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Evaluation of a provenance trial with *Acacia albida, A. senegal* and *A. tortilis* at Dagar Kotli, Pakistan

Trial no. 21 in the arid zone series

by

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

Preface

This report belongs to a series of analysis reports published by the Danida Forest Seed Centre. It is the intention that the series should serve as a place for publication of trial results for the Centre itself as well as for our collaborators. The reports will be made available from the DFSC publication service and online from the web-site www.dfsc.dk. The scope of the series is in particular the large number of trials from which esults have not yet 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 1990-1994. 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). The team was assisted by M.I. Shah, Mushlaq and R. 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 two provenances of *Acacia albida* from Senegal, five provenances of *A. senegal* from Pakistan and one provenance of *A. tortilis* from Israel. The trial was established at Dagar Kotli, Pakistan in 1984 with a spacing of 3x3 metres. The trial was assessed at an age of eight years in 1992. Different growth parameters were measured and subjected to analyses of variance and multivariate analyses.

The provenances of *A. albida* had a markedly faster growth in height and crown area than the other provenances, although it did not differ in survival. The fastest growing provenance of this species had an increment rate in basal area of 1 m^2 ha^{-1} y^{-1}, corresponding to a dry weight production of approximately 1.5 t ha^{-1} y^{-1}. This is remarkable considering that the annual precipitation at the site is only 100 mm.

A. tortilis was growing very slowly, but since only one provenance was represented no conclusion can be made on the production of this species at the site. In *A. senegal*, there were significant differences between provenances in survival and crown area, and the best performance was obtained in a provenance from South-eastern Sind.

Contents

1. Introduction

This report describes the results from trial no. 21 in a large series of provenance trials within the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species'. The main goals of the series were to contribute to the knowledge on the genetic variation of woody species, their adaptability and productivity and to give recommendations for the use of the species. The species included in this series of trials are mainly of the genera *Acacia* and *Prosopis*. A more detailed introduction to the series is given by Graudal *et al.* (2003).

The trial includes eight provenances of the genus *Acacia*, two of *A. albida*, five of *A. senegal* and one of *A. tortilis*.

A. albida has a distribution covering most of Africa and is an important component in agricultural systems in the Sahel (Boffa 1999, Brenan 1983). There is dispute on the taxonomy of the species; some authors prefer to place it in a separate genus with the name *Faidherbia albida* (Fagg & Barnes 1990). In West Africa the species is conspicuous because of its reverse growth habit: The leaves flush at the start of the dry season and are shed at the beginning of the rainy season. The species has several properties making it valuable for agroforestry and also produce leaves and pods that are used as fodder. Both provenances in this trial are from Senegal.

A. senegal is the species from which most of what is called 'gum Arabic' is collected and it is an important cash crop in parts of Africa (von Maydell 1986, Hanson 1992). There is a large interest in exploring the gum production and the ecology of the species in further detail. In this report, however, only the growth characters are investigated. The species is widespread in Africa but also occurs in Arabia, Pakistan and India (Brenan 1983). The provenances in this trial are all from Pakistan, however, thus giving important information on the variation of the species within the country.

Finally the trial include a provenance of *A. tortilis*. This species is found in large parts of Africa and the Arabic peninsula, and the provenance in this trial is from Israel (Brenan 1983).

2. Methods and materials

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.

2.2 Species and provenances

The trial includes 8 provenances of three species, as is mentioned in the introduction (Table 1). The provenances are given identification numbers relating to their geographical origin (name of province or country followed by a number), and the original seedlot numbers are provided in *Annex* 2. For *A. senegal* there is one seedlot (Unknown1) where the origin is not described, but an unpublished travel report indicate that it is a provenance from Pakistan, possibly from Sind (Gadani) with the longitude 25 °06'N and latitude 66°43' E.

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. Only the 16 central trees were assessed. 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

Diameter and number of stems were registered only for *A. albida* because trees of this species were the only large trees in the trial. 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. Species and provenances of *Acacia*, tested in trial no. 21 at Dagar Kotli, Pakistan. Data from seed suppliers, except for 1) from Pélissier (1983).

Provenance	Species	Seed collection site	Country of origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
Senegal9	*Acacia albida*	Merina Dakhar, Thies	Senegal	15° 06' N	16° 32' W	21	700	30
Senegal10	*Acacia albida*	Niakha Fall, Thies	Senegal	14° 56' N	16° 46' W	40	600[1]	31
Sind3	*Acacia senegal*	Bourberband, Dadu	Pakistan	25° N	67° E	100	200	25
Sind4	*Acacia senegal*	Dhabiji (Thatta)	Pakistan	24° 49' N	67° 32' E	14	204	25
Sind5	*Acacia senegal*	Loonio, Tharparkar, Sind	Pakistan	24° 38' N	70° 31' E	200	350	25
Sind6	*Acacia senegal*	Nagar-Parkar, Tharparkar, Sind	Pakistan	24° 21' N	70° 47' E	200	350	
Unknown1	*Acacia senegal*							
Israel3	*Acacia tortilis*	Ein-Hazeva, Arava	Israel	30° 47' N	35° 12' W	100	40	60

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

There were no apparent differences in the health status of the different provenances, except perhaps that the provenance of *A. tortilis* seemed to be more damaged by frost than the other provenances. Therefore no analysis of health is made. In stead a graphical presentation of the health scores is given in *Annex* 5.

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.

From the assessment data it appeared that for a number of small trees, no assessment of crown diameter was made. Of the 254 surviving trees 42 had no measurements of crown area. Since omission of these data will produce biased results and lead to an over-estimation of the provenances in question, the values for crown area for these observations have been set to zero. The estimates for crown area will thus be slightly biased, but it is believed that this is to a smaller extent than without the correction. Because the provenance of *A. tortilis* was not measured at all, it was excluded from the analysis.

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.). Since diameter was measured only for *A. albida*, calculation of dry weight was possible only for this species. The regression used was

$$TreeDW = e^{(2.055 \times \ln(basalarea) - 1.976)}$$

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}.

3.2 Statistical model and estimates

The statistical analysis of the trial was based on a two-step approach. The first step involved a test of species differences, whereas the second step was performed separately for each species and tested whether there were significant differences between the provenances within the species in question.

The test of species differences was based on the model:

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

where X_{ijk} is the value of the trait (e.g. height) in plot *ijk*, μ is the grand mean, $species_i$ is the fixed effect of species number *i*, $provenance(species)_{ij}$ is the effect of provenance number *j* nested within species *i*, assumed to be a random effect with an expected value of zero and variance σ_{pr}^2, $block_j$ is the effect of block (replication) *k* in the trial, assumed to be a random effect (or, in the case of calculating least square means, a fixed effect), and ε_{ijk} is the residual of plot *ijk*, and is assumed to follow the normal distribution $N(0, \sigma_e^2)$. This test was performed only for the variables survival, height and crown area, since the other variables were measured only for *A. albida*.

The test of significant differences between provenances was performed separately for the species *A. albida* and *A. senegal*. These analyses were based on the model:

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

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

To complement blocks in adjusting for uneven environments, co-variates related to the plot position were included in the initial model. The co-variates were distance along the axe of the blocks, plotx, and squared values of this distance, plotx2. Since block 4 is situated separately from the other blocks, the covariates were nested within two groups. The first group consisted of block 1, 2 and 3, and the second group consisted of block 4. It should be noted that due to lack of degrees of freedom the co-variates were not included in the models for *A. albida* only. 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). For crown area the data were weighted with the inverse of the variance for the seedlots 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 tablewide 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 the analyses of species differences and differences within *A. senegal* the number of tests was three, but in the analyses of differences between the provenances of *A. albida* the number was eight, 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. In this trial only *A. senegal* is represented by a larger number of provenances, and BLUP-values are presented only for this 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).

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

4. Results

4.1 Survival

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

Statistical analysis

The analysis of survival was straightforward, and no transformations were needed. None of the covariates were significant.

Results

Survival varied between 25 and 75 %, the lowest survival being in the provenance of *A. tortilis* (Fig. 1). Even though *A. albida* and *A. senegal* had higher survival than *A. tortilis*, the differences between species were far from significant (Table 2). According to the analysis of variance, the two provenances of *A. albida* were not significantly different, but the variation between the provenances of *A. senegal* was significant.

For *A. senegal*, Sind4 had the lowest survival, and Sind6 the highest. The BLUP values indicated that by selection within the tested group of provenances the gains could be between −12 and +18 percentage point (Fig 2).

Table 2. Results from analysis of variance of provenance differences of survival in trial 21.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Species	2; 5	1384	1.6	0.29	n.s.
Provenance(species)	5; 21	867	3.1	0.03	
Block	3; 21	776	2.8	0.06	
Error	21	276			
A. albida					
Provenance	1; 3	957	1.5	0.31	n.s.
Block	3; 3	585	0.9	0.54	
Error	3	658			
A. senegal					
Provenance	4; 12	845	4.2	0.02	*
Block	3; 12	358	1.8	0.20	
Error	12	199			

Figure 1. Survival in the *Acacia* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are least square means with 95 % confidence limits.

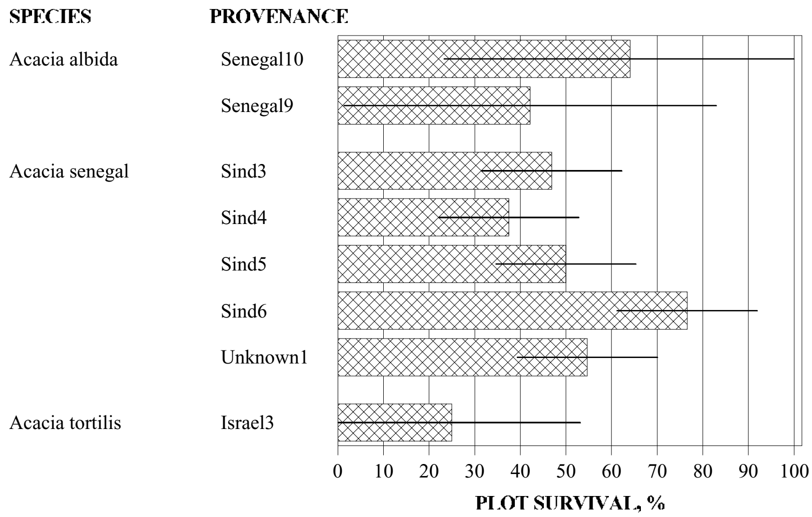
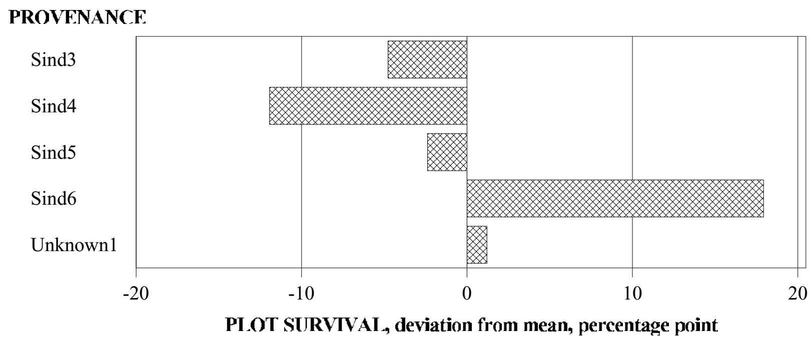


Figure 2. Best linear unbiased predictors (BLUPs) for survival of *A. senegal* in the trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are deviations from the mean value in percentage point.



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 trees are suddenly affected by stress and subsequent death.

Statistical analysis

The residuals were acceptable without transformations. The co-variate plotx2 was close to significance in the model testing species differences and was kept in the model. In the other models the co-variate was not significant and was omitted.

Results

The height in the trial was very variable, with highly significant differences between species (Table 3). The provenances of *A. albida* had the fastest growth and had attained heights of more than 4 m (Fig. 3). In contrast, the provenances of *A. senegal* had heights of only 1 – 1.5 m, and the provenance of *A. tortilis* had an average height of only 50 cm. Within species, there were no significant differences, but for *A. senegal* the BLUP-values varied between −11 and +15 %, indicating moderate gains (Fig. 4).

Table 3. Results from analysis of variance of provenance differences of height in trial 21.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Species	2; 5.0	29.4	197.0	<0.0001	***
Provenance(species)	5; 19	0.14	0.8	0.58	
Block	3; 19	0.11	0.6	0.63	
Plotx2	2; 19	0.53	2.8	0.09	
Error	19	0.19			
A. albida					
Provenance	1; 3	0.05	0.1	0.82	n.s.
Block	3; 3	0.76	1.0	0.49	
Error	3	0.75			
A. senegal					
Provenance	4; 12	0.14	2.3	0.12	n.s.
Block	3; 12	0.12	1.9	0.19	
Error	12	0.06			

Figure 3. Vertical height in the *Acacia* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are least square means with 95 % confidence limits.

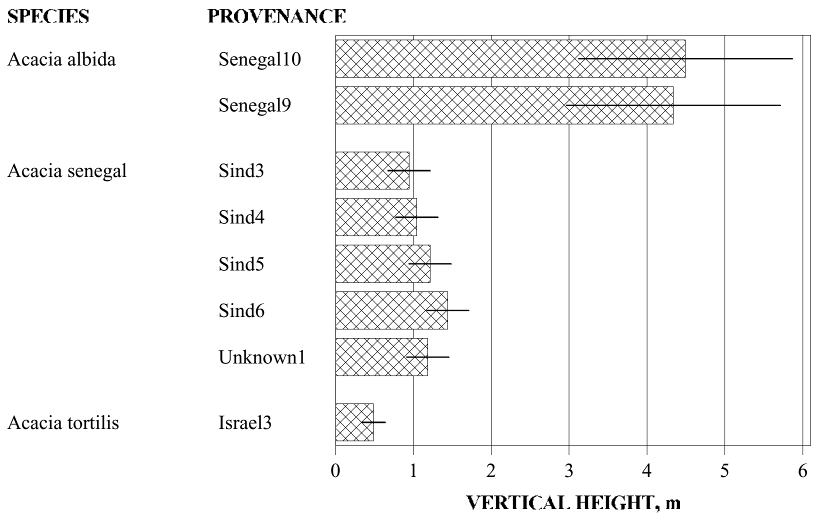
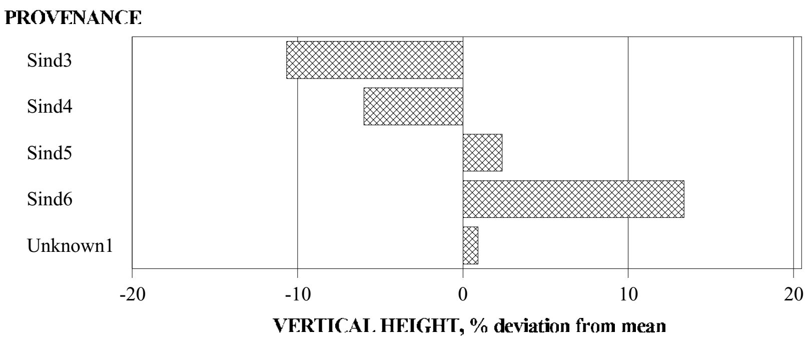


Figure 4. Best linear unbiased predictors (BLUPs) for vertical height in the *A. senegal* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values are presented as deviations in percent of the mean value



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.

Statistical analysis

Note that for a few small trees, crown area was set to zero (section 3.1), and that *A. tortilis* was excluded from the analyses due to lack of observations. In the first analysis there were signs of variance heterogeneity, and the data were weighted to fulfil assumptions of the model. The co-variate plotx was almost significant in the test of species differences and was kept in the model. In the model used for testing of provenance differences plotx was not significant.

Results

Again there were highly significant differences between the two species (Table 4). *A. albida* had the largest crown areas with approximately 8 m^2 $tree^{-1}$, whereas *A. senegal* was varying between 1 and 2.7 m^2 $tree^{-1}$ (Fig. 5). There were no significant differences between the provenances of *A. albida*. Within *A. senegal*, the differences were significant, and Sind6 had the largest crown area. The predicted gains by provenance selection were also larger than in the previous variables, ranging from –26 to +18 % (Fig. 6).

Table 4. Results from analysis of variance of provenance differences of crown area in trial 21.

Effect	DF (nominator, denominator)	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Species	1; 13.4	201	133.2	<0.0001	***
Provenance(species)	5; 16	2.6	2.6	0.06	
Block	3; 16	4.4	4.5	0.02	
Plotx	2; 16	3.2	3.2	0.07	
Error	16	1.0			
A. albida					
Provenance	1; 3	0.01	0.004	0.95	n.s.
Block	3; 3	3.9	1.1	0.48	
Error	3	3.7			
A. senegal					
Provenance	4; 12	6.5	7.2	0.003	**
Block	3; 12	10.4	11.4	0.0008	
Error	12				

Figure 5. Crown area in the *Acacia* species and provenance trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are least square means with 95 % confidence limits.

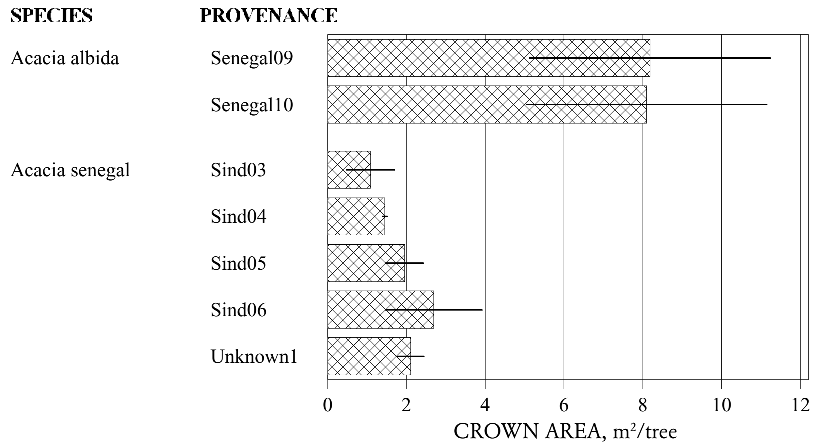
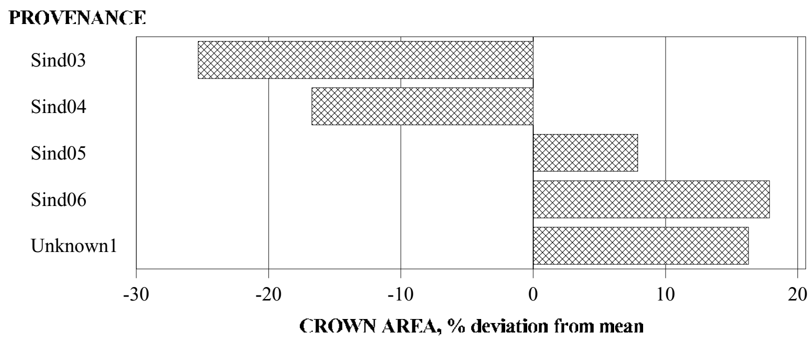


Figure 6. Best linear unbiased predictors (BLUPs) for crown area in the *A. senegal* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values are presented as deviations in percent of the mean value.



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

Like the rest of the variables analysed below, number of stems was assessed only for *A. albida*, and only this species is included in the analysis. Co-variates were not included in the model.

Results

The average number of stems was 1.3 for Senegal9 and 1.7 for Senegal10 (Fig. 7). The provenances were not significantly different (Table 5).

Table 5. Results from analysis differences in number of stems of the provenances of *A. albida* in trial 21.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Provenance	1	0.22	2.7	0.20	n.s.
Blocks	3	0.02	0.2	0.88	
Error	3	0.08			

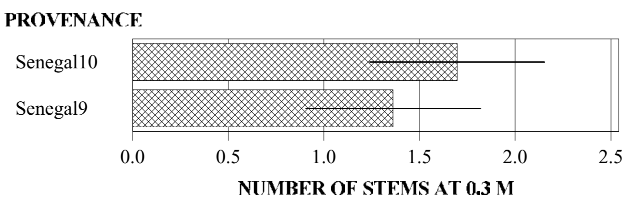


Figure 7. Number of stems of *A. albida* in the trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.5 Basal area of the mean tree

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

Statistical analysis

This variable was analysed without transformations or weights.

Results

The two provenances of *A. albida* had almost the same basal area of the mean tree, approximately 115 cm^{-2} $tree^{-1}$, and were not significantly different (Table 6, Fig. 8). This corresponds to a growth rate of 14 cm^{-2} y^{-1}.

Table 6. Results from analysis of differences in basal area of the mean tree of the *A. albida* provenances in trial 21.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Provenance	1	63	0.02	0.90	n.s.
Blocks	3	3681	1.4	0.40	
Error	3	2646			

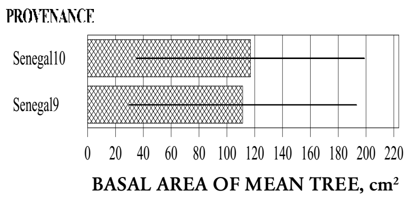


Figure 8. The basal area of the mean tree of the *A. albida* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.6 Total basal area

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

Statistical analysis

The analysis was straightforward, and no transformations or weights were used.

Results

It appeared that the two provenances of *A. albida* had different basal areas when expressed on a per unit area basis. The differences were significant, or at the border of significance when the correction for multiple comparisons was made (Table 7). Senegal10 was the largest provenance with a basal area of almost 8 m^2 ha^{-1}, whereas Senegal9 had a basal area of 5 m^2 ha^{-1}. For Sind10 this corresponds to a growth of 1 m^2 ha^{-1} y^{-1}.

Table 7. Results from analysis of differences in total basal area of the *A. albida* provenances in trial 21.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Provenance	1	15.5	34.8	0.01	(*)
Blocks	3	30.2	67.8	0.003	
Error	3	0.4			

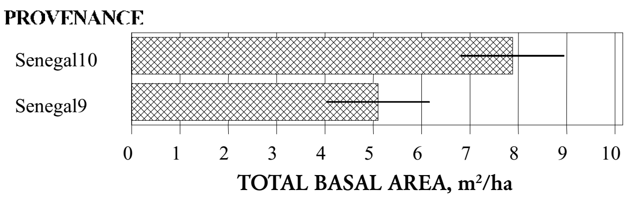


Figure 9. Total basal area the *A. albida* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are least square means with 95 % confidence limits.

4.7 Dry weight of the mean tree

The dry weight of the mean tree is comparable to the basal area of the mean tree in that they both are calculated on the live trees only and thus serve as a measure of the potential production at the site, provided that all trees survive. Furthermore, the two variables are linked closely 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 with a large dry mass are weighted heavily in this variable. The dry weight of the mean tree is thus the best estimate for the production of biomass at the site.

Statistical analysis

Again the analysis was performed on untransformed values.

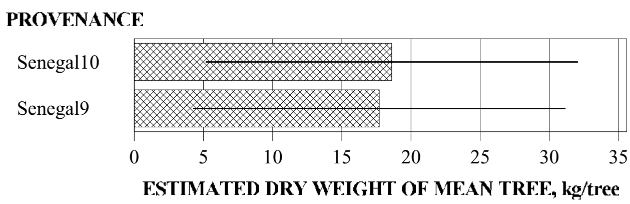
Results

Again the two provenances had almost the same value (Fig. 10). The dry weight of the mean tree amounted to 17-18 kg tree^{-1}, and there were no signs of significant differences (Table 8).

Table 8. Results from analysis of differences in dry weight of the mean tree of the *A. albida* provenances in trial 21.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Provenance	1	1.6	0.02	0.89	n.s.
Blocks	3	100.0	1.4	0.39	
Error	3	71.2			

Figure 10. Dry weight of the mean tree of the *A. albida* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are least square means with 95 % confidence limits.



4.8 Total dry weight

In parallel with the total basal area, the total dry weight includes missing trees and gives the best measure of the actual production on the site.

Statistical analysis

The analysis was performed without transformations or weights.

Results

The results were very similar to those of total basal area. The statistical test showed that the differences between provenances were significant, but when the correction for multiple comparisons was made, the difference was only at the border of significance (Table 9). The largest provenance was Senegal10 with 12.5 t ha^{-1}. In contrast, Senegal9 had a dry weight of only 8 t ha^{-1}. For Senegal10, this corresponds to a growth rate of approximately 1.5 t ha^{-1} y^{-1}.

Table 9. Results from analysis of differences in total dry weight of the *A. albida* provenances in trial 21.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Provenance	1	39.2	29.2	0.01	(*)
Blocks	3	79.2	59.1	0.004	
Error	3	1.3			

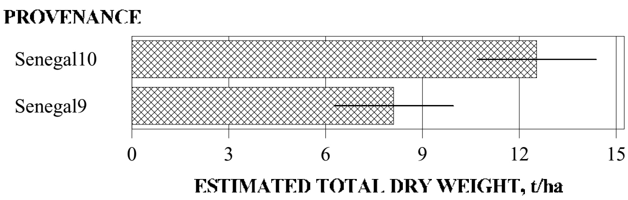


Figure 11. Total dry weight of the *A. albida* provenances in the trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). Values presented are least square means with 95 % confidence limits.

Table 10. Results from the canonical variate analyses for the two canonical variates in trial 21.

Canonical variate no.	**1**	**2**
Proportion of variation accounted for	0.93	0.07
Significance, P-value	<0.0001	0.001

	Raw canonical coefficients		**Standardised canonical coefficients**		**Canonical directions**	
Canonical variate no.	**1**	**2**	**1**	**2**	**1**	**2**
Survival	0.012	0.059	0.26	1.32	33.3	347.3
Height	2.12	-0.20	3.31	-0.32	9.7	-2.0

4.9 Multivariate analysis

The multivariate analysis was made in two steps. The first step was a test of the differences between species, and the second step was a test of differences between the provenances of *A. senegal*.

Test of differences between species

Since only survival and height were available for the *A. tortilis* provenance, only these variables were included in the multivariate analysis.

The analysis demonstrated that both canonical variates were highly significant (Table 10). The first canonical variate accounted for as much as 93 % 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).

The plot of scores for the two canonical variates is given in Fig. 12. Apart from the scores, the mean values for the provenances are given together with their approximate 95 % confidence regions. In the diagram, provenances that are far apart are interpreted as being different, and if the confidence regions do not overlap, it is likely that the two provenances in reality have different properties.

The diagram indicates that there are two groups of provenances. The provenances of *A. albida*, Senegal09 and Senegal10, are located at a distance from the provenances of *A. senegal* and *A. tortilis*, clumping together in the left side of the diagram. As the second canonical variate is significant, it is allowable to interpret the variation on the other scale as well, and here it seems that Israel3, the provenance of *A. tortilis*, is separated from at least the provenance Sind06 of *A. senegal*. An additional test in the multivariate setting demonstrated that the effect of species was also highly significant (results not shown).

Test of differences within *A. senegal*

This test included the three variables survival, height and crown area. The analysis demonstrated that no canonical variates were significant, and that the provenances were not significantly different (P-value for Wilks′ lambda=0.17 and P-value for Pillai′s trace=0.27). Therefore no further results are presented for this test. The reason for the lack of significant provenance differences could be that the test does not account for variance heterogeneity, as was observed in the analysis of crown area.

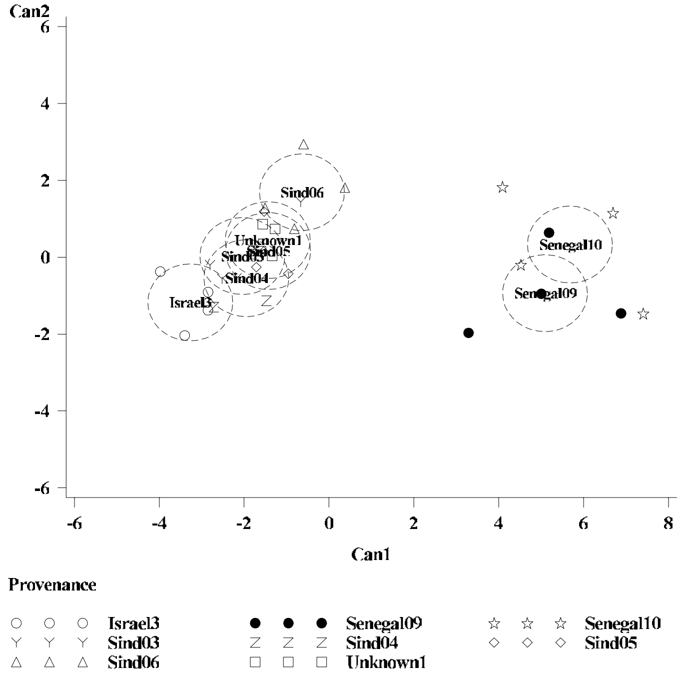


Figure 12. Score plot of the first and the second canonical variate from the canonical variate analysis for the provenances in the *Acacia* provenance trial at Dagar Kotli, Pakistan (Trial no. 21 in the arid zone series). The variables survival and height were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region. The provenances Senegal09 and Senegal10 are *A. albida*, Israel3 is *A. tortilis*, and the rest are *A. senegal.*

5. Discussion and conclusions

Productivity

The provenances of *Acacia albida* in this trial had a high productivity, considering that the rainfall at the site is only 2-300 mm. The production of 1.5 t dry weight ha^{-1} y^{-1} compares to the production of a number of trials in Africa and Brazil (also in the arid zone series) where the production is the same, but precipitation is higher. However, this relatively high production fades when comparing to a trial of *A. nilotica* at Dagar Kotli (trial no. 22 in the arid zone series), where the production reached an astonishing 6.6 t dry weight ha^{-1} y^{-1}. The reasons for the fast growth are not evident – the trials are not located in a depression in the terrain and there are no signs of the ground water being close to the surface.

Species and provenance differences

The differences between species were obvious. Even though there were no significant differences between the species in survival, *A. albida* had a much faster growth than the two other species. The height and crown area were three to four times those of *A. senegal*. The provenance of *A. tortilis* had a very slow growth, also compared to *A. senegal*. However, the conclusions on *A. tortilis* should not be taken too far, since Israel3 in a trial in Senegal had a very poor performance compared to other provenances of *A. tortilis* (trial no. 24 in this series). We cannot exclude that other provenances of this species would have had a faster growth. An indication of this is that outside of the trial, *A. tortilis* has a good performance. Only the provenance from Israel is damaged by frost.

Of the two provenances of *A. albida***,** it seemed that Senegal10 had the fastest growth, and this provenance is recommended for future experiments in larger scale. Within *A. senegal***,** there were significant differences in survival and crown area, with Sind06 as the best. The provenances from western Sind, i.e. Sind03 and Sind04, had a poorer performance and cannot be recommended, whereas Sind05 and the unknown provenance were intermediate.

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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) 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. Seedlots of *Acacia* tested in trial no. 21 at Dagar Kotli, Pakistan

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

Provenance	Seedlot numbers			Provenance information							
	Plot	DFSC	Country of origin	Species	Origin	Country of origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
Senegal9	7	1043/82		*Acacia albida*	MERINA DAKHAR, THIES	SENEGAL	15 06 N	16 32 W	21	700	30
Senegal10	8	1044/82		*Acacia albida*	NIAKHA FALL, THIES	SENEGAL	14 56 N	16 46 W	40		31
Sind3	2	1172/83		*Acacia senegal*	BOURBERBAND, DADU	PAKISTAN	25 N	67 E	100	200	25
Sind4	5	1173/83		*Acacia senegal*	DHABIJI (THATTA)	PAKISTAN	24 49 N	67 32 E	14	204	25
Sind5	4	1174/83		*Acacia senegal*	LOONIO, THARPARKAR, SIND	PAKISTAN	24 38 N	70 31 E	200	350	25
Sind6	1	1175/83		*Acacia senegal*	NAGAR-PARKAR, THARPARKAR, SIND	PAKISTAN	24 21 N	70 47 E	200	350	
Unknown1	3		DKotli1	*Acacia senegal*							
Israel3	6	1066/82		*Acacia tortilis*	EIN-HAZEVA, ARAVA	ISRAEL	30 47 N	35 12 W	100	40	60

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

4	8	3	
3	2	6	
2	1	5	
1	7	4	
	9	10	x

Block 4

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

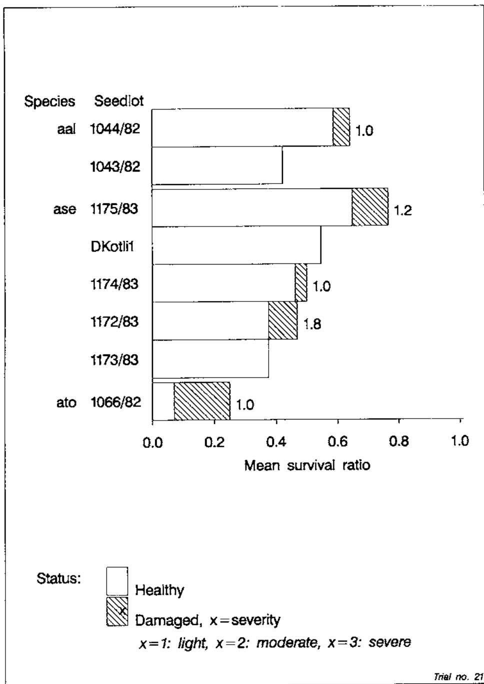
Block	Plot	Plotx	Ploty	Species	Provenance	Survival	Height	Crown area	Number of stems	Basal area of the mean tree	Total basal area	Dry weight of the mean tree	Total dry weight
						%	m	m^2 $tree^{-1}$	no. $tree^{-1}$	cm^2 $tree^{-1}$	m^2 ha^{-1}	kg $tree^{-1}$	t ha^{-1}
1	1	6	3	*A. senegal*	Sind06	88	1.19	1.63					
1	2	4	3	*A. senegal*	Sind03	63	1.30	1.55					
1	3	7	3	*A. senegal*	Unknown1	50	1.09	1.78					
1	4	2	3	*A. senegal*	Sind05	31	1.34	2.47					
1	5	8	3	*A. senegal*	Sind04	19	1.17	1.44					
1	6	1	3	*A. tortilis*	Israel3	13	0.55	0.00					
1	7	5	3	*A. albida*	Senegal09	13	3.45	9.16	1.50	90.8	1.26	14.2	2.0
1	8	3	3	*A. albida*	Senegal10	44	3.86	7.07	1.29	61.4	2.99	9.6	4.6
2	1	1	2	*A. senegal*	Sind06	63	1.49	2.89					
2	2	7	2	*A. senegal*	Sind03	44	0.66	1.09					
2	3	8	2	*A. senegal*	Unknown1	50	1.31	2.43					
2	4	6	2	*A. senegal*	Sind05	69	1.12	1.83					
2	5	3	2	*A. senegal*	Sind04	50	1.09	1.52					
2	6	5	2	*A. tortilis*	Israel3	13	0.55	0.00					
2	7	2	2	*A. albida*	Senegal09	44	4.34	9.92	1.29	182.0	8.85	29.5	14.3
2	8	4	2	*A. albida*	Senegal10	81	4.93	8.83	1.83	147.7	12.31	23.6	19.7
3	1	7	1	*A. senegal*	Sind06	75	1.74	4.16					
3	2	6	1	*A. senegal*	Sind03	31	0.62	0.14					
3	3	1	1	*A. senegal*	Unknown1	56	0.93	1.64					
3	4	4	1	*A. senegal*	Sind05	38	0.97	1.33					
3	5	2	1	*A. senegal*	Sind04	19	0.60	1.23					
3	6	3	1	*A. tortilis*	Israel3	25	0.50	0.00					
3	7	8	1	*A. albida*	Senegal09	31	5.06	6.73	1.20	95.4	3.31	15.0	5.2
3	8	5	1	*A. albida*	Senegal10	81	3.46	5.64	1.92	66.9	5.57	10.4	8.7
4	1	2	2	*A. senegal*	Sind06	81	1.34	2.09					
4	2	3	3	*A. senegal*	Sind03	50	1.20	1.56					
4	3	4	4	*A. senegal*	Unknown1	63	1.40	2.59					
4	4	1	1	*A. senegal*	Sind05	63	1.43	2.19					
4	5	2	2	*A. senegal*	Sind04	63	1.31	1.63					
4	6	3	3	*A. tortilis*	Israel3	50	0.35	0.00					
4	7	1	1	*A. albida*	Senegal09	81	4.50	6.91	1.46	77.1	6.96	12.1	10.9
4	8	4	4	*A. albida*	Senegal10	50	5.73	10.84	1.75	191.8	10.66	30.9	17.2

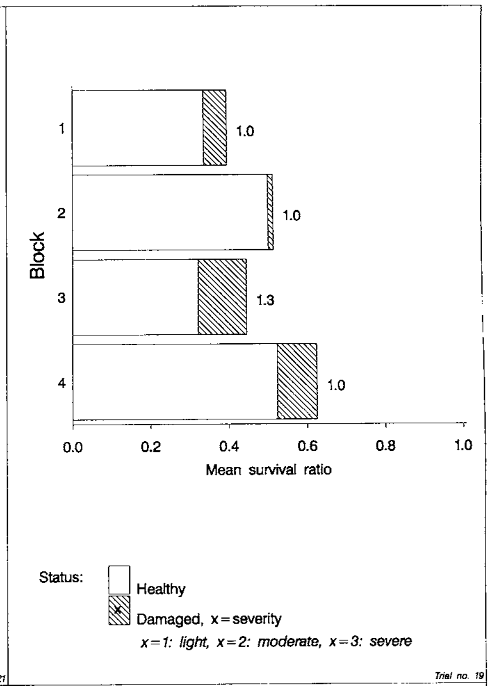
Annex 5. Graphical presentation of the health data

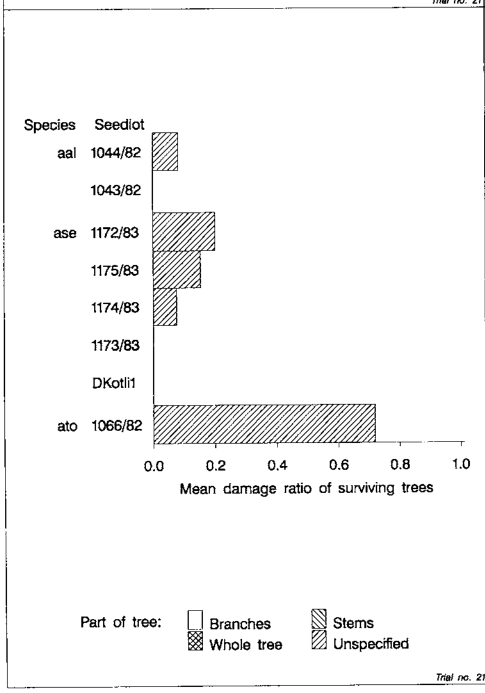
The health status of the trees were evaluated on a scale from 0 to 3, where 0 indicates no damage, and 1, 2 and 3 indicates light, moderate and severe damage, respectively. The health status code is named SCSEV in the diagrams on the following pages.

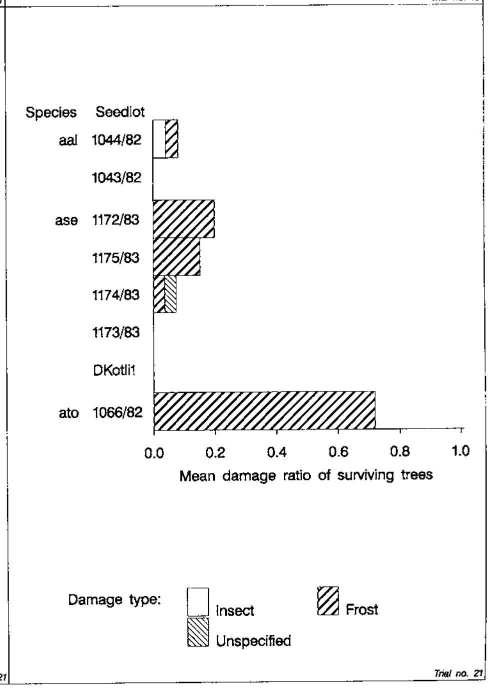
The diagrams present the mean survival ratios, the damage ratios of the surviving trees and the average damage scores for the damaged trees. They also indicate the distribution of the damage on the trees and the cause of the damage. The damage scores are presented according to plots, blocks and seedlots.

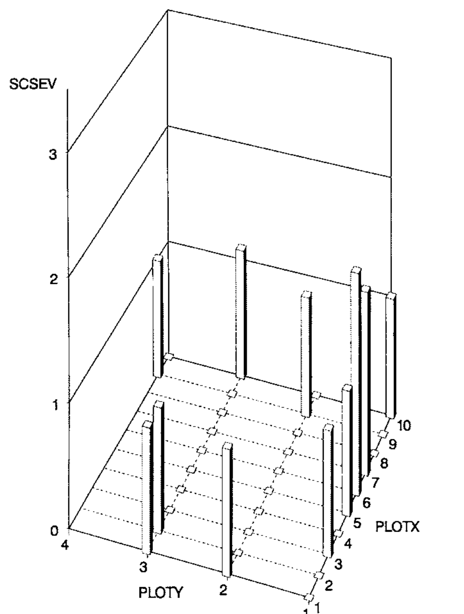
Please note that the seedlot codes correspond to the numbers given in Annex 2.





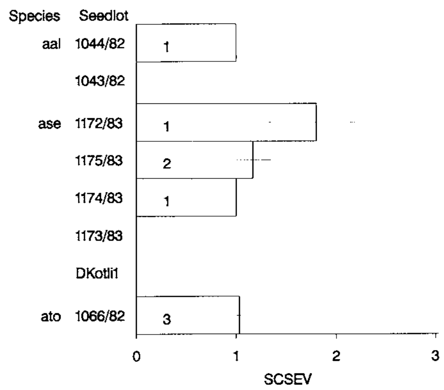






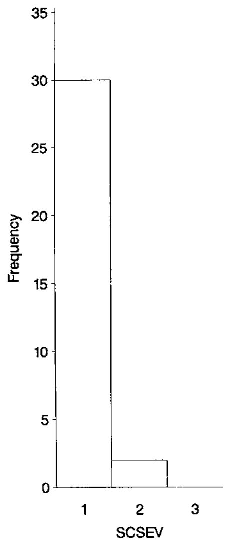
SCSEV = Health status code, severity of attack
Scatter of plot mean values

Trial no. 21



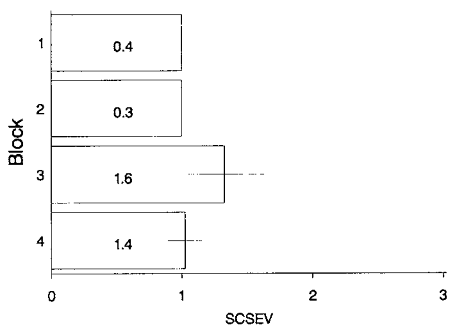
Mean SCSEV of seedlot with error bar line (+/− standard deviation of the mean) and the average number of assessed (living) trees per plot for each seedlot.

Trial no. 21



Frequency distribution of plot mean values

Trial no. 21



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. 21