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Evaluation of a species and provenance trial of *Prosopis* at Dori, Burkina Faso

Trial no. 9 in the arid zone series

by

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A well performing individual of *Prosopis chilensis* in the trial. Phot: Lars Graudal. DFSC. 1993.

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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 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 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 Centre National de Semences Forestières (CNSF) in Burkina Faso in collaboration with IBN-DLD (Institute for Forest and Nature Research, Wageningen), The Netherlands. The assessment team consisted of Traoré Adama, Sanogo-Moussa, Hama Hadsou, Hama Hamidou, Derra Hamado, Amadou Mamadou, Sambaré, all from CNSF, Agnete Thomsen (FAO) and Lars Graudal (DFSC).

The authors wish to acknowledge the help of the personnel at CNSF with the establishment, maintenance and assessment, and thank the personnel of DFSC for their help with the data management and preliminary analyses. Dr. agro. Axel Martin Jensen and Marcus Robbins, consultant to FAO, commented drafts of the manuscript.

Abstract

This report describes the results from a trial with twelve provenances of the genus *Prosopis*. The trial was established with a spacing of 4 x 4 metres at Dori, Burkina Faso in1988, and was measured at the age of 5 years in 1993. Six of the provenances were of the species *P. chilensis* and were all from Chile, whereas the species identity of the rest (one from Chile, five from Mexico) is not known.

There were highly significant differences between the provenances in all the analysed variables (survival, height, crown area and number of stems). Basal area was measured in only one block and could not be analysed. A multivariate analysis demonstrated that the provenances from Chile (including the one with unknown species identity) behaved in a similar way, and differently from the group of provenances with origin in Mexico. Provenances from Chile had a very low survival (10-20 %) in comparison to the Mexican provenances (45-70 %). On the other hand they had the largest heights and the smallest number of stems.

Résumé en français

Le présent rapport décrit les résultats obtenus d'un essai comparatif de douze (12) provenances de *Prosopis ssp*. Six (6) de ces provenances appartiennent à l'espèce *Prosopis chilensis* et sont toutes originaires du Chilie.

Pour les six (6) autres provenances, dont une est du Chilie et les cinq (5) autres de Mexique, l'identité exacte des espèces n'a pas pu être établie. L'essai a été mis en place en 1988 à Dori (Burkina Faso) suivant un écartement de 4 x 4 mètres. Les mensurations ont eu lieu en 1993, soit à cinq (5) d'âge de la plantation.

L'analyse révèle une importante différence significative entre les provenances pour touts les variables étudiées (taux de survie, hauteur, surface du houppier et nombre de tiges). La surface terrière a été mesurée dans un seul bloc et ne pouvait être analysée.

Une analyse multivariable a démontré que les provenances du Chilie (y incluse la provenances dont l'identité de l'espèce n'a pu être décrite) évoluent dans les mêmes proportions et se différencient du groupe des provenances issues du Mexique. Les provenances du Chilie ont un très faible taux de survie (10 à 20%) comparées aux mexicaines (45 à 70%). Par ailleurs, elles ont les plus grandes hauteurs et le plus faible nombre de tiges.

Contents

1. Introduction

This report describes the results from trial no. 9 in a large series of species and 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). It has therefore been suggested to test Neotropical species of the genus in similar zones (in particular the Sahel) in Africa. The current trial includes twelve provenances of the genus *Prosopis*, all of Chilean or Mexican origin. Five of the provenances are *P. chilensis* whereas the species identity of the rest is not known with certainty, partly because the taxonomy of *Prosopis* is still a matter of debate (cf. Ffolliott & Thames 1983).

2. Materials and methods

2.1 Site and establishment of the trial

The trial is located at Dori (14°02′N, 00°01′W) in Burkina Faso at an altitude of 275 m. The mean annual temperature is 28.8°C, and the annual average rainfall is approximately 400-600 mm, depending on the source of information (DFSC 1994). The dry period is about eight months. Further information is given in the assessment report (DFSC 1994) and summarised in Annex 1.

In order to facilitate the water infiltration the soil was scarified by sub-soiling with a bulldozer to a depth of 60 cm, and manual planting holes were prepared in June-July before planting. Seed was sown in April 1988, and the trial was established in August 1988. Beating up took place only in the first 4 weeks after establishment. The trial was weeded once a year.

2.2 Species and provenances

The trial includes 5 provenances of the species *Prosopis chilensis* and 7 *Prosopis* provenances whose exact botanical classification is not known (Table 1). The seven provenances will be referred to in the following as "unknown". All provenances of *P. chilensis* are from Chile, whereas the provenances of unknown species are all from Mexico, except for one that is from Chile. The Mexican provenances are all from the peninsula Baja California. For convenience, the provenances are given names relating to the origin. The original seedlot numbers can be found in Annex 1. One of the provenances, Mexico07, is a mixture of two seedlots of the same origin (collected in different years).

The original rainfall data supplied from the seed collectors in Mexico was smaller by a factor 100. However, a comparison with climatic data (FAO 1985) indicated that the data was much too small, and we believe that the difference to the original data is due to a scaling problem. Therefore the data for the Mexican provenances given in Table 1 is the original data multiplied by 100, which brings it within the range observed elsewhere in Baja California. Still the data should be considered with care.

Table 1. Species and provenances of *Prosopis* tested in trial no. 9 at Dori, Burkina Faso. Rainfall data was given by the institutions collecting the seed. See text for note on the Mexican provenances.

Provenance identification	Species	Seed collection site	Country of origin	Latitude	Longitude	Altitude (m)	Ann. rainfall (mm)	No. of mother trees
Chile02	*P. chilensis*	Rio Pama, Limari	Chile	31°09' S	71°04'W	.	250	26
Chile03	*P. chilensis*	C.A. Mt.Patria, Limari	Chile	30°39' S	71°58'W	.	175	25
Chile04	*P. chilensis*	Combarbala, Cogoti	Chile	31°00' S	71°05'W	650	161.6	2
Chile05	*P. chilensis*	Lampa	Chile	33°17'S	71°53'W	500	306	5
Chile07	*P. chilensis*	Monte Patria, Aqua Chica	Chile	30°42'S	70°57'W	475	150	7
Chile11	*Prosopis sp*	Colina, Chacabuca	Chile	33°02'S	70°45'W	840	306	15
Mexico07	*Prosopis sp*	Las Posas	Mexico	23°09'N	110°09'W		82	.
Mexico08	*Prosopis sp*	El Triunfo, La Paz (Cabo San Lucas)	Mexico	23°50'N	110°12'W	.	300	25
Mexico09	*Prosopis sp*	San Ignacio	Mexico	27°15'N	112°52'W	.	100	25
Mexico11	*Prosopis sp*	Rancho S. Juan (Loreto Bcs)	Mexico	25°48'N	111°15'W	.	47	25
Mexico12	*Prosopis sp*	El Triunfo, La Paz Bcs	Mexico	23°50' N	110°12'W	.	341	25
Mexico13	*Prosopis sp*	San Ignacio Bcs	Mexico	27°15' N	112°52'W	.	62	25

2.3 The experimental design

The trial is a randomised complete block design with 6 blocks. Within each block, each provenance is represented by 25 trees in a plot, planted in a square of 5 × 5 trees with a spacing of 4 × 4 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 March 1993 CNSF, IRBET, FAO and DFSC undertook a joint assessment. The assessment included the following characters: survival, vertical height, number of stems at 0.3 m, crown diameter and health. The diameter at 0.3 m of the three largest stems was measured only in block 5 and is thus not replicated. A detailed description of the assessment methods is given by DFSC (Graudal *et al.* 2003), and the raw data from the assessment is documented in DFSC 1994. The plot data set on which the statistical analyses in this report are performed is shown in Annex 4.

3. Statistical analyses

3.1 Variables

In the report the four variables: survival, vertical height, crown area and number of stems at 0.3 m are analysed. Since the diameters were measured in only one of the blocks, no analysis of basal area is made. However, the results from the measurements are presented. Survival was analysed as the rate of surviving trees to the total number of trees per plot, whereas height, crown area and number of stems were analysed as the mean of surviving trees for each plot.

A number of health characters were evaluated, and it appeared that more than half of the surviving trees in block 5 were damaged, especially by insects. However, since there was little or no damage to the trees in the other blocks, and there were no apparent differences in the proportion of damaged trees between the provenances, these characters are not analysed in the present report. Instead a graphical presentation of the health data is given in Annex 5.

A special problem with the assessment data is that for trees with heights below 1 m, no assessment of diameter, number of stems and crown diameter was made. Out of the total 1793 observations (trees), this occurred for 57 trees or 4% of the population. Since the omission of this data will produce biased results and lead to an overestimation 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 value has been set for this variable. In any case, the estimates of these variables will be slightly biased.

3.2 Statistical model and estimates

For some reason none of the trees in block 3 had survived. Since this would have a profound influence on the tests and estimates of the models, all observations from this block were excluded from the analysis, and the analyses are based on measurements from the five remaining blocks only. The results thus rely on the assumption that the poor survival in block 3 is an artefact, perhaps due to problems in the establishment phase, or that the conditions in this block are extremely adverse and not representative of the site. No explanation of the poor survival is given in the assessment report (DFSC 1994).The statistical software package used was the Statistical Analysis System (SAS 1988a, 1988b, 1991, Littell *et al.* 1996). A total of five tests were made for each variable. The first test was a test for differences between all provenances, analysed according to the model:

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

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

However, in no case were the co-variates significant, and will not be mentioned further in the report.

Since the provenances from Chile appeared to behave differently from the provenances from Mexico, a formal test was performed to confirm this tendency. This was done according to a test in which the provenances were nested within the country of origin:

$$X_{cjk} = \mu + country_c + provenance(country)_{cj} + block_k + \varepsilon_{cjk}$$

where X_{ijk} is the value of the trait in question (e.g. height) in plot ijk, μ is the grand mean, $country_c$ is the fixed effect of country c, $provenance(country)_{cj}$ is the random effect of provenance number j nested within country c, $block_k$ is the random effect of block k in the trial, and ε_{cjk} is the residual of observation cjk which is assumed to follow the normal distribution $N(0, \sigma_e^2)$. In the test of the country effect the degrees of freedom were calculated by using the Satterthwaite approximation.

The third and fourth tests were tests of provenance differences within *P. chilensis* and the group of unknown species, respectively. The fifth test was another test of provenance differences within the unknown species but excluding the provenance Chile11, which means that the provenances tested were only from Mexico. The three tests were all performed according to the first model.

Standard graphical methods and calculated standard statistics were applied to test model assumptions of independence, normality and variance homogeneity (Snedecor & Cochran 1980, Draper & Smith 1981, Ræbild *et al.* 2002). Weighting of data with the inverse of the variance for the seedlots was used to obtain normality of the residuals where the seedlots appeared to have different variances. Where large provenances tended to have larger variances (crown area) than small provenances, a square root transformation was used to stabilise variance (ibid.; Affi & Clark 1996).

The P-values from the tests of provenance differences were corrected for the effect of multiple comparisons by the sequential tablewide Bonferroni method (Holm 1979). The tests were ranked according to their P values. 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 (Kjaer & Siegismund 1996). In this case the number of tests was set to four, thus equalling the number of variables analysed. The significance levels are indicated by (*) (10%), * (5%), ** (1%), *** (1 ‰) and N.S. (not significant).

Two sets of estimates are presented: The least square means (LS-means) and the Best Linear Unbiased Predictors (BLUPs) (White & Hodge 1989). Since it is assumed in the calculation of BLUPs that the provenances represent a random selection, it is usually presented for the species separately. As there is uncertainty on the species identification of the unknown group of provenances, no BLUP estimates are shown for these provenances. 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.

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).

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 results 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 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.

Statistical analysis

When analysing the total, untransformed data set, the residuals seemed to be larger for *P. chilensis* than for the group of unknown species. An arcsine transformation was attempted but did not solve the problem, and instead a weight statement on the untransformed data was used. Similarly it proved necessary to use weight statements in the analysis of provenance differences within *P. chilensis,* but in the analyses of the unknown provenances the raw data gave a satisfactory distribution of the residuals, and no weight statements were used.

Note that the survival in block 3 was zero for all provenances, and that data from this block are not included in the analyses or presentation.

Results

The average survival for the provenances varied between 10 and 70 % (Fig. 1). According to the analysis of variance the differences were highly significant, and a large proportion of this variation could be explained by differences in origin, provenances from Mexico having a much higher survival than provenances from Chile (Table 2, Fig. 1). Within the two groups of provenances, the differences were significant or almost significant. However, in *P. chilensis* the close-to-significance disappeared when accounting for multiple comparisons, and in the group of unknown species the significance disappeared when excluding the provenance Chile11, leaving no significant differences between the provenances from Mexico.

It appears from the predicted values in Fig. 2 that there are only modest gains of 2-3 % better survival by choosing the best provenance of *P. chilensis* in comparison to the mean value. The best provenance of this species was Chile04 with a survival of 20 %, whereas the overall best provenances were the unknown provenances Mexico08 and Mexico13.

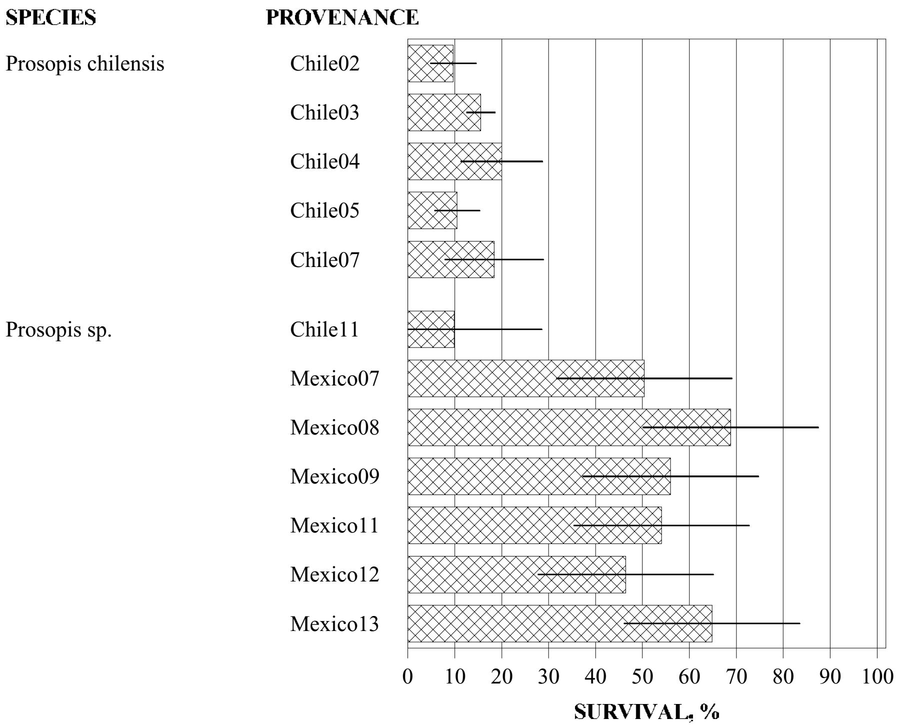

Figure 1. Survival in the *Prosopis* species and provenance trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Values presented are least square means with 95 % confidence limits. Before analysis the values were weighted with the reciprocal of the variance of the provenances, and the confidence intervals are therefore of uneven lengths.

Table 2. Results from analysis of variance of species and provenance differences of survival in trial 9.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of differences between all provenances					
Provenance	11; 44	25.3	30.4	<0.0001	***
Block	4; 44	6.44	7.8	<0.0001	
Error	44	0.830			
Test of differences between provenances from Mexico vs. provenances from Chile					
Country	1; 29.8	92.8	78.5	<0.0001	***
Provenance(country)	9; 40	2.07	2.5	0.02	
Block	4; 40	6.30	7.6	<0.0001	
Error	40	0.834			
Test of differences between provenances of P. chilensis					
Provenance	4; 16	3.04	2.5	0.08	n.s.
Block	4; 16	14.6	12.1	<0.0001	
Error	16	1 .21			
Test of differences between provenances of the unknown species					
Provenance	6; 24	1874	4.6	0.003	**
Block	4; 24	1873	4.6	0.007	
Error	24	410			
Test of differences between provenances of the unknown species, excluding Chile11					
Provenance	5; 20	365	0.8	0.58	n.s.
Block	4; 20	1933	4.1	0.01	
Error	20	469			

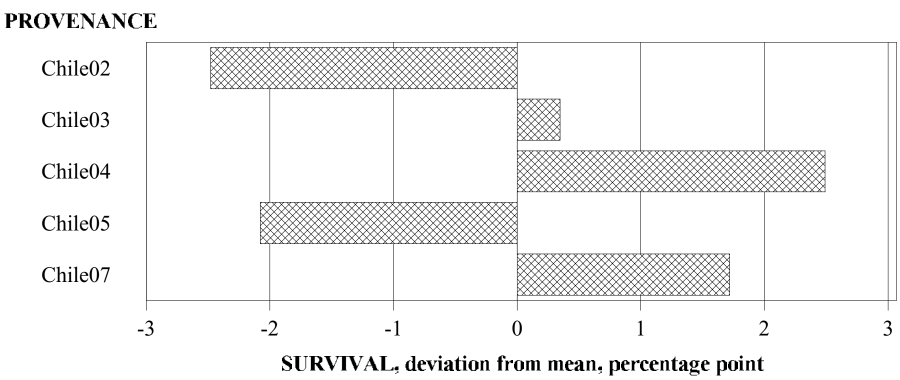

Figure 2. Best linear unbiased predictors (BLUPs) for survival in the *P. chilensis* provenances in the trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Values presented are deviations from the mean value in percentage point.

4.2 Height

Height is usually considered an important variable in the evaluation of species and provenances. 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 interpretation need not always be true, however: cases have been observed where the tallest provenances are suddenly affected by stress with a subsequent die-off of the trees.

Statistical analysis

Since there were signs of variance heterogeneity in the analysis of all provenances, a weight statement was applied. This was not necessary in the analysis of differences within the two groups of provenances.

Results

The vertical height of the provenances ranged between 1.6 and 2.7 m (Fig. 3). There were highly significant differences between the provenances, which was in part explained by differences in origin – the data indicated that the provenances from Chile were taller than the provenances from Mexico (Table 3). Note that in this variable Chile11 seems to differ from the other provenances from Chile, being more alike the other provenances in the group of unknown provenances.

When testing differences between the provenances within the groups, the P-values were far from significant. Therefore there are only small gains by choosing one provenance instead of another (when choosing within the group), which is also seen by the fact that the differences between provenances were too small to allow calculation of BLUP estimates for *P. chilensis.* This is the reason why no BLUP estimates are presented.

Table 3. Results from analysis of variance of species and provenance differences of vertical height in trial 9.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of differences between all provenances					
Provenance(species)	11; 36	5.3	5.5	<0.0001	***
Block	4; 36	24.4	25.3	<0.0001	
Error	36	1.0			
Test of differences between provenances from Mexico vs. provenances from Chile					
Country	1; 24.9	7.0	4.1	0.05	(*)
Provenance	10; 36	3.5	3.7	0.002	
Block	4; 36	24.4	25.3	<0.0001	
Error	36	1.0			
Test of differences between provenances of P. chilensis					
Provenance	4; 12	0.29	0.6	0.65	n.s.
Block	4; 12	1.10	2.4	0.11	
Error	12	0.46			
Test of differences between provenances of the unknown species					
Provenance	6; 20	0.119	1.0	0.43	n.s.
Block	4; 20	0.574	5.0	0.01	
Error	20	0.115			
Test of differences between provenances of the unknown species, excluding Chile11					
Provenance	5; 17	0.0846	0.8	0.57	n.s.
Block	4; 17	0.453	4.2	0.01	
Error	17	0.107			

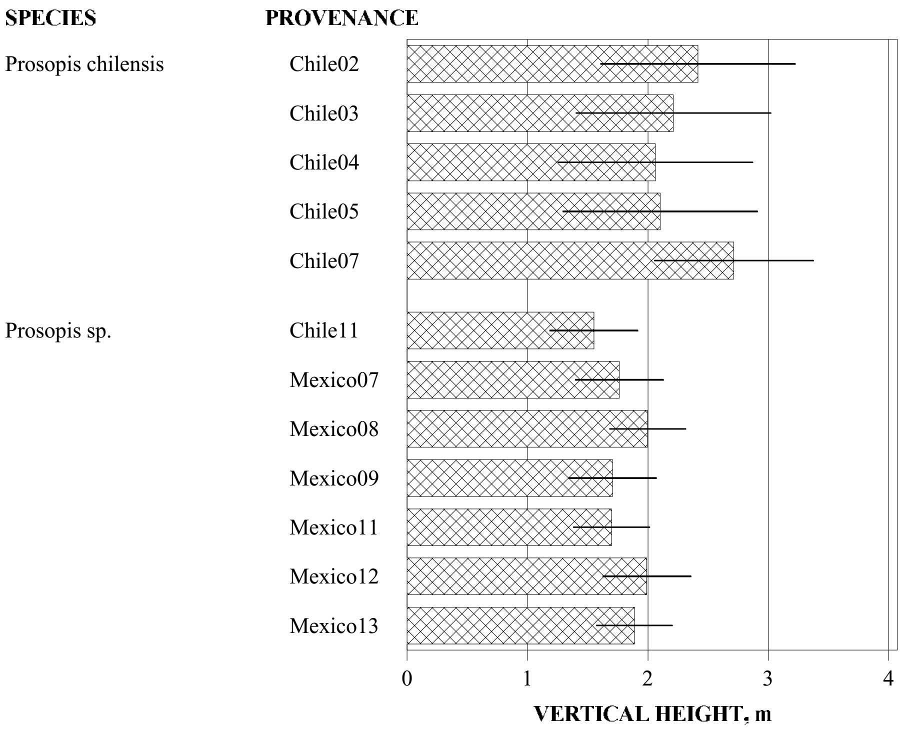

Figure 3. Vertical height in the *Prosopis* species and provenance trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Values presented are least square means with 95 % confidence limits.

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

Since the initial analysis of all provenances demonstrated that there was variance heterogeneity in the data, the data were transformed with the square root to obtain residuals that were in accordance with the assumptions of the model. This was done throughout the analyses.

Results

The average crown area for the provenances varied between 1.9 m^2 $tree^{-1}$ for Chile11 and 8.9 m^2 $tree^{-1}$ for Mexico08. Due to the square root transformation, the back-transformed least square means presented in Fig. 4 are slightly lower. Comparing with the growth space of 16 m^2 $tree^{-1}$ one can see that even in the largest provenances the canopy was still not closing.

There were highly significant differences between the provenances of the trial (Table 4). There were no significant differences between the Mexico and Chile provenances. In *P. chilensis* the variation within provenances was too large to make the differences significant, but the BLUP-estimates nevertheless indicated that Chile07 had a crown area 23 % larger than the average (Fig. 5). In the group of provenances of unknown species, there were highly significant differences, with Chile11 and Mexico08 being the low and high extremes respectively. The differences between this group of provenances was significant without Chile11, but at a lower level (Table 4).

Table 4. Results from analysis of variance of species and provenance differences of crown area in trial 9.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of differences between all provenances					
Provenance(species)	11; 36	1.01	3.5	0.002	**
Block	4; 36	2.40	8.5	<0.0001	
Error	36	0.28			
Test of differences between provenances from Mexico vs. provenances from Chile					
Country	1; 10.1	2.73	3.1	0.11	n.s.
Provenance(country)	10; 36	0.88	3.1	0.006	
Block	4; 36	2.40	8.5	<0.0001	
Error	36	0.28			
Test of differences between provenances of P. chilensis					
Provenance	4; 12	0.68	1.4	0.29	n.s.
Block	4; 12	1.22	2.5	0.10	
Error	12	0.48			
Test of differences between provenances of the unknown species					
Provenance	6; 20	1.35	6.7	0.0005	**
Block	4; 20	1.28	6.4	0.002	
Error	20	0.20			
Test of differences between provenances of the unknown species, excluding Chile11					
Provenance	5; 17	0.61	3.3	0.03	n.s.
Block	4; 17	0.90	4.8	0.008	
Error	17	0.18			

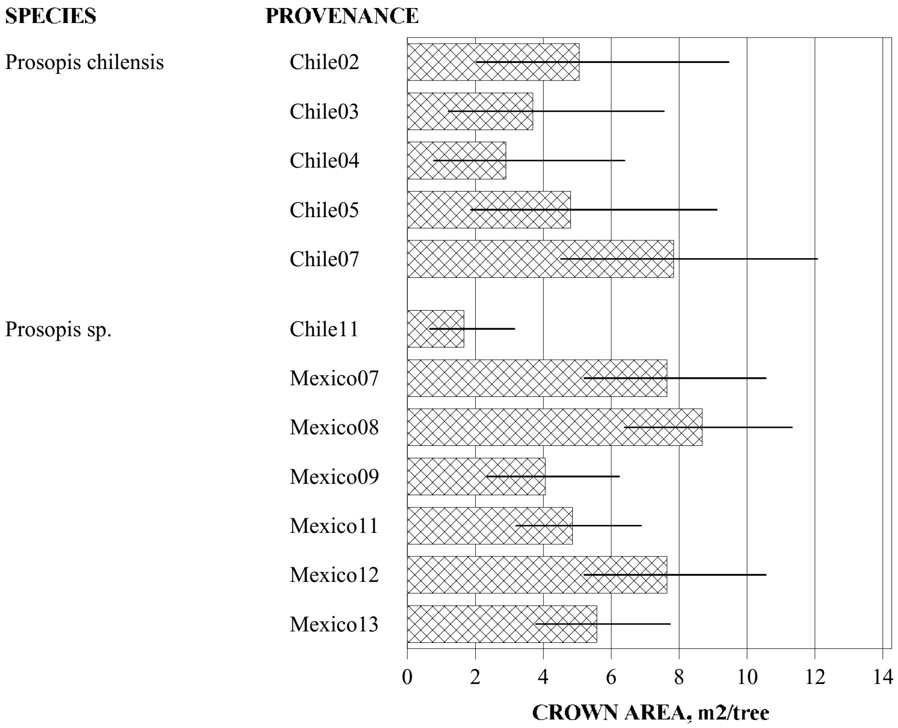

Figure 4. Crown area in the *Prosopis* species and provenance trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Before analysis, the data were transformed with the square root. Values presented are back-transformed least square means with 95 % confidence limits. Due to the transformation, the upper and lower confidence intervals have different lengths.

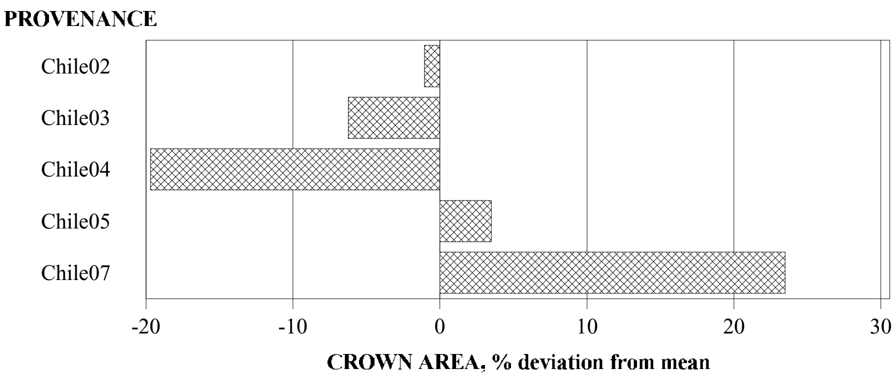

Figure 5. Best linear unbiased predictors (BLUPs) for crown area in the *P. chilensis* provenances in the trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.4 Number of stems

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

Statistical analysis

The analyses were straightforward, and no transformations were used.

It should be noted that trees below 1 m were not assessed, which introduces a bias in the analysis. It is difficult to extrapolate the number of stems for such small trees from the larger trees, and the small trees have been omitted from the analysis. Therefore the estimates presented do not represent values for all trees, but only for trees above 1 m height. The trees that were not assessed correspond to 4% of the total.

Results

The average number of stems varied from 1.8 (Chile02) to 5.8 (Mexico08). There were significant differences between the provenances, which could mainly be ascribed to differences in geographical origin, provenances from Chile having a smaller number of stems than provenances from Mexico (Fig. 6, Table 5). The differences between provenances within the two groups were not significant. However, the BLUP-estimates indicated that the number of stems could be increased or decreased by 20 % compared to the average by choosing the provenances Chile07 and Chile02, respectively (Fig. 7).

Table 5. Results from analysis of variance of species and provenance differences of number of stems in trial 9.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of differences between all provenances					
Provenance(species)	11; 35	4.04	3.0	0.006	**
Block	4; 35	2.35	1.8	0.16	
Error	35	1.33			
Test of differences between provenances from Mexico vs. provenances from Chile					
Country	1; 10.6	5.41	8.9	0.01	*
Provenance	3; 12	0.400	0.4	0.77	
Block	4; 12	1.11	1.0	0.43	
Error	12	1.07			
Test of differences between provenances of P. chilensis					
Provenance	4; 12	2.63	1.9	0.18	n.s.
Block	4; 12	0.319	0.2	0.92	
Error	12	1.39			
Test of differences between provenances of the unknown species					
Provenance	6; 19	1.83	1.4	0.27	n.s.
Block	4; 19	3.23	2.4	0.08	
Error	19	1.32			
Test of differences between provenances of the unknown species, excluding Chile11					
Provenance	5; 17	0.925	0.6	0.67	n.s.
Block	4; 17	2.89	2.0	0.14	
Error	17	1.44			

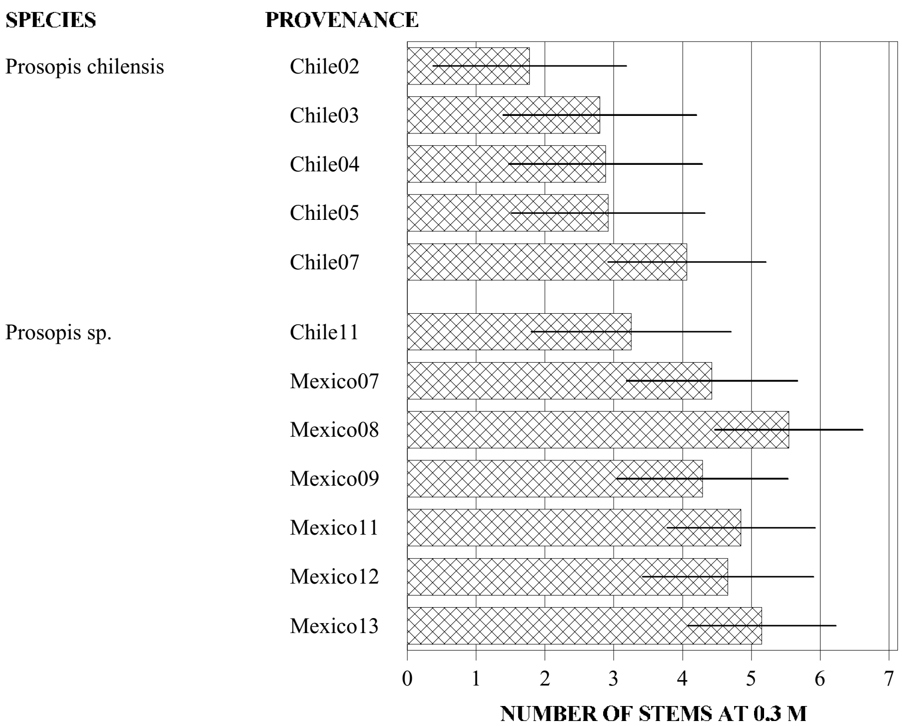

Figure 6. Number of stems in the *Prosopis* species and provenance trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Values presented are least square means with 95 % confidence limits.

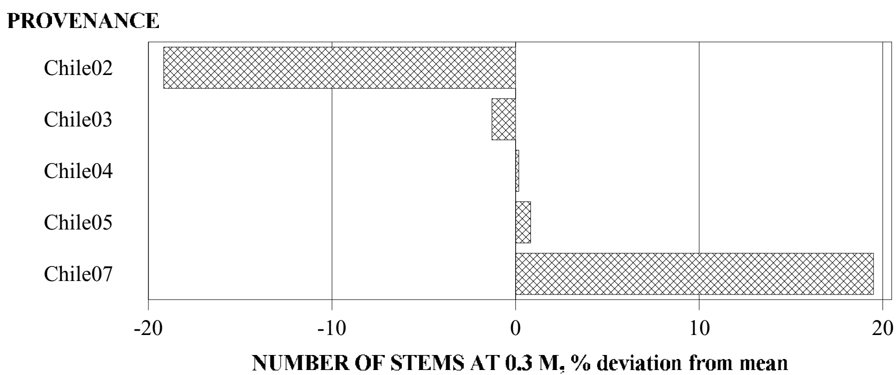

Figure 7. Best linear unbiased predictors (BLUPs) for number of stems in the *P. chilensis* provenances in the trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.5 Basal area of the mean tree

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

Statistical analysis

No statistical analyses were made, because the diameter was measured in only one block (no. 5). One may wonder if block 5 is a fair representative of the trial, since insects especially damaged this block (see Annex 5). However, the height data indicate that the block falls close to the average for the trial. The average range for height of the blocks was from 1.6 to 2.6 m with a mean value of 2.0 m. The average height for block 5 was 2.2 m, a little above the average. Of course, the basal area distribution could be different, and results should be interpreted only as an indication of the range of basal areas.

Results

The basal areas of the mean tree varied from only 6 cm^2 in Chile11 to 92 cm^2 in Chile05 (Fig. 8). Note that due to the poor survival, the values of especially *P. chilensis* are based on very few observations, the extreme being only one tree in Chile05. It seemed that *P. chilensis* had larger basal areas of the mean tree than the group of provenances from the unknown species. An analysis of variance with group as the only effect demonstrated that there were significant differences between the two groups of provenances (F=6.7, P=0.03, analysis not shown), even though the significance would disappear if the values were corrected for multiple comparisons. Differences between the countries were not significant (analysis not shown).

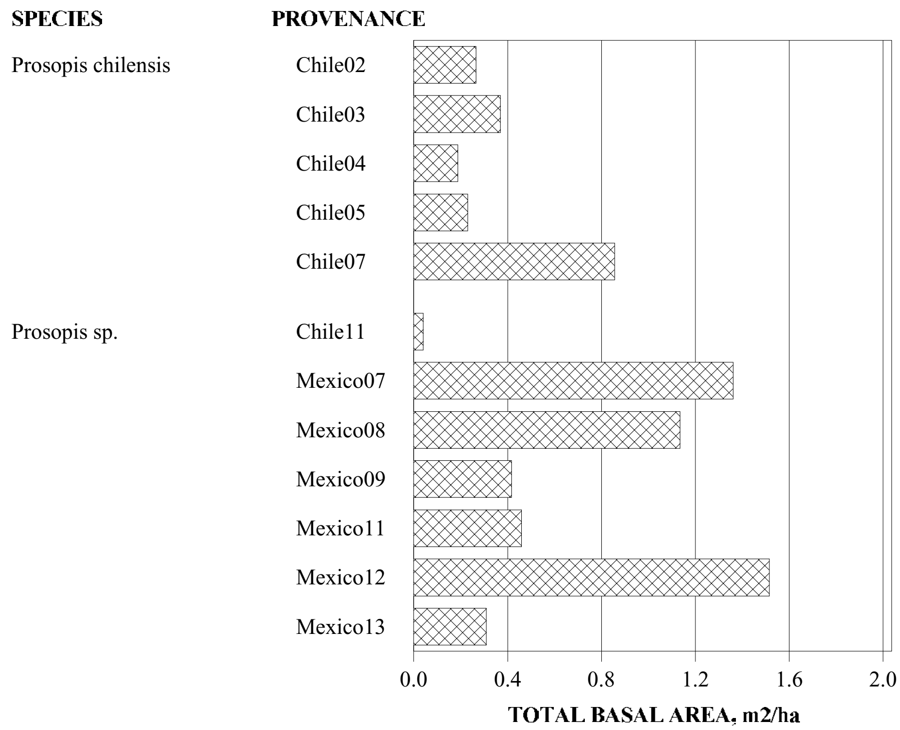

Figure 8. The basal area of the mean tree in the block 5 of the *Prosopis* species and provenance trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Values presented are simple averages.

4.6 Total basal area

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

Statistical analysis

Again no statistical analyses were made because only block 5 was measured, meaning that there are no replicates. See the previous section for considerations on the representativeness of block 5.

Results

The total basal areas varied from 0.8 to 1.5 m^2 ha^{-1}, corresponding to an average annual increment of approximately 0.3 m^2 ha^{-1} for the largest provenance (Mexico12) (Fig. 9). There were no significant differences between the two groups of provenances (F=1.7, P=0.22, analysis not shown). A test of the differences between the two countries represented demonstrated that provenances from Chile could have significantly smaller basal area than the provenances from Mexico (F=4.9, P=0.05, analysis not shown). The largest provenances were Mexico07, Mexico08 and Mexico12 of the unknown species, and Chile07 of *P. chilensis*.

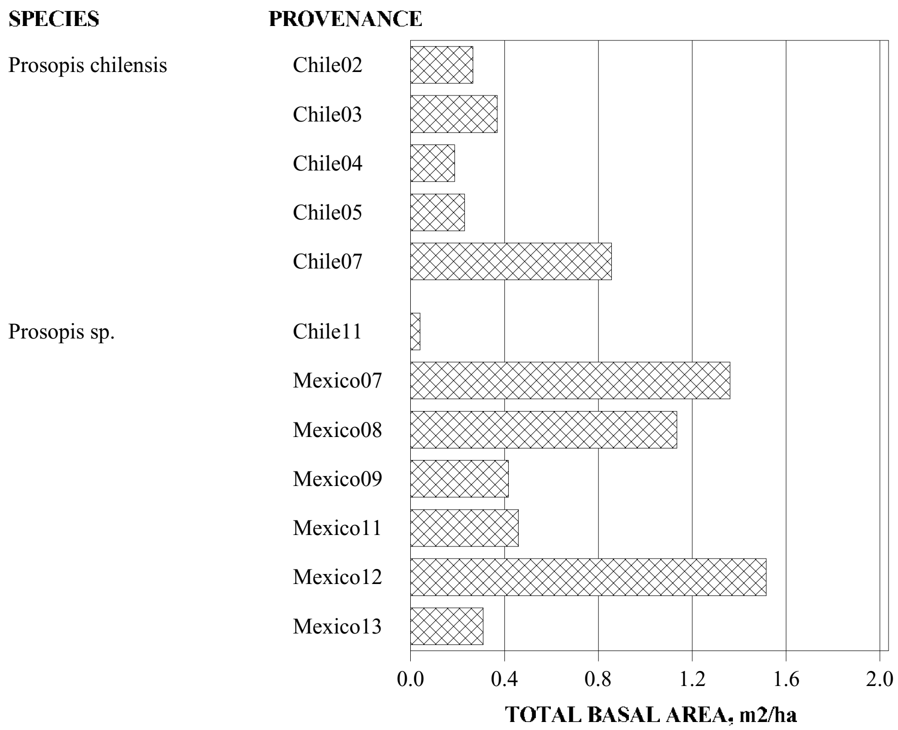

Figure 9. Total basal area for the provenances in block 5 in the *Prosopis* species and provenances trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). Values presented are simple means.

4.7 Multivariate analysis

The multivariate analysis included the four variables analysed in the univariate analyses. Crown area was again transformed with the square root. The multivariate part included an analysis of all provenances and an analysis of the *P. chilensis* provenances only.

All provenances

The first canonical variate was highly significant, whereas the second was only significant at the 5 % level (Table 6). In total, the two variates accounted for 94 % of the variation. The differences between the provenances were highly significant (P-value for Wilk‘s lambda and Pillai‘s trace both below 0.0001).

Figure 10 gives the scores of the canonical variates for the first and the second canonical variate together with the mean values for the provenances and their approximate 95 % confidence regions. In the diagram, provenances that are far apart are interpreted as being very different, and if the confidence regions do not overlap, it is likely that the two provenances in reality have different properties.

It seems that there is a clear geographical clustering between the provenances – the provenances from Chile form one group whereas the provenances from Mexico form another. Note that Chile11, which belongs to the group with unknown species identity, is located at the centre of the *P. chilensis* provenances, i.e. together with the other provenances from Chile.

Prosopis chilensis

The provenances of *P. chilensis* were subject to another analysis to investigate whether there were true differences amongst the provenances. However, according to the multivariate tests there were no significant differences (P-value for Wilk‘s lambda=0.45, P-value for Pillai‘s trace=0.38), and none of the canonical variates were significant (data not shown).

Table 6. Results from the canonical variate analyses for the first two canonical variates in trial 9.

Canonical variate no.	**1**	**2**				
Proportion of variation accounted for	0.82	0.12				
Significance, P-value	<0.0001	0.02				
	Raw canonical Coefficients		**Standardised canonical coefficients**		**Canonical directions**	
Canonical variate no.	**1**	**2**	**1**	**2**	**1**	**2**
Survival	0.03	-0.06	0.9	-1.6	184	-430
Height	-3.8	-2.1	-2.4	-1.3	-32	-19
Crown area	3.6	3.1	2.7	2.3	-30	-19
Number of stems	0.02	0.10	0.03	0.15	-2.0	-14

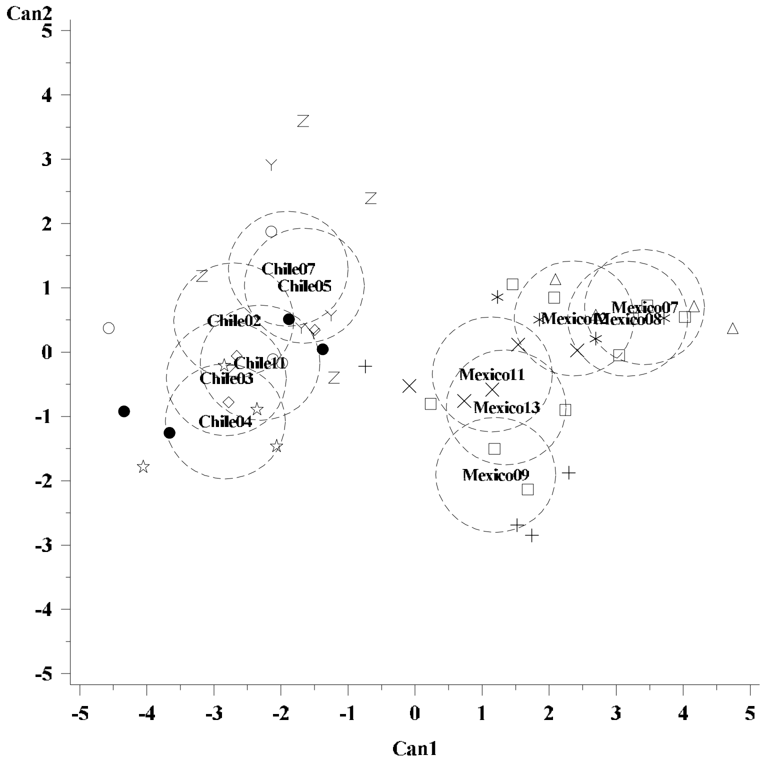

Figure 10. Score plot of the first and the second canonical variate from the canonical variate analysis for provenances in the *Prosopis* provenance trial at Dori, Burkina Faso (Trial no. 9 in the arid zone series). The variables survival, height, crown area and number of stems were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region. The provenances Chile02 to Chile07 are *P. chilensis*, whereas the species identifications of the provenances from Mexico and of Chile11 are not known.

5. Discussion and conclusions

Productivity

Two other trials in the arid zone series are located at Dori. No. 7 is a combined species and provenance trial with provenances of *Acacia nilotica, A. seyal* and *A. tortilis*, and no. 8 is a provenance trial with *A. seyal.* These trials were also established in 1988 and may serve as a basis of comparison for this trial. The tallest provenance in this trial, Chile07 of *P. chilensis* with a height of 2.7 m, is taller than any of the provenances in the other trials, but still comparable to the provenances of *A. seyal* which obtained heights of 2.6 m. *A. nilotica* obtained heights of 2.2 m, whereas *A. tortilis* and *A. senegal* had maximum height of about 1.6 m. The group of unknown provenances in this trial had heights of 1.5 to 2.0 m and are thus in the intermediate range.

Since diameter was only measured in one of the blocks in this trial, it is difficult to compare the productivity of the trials. Acknowledging that there is a great deal of uncertainty associated with the basal areas, it still seems that the growth of the best of the unknown provenances was comparable to that in the other trials. Mexico12 in block 5 had an annual growth rate in the total basal area of 0.3 m^2 ha^{-1}, which is the same as the best provenances of *A. nilotica* and *A. seyal*, but slightly more than *A. senegal* and *A. tortilis*. The provenances of *P. chilensis* have a production way below the other species, which is mainly due to a poor survival (see below).

Provenance differences

It was clear from the trial that the provenances from Chile all had a very poor survival (all below 20 %), and that the provenances from Mexico were much better in this respect. On the other hand it appeared that the surviving trees from Chile (at least those that with certainty belong to *P. chilensis*) had an impressive growth potential, being higher than the provenances from Mexico and having larger basal areas of the mean trees. However, due to the poor survival the total basal area was small compared to the provenances from Mexico.

Unpublished data by CNSF show that most trees were alive in December 1988, after the first rainy season. In June 1989, one year after planting and after the first dry season the mortality was still low, but at an assessment in December the same year many trees had died off. At the assessment in November 1992 only a fraction of the trees were left. This sequence of death of the trees suggests two things. First, the trees were not dying because of problems in the establishment phase, since they were able to survive during the first dry season. Second, the high mortality during the rainy season indicates that the trees were maladapted to periods with humid climate. Possible reasons could include attacks by fungi or poor tolerance to high levels of humidity in the soil. At an inspection of the trial in April 2000, virtually no trees were left. This could, however, also be due to the fact that logging was taking place on the trials at the site.

In the multivariate analysis, the provenances from Chile were clearly separated from the provenances from the Mexican provenances. Chile11, the only provenance with unknown identity, was situated in the middle of the group of *P. chilensis* provenances, and one could hypothesise that Chile11 is actually of this species.

If the provenance Chile11 was excluded from the group with unknown species identification, the only significant differences between the provenances of this group were found in the crown area. Assuming that the remaining provenances are from the same species, it is noteworthy that the three provenances having the largest crown areas, Mexico07, Mexico08 and Mexico12, all are from the same small area within southern Baja California. These three provenances also have the largest basal area of the mean tree and total basal area, and their growth seems to be comparable to other species tested in trials at the same site (see above). However, it will be necessary to make an identification of the species before testing the provenances on a larger scale. Also it would be interesting to test a wider range of provenances.

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Annex 1. Description of the trial (from DFSC 1994)

Name of site:	Dori, Burkina Faso Latitude: 14°02'N Longitude: 00°01'W Altitude: 275 m
Meteorological stations:	Dori (14°02'N, 00°03'W, 277 m (FAO 1984))
Rainfall:	Annual mean (period): 563 mm (FAO 1984) 410.1 (1971-80 (DSM)) Yearly registrations (DSM): 1981: 457.7 1982: 308.8 1983: 322 1984: 226.5
Rainy season:	June-September (FAO 1984) Type: Normal with dry period (FAO 1984)
Dry months/year:	No. of dry months (<50 mm): 8 No. of dry periods: 1
Temperature (°C (FAO 1984)):	Annual mean: 28.8 Coldest month: 13.1 (mean minimum) Hottest month: 41.5 (mean maximum)
Wind:	Speed at 2 m: 2.2 m/s (FAO 1984)
Topography:	Flat
Soil:	Type: Sandy, some clay in depth Depth: Deep (> 1 m)
Climatic/agroecological zone:	Semi-arid, Sahelian zone
Dominant natural vegetation:	Shrub/woody savanna (Acacia raddiana, Acacia albida, Acacia seyal
Koeppen classification:	BSh

Annex 2. Species and provenances of Prosopis tested in trial no. 9 at Dori, Burkina Faso

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

Seedlot numbers				**Provenance information**						
Provenance identification	DFSC	Plot	Species code	Provenance name	Country of origin	Latitude	Longitude	Altitude (m)	Ann. rain-fall (mm)	No. of mother trees
Chile02	1027/82	9	P. chilensis	Rio Pama, Limari	Chile	31°09' S	71°04'W	.	250	26
Chile03	1028/82	10	P. chilensis	C.A. Mt.Patria, Limari	Chile	30°39' S	71°58'W	.	175	25
Chile04	1131/83	11	P. chilensis	Combarbala, Cogoti	Chile	31°00' S	71°05'W	650	161.6	2
Chile05	1161/83	12	P. chilensis	Lampa	Chile	33°17'S	71°53'W	500	306	5
Chile07	1420/84	13	P. chilensis	Monte Patria, Aqua Chica	Chile	30°42'S	70°57'W	475	150	7
Chile11	1455/84	8	Prosopis sp.	Colina, Chacabuca	Chile	33°02'S	70°45'W	840	306	15
Mexico07	1279 and 1475/84	1	Prosopis sp.	Las Posas	Mexico	23°09'N	110°09'W		82	.
Mexico08	1280/84	3	Prosopis sp.	El Triunfo, La Paz (Cabo San Lucas)	Mexico	23°50'N	110°12'W	.	300	25
Mexico09	1281/84	4	Prosopis sp.	San Ignacio	Mexico	27°15'N	112°52'W	.	100	25
Mexico11	1476/84	5	Prosopis sp.	Rancho S. Juan (Loreto Bcs)	Mexico	25°48'N	101°15'W	.	47	25
Mexico12	1478/84	6	Prosopis sp.	El Triunfo, La Paz Bcs	Mexico	23°50' N	110°12'W	.	341	25
Mexico13	1479/84	7	Prosopis sp.	San Ignacio Bcs	Mexico	27°15' N	112°52'W	.	62	25

Annex 3. Layout of the trial

The numbers correspond to the seedlots given in Annex 2.

N

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

Individual tree positions in each plot:

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

Annex 4. Plot data set, used for the analyses

Block	Plot	Plotx	Ploty	Species	Provenance	Survival	Height	Crown area	Number of stems	Basal area, mean tree	Total basal area
						Proportion	m	m^2	no. $tree^{-1}$	cm^2 $tree^{-1}$	tons ha^{-1}
1	1	1	5	*Prosopis sp.*	Mexico07	0.76	1.83	9.89	4.84		
1	9	1	6	*P. chilensis*	Chile02	0.12	2.77	9.14	3.33		
1	4	1	7	*Prosopis sp.*	Mexico09	0.92	2.12	7.72			
1	5	1	8	*Prosopis sp.*	Mexico11	0.56	1.46	6.17	4.70		
1	3	2	5	*Prosopis sp.*	Mexico08	0.72	2.02	10.18	5.29		
1	13	2	6	*P. chilensis*	Chile07	0.04	3.30	14.52	3.00		
1	10	2	7	*P. chilensis*	Chile03	0.16	1.68	2.59	1.33		
1	7	2	8	*Prosopis sp.*	Mexico13	0.80	1.55	5.23	4.59		
1	12	3	5	*P. chilensis*	Chile05	0.16	1.20	4.73	5.00		
1	6	3	6	*Prosopis sp.*	Mexico12	0.72	2.21	10.14	4.33		
1	8	3	7	*Prosopis sp.*	Chile11	0.21	2.12	4.38	4.00		
1	11	3	8	*P. chilensis*	Chile04	0.36	2.86	5.52	3.33		
2	13	4	5	*P. chilensis*	Chile07	0.12	3.13	10.54	3.33		
2	7	4	6	*Prosopis sp.*	Mexico13	0.72	2.03	7.64	4.82		
2	12	4	7	*P. chilensis*	Chile05	0.00					
2	1	4	8	*Prosopis sp.*	Mexico07	0.00					
2	3	5	5	*Prosopis sp.*	Mexico08	0.64	2.64	13.39	6.69		
2	11	5	6	*P. chilensis*	Chile04	0.00					
2	9	5	7	*P. chilensis*	Chile02	0.00					
2	4	5	8	*Prosopis sp.*	Mexico09	0.00					
2	5	6	5	*Prosopis sp.*	Mexico11	0.56	2.41	9.73	7.33		
2	6	6	6	*Prosopis sp.*	Mexico12	0.00					
2	10	6	7	*P. chilensis*	Chile03	0.00					
2	8	6	8	*Prosopis sp.*	Chile11	0.00					
3	11	7	5	*P. chilensis*	Chile04	0.00					
3	4	7	6	*Prosopis sp.*	Mexico09	0.00					
3	1	7	7	*Prosopis sp.*	Mexico07	0.00					
3	6	7	8	*Prosopis sp.*	Mexico12	0.00					
3	13	8	5	*P. chilensis*	Chile07	0.00					
3	10	8	6	*P. chilensis*	Chile03	0.00					
3	8	8	7	*Prosopis sp.*	Chile11	0.00					
3	7	8	8	*Prosopis sp.*	Mexico13	0.00					
3	5	9	5	*Prosopis sp.*	Mexico11	0.00					
3	3	9	6	*Prosopis sp.*	Mexico08	0.00					
3	9	9	7	*P. chilensis*	Chile02	0.00					
3	12	9	8	*P. chilensis*	Chile05	0.00					
4	3	1	1	*Prosopis sp.*	Mexico08	0.60	1.68	6.63	4.38		
4	12	1	2	*P. chilensis*	Chile05	0.20	2.06	3.83	3.40		
4	1	1	3	*Prosopis sp.*	Mexico07	0.52	1.55	7.43	4.33		
4	10	1	4	*P. chilensis*	Chile03	0.24	2.12	4.09	2.50		
4	6	2	1	*Prosopis sp.*	Mexico12	0.40	1.27	3.83	3.44		
4	4	2	2	*Prosopis sp.*	Mexico09	0.16	0.95	1.42	1.00		
4	11	2	3	*P. chilensis*	Chile04	0.28	1.63	1.86	2.83		
4	7	2	4	*Prosopis sp.*	Mexico13	0.44	2.15	6.99	5.73		
4	8	3	1	*Prosopis sp.*	Chile11	0.08	1.30	1.65	2.00		
4	9	3	2	*P. chilensis*	Chile02	0.12	1.60	2.02	1.00		

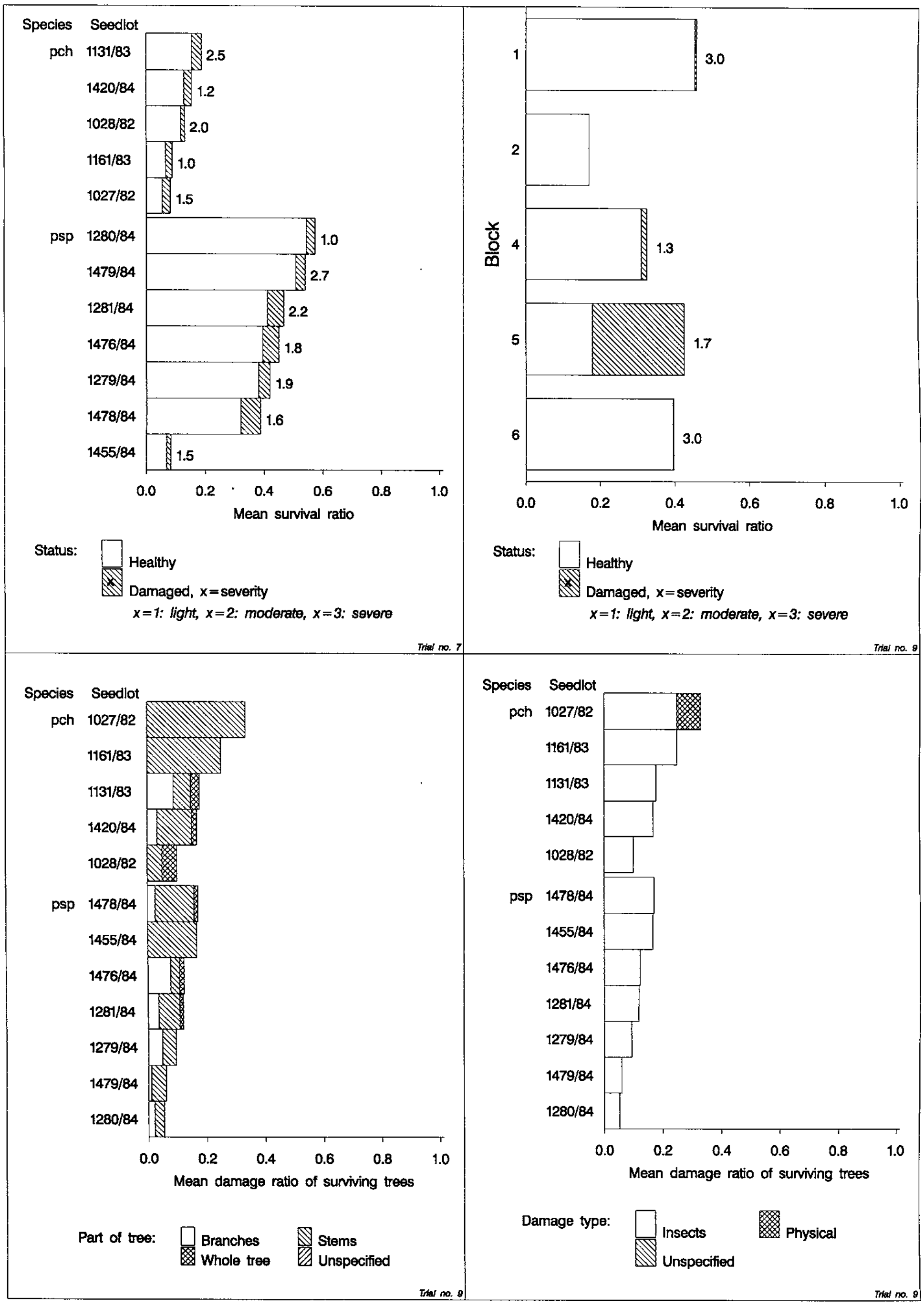
Block	Plot	Plotx	Ploty	Species	Provenance	Survival Proportion	Height m	Crown area m^2	Number of stems no. $tree^{-1}$	Basal area, mean tree cm^2 $tree^{-1}$	Total basal area tons ha^{-1}
4	13	3	3	*P. chilensis*	Chile07	0.32	2.10	3.86	4.13		
4	5	3	4	*Prosopis sp.*	Mexico11	0.54	1.52	4.97	3.27		
5	7	4	1	*Prosopis sp.*	Mexico13	0.48	1.73	4.05	5.82	10.31	0.31
5	4	4	2	*Prosopis sp.*	Mexico09	0.84	1.66	4.11	4.53	7.94	0.42
5	8	4	3	*Prosopis sp.*	Chile11	0.13	1.53	2.53	3.00	5.33	0.04
5	13	4	4	*P. chilensis*	Chile07	0.28	2.91	6.58	4.86	48.92	0.86
5	12	5	1	*P. chilensis*	Chile05	0.04	3.60	13.85	2.00	92.14	0.23
5	1	5	2	*Prosopis sp.*	Mexico07	0.80	1.92	11.18	4.29	27.22	1.36
5	10	5	3	*P. chilensis*	Chile03	0.22	2.54	10.15	4.33	29.58	0.37
5	9	5	4	*P. chilensis*	Chile02	0.08	3.55	8.68	2.00	53.21	0.27
5	6	6	1	*Prosopis sp.*	Mexico12	0.76	2.44	11.50	5.16	31.90	1.52
5	5	6	2	*Prosopis sp.*	Mexico11	0.52	1.86	5.15	3.50	14.13	0.46
5	11	6	3	*P. chilensis*	Chile04	0.20	1.70	2.12	2.75	15.05	0.19
5	3	6	4	*Prosopis sp.*	Mexico08	0.76	2.07	12.83	7.29	23.91	1.14
6	13	7	1	*P. chilensis*	Chile07	0.16	2.13	5.81	5.00		
6	1	7	2	*Prosopis sp.*	Mexico07	0.44	1.26	6.23	3.14		
6	12	7	3	*P. chilensis*	Chile05	0.13	1.13	1.82	2.00		
6	7	7	4	*Prosopis sp.*	Mexico13	0.80	1.98	7.03	4.81		
6	10	8	1	*P. chilensis*	Chile03	0.16	2.10	1.84	3.75		
6	9	8	2	*P. chilensis*	Chile02	0.16	1.33	1.79	1.50		
6	8	8	3	*Prosopis sp.*	Chile11	0.08	0.75				
6	3	8	4	*Prosopis sp.*	Mexico08	0.72	1.58	6.04	4.07		
6	11	9	1	*P. chilensis*	Chile04	0.28	1.65	2.24	3.33		
6	5	9	2	*Prosopis sp.*	Mexico11	0.52	1.24	4.26	5.44		
6	4	9	3	*Prosopis sp.*	Mexico09	0.88	1.59	3.19	4.81		
6	6	9	4	*Prosopis sp.*	Mexico12	0.44	1.55	4.64	4.60		

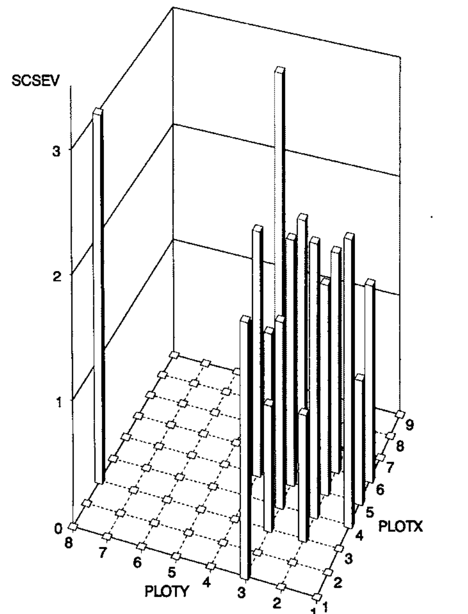
Annex 5. Graphical presentation of the health data

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.

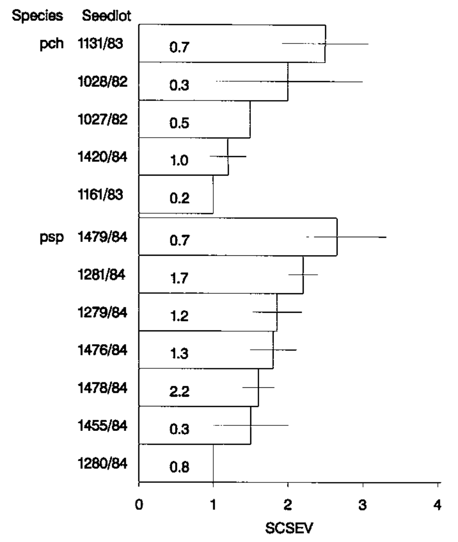
Please note that the seedlot codes correspond to the numbers given in annex 2.





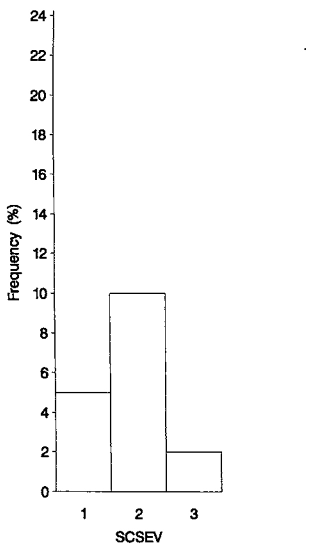
SCSEV = Health status code, severity of attack
Scatter of plot mean values

Trial no. 9



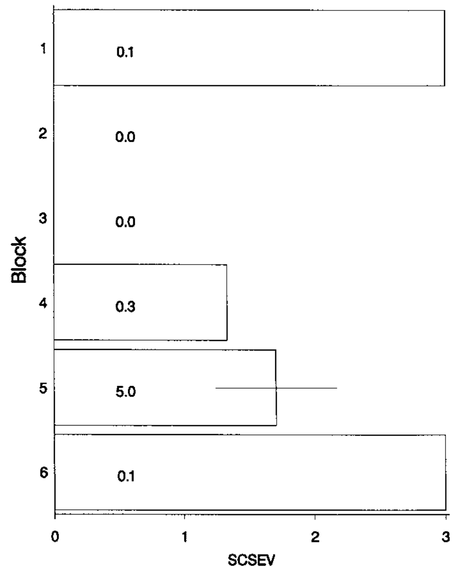
Mean SCSEV of seedlot with error bar line (+/− standard deviation of the mean) and the average number of assessed (living) trees per plot for each seedlot.

Trial no. 9



Frequency distribution of plot mean values

Trial no. 9



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. 9