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by

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Assessment of the trial of *Acacia senegal* in Djibo. Sampling of leaves for biomass assessment. Lars Graudal. DFSC phot. 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 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.

The report presents the results from a trial 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 Institut de l'Environnement et de Recherches Agricoles (INERA, formerly Institut de Recherche en Biologie et Ecologie Tropical, IRBET) in Burkina Faso. The assessment team consisted of Diallo Boukary, Karim Kiendrebeogo, Tamboura Saïdou, Tamboura Adama, Tamboura Amadou, Adama Douramani, all from INERA/IRBET, Traoré Adama from Centre National de Semences Forestières, Agnete Thomsen of FAO, and Lars Graudal from DFSC. The authors wish to acknowledge the help of the personnel at IRBET 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 Dr. agro. Axel Martin Jensen and Marcus Robbins, consultant to FAO.

Abstract

This report describes results from the analysis of a trial including 6 provenances of *Acacia senegal*. The trial was established in 1988 with a spacing of 4 x 4 metres at Djibo in Burkina Faso. The assessment took place five years later in 1993, and included a number of vegetative and growth characters. Gum production was not measured. The provenances included a selection of seedlots from the Sahel (Burkina Faso, Niger, Mali and Sudan) and one provenance from Rajasthan in India.

The differences between provenances were highly significant for all characters except number of stems. In particular, the provenance from India had a very poor performance, but even when this seedlot was excluded there were significant differences (in height and crown area) between the remaining provenances from Africa. Provenances from the Sahelian phytogeographical zone had a faster height growth than the two provenances from the Sudanian zone. A multivariate analysis confirmed that the provenance from India was clearly separated from the other seedlots. The best provenance had a dry weight production of approximately 1.4 t ha^{-1} y^{-1}.

Résumé en français

Ce rapport présente les résultats d'un essai de six provenances de *Acacia senegal*. L'essai a été installé en 1988. L'évaluation est intervenue cinq ans après la mise en place (c.à.d. 1993). Les lots de semences sont originaires de la zone sahélienne (Burkina Faso, Niger, Mali), du Soudan et de l'Inde (Rajasthan). Les paramètres mesurés portent sur le nombre de tiges et la vigueur de croissance et la production de matière sèche. La production de gomme n'a pas été mesurée à cette période.

Les différences entre les provenances sont hautement significatives pour tous les caractères mesurés exception faite du nombre de tiges. Particulièrement la provenance indienne a des performances médiocres. Cependant, même si on exclu cette provenance de l'analyse les différences entre les provenances africaines restent significatives. Les provenances sahéliennes sont alors celles qui présentent une croissance en hauteur la plus élevée par rapport à celles de la zone soudanienne. Une analyse multivariée confirme la particularité de la provenance de l'Inde qui se singularise des autres par sa faible performance. Notons que les arbres de la meilleure provenance ont une production de matière sèche proche de 1.4 t ha^{-1} an^{-1}.

Contents

1. Introduction

This report describes the results from trial no. 5 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).

The trial includes seven provenances of *Acacia senegal*. It is the species from which 'gum Arabic' is mostly collected (von Maydell 1986). In the 18th century most of the gum Arabic came from West Africa, but today the largest proportion is produced in Eastern Africa (Hanson 1992). As gum Arabic is considered a cash crop, 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.

A. senegal is found in most of the Sahel and in Eastern and Southern Africa. The species is considered quite variable, and some authors distinguish four varieties, although this is subject to debate (Ross 1979, Fagg & Barnes 1990). In Burkina Faso, natural populations of *A. senegal* are found between 13° and 14°30' Northern latitude with the largest concentration between 1° and 4° Western longitude (Sina 1989). The provenances in this trial represent a selection from Sahel, including Burkina Faso, Mali, Niger and Sudan. A provenance from Rajasthan in India (introduced to India) is included as the only provenance from outside Africa. All are supposedly of the variety *senegal*, even though this does not appear in the collection sheets. Other trials of *A. senegal* were established by CNSF at Dori and Gonsé, also in Burkina Faso (trials no. 8 and 12 in this series).

2. Materials and methods

2.1 Site and establishment of the trial

The trial is located at Djibo (14°06′N, 01°37′W) in Burkina Faso. The annual average rainfall was 570 mm from 1961 to 1970, but had decreased to 300 mm in the period 1981-1987 (reference in DFSC 1994). The dry period has a length of eight to ten months. Further information is given in the assessment report (DFSC 1994) and summarised in Annex 1.

The trial was established in July 1988.

2.2 Provenances

The trial includes 6 provenances of *A. senegal* (Table 1). There is one provenance from each of the countries Burkina Faso, Niger, Mali, Sudan and India, and two provenances from Sudan. The provenances are given names relating to the geographical origin (name of province or country followed by a number). The original seedlot numbers are provided in Annex 2.

2.3 Experimental design

The trial is a single tree plot trial with 6 blocks and 12 trees of each provenance represented in each block. Within each block, the trees are placed at random with a spacing of 4 × 4 m. The layout of the trial is shown in Annex 3.

2.4 Assessment of the trial,

In March 1993 INERA, FAO, CNSF and DFSC undertook a joint assessment. The assessment included the characters survival, vertical height, diameter at 0.3 m, number of stems at 0.3 m, crown diameter and health. The raw data from the assessment are documented in DFSC (1994), and the plot data set on which the statistical analyses are performed is presented in Annex 4. Note, however, that the provenance Sudan11 has been named incorrectly Junapatarasat Barmer, India, in the assessment report. A detailed account of the assessment methods is given by DFSC (Graudal *et al.* 2003).

Table 1. Provenances of *Acacia senegal* tested in trial no. 5 at Djibo, Burkina Faso.

Provenance identification	Seed collection site	Country of origin	Latitude	Longitude	Altitude (m)	Ann. rainfall (mm)	No. of mother trees
Burkina09	Lac Dem, Kaya, Sanmatenga	Burkina Faso	13°06'N	01°05'E	311	700	
Mali1	Kadiel N.E. De Nioro	Mali	15°20'N	09°27'W	100	490	24
Niger1	Kardofane	Niger	14°20'N	06°10'E	320	387	23
Rajasthan03	Jodhpur (Cazri)	India	26°19'N	73°08'E	210	325	7
Sudan11	Northern Kordofan	Sudan	13°10'N	30°14'E	570	365	27
Sudan12	Wad Elnail, Singa	Sudan	12°30'N	34°05'E	440	600	30

3. Statistical analyses

3.1 Variables

In the 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

All variables were analysed as block means, even though the design allows for a more complex analysis (in theory, it would be possible to analyse interactions between blocks and provenances). Survival was calculated for each provenance as the proportion of surviving trees to the number of trees originally planted. Height, crown area, number of stems, basal area of the mean tree and dry weight of the mean tree were calculated as the mean of surviving trees. The area-related measures, total basal area and total dry weight, were calculated as the sum of the variables for each block and provenance and then related to the growth space of the trees, expressing the variables on an area basis. Due to competition, trees from different provenances may experience different growth space, but here it is assumed that all trees have the same growth space (4×4 m^2).

A number of health characters were evaluated, but since the trees were generally in good health and there were only little apparent differences 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. Since ignoring these data will produce biased results and result in over-estimation of the provenances in question, the values for crown area and basal area for these trees were set to 0.2 m^2 and 1 cm^2, respectively. There is no reasonable way to estimate the number of stems of such trees, and no default values have been set for this variable. In any case, the estimates of the variables will be slightly biased.

The dry weight values were calculated from regressions between biomass and basal area, established in another part of this study (Graudal *et al.*, in prep.). For *A. senegal* the regression is

$$TreeDW = e^{(2.474 \times \ln(basalarea) - 2.233)}$$

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 variables were analysed in two stages. The first stage was a test of differences between all provenances. As it was quite clear that the provenance from India behaved quite differently from the rest of the provenances, a second test was performed to see if there were differences without Rajasthan03. All tests were performed 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 fixed effect of provenance number *j*, $block_k$ is the random effect of block *k* in the trial, and ε_{jk} is the residual of plot *jk* which is assumed to follow a normal distribution $N(0, \sigma_e^2)$.

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). Where appropriate, weighting of data with the inverse of the variance for the seedlots was used to obtain normality of the residuals where the seedlots appeared to have different variances (*ibid.*; Afifi & Clark 1996, Ræbild *et al.* 2002). No transformations were needed.

The P-values from the tests of provenance differences were corrected for the effect of multiple comparisons by the sequential tablewide Bonferroni method. The tests were ranked according to their P values. The test corresponding to the smallest P value (P_1) was considered significant on a 'tablewide' significance level of α if $P_1 < \alpha/n$, where n is the number of tests. The second smallest P value (P_2) was declared significant if $P_2 < \alpha/(n-1)$, and so on (c.f. Kjaer & Siegismund 1996). In this case the number of tests was set to 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). 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. It should be noted that in the calculation of BLUPs it is assumed that the provenances represent a random selection, which may not be true in this case.

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

4. Results

4.1 Survival

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

Statistical analysis

In the analysis of all provenances it seemed that there was variance heterogeneity, and the data was weighted before analysis to account for this. In the analysis of the data without Rajasthan03, there were no problems, and the data was used without weighting.

Results

The provenance Rajasthan03 (India) had a survival of just below 50 %, whereas the rest of the provenances had survivals in the range of 70 to 80 % (Fig. 1). The analysis of variance demonstrated that the differences were highly significant, but the differences disappeared when Rajasthan03 was removed from the data set (Table 2). Mali1 and Sudan11 had the highest survivals, resulting in average gains of survival of more than 10 % (Fig. 2).

Table 2. Results from analysis of variance of provenance differences of survival in trial 5.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	5	10.8	9.8	<0.0001	***
Block	5	4.5	4.0	0.008	
Error	25	1.1			
Without Rajasthan03					
Provenance	4	0.020	1.45	0.25	n.s.
Block	5	0.025	1.78	0.16	
Error	20	0.014			

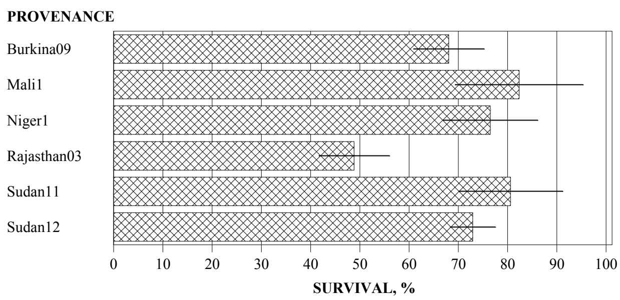

Figure 1. Survival in percent for the 6 provenances in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are least square means with 95 % confidence limits.

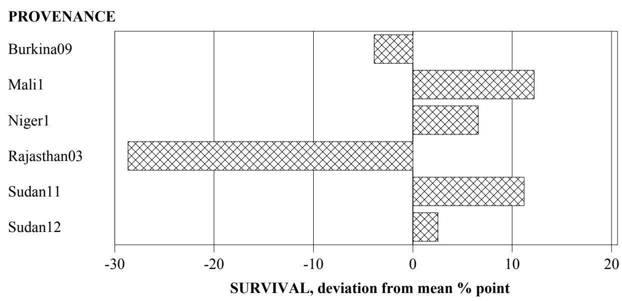

Figure 2. Best linear unbiased predictors (BLUPs) for survival in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are deviations from the mean value in percent.

4.2 Height

Height is usually considered an important variable in the evaluation of species and provenances, depending 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 environmental conditions, tall provenances/trees usually being better adapted to the site than short provenances/trees. As there have been cases where the tallest provenances are suddenly affected by stress with subsequent die-off of the trees, this interpretation need not always be true.

Statistical analysis

Both the analyses with and without Rajasthan03 were straightforward, and no transformations were used.

Results

The provenance Rajasthan03 had the shortest height with only about 0.8 m. The other provenances varied between 2.3 and 2.8 m (Fig. 3). Differences between the provenances were highly significant, both with and without Rajasthan03 (Table 3). The highest-ranking provenances were Mali1, Niger1 and Sudan11, with Burkina09 and Sudan12 in the intermediate group (Figs. 3 and 4).

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

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	5	3.68	66.8	<0.0001	***
Block	5	0.45	8.1	<0.0001	
Error	25	0.06			
Without Rajasthan03					
Provenance	4	0.43	8.4	0.0004	**
Block	5	0.27	5.3	0.003	
Error	20	0.05			

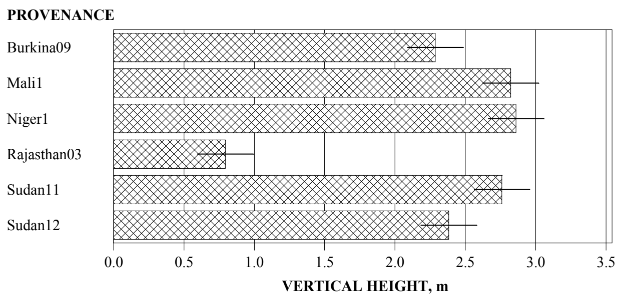

Figure 3. Vertical height for the 6 provenances in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are least square means with 95 % confidence limits.

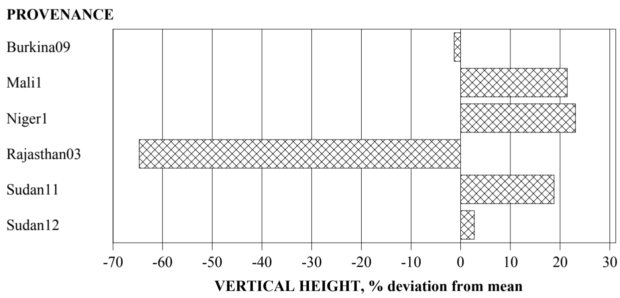

Figure 4. Best linear unbiased predictors (BLUPs) for height in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are deviations from the mean value in percent.

4.3 Crown area

The crown area variable indicates the ability of the trees to cover the ground. This 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

The statistical analysis was straightforward, and no transformations were used.

Results

Rajasthan03 had a crown diameter of below 2 m^2 $tree^{-1}$, and was significantly smaller than the rest of the provenances (Table 4, Fig. 5). The other provenances had average crown areas in the range of 8 to 13 m^2 $tree^{-1}$, with Niger1 as the top provenance. Since the trees were planted at 4 × 4 m (corresponding to a growth space of 16 m^2 $tree^{-1}$) this means that in the largest provenances, the canopy would be about to close had the trial not been a single tree plot design. The provenance differences were significant without the provenance from Rajasthan (Table 4), again with Burkina09 and Sudan12 having the smallest crown areas. By choosing Niger1, large predicted gains of above 40 % of the mean may be foreseen (Fig. 6).

Table 4. Results from analysis of variance of provenance differences of crown area in trial 5.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	5	92.9	28.6	<0.0001	***
Block	5	47.3	14.6	<0.0001	
Error	25	3.2			
Without Rajasthan03					
Provenance	4	21.6	6.6	0.002	*
Block	5	44.2	13.5	<0.0001	
Error	20	3.3			

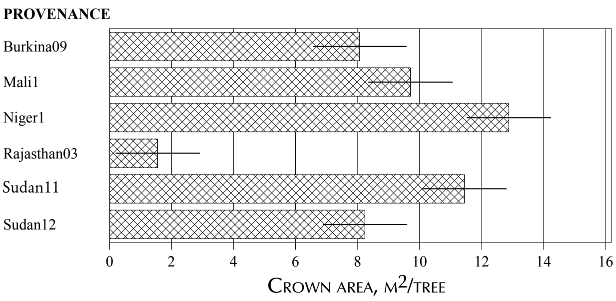

Figure 5. Crown area for the 6 provenances in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are least square means with 95 % confidence limits.

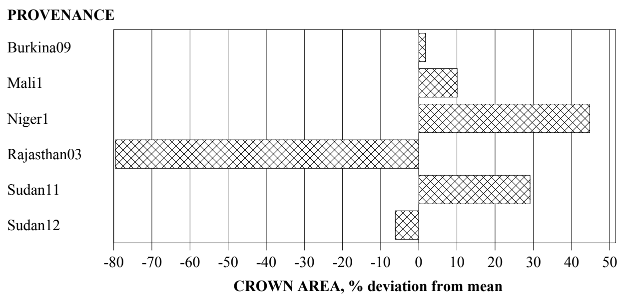

Figure 6. Best linear unbiased predictors (BLUPs) for crown area in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.4 Number of stems

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

Statistical analysis

Since there was variance heterogeneity in the data, it was necessary to weight the data. The weight statement was used both in the analysis of all provenances and in the analysis of the data without Rajasthan03. Note that there was no assessment of number of stems for trees below 1, which introduces a bias in the analysis of variance as well as the estimates. For Rajasthan03 this means that values from three blocks were missing. Therefore the results from this analysis should be considered with caution.

Results

The average number of stems varied from 1.5 to 2.1 (Fig. 7), but the differences were not significant (Table 5). Niger1 and Mali1 ranked at top, while Rajasthan03 ranked at the bottom (Fig. 8). Removing Rajasthan03 did not improve the P-value for the provenance effect.

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

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	5	3.2	2.0	0.12	n.s.
Block	5	9.9	6.2	0.001	
Error	22	1.6			
Without Rajasthan03					
Provenance	4	1.3	1.2	0.33	n.s.
Block	5	6.0	5.8	0.002	
Error	20				

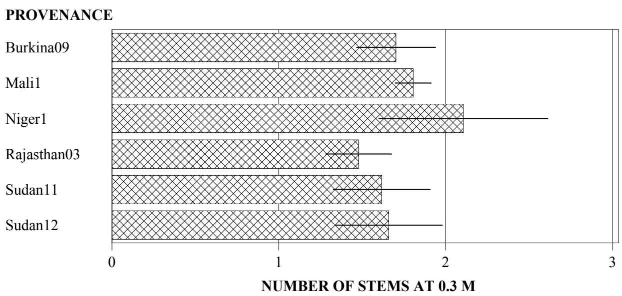

Figure 7. Number of stems for the 6 provenances in the provenance trial atDjibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are least square means with 95 % confidence limits. In the analysis, the number of stems was weighted, and the confidence intervals are therefore of unequal lengths.

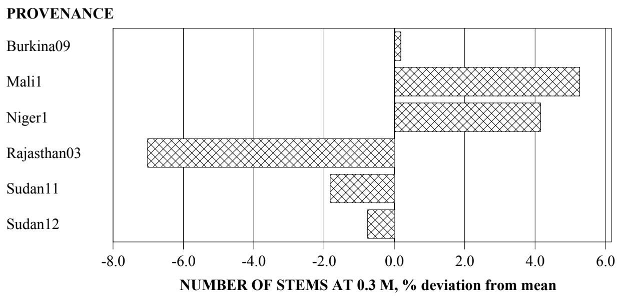

Figure 8. Best linear unbiased predictors (BLUPs) for number of stems in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values are presented as deviations in percent of the mean value.

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 to the production of wood. The basal area of the mean tree is calculated on the live trees only and can be interpreted as a measure of the potential basal area production of the provenance provided that all trees survive.

Statistical analysis

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

Results

As would be expected from the other analyses, Rajasthan03 was again the smallest provenance with a basal area of the mean tree of only 3 cm^2 $tree^{-1}$. The other provenances had basal areas in the range from 36 to 42 cm^2 $tree^{-1}$with Niger1 as the extreme of 55 cm^2 $tree^{-1}$ (Fig. 9). The differences between the provenances were significant with and without Rajasthan03, even though the significance without Rajasthan03 disappeared when accounting for multiple comparisons (Table 6). Fig. 10 indicates that there are substantial gains by choosing the provenance Niger1 instead of the other provenances, although these gains are less substantial if one excludes the provenance from Rajasthan.

Table 6. Results from analysis of variance of provenance differences of basal area of the mean tree in trial 5.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	5	1751	20.2	<0.0001	***
Block	5	734	8.5	<0.0001	
Error	25	87			
Without Rajasthan03					
Provenance	4	353	3.8	0.02	n.s.
Block	5	774	8.3	0.0002	
Error	20	92			

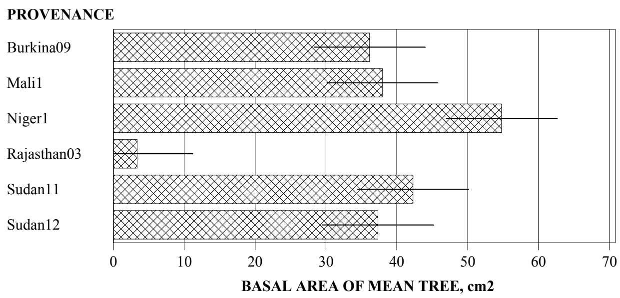

Figure 9. The basal area of the mean tree for the 6 provenances in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are least square means with 95 % confidence limits.

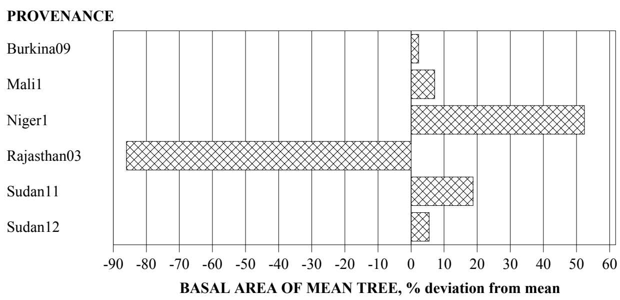

Figure 10. Best linear unbiased predictors (BLUPs) for basal area of the mean tree in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.6 Total basal area

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

Statistical analysis

The analysis of total basal area was straightforward, and no transformations or weights were used.

Results

The provenance Rajasthan03 had the smallest total basal area with a value of less than 0.1 m^2 ha^{-1}, and with this provenance included the provenance effect was highly significant (Fig. 11, Table 7). The other provenances had basal areas between 1.25 and 2.3 m^2 ha^{-1} with Niger1 as the biggest. For Niger1 this corresponds to an average annual growth of a little less than 0.5 m^2 ha^{-1}. However, without Rajasthan03 the differences between provenances were on the limit of significance, and after correction for multiple comparisons they were no longer significant (Table 7). Again the data indicate that there are substantial gains by choosing the best provenances, but only if the provenance from Rajasthan is included (Fig. 12).

Table 7. Results from analysis of variance of provenance differences of total basal area in trial 5.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	5	3.48	10.3	<0.0001	***
Block	5	2.19	6.5	0.0005	
Error	25	0.34			
Without Rajasthan03					
Provenance	4	0.97	2.8	0.05	n.s.
Block	5	2.50	7.3	0.0005	
Error	20				

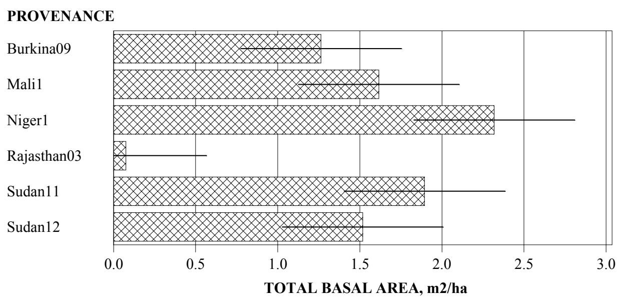

Figure 11. Total basal area for the 6 provenances in the trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are least square means with 95 % confidence limits.

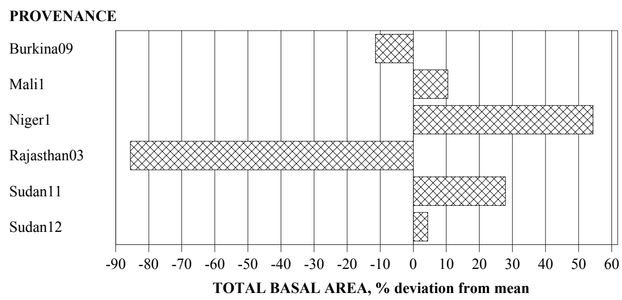

Figure 12. Best linear unbiased predictors (BLUPs) for total basal area in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.7 Dry weight of the mean tree

The dry weight of the mean tree is comparable to the basal area of the mean tree in that they both are calculated on the live trees only and thus can be interpreted 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 estimation of the dry weight is the basal area. However, an important difference is that the dry weight includes a cubic term (in comparison to basal area having only a square term), meaning that large trees with a large dry mass are weighted heavily in this variable.

Statistical analysis

The analysis was performed without transformations or weights.

Results

There were highly significant differences between the provenances in the dry weight of the mean tree (Table 8). Rajasthan03 had the lowest dry weight with only 0.6 kg tree^{-1}, and Niger1 was again taking the lead with 16 kg tree^{-1}. The rest of the provenances had dry weights in the range of 10 to 12 kg tree^{-1} (Fig. 13). The difference between provenances was significant even without the provenance from Rajasthan, although the differences without Rajasthan03 were no longer significant when the correction for multiple comparisons was made. According to Fig. 14, the gain by using Niger1 instead of a random sample of provenances would be more than 50 %.

Table 8. Results from analysis of variance of provenance differences of dry weight of the mean tree in trial 5.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	5	154	14.5	<0.0001	***
Block	5	78	7.3	0.0003	
Error	25	11			
Without Rajasthan03					
Provenance	4	39	3.5	0.02	n.s.
Block	5	85	7.7	0.0004	
Error	20	11			

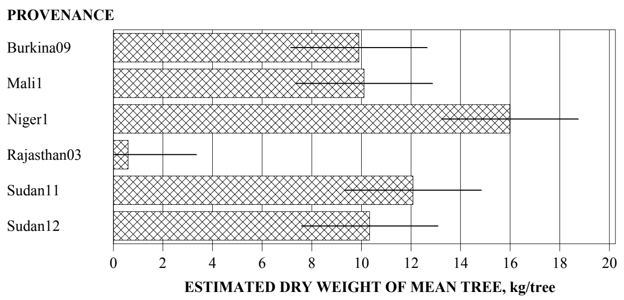

Figure 13. Dry weight of the mean tree for the 6 provenances in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are least square means with 95 % confidence limits.

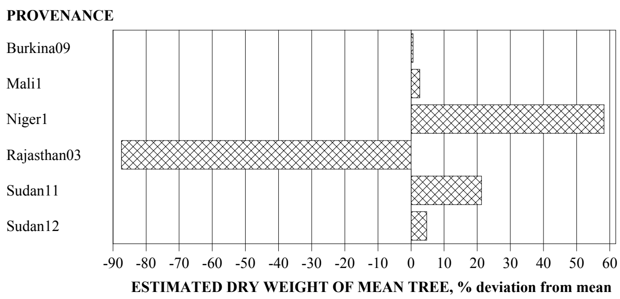

Figure14. Best linear unbiased predictors (BLUPs) for dry weight of the mean tree in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.8 Total dry weight

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

Statistical analysis

Both with and without the provenance from Rajasthan, the simple model without weights and transformations model was applied.

Results

There were large and highly significant differences in the production of biomass between the provenances. Rajasthan03 had a production of only 0.13 t ha^{-1}, whereas Niger1 had a production of 6.8 t ha^{-1} (Table 9, Fig. 15). For Niger1 this corresponds to a production of almost 1.4 t ha^{-1} annually. The rest of the provenances were intermediate with an average total dry weight between 3.5 and 5.5 t ha^{-1}, Sudan11 being the second largest producer. When Rajasthan03 was excluded from the analysis, the differences between provenances were barely significant and were no longer significant when accounting for multiple comparisons (Table 9). Thus differences between the rest of the provenances should be interpreted cautiously. The predicted gains by choosing Niger1 are large, but again it should be remembered that it might not be fair to include the provenance from Rajasthan in the mean value (Fig. 16).

Table 9. Results from analysis of variance of provenance differences of total dry weight in trial 5.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	5	30.4	8.4	<0.0001	***
Block	5	22.3	6.2	0.0008	
Error	25	3.6			
Without Rajasthan03					
Provenance	4	10.0	2.8	0.06	n.s.
Block	5	25.9	7.1	0.0006	
Error	20	3.6			

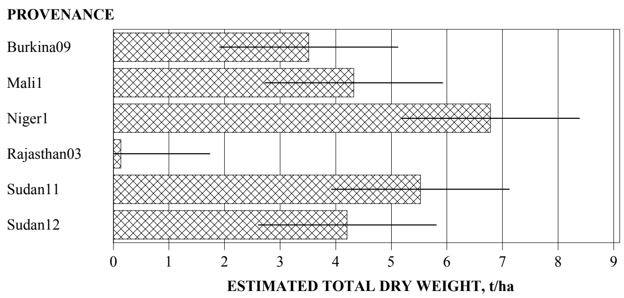

Figure 15. Total dry weight for the 6 provenances in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values presented are least square means with 95 % confidence limits.

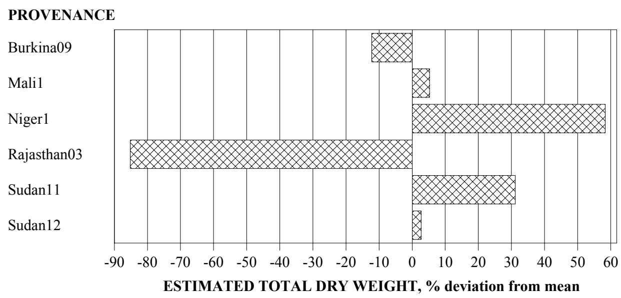

Figure 16. Best linear unbiased predictors (BLUPs) for total dry weight in the provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.9 Multivariate analysis

The multivariate analysis included the eight variables analysed in the univariate analyses. All the variables were used without transformations. Again two analyses were made: one with and one without the provenance Rajasthan03.

Analysis of all provenances

The two first canonical variates accounted for 88 % of the variation, and both were highly significant (Table 10, left half). Differences between the provenances were highly significant (P-values for Wilk's lambda and Pillai's trace both below 0.0001).

The plot of scores for the two first canonical variates is given in Fig. 17 together with the mean values for the provenances and their approximate 95 % confidence regions. In the interpretation of the diagram the distance between provenances is assumed to be proportional to the "genetic distance", i.e. the further apart, the more different the provenances. It is clear from the diagram that the Indian provenance Rajasthan03 is distant from the other provenances, which appear to lie in a cluster. This support the observation from the univariate analyses, indicating that Rajasthan03 behaves very different from the other provenances.

Analysis without Rajasthan03

Since Rajasthan03 acted completely differently from the other provenances and was far from these in the canonical variate analysis, it is likely that it dominated the analysis, meaning that in the diagram the differences between the other provenances do not appear clearly. Therefore another analysis was made without Rajastahn03.

Again the first two canonical variates were significant, this time accounting for 90 % of the variation (Table 10, right half). The differences between the provenances were also significant, but not as much as in the analysis of all provenances (P for Wilk's lambda=0.0008, P for Pillai's trace=0.003). Still the provenances separated very clearly in the score plot (Fig. 18). The provenances Niger1, Sudan11 and Mali1 were separated from each other as well as from the two last provenances. Apparently there were only minor differences between Burkina09 and Sudan12. There was no conspicuous clustering of the provenances, and it is noteworthy that the two provenances from Sudan were quite separate from each other, indicating the existence of different races of *A. senegal* within Sudan.

Table 10. Results from the canonical variate analyses for the first two canonical variates in trial 5, with and without Rajasthan03.

Analysis	**All provenances**		**Without provenance from India**	
Canonical variate no.	**1**	**2**	**1**	**2**
Proportion of variation accounted for	63	25	59	31
Significance, P-value	<0.0001	0.001	0.0008	0.04
Raw canonical coefficients				
Survival	3.8	-11.0	8.7	-3.8
Height	4.3	-8.7	9.3	-2.4
Crown area	0.03	0.2	0.05	0.8
Number of stems	0.4	-1.6	2.0	1.8
Basal area of mean tree	0.7	1.4	-0.4	1.3
Total area basal area	-10.1	-4.6	-7.2	-23.3
Dry weight of mean tree	-2.3	-3.9	0.7	-4.5
Total dry weight	3.4	2.7	1.8	8.6
Standardised canonical coefficients				
Survival	0.54	-1.5	1.1	-0.49
Height	2.42	-4.9	3.5	-0.91
Crown area	0.15	0.88	0.16	2.9
Number of stems	0.16	-0.65	0.82	0.7
Basal area of mean tree	12.4	25.7	-6.8	19.9
Total area basal area	-9.8	-4.4	-6.4	-20.8
Dry weight of mean tree	-13.3	-23.2	3.6	-23.6
Total dry weight	10.4	8.2	5.3	24.9
Canonical directions				
Survival	0.8	-0.2	8.7	-3.8
Height	4.3	0.4	9.2	-2.4
Crown area	24.1	12.7	0.05	0.8
Number of stems	0.8	1.0	2.0	1.8
Basal area of mean tree	107.7	80.6	-0.4	1.2
Total area basal area	5.4	2.8	-7.2	-23.3
Dry weight of mean tree	32.5	26.5	0.69	-4.5
Total dry weight	16.0	9.5	1.8	8.6

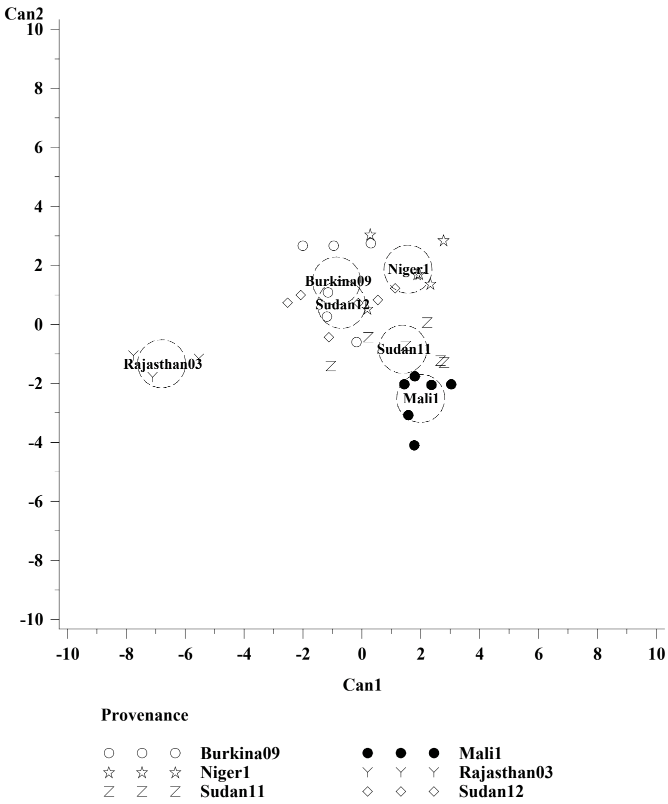

Figure 17. Score plot of the first and the second canonical variate from the canonical variate analysis of all provenances in the *A. senegal* provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). The variables survival, height, crown area, number of stems, basal area of the mean tree, total basal area, dry weight of the mean tree and total dry weight were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.

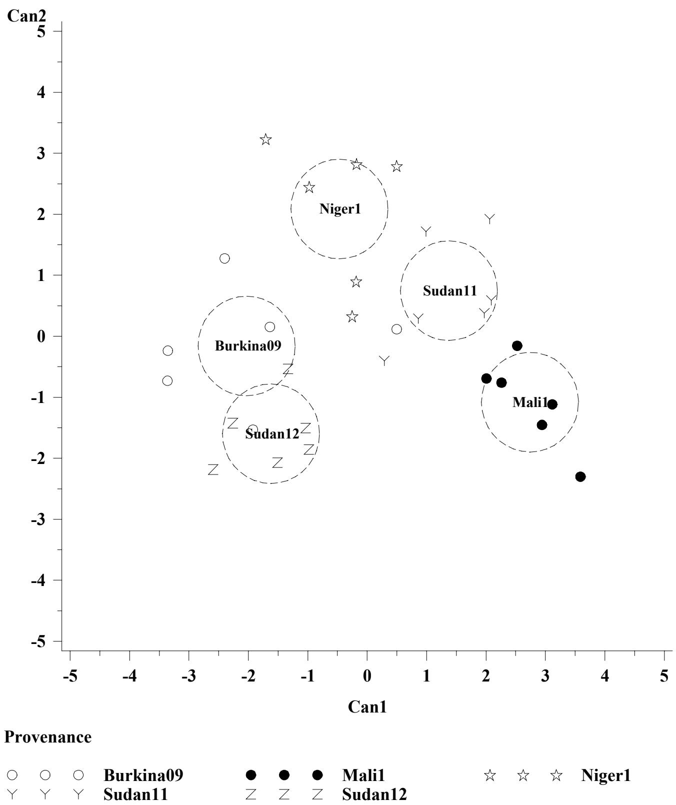

Figure 18. Score plot of the first and the second canonical variate from the canonical variate analysis for the 5 provenances, excluding Rajasthan03, in the *A. senegal* provenance trial at Djibo, Burkina Faso (Trial no. 5 in the arid zone series). The variables survival, height, crown area, number of stems, basal area of the mean tree, total basal area, dry weight of the mean tree and total dry weight were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.

5. Discussion and conclusions

Productivity

The provenance with the highest dry weight (Niger1), had an annual production of approximately 1.4 t ha^{-1} y^{-1}. This is more than double the amount produced by the best provenance of the comparable trial of *A. senegal* in Dori, but slightly less than in the trial at Gonsé. The same trend appeared when considering the average dry weight (of all provenances) and height growth.

Gonsé is situated 200 km south of Djibo and has a higher precipitation than Djibo. Therefore it would be expected that production would also be somewhat higher. Dori, on the other hand, is situated at the same latitude as Djibo in the same climatic zone but 175 km to the east. The soil at Djibo may be a bit more clayey than at Dori (DFSC 1994), but apart from that there are no obvious differences explaining the variation in growth between the two sites.

Provenance differences

The provenance from India, Rajasthan03, was clearly the inferior of the provenances. In all variables except number of stems, Rajasthan03 was significantly smaller than the provenances from Africa, and also in the multivariate analysis there was a large distance between the Rajasthan03 and the rest. Thus this provenance cannot be recommended for use in areas similar to the trial in Djibo. The reason for the poor adaptability of Rajasthan03 could be that this provenance was introduced to India with subsequent landrace formation and possible genetic narrowing.

Differences were not as pronounced between the rest of the provenances, but there were several signs that the provenances differed. The differences in height and crown area were significant, and the variables with basal area and dry weight were at the border of significance (acknowledging that the significance disappeared when accounting for multiple comparisons). For all these variables, Niger1 and Sudan11 took the lead, while Mali1, Sudan12 and Burkina09 were at the intermediate to low end. It is important to stress that the differences between the five provenances in this group are moderate, and that all provenances seem to have an acceptable performance at the site. Nevertheless, in the ultimate measure of biomass production, total dry weight, there was a variation from 3.5 to almost 7 t ha^{-1} between the worst and the best provenances in the group, indicating that there may be large gains by selecting the right seed source. It should be noted that this difference was only close to being significant.

Summarising the analysis in a provenance recommendation, it seems that the best choice would be Niger1 or Sudan11. However, there are no local provenances included in the trial, and it would be an advantage to test the exotic provenances against local material before introducing foreign material on a large scale. A more systematic test of the variation in the provenances from the Sahelian area could also reveal whether provenances with origin in dryer climates are doing better than provenances from more humid areas. Niger1, Sudan11 and Mali1 belong to the Sahelian phytogeographical group, whereas Burkina09 and Sudan12 belong to the Sudanian group (White 1981). In a period with dryer climate it would be natural to assume that provenances adapted to the dry climates of the Sahel would do better than provenances from the southern and more wet areas. However, the number of provenances in this trial is not sufficient to allow for such conclusions.

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Annex 1. Description of the trial site

Name of site:	Djibo, Burkina Faso Latitude: 14°06'N Longitude: 01°37'W
Meteorological station:	Djibo (14°06'N, 01°37'W (Graf et al. 1989))
Rainfall:	Annual mean (period): 574 mm (1961-70)(Graf *et al.* 1989)) 410.1 (1971-80 (Graf *et al.* 1989)) 298 (1981-87 (Graf *et al.* 1989)) Yearly registrations: 1981: 457.7 1982: 308.8 1983: 322 1984: 226.5 1985: 174.7 1986: 298.5 1987: 297.6
Rainy season:	June-September Type: Normal with dry period
Dry months/year:	No. of dry months (<50 mm): 8-10 No. of dry periods: 1
Temperature (°C):	Annual mean: Coldest month: Hottest month:
Wind:	Prevailing directions: L'harmattan ENE (dry season) La mousson SSW
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, Balanites aegyptiaca*).
Koeppen classification:	BSh

Annex 2. Seedlot numbers

Provenances of *Acacia senegal* tested in trial no. 5 at Djibo, 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	Country of origin	Plot	Provenance site	Country of origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
Burkina09		309 (CNSF)	6	Lac Dem, Kaya, Sanmatenga	Burkina Faso	13°06'N	01°05'E	311	700	
Mali1		87/7496N (CTFT)	5	Kadiel N.E. De Nioro	Mali	15°20'N	09°27'W	100	490	24
Niger1		87/7490N (CTFT)	4	Kardofane	Niger	14°20'N	06°10'E	320	387	23
Rajasthan03	1224/83	85/4784N (CIRAD)	1	Jodhpur (Cazri)	India	26°19'N	73°08'E	210	325	7
Sudan11	1332/84	85/04786N (CIRAD)	2	Northern Kordofan	Sudan	13°10'N	30°14'E	570	365	27
Sudan12	1333/84	3/1984 (FRC), 85/4787N (CIRAD)	3	Wad Elnail, Singa	Sudan	12°30'N	34°05'E	440	600	30

Annex 3. Layout of the trial

Layout of blocks in the field
The numbers refer to the plot numbers given in Annex 2, corresponding to individual trees of each provenance.

	y			
	36	5 6 4 2 1 3	1 2 4 3 6 5	
	35	5 1 2 6 3 4	5 4 6 2 1 3	
	34	6 3 1 2 4 5	2 3 5 1 4 6	
	33	1 5 4 3 6 2	2 5 1 4 3 6	
	32	1 4 3 2 6 5	4 6 1 5 2 3	
	31	2 3 6 4 5 1	6 5 1 2 3 4	
BLOCK 5	30	5 6 3 2 4 1	3 6 1 4 2 5	BLOCK 6
	29	4 6 5 2 3 1	5 1 4 6 3 2	
	28	2 5 4 1 6 3	6 2 1 4 5 3	
	27	2 5 3 6 1 4	4 1 2 3 6 5	
	26	1 5 3 4 2 6	3 2 6 5 4 1	
	25	5 2 4 6 3 1	4 1 6 2 5 3	
	24	2 5 1 6 4 3	1 5 4 6 2 3	
	23	5 1 4 6 3 2	6 4 2 5 1 3	
	22	1 6 5 2 3 4	3 6 4 1 5 2	
	21	6 2 3 5 4 1	3 4 2 5 1 6	
	20	1 4 2 3 5 6	1 2 3 5 4 9	
	19	5 2 3 6 4 1	4 1 6 5 2 3	
BLOCK 3	18	3 1 4 5 6 2	5 4 3 6 2 1	BLOCK 4
	17	3 4 5 2 1 6	1 5 2 6 4 3	
	16	5 6 4 1 2 3	6 4 2 3 5 1	
	15	1 3 6 4 2 5	1 5 2 4 6 3	
	14	2 6 5 1 4 3	4 5 1 3 2 6	
	13	4 2 6 3 5 1	5 1 3 4 2 6	
	12	3 4 2 5 1 6	5 6 4 3 1 2	
	11	6 3 2 5 4 1	5 1 4 2 3 6	
	10	3 5 2 1 6 4	6 5 4 2 3 1	
	9	6 2 4 1 3 5	3 5 4 2 1 6	
	8	6 5 3 2 1 4	5 3 6 4 2 1	
	7	1 4 6 5 3 2	3 2 6 1 4 5	
BLOCK 1	6	6 5 1 3 4 2	3 5 2 4 6 1	BLOCK 2
	5	6 1 2 3 4 5	4 6 1 5 3 2	
	4	3 6 2 1 5 4	5 2 3 1 6 4	
	3	2 4 1 5 6 3	6 1 5 4 3 2	
	2	2 6 4 5 1 3	2 3 6 1 5 4	
	1	4 1 6 2 5 3	6 1 5 3 4 2	
		1 2 3 4 5 6	7 8 9 10 11 12	x

Annex 4. Plot data set

The values are means or sums for each provenance in each block.

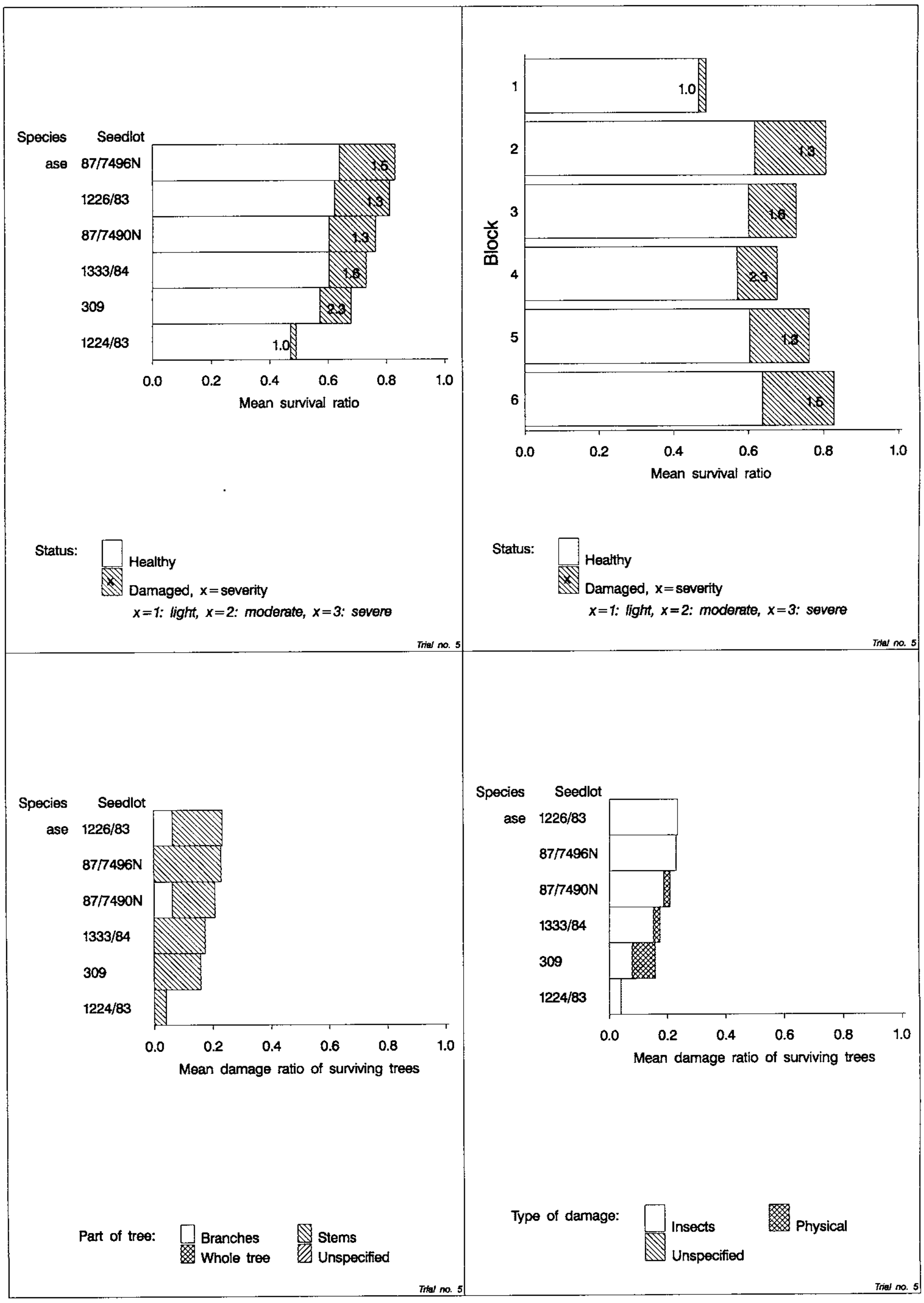
Block	Provenance	Survival	Height	Crown area	Number of stems	Basal area of mean tree	Total basal area	Dry weight of mean tree	Total dry weight
		proportion	m	m^2 $tree^{-1}$	no. $tree^{-1}$	cm^2 $tree^{-1}$	m^2 ha^{-1}	kg $tree^{-1}$	tons ha^{-1}
1	Burkina09	0.78	2.07	6.33	1.83	31.3	1.14	8.45	3.08
1	Mali1	0.89	2.61	7.38	1.50	30.8	1.28	8.04	3.35
1	Niger1	0.64	2.86	10.12	2.29	49.6	1.81	14.15	5.16
1	Rajasthan03	0.38	0.33	0.20		1.0	0.02	0.11	0.02
1	Rajasthan04	0.78	2.49	8.67	1.17	34.8	1.27	9.75	3.55
1	Sudan12	0.67	1.80	3.79	1.20	15.7	0.49	3.38	1.06
2	Burkina09	0.71	2.36	6.17	1.20	17.3	0.45	3.72	0.97
2	Mali1	0.88	3.06	6.95	1.57	37.3	1.36	9.88	3.60
2	Niger1	0.60	2.77	9.98	2.83	52.0	1.63	15.41	4.82
2	Rajasthan03	0.50	0.45	0.20		1.0	0.01	0.11	0.01
2	Rajasthan04	0.63	2.26	5.20	1.60	13.2	0.34	2.66	0.69
2	Sudan12	0.80	2.05	4.31	1.25	18.1	0.76	4.08	1.70
3	Burkina09	0.64	2.71	13.72	2.17	61.2	2.23	18.07	6.59
3	Mali1	0.82	3.14	12.18	2.33	51.9	2.43	14.88	6.97
3	Niger1	0.90	3.19	18.73	2.11	71.7	3.36	21.70	10.17
3	Rajasthan03	0.40	1.63	6.55	2.00	12.5	0.26	2.57	0.54
3	Rajasthan04	1.00	3.32	16.20	1.36	73.3	4.20	23.58	13.51
3	Sudan12	0.73	2.88	11.61	2.50	58.6	2.44	16.76	6.98
4	Burkina09	0.80	2.63	13.76	1.71	54.4	2.27	16.44	6.85
4	Mali1	0.71	2.60	8.98	1.80	32.4	0.84	8.18	2.13
4	Niger1	1.00	2.87	12.62	1.80	56.4	2.94	16.84	8.77
4	Rajasthan03	0.67	1.08	1.18	1.25	2.9	0.09	0.45	0.14
4	Rajasthan04	1.00	2.85	13.23	2.00	50.0	2.08	14.32	5.97
4	Sudan12	0.82	2.43	9.57	1.33	36.4	1.71	10.03	4.70
5	Burkina09	0.60	1.97	6.13	1.50	23.2	0.72	5.57	1.74
5	Mali1	0.73	2.71	9.77	1.63	34.7	1.45	8.93	3.72
5	Niger1	0.82	2.81	13.18	1.89	54.9	2.58	15.66	7.34
5	Rajasthan03	0.55	0.85	0.97	1.50	1.8	0.06	0.23	0.07
5	Rajasthan04	0.83	2.81	11.15	1.90	43.0	2.24	11.87	6.18
5	Sudan12	0.73	2.58	10.25	1.50	45.5	1.90	12.96	5.40
6	Burkina09	0.56	1.98	7.62	1.80	29.5	0.77	7.13	1.86
6	Mali1	0.92	2.81	12.99	2.00	40.6	2.32	10.75	6.16
6	Niger1	0.64	2.67	12.63	1.71	44.0	1.60	12.17	4.44
6	Rajasthan03	0.44	0.43	0.20		1.0	0.02	0.11	0.02
6	Rajasthan04	0.60	2.83	14.24	1.67	39.5	1.23	10.34	3.23
6	Sudan12	0.64	2.56	9.86	2.17	49.7	1.81	14.79	5.39

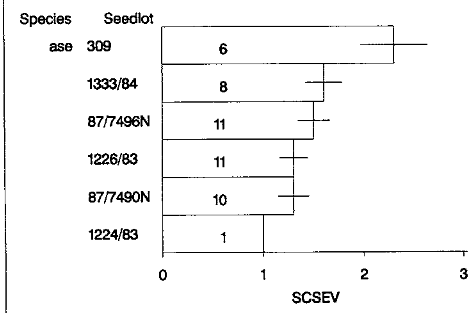
Annex 5. Graphical presentation of the health data

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.

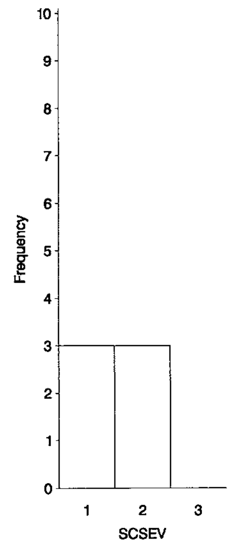
Please note that the seedlot codes correspond to the numbers given in annex 2.





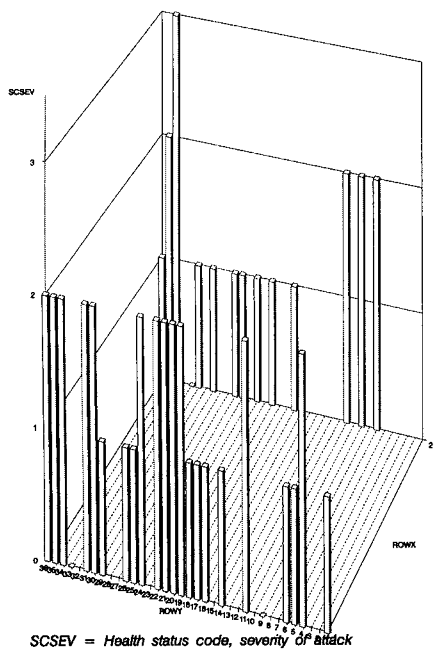
Mean SCSEV of seedlot with error bar line (+/− standard deviation of the mean) and the average number of assessed (living) trees per seedlot.

Trial no. 5



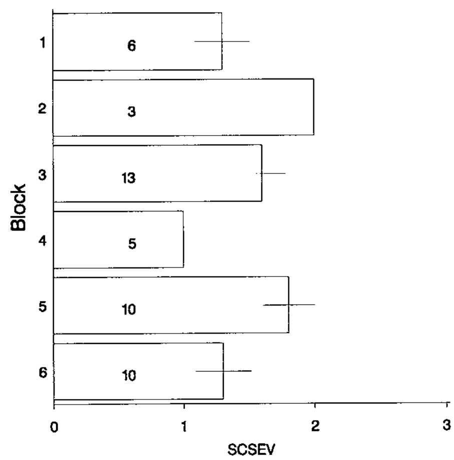
Frequency distribution of seedlot mean values

Trial no. 5



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

Trial no. 5



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

Trial no. 5