.

Canonical variate no.	**1**	**2**
Proportion of variation accounted for	0.46	0.32
Significance, P-value	0.0005	0.04

	Raw canonical coefficients		**Standardised canonical coefficients**		**Canonical directions**	
Canonical variate no.	**1**	**2**	**1**	**2**	**1**	**2**
Survival	-0.023	-0.0019	-0.6	-0.1	-101.2	258.9
Height	1.0	-0.055	1.6	-0.1	13.2	15.1
Crown area	0.77	-0.023	4.9	-0.1	79.3	20.1
Number of stems	-0.78	-0.43	-0.6	-0.3	7.4	-0.38
Basal area of the mean tree	-0.061	0.0032	-4.9	0.3	744.7	640.1
Total basal area	0.21	0.38	0.9	1.7	8.3	69.8

Figure 17. Score plot of the first and the second canonical variate from the canonical variate analysis for all provenances in the trial at Dagar Kotli, Pakistan (Trial no. 23 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. Chile02 is the provenance of *P. chilensis*, the rest are *P. cineraria*.



Analysis of P. cineraria

In this analysis all variables were included, but due to missing observations 9 plots were not included. Again it should be noted that the analysis does not account for variance inhomogeneity.

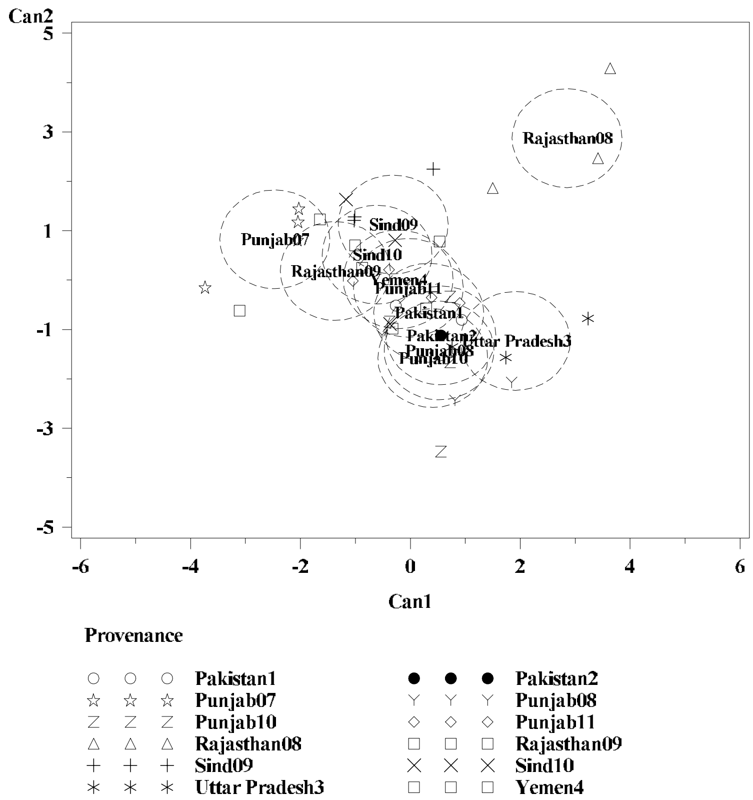
Only the first canonical variate was significant, accounting for only 38 % of the variation (Table 11). According to the test, the differences between provenances were at the limit of significance (P-value for Wilk's lambda=0.05, P-value for Pillai's trace=0.07). The plot of scores in Fig. 18 demonstrates essentially the same as Fig. 17. Since the second canonical variate is not significant, differences in this direction should be interpreted with caution. Rajahsthan08 is again separated from the rest of the provenances, which are located in the same cluster. In the cluster, there appear no geographical patterns, as the provenances from India, Pakistan and Yemen are scattered between each other. Similarly, it is difficult to find any relation with precipitation at the origin.

Table 11. Results from the canonical variate analyses for the first two canonical variates in trial 23.

Canonical variate no.	**1**	**2**
Proportion of variation accounted for	0.38	0.31
Significance, P-value	0.05	0.25

	Raw canonical coefficients		**Standardised canonical coefficients**		**Canonical directions**	
Canonical variate no.	**1**	**2**	**1**	**2**	**1**	**2**
Survival	-0.051	0.025	-1.4	0.68	101.1	229.5
Height	-2.29	0.53	-2.9	0.69	3.7	14.1
Crown area	-1.4	0.70	-3.0	1.6	-2.3	25.7
Number of stems	0.056	-0.49	0.023	-0.19	1.2	0.9
Average basal area	0.059	0.12	2.8	5.4	265.2	527.7
Total basal area	5.7	-2.6	26.7	-12.1	33.5	53.3
Average dry weight	0.13	-0.56	1.6	-6.8	76.3	135.4
Total dry weight	-2.0	1.1	-24.3	12.8	89.7	135.1

Figure 18. Score plot of the first and the second canonical variate from the canonical variate analysis for the provenances of *P. cineraria* in the trial at Dagar Kotli, Pakistan (Trial no. 23 in the arid zone series). All variables from the univariate analyses were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.



5. Discussion and conclusions

Productivity
The three trials at Dagar Kotli (the current trial and trials no. 21 and 22 in the arid zone series) all have remarkably high productivity compared to the rainfall at the site. This trial is no exception, since the provenance Rajasthan08 (*P. cineraria*) had an average production of 3.5 t ha^{-1} y^{-1}. The dry weight production of the provenance of *P. chilensis* could not be evaluated, but is probably somewhat lower, because the total basal area was only about half the basal area of Rajasthan08. It should be noted that there is a large uncertainty associated with the estimates of these two provenances.

Comparing to the two other trials, Rajasthan08 was intermediate between the best provenances of *Acacia albida* (trial no. 21) with a production of 1.6 t ha^{-1} y^{-1} and the best provenances of *A. nilotica* (trial no. 22) with 6.5 t ha^{-1} y^{-1}.

Provenance differences
The survival of the provenance of *P. chilensis* was relatively poor, but the surviving trees had a fast growth, both in terms of height, crown area and basal area. The provenance also had a large number of stems. It would be interesting to investigate the species in more detail, especially if the problems with survival could be solved.

Within *P. cineraria*, there were significant differences in all variables but total basal area and total dry weight. As mentioned in section 2.2 and annex 2, the identity of some of the seedlots is uncertain, meaning that it is difficult to give recommendations on the basis of the results. Therefore the following results should serve as indications rather than facts, and only small test plantations should result from them.

Provenances having an overall poor performance included Pakistan2, which had a very poor survival, and Punjab08 and Punjab10 with a relatively slow growth. On the other hand, Punjab11, Rajasthan08 and Sind09 were usually between the best provenances, and would be interesting to consider in the future.

The data do not demonstrate clear differences between provenances from India, Pakistan and Yemen. In the multivariate tests all provenances except Rajasthan08 came out in a cluster, mixed in between each other. On the other hand, both multivariate and univariate analyses demonstrated that there is a considerable variation between the provenances from Pakistan, even within provenances from Punjab. This is all under the assumption that the provenances have been labelled with the correct origin.

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Annex 1. Description of the trial site

Name of site:	Dagar Kotli Latitude: 31°33'N Longitude: 71°07'E Altitude: 200 m
Meteorological stations:	Dagar Kotli (Establishment Report 1984, Sheikh 1986) Mankera (9 km (Sheikh 1986)) D.I. Khan (31°49'N, 70°55'E, 172 m (FAO 1987))
Rainfall:	Mean (period): 100 mm (Mankera - 15 years, 1970-1985) Yearly registrations: 1981: 377 mm (Dagar Kotli, Sheikh 1986) 1982: 117.8 mm (Dagar Kotli, Sheikh 1986) 1982/83: 164.7 mm (Dagar Kotli)
Rainy season:	July-August Type: All year round (FAO 1987) Length (days): 0 (FAO 1987)
Dry months/year:	No. of dry months (< 50 mm): 10-11 (1982/83, Dagar Kotli) No. of dry periods: 1
Temperature:	Annual mean: 24.6 (FAO 1987) Coldest month: 4.4 (min. monthly temp., Establishment Report 1984) Hottest month: 42.8 (max. monthly temp., Establishment Report 1984) Occurrence of frost: 10 days/year (Establishment Report 1984).
Wind:	Prevailing directions: Summer: S; spring and fall: E, SE; winter: N (Sheikh 1986). Speed (at 2 m in m/s): 1.2 (FAO 1987).
Topography:	Flat
Soil:	(Establishment Report 1984 and Sheikh 1986): Type: Moderately calcerous, fine brown sand with fine kanker, clayey loam, no stones, alkaline, sand dunes occurring. Depth: deep, well drained (sand dunes shallow).
Climatic/agroecological zone:	Arid zone, Thal Desert
Koeppen classification:	BWh

Annex 2. Provenances of *Prosopis* tested in the trial

The plot numbers refer to the seedlots in the map of the trial, see Annex 3.

There is some confusion about a few of the seedlots. In principle, numbering follows the establishment report (PFI 1984b). Source no. 10 (local number) was originally *Prosopis* tamarugo, DFSC No. 1018/82. This seedlot failed and was replaced with a local source of *Prosopis cineraria* in 1986 (here called DKotli3). Source no. 11 and 12 are listed as, respectively, *P. chilensis* (DFSC No. 1027/82) and a local control of *P. cineraria* in the establishment report. They may both have been 1027/82. Source 12 is *P. chilensis* and source 11 *P. cineraria*. According to PFI (1989) and Hussain (1989b) source no. 7 is DFSC No. 1184/83 (Goharwala, Pakistan), source no. 8 DFSC No. 1182/83, source no. 9 DFSC No. 1180/83 and source no. 10 DFSC No. 1181/83. DFSC No. 1184/83 is not listed in the establishment report (PFI 1984b), but should be in the trial according to PFI 1986 and 1989, and Hussain 1989a and 1989b. The identity of sources no. 7 to no. 13 should be verified to be included in the analysis (Extract from the assessment report, DFSC 1994).

Provenance	DFSC	Country of origin	Plot	Species	Provenance name	Country of origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
Chile02	1027/82		12	*P. chilensis*	Rio Pama	Chile	31 09 S	71 04 W		250	26
Punjab11	1183/83		5	*P. cineraria*	Darya Khan, Bhakkar	Pakistan	31 47 N	71 10 N	200	200	30
Pakistan1		DKotli3	10	*P. cineraria*							
Pakistan2		DKotli4	11	*P. cineraria*							
Punjab07	1180/83		8	*P. cineraria*	Greater Cholistan, Toofan, Bahawalpur	Pakistan	29 – N	72 -- E	160	125	32
Punjab08	1181/83		9	*P. cineraria*	Lesser Cholistan, Bhodan, Bahawalpur	Pakistan	29 – N	72 -- E	160	125	30
Rajasthan08	1090/82		3	*P. cineraria*	Sidhari-Guda, Barmer	India	25 45 N	71 23 E	194	310	20
Rajasthan09	1091/82		4	*P. cineraria*	Jhunjhunu	India	28 10 N	75 15 E	338	648	27
Sind09	1179/83		6	*P. cineraria*	Islam-Kot, Tharparkar, Registan (Loonio)	Pakistan	24 40 N	70 17 E	50	150	25
Sind10	1182/83		7	*P. cineraria*	Saeed-Abad, Hyderabad	Pakistan	25 25 N	68 24 E	30	157	25
Punjab10		DKotli5	13	*P. cineraria*	Gadani	Pakistan	31 42 N	71 36 E	200	200	
Uttar Pradesh3	1088/82		2	*P. cineraria*	Yamuna/ Chambal, Etawah	India	27 14 N	79 03 E	157	762	30
Yemen4	1062/82	(1)	1	*P. cineraria*	Khanfar (Aden)	Yemen	13 00 N	45 10 E	15	50	20

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														
7	10	4	8	13	11	9	12	1	5	6	3	2	7	BLOCK 1
6	4	6	9	12	10	13	1	7	8	3	5	11	2	BLOCK 2
5	6	11	10	13	5	9	2	4	7	12	3	1	8	BLOCK 3
	1	2	3	4	5	6	7	8	9	10	11	12	13	x

BLOCK 4

y				
4				9
3	5	11	13	6
2	8	1	7	12
1	2	3	4	10
	1	2	3	4	x

N

Individual tree positions in each plot:

y						
6	*	*	*	*	*	*
5	*	+	+	+	+	*
4	*	+	+	+	+	*
3	*	+	+	+	+	*
2	*	+	+	+	+	*
1	*	*	*	*	*	*
	1	2	3	4	5	6	x

*: plot border trees

+: plot core trees

Annex 4. Plot data set

Provenance	Species	Block	Plot	Plotx	Ploty	Survival	Height	Crown area	Number of stems	Basal area of the mean tree	Total basal area	Dry weight of the 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}
Chile02	*P. chilensis*	1	12	7	7	0.15	7.63	38.7	4.00	454	9.45	0.0	0.00
NW Frontier1	*P. cineraria*	1	5	9	7	0.88	5.83	4.6	1.07	80	7.82	17.0	16.51
Pakistan1	*P. cineraria*	1	10	1	7	0.25	3.30	6.0	1.00	93	3.22	21.7	7.54
Pakistan2	*P. cineraria*	1	11	5	7	0.00					0.00		0.00
Punjab7	*P. cineraria*	1	8	3	7	0.25	2.60	5.2	1.00	37	1.02	7.0	1.94
Punjab8	*P. cineraria*	1	9	6	7	0.63	3.06	3.8	1.33	47	3.26	9.5	6.61
Rajasthan08	*P. cineraria*	1	3	11	7	1.00	6.60	6.8	1.27	213	23.64	56.5	62.73
Rajasthan09	*P. cineraria*	1	4	2	7	0.25	3.14	4.8	1.33	50	1.40	10.7	2.96
Sind09	*P. cineraria*	1	6	10	7	1.00	4.84	8.3	1.25	105	11.69	23.8	26.44
Sind10	*P. cineraria*	1	7	13	7	1.00	3.21	4.0	1.38	40	4.43	7.4	8.25
Sind12	*P. cineraria*	1	13	4	7	0.06	1.70	1.1	1.00	7	0.05	0.9	0.06
Uttar Pradesh3	*P. cineraria*	1	2	12	7	0.69	3.39	4.8	1.22	96	7.36	22.8	17.40
Yemen4	*P. cineraria*	1	1	8	7	0.63	4.16	6.9	1.11	119	8.25	29.0	20.12
Chile02	*P. chilensis*	2	12	4	6	0.25	4.64	16.7	3.00	143	4.97	0.0	0.00
NW Frontier1	*P. cineraria*	2	5	11	6	0.69	3.17	3.9	1.22	38	2.87	7.2	5.50
Pakistan1	*P. cineraria*	2	10	5	6	0.00					0.00		0.00
Pakistan2	*P. cineraria*	2	11	12	6	0.00					0.00		0.00
Punjab7	*P. cineraria*	2	8	9	6	0.56	3.37	6.6	1.89	59	3.72	12.2	7.64
Punjab8	*P. cineraria*	2	9	3	6	0.06	2.50	1.4	2.00	21	0.14	3.3	0.23
Rajasthan08	*P. cineraria*	2	3	10	6	0.69	5.83	8.0	1.36	178	13.58	44.7	34.18
Rajasthan09	*P. cineraria*	2	4	1	6	0.38	3.95	6.3	1.20	94	3.90	22.3	9.31
Sind09	*P. cineraria*	2	6	2	6	0.50	3.34	6.7	1.38	70	3.86	14.6	8.10
Sind10	*P. cineraria*	2	7	8	6	0.88	3.14	5.8	1.54	51	4.97	10.2	9.93
Sind12	*P. cineraria*	2	13	6	6	0.56	2.00	2.0	1.38	19	1.19	3.2	2.02
Uttar Pradesh3	*P. cineraria*	2	2	13	6	0.50	2.21	2.3	1.00	24	1.35	4.3	2.41
Yemen4	*P. cineraria*	2	1	7	6	0.44	2.30	2.9	1.14	24	1.16	4.2	2.03
Chile02	*P. chilensis*	3	12	10	5	0.25	6.28	18.9	4.50	196	5.43	0.0	0.00
NW Frontier1	*P. cineraria*	3	5	5	5	0.13	2.25	3.1	1.00	37	0.52	7.6	1.06
Pakistan1	*P. cineraria*	3	10	3	5	0.38	2.12	2.4	1.60	28	1.19	5.5	2.28
Pakistan2	*P. cineraria*	3	11	2	5	0.19	1.63	1.9	1.00	10	0.22	1.6	0.33

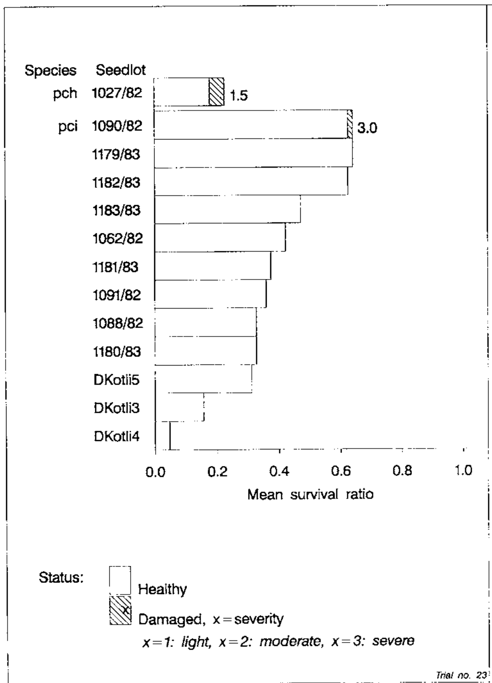
Provenance	Species	Block	Plot	Plotx	Ploty	Survival	Height	Crown area	Number of stems	Basal area of the mean tree	Total basal area	Dry weight of the mean tree	Total dry weight
						proportion	m	m^2 tree^{-1}	no. tree^{-1}	cm^2 tree^{-1}	m^2 ha^{-1}	kg tree^{-1}	t ha^{-1}
Punjab7	*P. cineraria*	3	8	13	5	0.38	2.33	4.0	1.00	26	1.09	4.8	2.00
Punjab8	*P. cineraria*	3	9	6	5	0.31	1.22	0.9	1.50	6	0.22	1.0	0.34
Rajasthan08	*P. cineraria*	3	3	11	5	0.88	3.46	5.7	1.23	77	6.91	17.0	15.38
Rajasthan09	*P. cineraria*	3	4	8	5	0.63	1.82	1.8	1.00	15	1.03	2.4	1.64
Sind09	*P. cineraria*	3	6	1	5	0.56	2.43	4.9	1.13	45	2.81	9.7	6.06
Sind10	*P. cineraria*	3	7	9	5	0.56	3.10	5.6	1.44	57	3.56	12.0	7.49
Sind12	*P. cineraria*	3	13	4	5	0.19	1.67	2.4	1.33	9	0.19	1.3	0.26
Uttar Pradesh3	*P. cineraria*	3	2	7	5	0.00					0.00		0.00
Yemen4	*P. cineraria*	3	1	12	5	0.63	2.10	3.2	1.25	22	1.51	3.8	2.63
Chile02	*P. chilensis*	4	12	4	2	0.25	2.23	2.5	1.00	20	0.56	0.0	0.00
NW Frontier1	*P. cineraria*	4	5	1	3	0.19	1.87	1.5	2.50	17	0.35	2.9	0.60
Pakistan1	*P. cineraria*	4	10	4	1	0.00					0.00		0.00
Pakistan2	*P. cineraria*	4	11	2	3	0.00					0.00		0.00
Punjab7	*P. cineraria*	4	8	1	2	0.13	2.85	2.7	1.50	26	0.36	4.3	0.59
Punjab8	*P. cineraria*	4	9	4	4	0.50	1.51	0.6	1.33	4	0.23	0.6	0.32
Rajasthan08	*P. cineraria*	4	3	2	1	0.00	0.00		0.00				
Rajasthan09	*P. cineraria*	4	4	3	1	0.19	2.13	2.7	1.00	15	0.31	2.4	0.51
Sind09	*P. cineraria*	4	6	4	3	0.50	1.23	0.3	1.00	1	0.06	0.1	0.07
Sind10	*P. cineraria*	4	7	3	2	0.06	1.00	0.0		0	0.00	0.0	0.00
Sind12	*P. cineraria*	4	13	3	3	0.44	1.29	0.8	1.50	5	0.26	0.8	0.41
Uttar Pradesh3	*P. cineraria*	4	2	1	1	0.13	1.20	0.9	3.00	4	0.05	0.5	0.06
Yemen4	*P. cineraria*	4	1	2	2	0.00					0.00		0.00

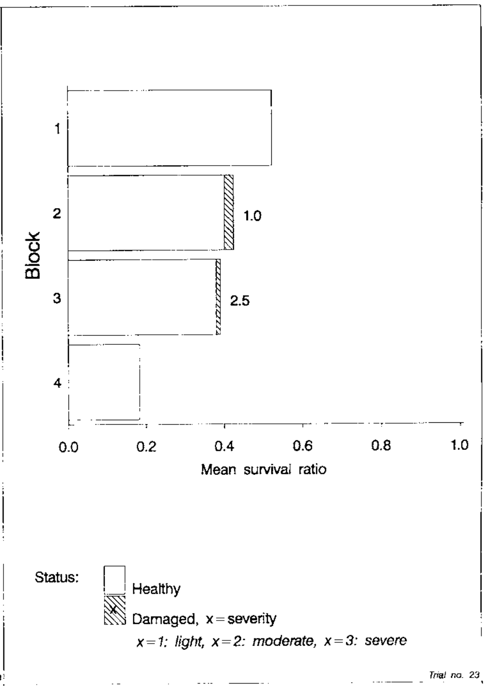
Annex 5. Graphical presentation of health data

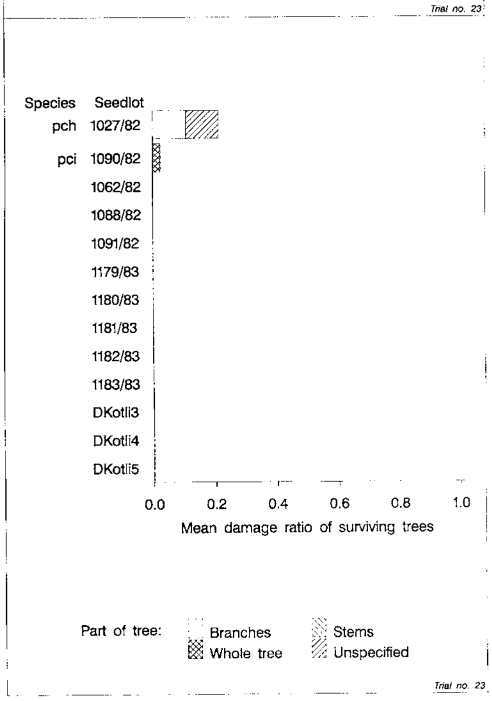
The health status of the trees were evaluated on a scale from 0 to 3, where 0 indicates no damage, and 1, 2 and 3 indicates light, moderate and severe damage, respectively. The health status code is named SCSEV in the diagrams on the following pages.

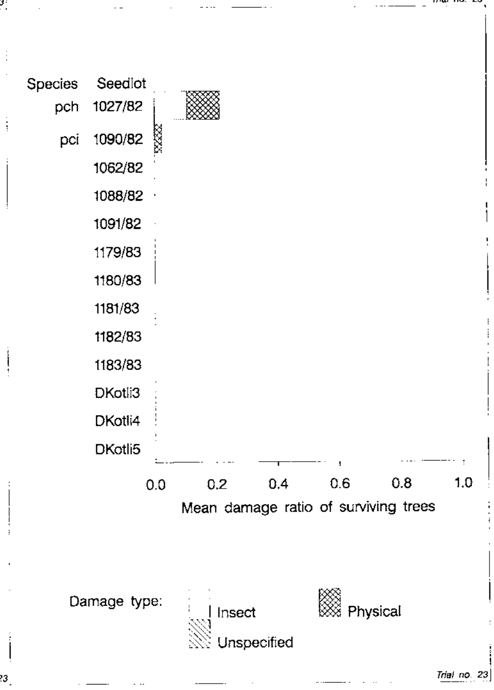
The diagrams present the mean survival ratios, the damage ratios of the surviving trees and the average damage scores for the damaged trees. They also indicate the distribution of the damage on the trees and the cause of the damage. The damage scores are presented according to plots, blocks and seedlots.

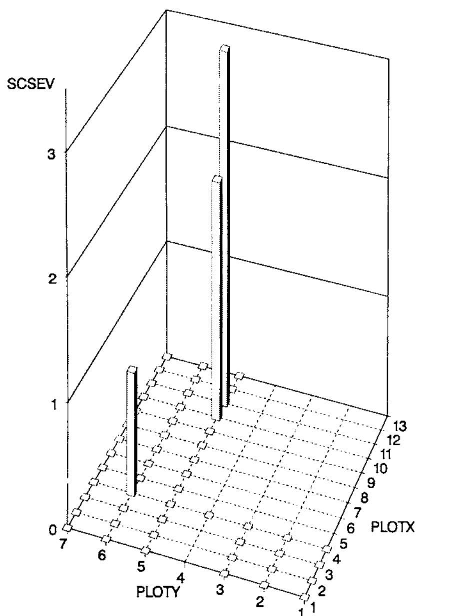
Please note that the seedlot codes correspond to the numbers given in annex 2.





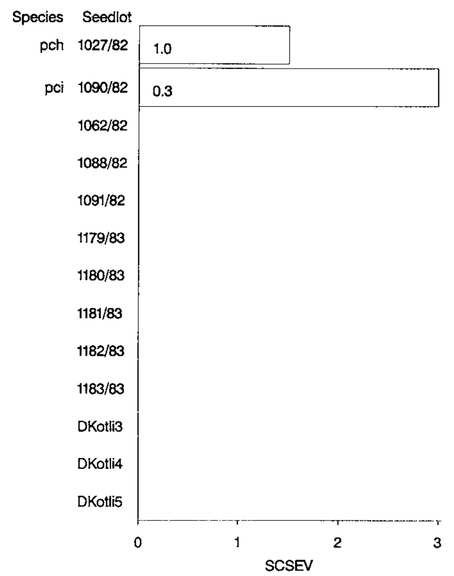






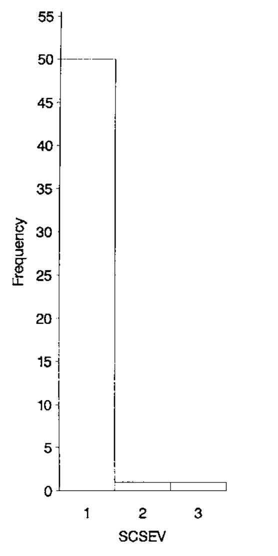
SCSEV = Health status code, severity of attack
Scatter of plot mean values

Trial no. 23



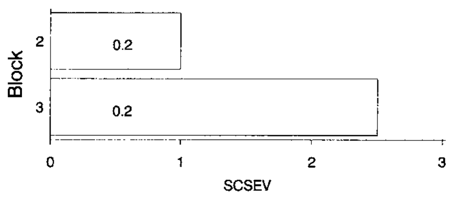
Mean SCSEV of seedlot with error bar line (+/− standard deviation of the mean) and the average number of assessed (living) trees per plot for each seedlot.

Trial no. 23



Frequency distribution of plot mean values

Trial no. 23



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. 23