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Evaluation of a provenance trial of *Acacia senegal* at Gonsé, Burkina Faso

Trial no. 12 in the arid zone series

by

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The sign at the trial site, Gonsé, Burkina Faso and a close-up of 'gum arabic' oozing from *A. senegal* at the site. Phot: Lars Graudal, DFSC. 1993.

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

Preface

This report belongs to a new series of analysis reports published by the Danida Forest Seed Centre. It is the intention that the series should serve as a place for publication of trial results for the Centre itself as well as for our collaborators. The reports will be made available from the DFSC publication service and online from the web-site www.dfsc.dk. The scope of the series is in particular the large number of trials from which results have not been made available to the public, and which are not appropriate for publication in scientific journals. We believe that the results from these trials will contribute considerably to the knowledge on genetic variation of tree species in the tropics. Also, the analysis report will allow a more detailed documentation than is possible in scientific journals.

At the same time, the report represents the first results within the framework of the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species', initiated by FAO. Following collection and distribution of seed between 1983-87, a large number of trials were established by national institutions during 1984-1989. An international assessment of 26 trials took place from 1990 to1994. DFSC is responsible for the reporting of this assessment.

This trial was established and maintained by Centre National de Semences Forestières (CNSF), in Burkina Faso in collaboration with IBN-DLD (Institute for forest and Nature Research, Wageningen), The Netherlands. The assessment team consisted of Traoré Adama (CNSF), Diallo Boukary, Kiemdrébéogo Karim, Kaboré Ousmane, Sawadogo Abel, all from IRBET (Institut de Recherche en Biologie et Ecologie Tropical, Burkina Faso, now INERA), Agnete Thomsen (FAO) and Lars Graudal (DFSC).

The authors wish to acknowledge the help of the personnel at CNSF with the establishment, maintenance and assessment 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 by Marcus Robbins, consultant to FAO.

Abstract

This report describes results from the analysis of a trial including 10 provenances of *Acacia senegal.* The trial was established with a spacing of 4 x 4 metres in 1988 at Gonsé in Burkina Faso. The assessment took place after 5 years in 1993, and included a number of vegetative and growth characters. Gum production was not measured. The provenances included a selection of Sahelian seedlots (Burkina Faso, Senegal and Sudan) and two provenances from Sind in Pakistan.

There were several highly significant differences between the provenances. The provenances from Pakistan had a poor survival and growth and were clearly not adapted to the site. The African provenances had a much better performance, and two provenances from Senegal and one from Burkina Faso had the fastest growth at the site. The dry weight production of the best provenances was almost 2 tons ha^{-1} y^{-1}. There were significant differences both within the provenances from Senegal and within the provenances from Burkina Faso, documenting genetic variation within short distances.

Résumé en français

Le présent rapport décrit les résultats obtenus d'un essai comparatif de dix (10) provenances de *Acacia senegal.* Ces provenances comprennent d'une part les lots de semences sahelo-sahariennes du Burkina Faso, du Sénégal et du Soudan ainsi que deux provenances originaires de Sind au Pakistan. L'essai a été mis en place en 1988 à Gonsé (Burkina Faso) suivant un écartement de 4 x 4 m. Les mensurations ont eu lieu en 1993, soit 5 ans après l'implantation de l'essai. La production de gomme n'a pas été évalué.

L'analyse a révélé quelques hautes différences significatives entre les provenances. Les provenances du Pakistan avaient un taux de survie et une croissance faible ces dernières paraissaient clairement non adoptées au site. Les provenances africaines avaient des performances bien meilleures : deux (2) provenances du Sénégal et une du Burkina Faso avaient les croissances les plus rapides sur le site. La productivité en matière sèche des meilleures provenances était toujours de 2tha $^{-1}$ an $^{-1}$. Des différences significatives existaient entre les provenances du Sénégal et également entre celles du Burkina, traduisant une variation génétique entre populations peu distantes les unes des autres.

Contents

1. Introduction

This report describes the results from trial no. 12 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.).

This trial includes ten provenances of *Acacia senegal*. It is the species from which most of 'gum Arabic' is 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 from this trial represent a selection from Burkina Faso, Senegal, Sudan and Pakistan and are all supposedly of the variety *senegal*, even though this is not clear from the collection sheets.

2. Materials and methods

2.1 Site and establishment of the trial

The trial is placed at Gonsé (12°22′N, 01°19′W) in Burkina Faso at an altitude of 300 m. The trial is thus established south of the natural range of the species. The mean annual temperature is 28.1 °C, and the annual rainfall is 679 mm with a dry period of eight months. Further information is given in the assessment report (DFSC 1994) and summarised in Annex 1.

Seed was sown in April 1988. Prior to planting, the soil was scarified to a depth of 60 cm in the planting rows with a one-tooth plough on a D7 bulldozer. The trees were planted in August 1988, and the trial was beaten up until four weeks after establishment. Weeding took place once a year.

2.2 Provenances

The trial includes 10 provenance of *A. senegal* (Table 1). Five provenances are from Senegal, two are from Pakistan and one is from Sudan. The trial also includes two local provenances from Burkina Faso, thus representing a wide range of the natural distribution of the species. For convenience, the provenances in Table 1 have been given names relating to their geographical origin (name of province or country followed by a number). The original seedlot numbers are provided in Annex 2.

Table 1. Provenances of *Acacia senegal* tested in trial no. 12 at Gonsé, Burkina Faso. Data from seed suppliers except 1) Pigeonnière & Jomni (1998), data from before 1970 and 2) Pélissier (1981), data from before 1981.

Provenance identification	Seed collection site	Country of origin	Latitude	Longitude	Altitude (m)	Precipitation (mm)	No. of mother trees
Burkina10	Boron, Nouna	Burkina Faso	12°44'N	03°52'W		900[1]	
Burkina13	Lac Dem, Kaya	Burkina Faso	13°05'N	01°05'W		750[1]	
Senegal23	Windou Tiengoly, Linguere	Senegal	15°59'N	15°20'W	39	350	32
Senegal24	Namarel, Podor	Senegal	14°46'N	16°01'W	50	332	33
Senegal25	Diaguely, Linguere	Senegal	15°15'N	14°40' W		400	
Senegal26	Gueye Kadar, Podor	Senegal	15°52'N	14°20'W	58	309	50
Senegal31	Thiarene, Dagana	Senegal	16°68'N	15°35'W		300[2]	30
Sind07	Dhabiji, Thatta	Pakistan	24°49'N	67°32'E	24	204	25
Sind08	Loonio, Tharparkar	Pakistan	24°38'N	70°31'E	50	735	25
Sudan11	Fallatu Forest, Elobeid	Sudan	13°10'N	30°14'E	570	365	27

2.3 The experimental design

The experimental design is a single tree plot design with 50 blocks. Within each block each provenance was represented by one tree. The trees were planted with a spacing of 4 × 4 m. The layout of the trial is shown in Annex 3. Further details are given in DFSC (1994).

2.4 Assessment of the trial

In March 1993 CNSF, IRBET, FAO and DFSC undertook a joint assessment. The assessment included the characters survival, vertical height, diameter at 0.3 m, number of stems at 0.3 m, crown diameter and health. The single tree data set on which part of the statistical analyses in this trial are performed is documented in DFSC (1994), whereas the super-block data upon which another part of the analysis was performed is shown in Annex 4. The assessment methods are described in detail by DFSC (Graudal *et al.* 2003).

3. Statistical analyses

3.1 Variables

In the report 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

Furthermore a number of health characters were evaluated, but since the trees were generally in good health and there were only small apparent differences between the provenances, these characters are not analysed in the present report. Instead a graphical presentation of the results of the health assessment is given in Annex 5.

Since the trial is a single tree plot, some special problems arise. Analysing area-based measures is difficult since there is only one tree on each plot in the block. In order to analyse survival and total production (of basal area and biomass) we constructed five 'super-blocks', each consisting of 10 of the small blocks. For these super-blocks the average survival was calculated for each provenance as the proportion of surviving trees to the number of trees originally planted. The area related variables, total basal area and total dry weight, were calculated as the sum of the variables for each super-block and provenance and then related to the growth space of the trees, expressing the variables on an area basis. The single tree data set was used for the other variables in the univariate analyses. However, in the multivariate analysis all variables were included as super-block values (averages or sums). It should be noted that the area-based variables may tend to ignore competition between different seedlots.

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 the omission of these data will produce biased results and lead to an over-estimation of the provenances in question, the values for basal area and dry weight have been set to zero, and for crown area to 1 m^2. There is no reasonable way to estimate the number of stems of such trees, and no default value has been set for this variable. In any case, the estimates of these variables will be slightly biased.

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 statistical software package used was the Statistical Analysis System (SAS 1988a, 1988b, 1991, Littell *et al.* 1996).

Each variable was analysed in two stages. First stage was a test of differences between all provenances. However, the provenances from Pakistan behaved very differently from the rest of the provenances, and additional tests with only the African provenances were made for each variable to see whether the differences were significant without these provenances. In both cases the variables were analysed according to the following 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 $N(0, \sigma_e^2)$. It should be noted that in the analysis of survival, total basal area and total dry weight, the block effect was substituted by superblocks.

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

The P-values from the tests were corrected for the effect of multiple comparisons by the sequential tablewide Bonferroni method (Holm 1979). The tests were ranked according to their P values. The test corresponding to the smallest P value (P_1) was considered significant on a 'table-wide' significance level of α if $P_1 < \alpha/n$, where n is the number of tests. The second smallest P value (P_2) was declared significant if $P_2 < \alpha/(n-1)$, and so on (Kjær & Siegismund 1996). The number of tests was set to 8, 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.

A multivariate analysis providing canonical variates, and Wilk's lambda and Pillai's trace statistics, complemented the univariate analyses (Chatfield & Collins 1980, Afifi & Clark 1996, Skovgård & Brockdorf 1998).

A more detailed description of the methods used for the analyses of variance is given in Ræbild *et al.* (2002), and a short description of the analysis of each variable is given in the results section.

4. Results

4.1 Survival

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

Statistical analysis

The statistical analysis was performed on the ratio of surviving trees to the total number of trees, calculated for each of five super-blocks (see above). Even though there were signs of variance heterogeneity, using the arcsine transformation or a weight statement did not improve the residuals, and the results presented are based on the model with un-transformed data. Irrespective of the model assumptions, the plots of raw data clearly supported the conclusions from the models.

Results

There were clear differences in the survival among some of the provenances (Fig. 1). Most provenances had a survival close to 100 %, but the two provenances from Sind in Pakistan had a markedly lower survival of just about 50 %. This was also reflected in the analysis of variance (Table 2). Whereas there were highly significant differences between the provenances when all provenances were included, there were no significant differences without the provenances from Pakistan. In the best provenance, Senegal31, all trees survived. The predicted value for this provenance was 13 % better than the average value (Fig. 2). The provenances from Pakistan had a survival 30 % lower than the mean value.

Table 2. Results from analysis of variance of provenance differences of survival in trial 12.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	9	0.146	20.5	<0.0001	***
Super-blocks	4	0.0010	0.14	0.97	
Error	36	0.0071			
Without Sind-provenances					
Provenance	7	0.0072	1.06	0.41	n.s.
Super-blocks	4	0.0010	0.15	0.96	
Error	28	0.0068			

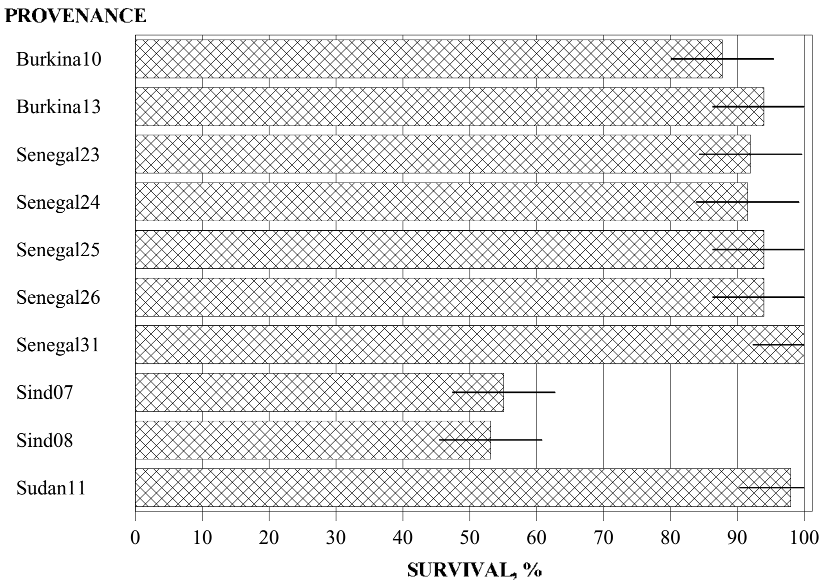


Figure 1. Survival in percent for the 10 provenances in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values presented are least square means with 95 % confidence limits (values above 100 % were truncated).

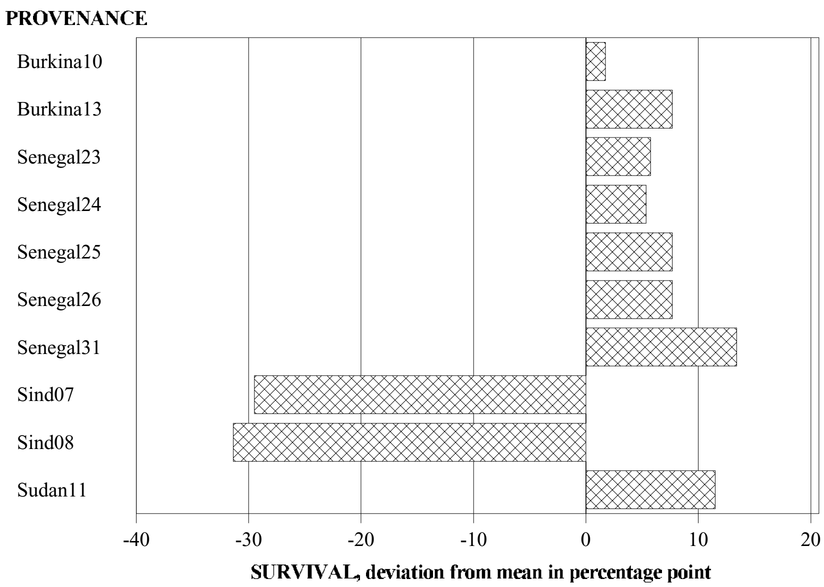


Figure 2. Best linear unbiased predictors (BLUPs) for survival in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values presented are deviations from the mean value in percent.

4.2 Height

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

Statistical analysis
Height was analysed on the single tree data. The analysis of height was straightforward, and no transformations or weights were needed.

Results
There were large and highly significant differences in height between the provenances (Table 3, Fig. 3). The provenances Sind07 and Sind08 from Pakistan had average heights below 1 m, whereas the rest of the provenances had heights of about 2 m.

Even without the provenances from Pakistan there were significant differences in height. Among the highest ranking were the provenances Senegal25, Burkina13 (from Lac Dem) and Sudan11, having heights of approx. 2.5, 2.3 and 2.2 m, respectively. The corresponding BLUP values varied from 67 % below to 34 % above the average value. Apart from the obvious poor adaptation of the Pakistan provenances there were no clear geographical patterns in the height growth of the provenances.

Table 3. Results from analysis of variance of provenance differences of vertical height in trial 12.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	9	10.7	31.0	<0.0001	***
Blocks	49	1.46	4.21	<0.0001	
Error	369	0.35			
Without Sind-provenances					
Provenance	7	1.89	5.32	<0.0001	***
Blocks	49	1.48	4.16	<0.0001	
Error	320	0.36			

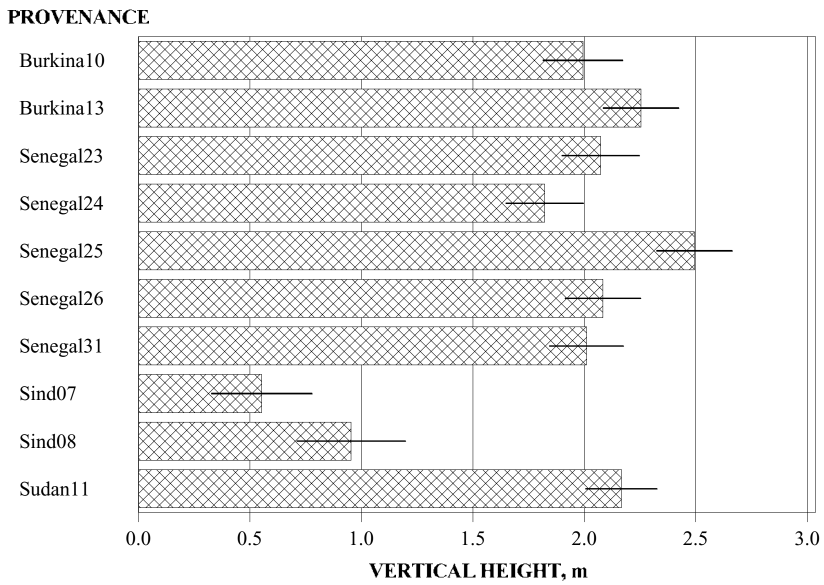


Figure 3. Vertical height for the 10 provenances in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values presented are least square means with 95 % confidence limits.

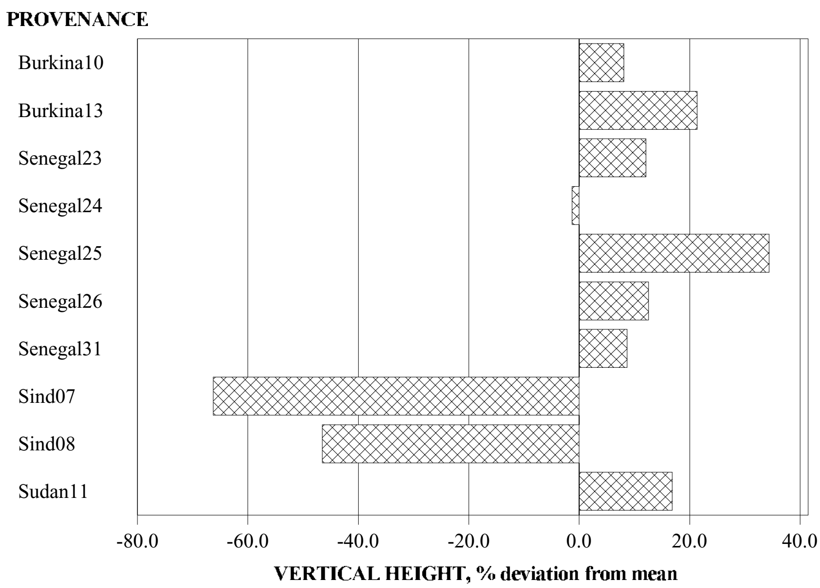


Figure 4. Best linear unbiased predictors (BLUPs) for height in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.3 Crown area

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

Statistical analysis

Crown area was analysed on single tree data. In the assessment, trees below a height of one m were not assessed, and since the distribution of residuals was odd when the crown area for live trees below 1 m was set to zero, the default value was changed to 1 m^2 instead. When interpreting the data, it should be kept in mind that this value is set more or less at random, and may influence the results of the data as well as the estimates. Even after this attempt to even out the residuals there was heterogeneity of variance, and crown area was transformed with the square root before analysis.

Results

The average crown area was 8.9 m^2. Due to the transformation the values in Fig. 5 are biased towards the low end. For example, the provenance with the highest crown area, Burkina13, had a raw mean value of 11.6 m^2, but the back-transformed lsmean value was only 9.5 m^2. However, the differences between the provenances in Fig. 5 are illustrated correctly.

There were highly significant differences between the provenances, mostly due to small crown areas in the provenances Sind07 and Sind08 (Table 4). When these provenances were excluded from the analysis, there was only significance on the 10 % level, and using the sequential Bonferroni tablewide test the significance disappeared completely. The BLUPs varied from −80 % in Sind07 to +40 % in Burkina13, relative to the mean value (Fig. 6).

Table 4. Results from analysis of variance of provenance differences of crown area in trial 12. Values were transformed with the square root before analysis.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	9	14.8	23.4	<0.0001	***
Blocks	49	1.78	2.81	<0.0001	
Error	369	0.64			
Without Sind-provenances					
Provenance	7	1.21	1.84	0.08	n.s.
Blocks	49	1.73	2.63	<0.0001	
Error	319	0.66			

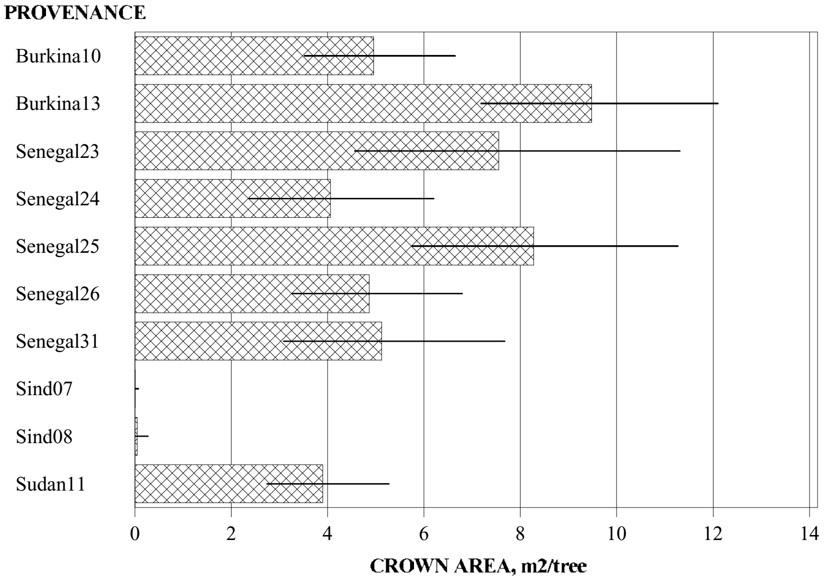


Figure 5. Crown area for the 10 provenances in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Before analysis, the crown area was transformed with the square root. Values presented are back-transformed least square means with 95 % confidence limits. Due to the transformation, the upper and lower confidence intervals are of different length.

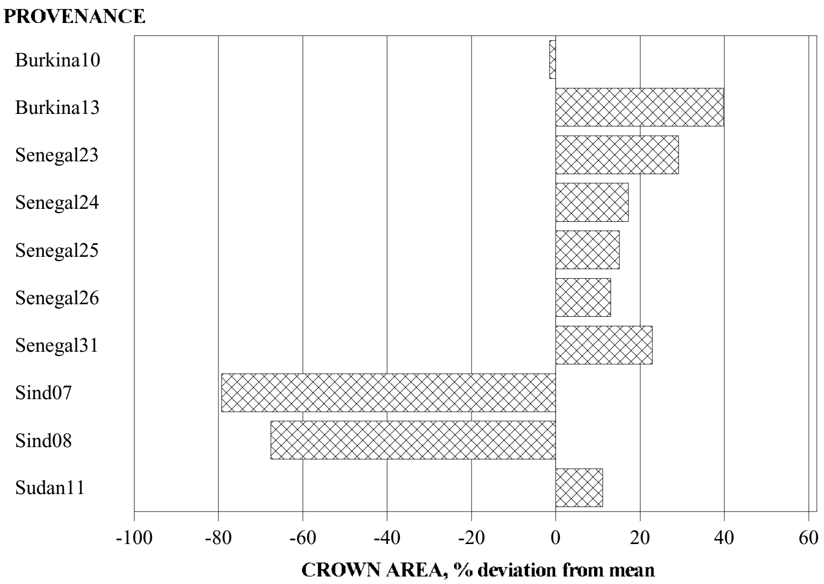


Figure 6. Best linear unbiased predictors (BLUPs) for crown area in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values are presented as deviations in percent of the mean value.

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 bushy, whereas trees with only one stem have a more tree-like growth.

Statistical analysis

The number of stems was analysed on single tree data. The analysis was difficult in the respect that it was impossible to obtain a proper distribution of the residuals. A number of transformations were attempted, and the natural logarithm proved to be the best. Still, the distribution of residuals did not follow the Gauss distribution, and the results should be interpreted cautiously. It should be noted that in all models the result of the test was the same, which may indicate that the results are robust. Another problem is that the number of stems was not registered on trees with heights below 1 m. This is especially prominent in the provenances Sind07 and Sind08, and the estimates for these provenances are therefore likely to be different from the real values.

Results

Acknowledging these reservations, the analysis demonstrated that there were significant differences in the number of stems (Table 5). The average number of stems was 1.8. Again the transformation tend to bias the estimates presented in Fig. 7 towards the lower end. The differences persisted without the provenances from Pakistan.

The provenance with the highest number of stems was Burkina13, with a predicted value for number of stems of 15 % above the average (Fig. 8). The lowest number of stems was found in Sudan11 and Senegal31, having predicted values of 13 % and 8 % below the average value.

Table 5. Results from analysis of variance of provenance differences of number of stems in trial 12. Values were transformed with the natural logarithm before analysis.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	9	0.51	2.84	0.003	**
Blocks	49	0.21	1.14	0.25	
Error	323	0.18			
Without Sind-provenances					
Provenance	7	0.62	3.56	0.001	**
Blocks	49	0.22	1.25	0.13	
Error	311	0.18			

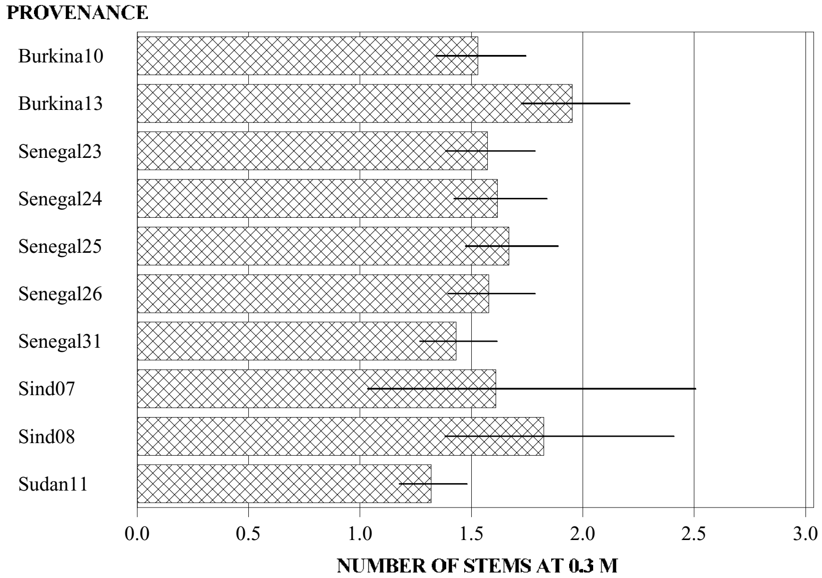


Figure 7. Number of stems for the 10 provenances in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Before analysis, the number of stems was transformed with the natural logarithm. Values presented are back-transformed least square means with 95 % confidence limits. Due to the transformation upper and lower confidence intervals are of unequal length.

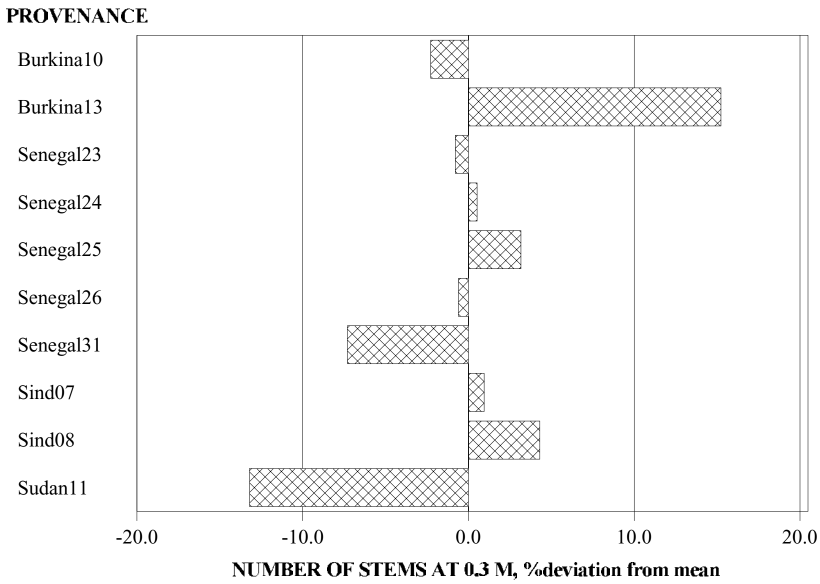


Figure 8. Best linear unbiased predictors (BLUPs) for number of stems in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.5 Basal area of the mean tree

The basal area of the mean tree corresponds to the average basal area for the trees of a specific provenance. Since this estimate is calculated on the live trees only, it can be interpreted as the potential production of the provenance, provided that all trees survive.

Statistical analysis

This variable was analysed on the single tree data. The first analysis demonstrated that there was clear variance heterogeneity, and a number of transformations were tested in order to fulfil the assumptions of the analysis of variance model. Unfortunately a number of very large trees distorted the picture, and it was impossible to obtain a Gaussian distribution of the residuals. The model giving the best distribution of the residuals was a weighted model of the raw data. This was used for presentation, and an analysis without the outliers demonstrated that the conclusions were robust. Since the distribution of residuals was not following the normal distribution, the confidence intervals presented in Fig. 9 will also be somewhat off the real values, but it is difficult to say how much.

Results

The two provenances from Pakistan, Sind07 and Sind08, had the lowest basal areas of the mean tree, being below 10 cm^2 $tree^{-1}$ for both provenances, whereas the rest of the provenances had basal areas varying from 30 to just above 50 cm^2 $tree^{-1}$ (Fig. 9). The differences between the provenances were highly significant, even after the provenances from Pakistan had been removed (Table 6). Burkina13, Senegal23 and Senegal25 had the largest basal areas, corresponding to predicted values of 40 to 50 % above the average value (Fig. 10).

Table 6. Results from analysis of variance of provenance differences of basal area of the mean tree in trial 12. A weight statement was applied to avoid variance heterogeneity.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	9	32.50	30.0	<0.0001	***
Blocks	49	3.49	3.22	<0.0001	
Error	369	1.08			
Without Sind-provenances					
Provenance	7	4.68	4.12	0.0002	***
Blocks	49	3.67	3.24	<0.0001	
Error	319	1.13			

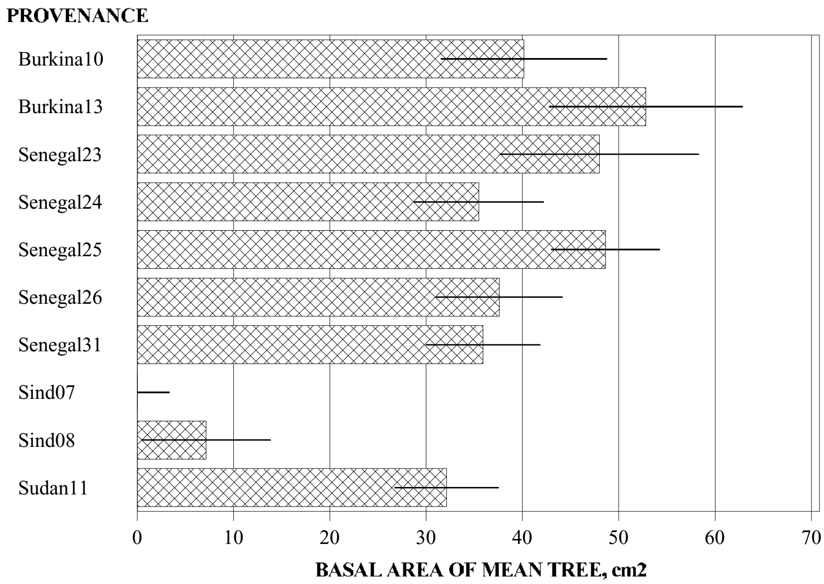


Figure 9. Basal area of the mean tree for the 10 provenances in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values presented are least square means with 95 % confidence limits. The model for analysis of variance was weighted, and the error bars have therefore different lengths.

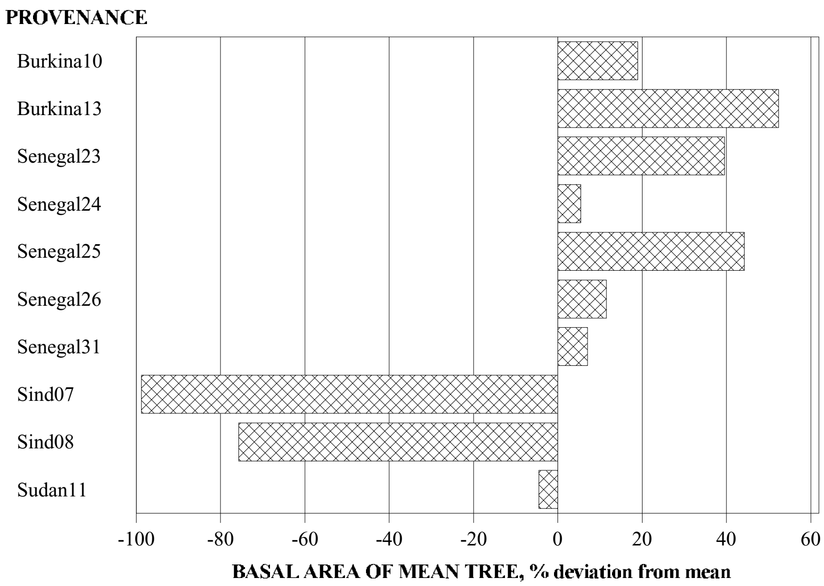


Figure 10. Best linear unbiased predictors (BLUPs) for basal area of the mean tree in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.6 Total basal area

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

Statistical analysis
The total basal area was calculated as the sum of the basal area of the provenance in the super-block and then related to the growing space for each tree, giving in effect a measure of basal area per hectare. It turned out that provenances having large basal areas also had large variances, and a weighted analysis was applied. In the test without the Sind provenances, there were no signs of variance heterogeneity, and the weight statement was not used.

Results
In the five years from establishment to assessment the provenances Sind07 and Sind08 had a basal area growth of less than 0.3 m^{-2}, corresponding to less than 0.05 m^{-2} y^{-1} (Fig. 11). In comparison, the rest of the provenances had basal areas between 2 and 3 m^{-2}, corresponding to basal area growth rates of approximately 0.5 m^{-2} y^{-1}. When all provenances were analysed together, there were highly significant differences, but even without the provenances from Pakistan, the differences were significant (Table 7). The highest-ranking provenance was Burkina13, followed by Senegal23 and Senegal25. These provenances had predicted values in the range of 35 to 55 % above the average (Fig. 12).

Table 7. Results from analysis of variance of provenance differences of total basal area in trial 12. In the test for differences between all provenances a weighted model was applied.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	9	57.7	53.2	<0.0001	***
Super-blocks	4	3.03	2.80	0.04	
Error	36	1.08			
Without Sind-provenances					
Provenance	7	0.873	3.36	0.01	*
Super-blocks	4	0.657	2.54	0.06	
Error	28	0.259			

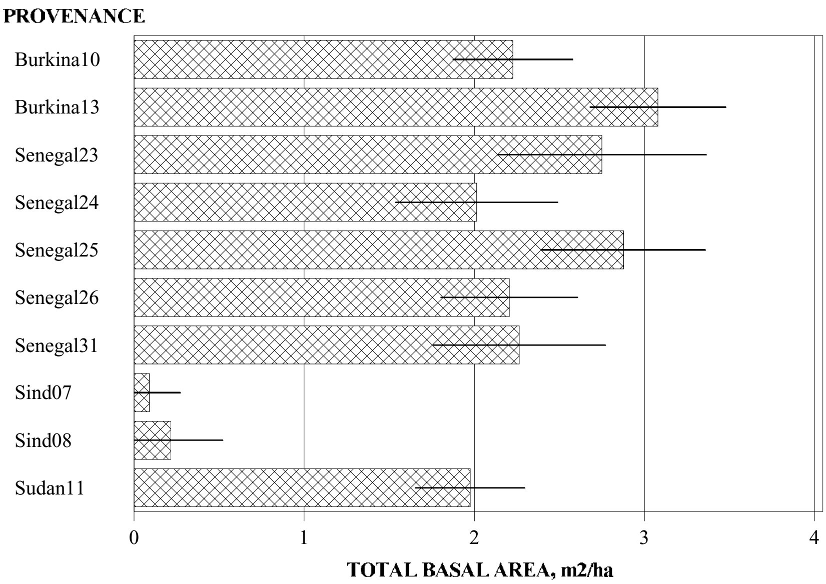


Figure 11. Total basal area for the 10 provenances in the trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values presented are least square means with 95 % confidence limits. Due to the weighted analysis of variance, the error bars have different lengths.

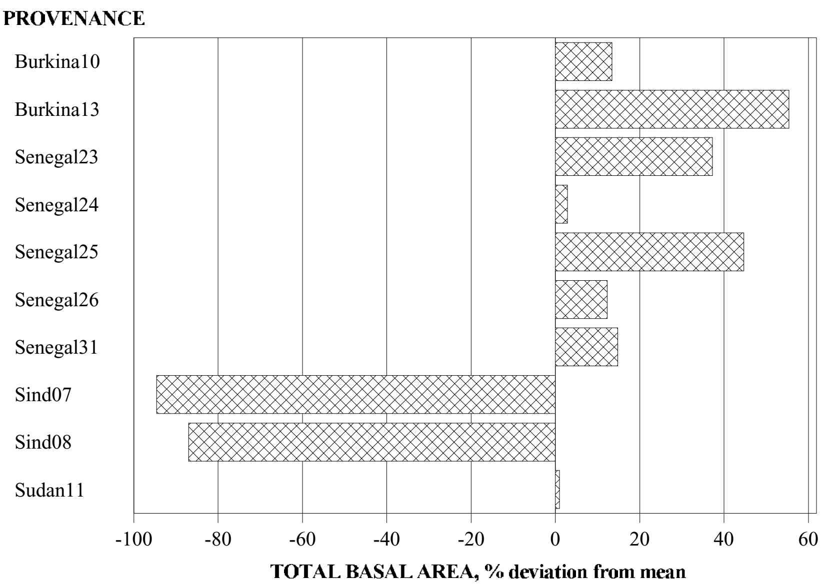


Figure 12. Best linear unbiased predictors (BLUPs) for total basal area in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.7 Dry weight of the mean tree

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

Statistical analysis

The analysis was performed on the single tree data set. The first analysis demonstrated that there was clear variance heterogeneity in the data, and it was decided to use a transformation with the natural logarithm. Overall the distribution of residuals from this model was alright, but there were a few large trees coming out as outliers in the plots. However, since it was obvious from the original data that there were clear differences between the provenances, this model was accepted, acknowledging that it may have produced confidence limits that are slightly off.

Results

The differences between provenances were highly significant and persisted even when the provenances from Pakistan were excluded (Table 8). As usual, these provenances had the lowest values with dry weights of less than 1 kg tree^{-1}, whereas the provenances with the largest dry weights had values of up to 15 kg tree^{-1}. It should be noted that the transformation means that the estimates presented in Fig. 13 are biased towards the low end. The provenances Burkina13, Senegal23 and Senegal25 again had the largest values, corresponding to predicted values in the range from 35 to 65 % above average (Fig. 14).

Table 8. Results from analysis of variance of provenance differences of dry weight of the mean tree in trial 12. Values were transformed with the natural logarithm before analysis.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	9	29.4	47.2	<0.0001	***
Blocks	49	1.61	2.58	<0.0001	
Error	369	0.62			
Without Sind-provenances					
Provenance	7	2.07	3.34	0.002	*
Blocks	49	1.45	2.34	<0.0001	
Error	319	0.62			

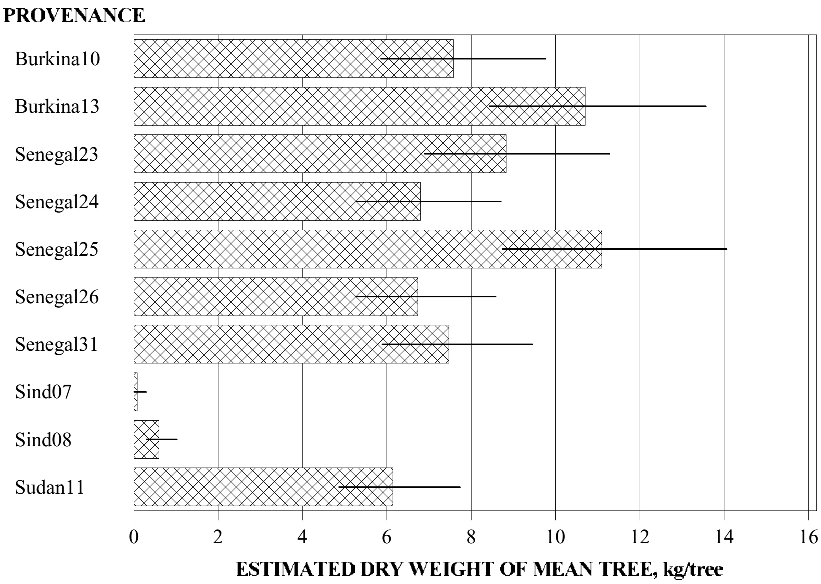


Figure 13. Dry weight of the mean tree for the 10 provenances in the trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Before analysis data were transformed with the natural logarithm. Values presented are back-transformed least square means with 95 % confidence limits. Due to the logarithmic transformation the upper and lower confidence intervals have different lengths.

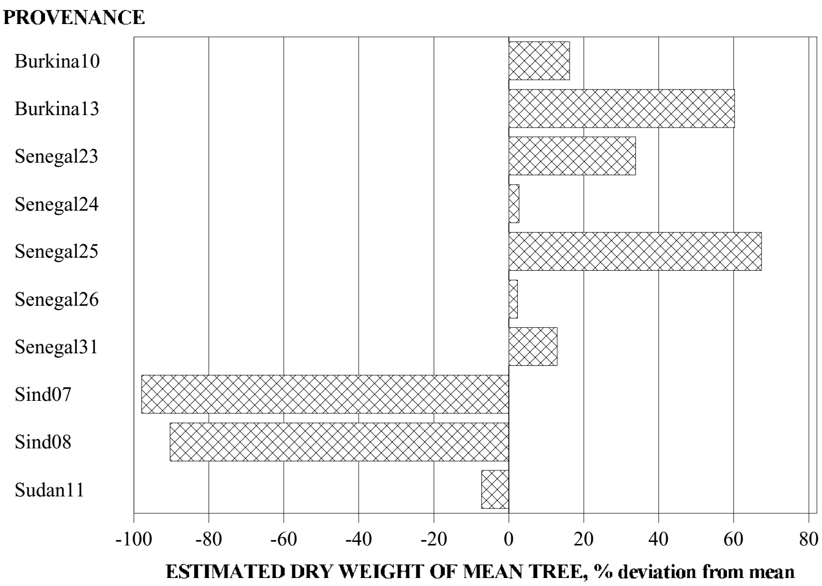


Figure 14. Best linear unbiased predictors (BLUPs) for dry weight of the mean tree in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.8 Total dry weight

As with the total basal area, total dry weight accounts for missing trees and gives the best measure of the actual production on the site.

Statistical analysis

The total basal area was calculated in a manner similar to the calculation of total basal area, using the sum of the provenance for the super-block and relating it to the growth space for the trees. Since the original data had variance heterogeneity, a weight statement was applied in the model including all provenances. This was not necessary in the model without the two provenances from Pakistan.

Results

There were highly significant differences in the total dry weight of the provenances (Table 9). The values varied from below 1 t ha^{-1} for the provenances from Pakistan to approximately 9 t ha^{-1} (Fig. 15). This corresponds to a maximum production of almost 2 t ha^{-1} y^{-1}. The differences were significant even without the provenances Sind07 and Sind08, and again the provenances Burkina13, Senegal23 and Senegal25 were forming the top range with predicted values in the range of 40 to 65 % above the average (Fig.16).

Table 9. Results from analysis of variance of provenance differences of total dry weight in trial 12. In the test for differences between all provenances a weighted model was applied.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
All provenances					
Provenance	9	33.9	31.7	<0.0001	***
Super-blocks	4	2.51	2.34	0.07	
Error	36	1.07			
Without Sind-provenances					
Provenance	7	10.5	3.15	0.01	*
Super-blocks	4	8.89	2.66	0.05	
Error	28	3.34			

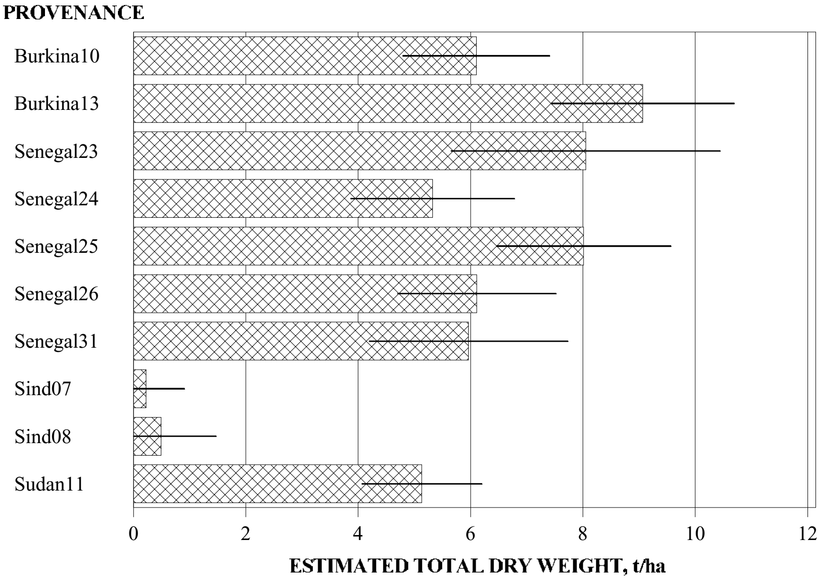


Figure 15. Total dry weight for the 10 provenances in the trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values presented are least square means with 95 % confidence limits.

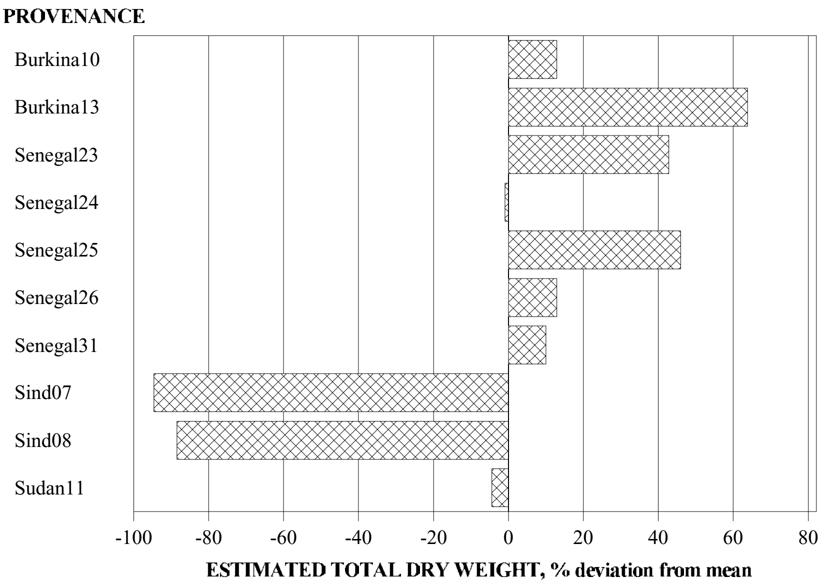


Figure 16. Best linear unbiased predictors (BLUPs) for total dry weight in the provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.9 Multivariate analysis

The multivariate analysis included all eight variables analysed in the univariate analyses, but on mean values (calculated as means of the sub-blocks). This was because some variables (e.g. survival) were not available for the single tree data. Since it is difficult to account for variance heterogeneity in the multivariate analysis, the variables that were transformed in the univariate analysis were also transformed for the multivariate analysis.

Analysis with all provenances

Results from the analysis of all provenances together are presented in Table 10, left half. In this analysis the two first canonical variates were significant and accounted for a total of 94 % of the variation, whereas the third canonical accounted for only 3 % of the variation but was close to being significant. The provenance differences were highly significant (P-values for Wilk's lambda and Pillai's trace both <0.0001).

An important aspect in the interpretation of the multivariate analysis is the plot of scores for the different canonical variates (Fig. 17). The mean values for the provenances are given together with their approximate 95 % confidence regions. Since the third canonical variate was close to being significant it was decided to include plots of both the second and the third canonical variate against the first.

Provenances that are far apart in the diagrams are interpreted as being different. It appears from both plots that there are two distinct groups of provenances. As would be expected also from the univariate analyses, the two provenances from Pakistan form their own group that is very distant from the other group, consisting of provenances from Africa. The African provenances clump together in both plots, and it is difficult to discern the differences between these provenances. Therefore, the analysis is performed without the provenances from Pakistan. In this way the differences within the group of provenances are maximised, and the differences are made clearer.

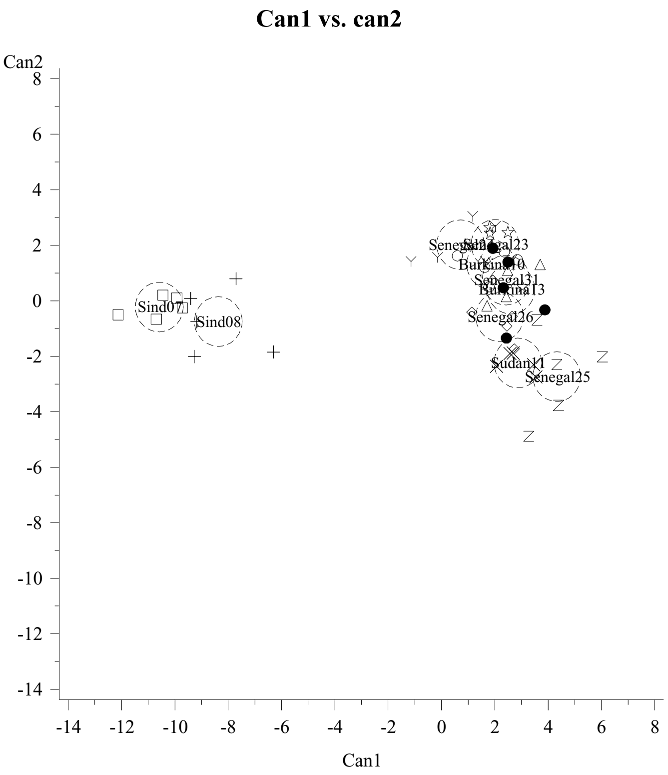
Analysis without provenances from Pakistan

In this analysis, the three first canonical variates were significant, accounting for a total of 91 % of the variation (Table 10, right half). The differences between provenances were highly significant (P-values for Wilk's lambda and Pillai´s trace below 0.0001).

In the graphical presentation of the results (Fig. 18), the provenances appeared scattered with clear differences between provenances, but with no obvious geographical patterns. The two provenances from Burkina Faso were clearly separated along the second canonical variate, and the provenances from Senegal were scattered along the first canonical variate. This suggests that there are different races of *A. senegal* within the two countries. The provenance from Sudan could be separated from the other Senegal and Burkina Faso provenances, but the distance did not seem large enough to justify letting it have a group of its own.

Table 10. Results from the canonical variate analyses for the first three canonical variates, with and without the provenances Sind07 and Sind08.

Analysis	**All provenances**			**Without provenances from Pakistan**		
Canonical variate no.	**1**	**2**	**3**	**1**	**2**	**3**
Proportion of variation accounted for	0.85	0.09	0.03	0.55	0.20	0.16
Significance, P-value	<0.0001	<0.0001	0.08	<0.0001	0.0009	0.03
Raw canonical coefficients						
Survival	-4.5	-2.4	-6.8	-44	-126	-38
Height	3.6	-12.3	-0.35	12.0	2.6	4.0
Basal area of mean tree	0.19	4.4	3.3	-1.2	-62	-22
Total area basal area	6.7	11.6	16.6	15.1	75	-15.4
Crown area	-1.9	-0.15	-0.74	-3.0	3.4	4.9
Number of stems	-1.4	-4.0	5.2	1.6	8.0	0.2
Dry weight of mean tree	-10.8	1.6	-6.8	33	-67	-27
Total dry weight	7.9	-2.6	-3.1	-26	66	41
Standardised canonical coefficients						
Survival	-0.8	-0.4	-1.2	-3.5	-10.0	-3.0
Height	2.2	-7.5	-0.2	3.4	0.7	1.1
Basal area of mean tree	0.2	5.	3.8	-0.4	-17.9	-6.1
Total area basal area	3.2	5.5	7.9	-2.9	14.3	-2.9
Crown area	-1.6	-0.1	-0.6	-0.9	1.0	1.4
Number of stems	-0.4	-1.0	1.3	0.3	1.5	0.04
Dry weight of mean tree	-9.4	1.4	-6.0	11.2	-23	-9.0
Total dry weight	10.8	-3.5	-4.2	-9.0	23	-14.3
Canonical directions						
Survival	1.2	0.3	-0.8	0.2	0.2	0.5
Height	4.2	-1.1	2.2	2.2	1.3	-1.9
Basal area of mean tree	7.4	3.5	3.4	0.2	1.8	-3.6
Total area basal area	3.2	1.4	2.4	0.3	1.5	-2.1
Crown area	4.3	3.3	1.4	-0.9	2.7	-0.7
Number of stems	0.4	0.5	4.2	-0.2	2.1	-2.1
Dry weight of mean tree	5.8	2.9	4.4	0.1	2.2	-4.1
Total dry weight	9.3	4.2	3.5	0.3	2.6	-3.9



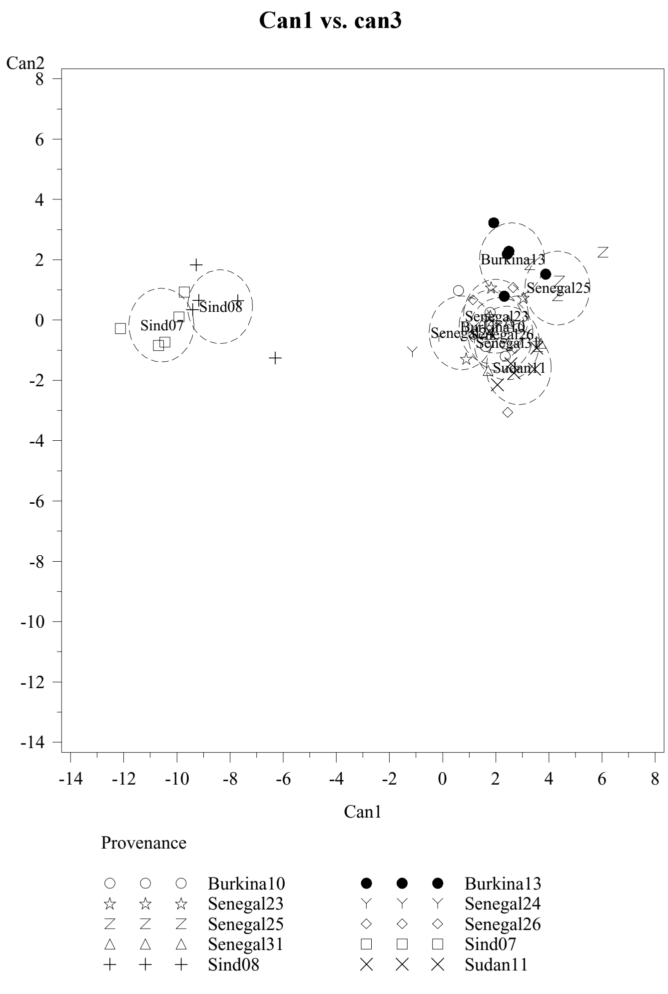


Figure 17. Score plot of the first and the second canonical variate (upper figure) and the first and the third canonical variate (lower firgure) from the canonical variate analysis for the 10 provenances in the *A. senegal* provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). The variables survival, height, basal area of the mean tree, total basal area, crown area, number of stems, dry weight of the mean tree and the total dry weight were included. See the text for details on transformation. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.

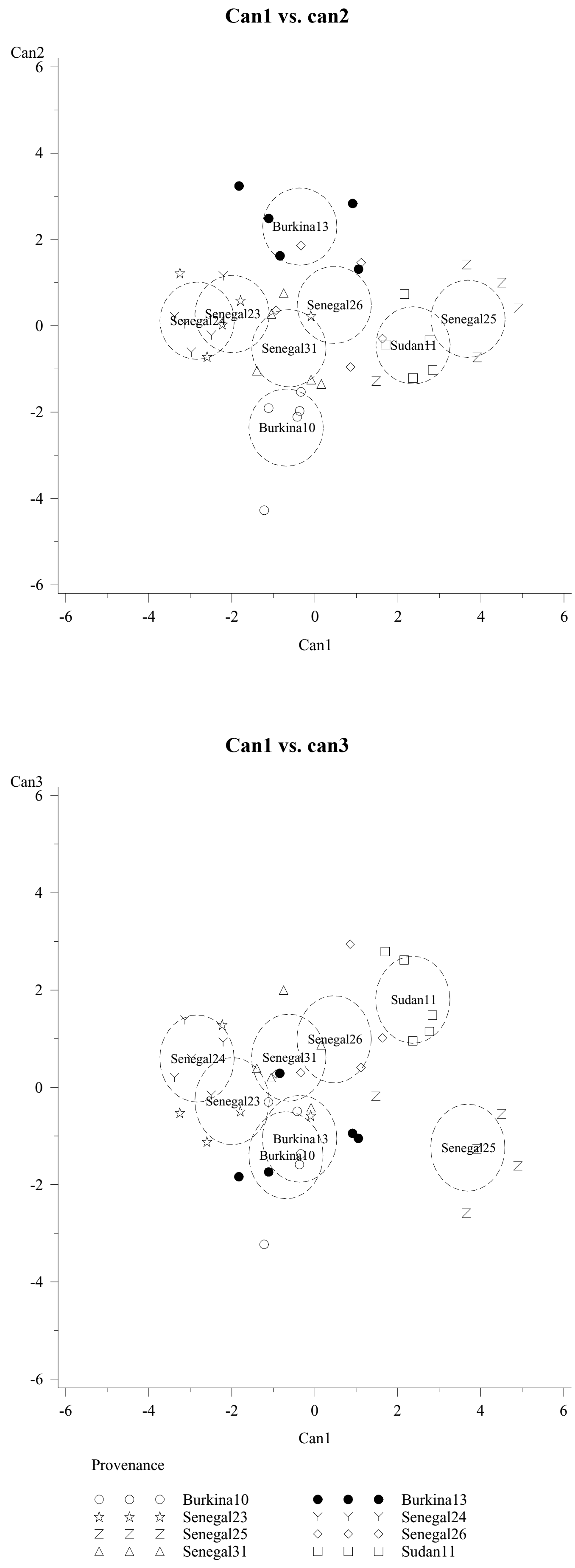


Figure 18. Score plot of the first and the second canonical variate from the canonical variate analysis for 8 of the provenances in *A. senegal* provenance trial at Gonsé, Burkina Faso (Trial no. 12 in the arid zone series). The provenances from Pakistan were excluded from this analysis. The variables survival, height, basal area of the mean tree, total basal area, crown area, number of stems, dry weight of the mean tree and the total dry weight were included without transformations. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.

5. Discussion and conclusion

Productivity of *A. senegal* at Gonsé

The trial is located next to an even aged species and provenance trial of *A. nilotica*, *A. tortilis* and *A. seyal* (trial no. 10 in the arid zone series). Since the site conditions appear to be quite similar, this trial may serve to compare the productivity of *A. senegal* with the other species.

Excluding the provenances from Rajasthan it appears that the survival was at the same level or even slightly higher than the survival of the three other *Acacia* species. The African provenances of *A. senegal* all had quite high survivals, and even though planted outside its natural range, the species seem to be well adapted to the site.

The highest provenance, Senegal25, had a height of 2.5 m, which was quite comparable to the height of the largest provenances of *A. seyal* (2.8 m). The highest provenances of *A. nilotica* and *A. tortilis* were 2.3 and 2.0 m. Considering the production of biomass, the best provenances of *A. nilotica* and *A. tortilis* both had an average dry weight production corresponding to 7 t ha^{-1} (no estimates available for *A. seyal*), which is actually a bit lower than the 9 t ha^{-1} for the *A. senegal* provenance Burkina13. Thus the productivity of *A. senegal* seems to be comparable to the other *Acacia* species.

Provenance differences

It can be stated quite clearly from the results that the *A. senegal* provenances from Sind in Pakistan are not adapted to the climate at Gonsé. In the univariate they come out with inferior survival, height and production of biomass, suggesting that they have a very low production potential at the site. The multivariate analysis clearly demonstrates that they form a group of their own, separated from the other provenances in the trial. This can be due to the original seed source (introduced to Pakistan) being poorly adapted to site conditions such as in Gonsé. Another possibility is that the provenances from Pakistan have undergone a land race formation, perhaps narrowing their genetic base and adaptability.

The other provenances differed in many characters, but with much less variation from the provenances from Pakistan. There were no clear geographical patterns in the differences, and there were no signs that provenances from e.g. Senegal are superior to the local provenances. Instead, there appeared to be different races within both Senegal and Burkina Faso, although only two provenances from Burkina Faso were included. Differences between the average rainfalls at the sites of origin for the provenances do not seem to explain the differences either. It is interesting to note that the provenances Senegal23 and Senegal25, separated by the shortest distances of them all, are in fact the most different when the provenances from Pakistan are not considered. These patterns of variation suggest a large degree of adaptation to the microclimate of the sites, but also that provenances from other climate regions in Sahel are also able to grow at Gonsé.

Finally, giving provenance recommendations, it seems that the most productive and best thriving provenances were the three provenances Burkina13, Senegal23 and Senegal25. Even though it is not significantly different from the other two provenances, Burkina13 had the highest production of biomass and would presumably be the preferred provenance at Gonsé. Another factor in favour of Burkina13 is that it is actually the provenance that originates closest to Gonsé. This is in accordance with the general advice of using local seed sources until others are proved to be better in long-term tests.

It should be noted, however, that the perhaps most important character in growing of *A. senegal*, i.e gum production, has not been included in the assessment and analysis. It would be interesting to compare the gum production of different provenances and tree sizes in a systematic fashion. Even though interpretation of such results may be hampered by the experimental design (the design possibly not reflecting the optimal arrangement of trees for gum production) this would still represent a significant advance in the knowledge of gum production.

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Annex 1. Description of the trial site

Name of site:	Gonsé, Burkina Faso (Bureau National des Sols, 1990): Latitude: 12°22'N Longitude: 01°19'W
Meteorological stations:	Region de Gonsé (Bureau National des Sols, 1990) Ouagadougou (12°21'N, 01°31'W, 306 (FAO 1984, Bureau National des Sols, 1990)
Rainfall:	Annual mean (period): 862 mm (FAO 1984) 678.55 (1985-88 (Bureau National des Sols, 1990)) Yearly registrations: 1985: 633.5 1986: 695.55 1987: 626.1 1988: 759.45 Month of establishment: 226.77
Potential evapotranspiration (Oct.-Apr., Penman (Bureau National des sols 1990)):	1985: 1057.8 1986: 1119.6 1987: 1021.8 1988: 1052.8
Rainy season:	June-September Type: Normal with dry period
Dry months/year:	No. of dry months (<50 mm): 8 No. of dry periods: 1
Temperature (°C (FAO 1984)):	Annual mean: 28.1 Coldest month: 15.8 (mean minimum) Hottest month: 38.5 (mean maximum)
Wind:	Prevailing directions: L'harmattan (March-April) Speed at 2 m: 2.3 m/s (FAO 1984)
Topography:	Flat
Soil:	Type: Ferruginous tropical leached soil, sandy with some clay/ leached gravel soil Depth: varying (Shallow-deep) (> 1 m)
Climatic/agroecological zone:	Semi-arid, Sudano-Sahelian zone.
Dominant natural vegetation:	Woody savanna (Butyrospermum parkii, Terminalia avicennoides).
Koeppen classification:	BSh.

Annex 2. Seedlots of *Acacia senegal* tested in trial no. 12 at Gonsé, Burkina Faso

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

Seedlot numbers				**Provenance information**						
Provenance identification	Plot	DFSC	Country of origin	Provenance name	Country of origin	Latitude	Longitude	Alti-tude (m)	Rain-fall (mm)	No. of mother trees
Burkina10	11		Nouna	Boron, Nouna	Burkina Faso	12°44'N	03°52'W			
Burkina13	10		Kaya	Lac Dem, Kaya	Burkina Faso	13°05'N	01°05'W			
Senegal23	8	1036/82	82/558	Windou Tiengoly, Linguere	Senegal	15°59'N	15°20'W	39	350	32
Senegal24	5	1185/83	83/559	Namarel, Podor	Senegal	14°46'N	16°01'W	50	332	33
Senegal25	6	1187/83	83/762	Diaguely, Linguere	Senegal	15°15'N	14°40' W		400	
Senegal26	7	1189/83	83/764	Gueye Kadar, Podor	Senegal	15°52'N	14°20'W	58	309	50
Sudan11	9	1332/84	2/1984	Fallatu Forest, Elobeid	Sudan	13°10'N	30°14'E	570	365	27
Sind07	1	1345/84	2 / 8 4 / PAK	Dhabiji, Thatta	Pakistan	24°49'N	67°32'E	24	204	25
Sind08	3	1347/84	4 / 8 4 / PAK	Loonio, Tharparkar	Pakistan	24°38'N	70°31'E	50	735	25
Senegal31	4	1389/84	84/998	Thiarene, Dagana	Senegal	16°68'N	15°35'W			30

Annex 3. Layout of the trial

N

Layout of superblock, blocks and trees in the field:
Each tree is indicated by the provenance code given in annex 2, blocks are indicated by thin lines and superblocks are indicated by bold lines.

BLOCK Y	1	2	3	4	5	6	7	8	9	10
5	4 11	2 11	3 8	10 2	4 7	5 11	2 3	11 5	5 11	4 2
	8 2	5 3	11 7	8 5	11 5	9 6	4 5	7 9	2 10	8 11
	6 5	4 7	2 10	3 7	9 10	10 2	11 10	6 3	7 4	3 5
	3 10	10 6	9 5	4 6	8 6	3 7	8 9	8 10	6 8	7 6
	7 9	8 9	6 4	11 9	3 2	8 4	7 6	2 4	3 9	10 9
4	5 10	11 8	10 8	5 6	10 7	7 8	11 3	5 11	5 11	4 2
	2 7	10 7	3 4	3 7	9 5	6 4	9 7	6 3	2 8	8 6
	8 4	6 2	9 6	9 11	8 6	11 5	8 4	4 9	4 6	11 7
	2 6	8 5	7 5	10 2	2 4	9 3	3 10	7 10	10 7	9 10
	9 11	4 9	11 2	4 8	11 3	10 2	2 6	2 8	3 9	3 5
3	10 4	10 3	4 6	6 2	5 2	4 3	8 5	7 3	5 9	8 6
	7 6	5 4	3 9	9 11	7 8	11 7	11 6	6 2	2 10	9 4
	5 9	2 11	11 2	8 3	3 6	8 5	7 3	8 5	3 7	5 7
	2 3	9 8	7 5	7 5	4 11	6 10	2 4	4 9	4 8	10 11
	8 11	6 7	8 10	4 10	9 10	9 2	9 10	11 10	11 6	2 9
2	2 5	5 6	8 10	7 10	11 2	11 5	4 11	2 5	10 7	11 6
	4 8	8 10	11 9	11 2	5 3	4 3	5 10	7 8	2 9	11 5
	10 3	3 4	5 2	4 3	6 9	2 8	9 6	4 6	5 4	9 8
	7 9	2 7	3 4	6 8	4 7	6 7	8 2	3 10	3 8	7 2
	6 11	9 11	7 6	5 9	8 10	9 10	3 7	9 11	6 11	3 10
1	11 9	2 5	9 3	8 5	8 3		3 6	8 6	8 3	5 6
	7 10	4 8	2 7	7 10	5 4	7 3	7 4	2 3	11 4	11 10
	2 6	10 11	6 10	3 2	9 6	6 2	11 2	11 4	2 10	2 7
	9 4	9 7	5 8	4 6	10 11	4 10	5 10	5 10	6 5	3 9
	5 8	9 6	11 4	9 11	2 7	5 9	8 9	7 9	7 9	9 4
BLOCK X	1	2	3	4	5	6	7	8	9	10
SUPER-BLOCKS	**I**		**II**		**II**		**IV**		**V**	

Annex 4. Super-block data set

Super-block	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
		proportion	m	m^2 $tree^{-1}$	no. $tree^{-1}$	cm^2 $tree^{-1}$	m^2 ha^{-1}	kg $tree^{-1}$	ton ha^{-1}
1	Burkina03	0.70	1.84	7.30	2.00	42.9	1.88	11.8	5.17
1	Burkina13	1.00	2.08	9.18	2.00	42.1	2.63	11.6	7.24
1	Senegal23	0.91	1.82	10.49	1.90	41.0	2.33	11.0	6.24
1	Senegal24	1.00	1.63	8.50	1.67	31.3	1.95	8.0	5.02
1	Senegal25	1.00	2.52	10.39	1.80	55.6	3.48	15.7	9.79
1	Senegal26	1.00	1.79	8.40	1.11	22.7	1.42	5.3	3.34
1	Senegal31	1.00	1.86	10.26	1.56	31.4	1.97	8.0	5.03
1	Sind07	0.45	0.58	6.29	1.00	0.6	0.02	0.1	0.03
1	Sind08	0.50	0.47			0.0	0.00	0.0	0.00
1	Sudan11	1.00	1.74	7.23	1.33	19.7	1.23	4.4	2.77
2	Burkina03	0.80	2.36	10.68	1.75	58.5	2.92	17.3	8.65
2	Burkina13	0.90	2.42	11.01	2.44	57.3	3.22	17.0	9.57
2	Senegal23	0.90	2.41	13.95	1.63	68.5	3.85	22.6	12.72
2	Senegal24	1.00	2.09	12.26	1.80	44.6	2.78	12.4	7.74
2	Senegal25	1.00	2.34	9.79	1.44	44.7	2.79	12.3	7.68
2	Senegal26	0.90	2.26	11.19	1.78	51.7	2.91	15.5	8.72
2	Senegal31	1.00	1.92	7.60	1.50	29.6	1.85	7.4	4.61
2	Sind07	0.50	0.78	4.39	2.00	4.4	0.14	0.9	0.28
2	Sind08	0.50	0.78	3.37	1.50	3.4	0.11	0.6	0.19
2	Sudan11	1.00	2.42	10.14	1.50	41.3	2.58	11.0	6.85
3	Burkina01	1.00	2.40	13.79	1.50	51.1	3.20	14.5	9.07
3	Burkina03	0.89	2.11	9.77	1.43	42.4	2.35	11.8	6.57
3	Burkina13	0.90	2.30	12.38	2.33	59.3	3.34	18.0	10.13
3	Senegal23	1.00	1.70	8.92	1.67	27.7	1.73	7.0	4.39
3	Senegal24	1.00	1.78	10.51	1.78	34.3	2.14	8.8	5.53
3	Senegal25	0.90	2.56	8.08	2.00	46.9	2.64	13.0	7.32
3	Senegal26	0.90	2.26	9.34	1.56	37.1	2.09	9.8	5.51
3	Senegal31	1.00	2.08	11.16	1.70	39.5	2.47	10.5	6.55
3	Sind07	0.50	0.52			0.0	0.00	0.0	0.00
3	Sind08	0.67	0.73	2.21	2.00	1.9	0.08	0.3	0.13
3	Sudan11	1.00	2.03	7.58	1.40	26.0	1.63	6.1	3.83
4	Burkina03	1.00	1.72	7.02	1.67	27.8	1.73	6.8	4.23
4	Burkina13	0.90	2.24	13.58	2.78	65.5	3.68	20.6	11.57
4	Senegal23	0.90	2.41	13.40	1.78	59.7	3.36	17.8	10.03
4	Senegal24	0.78	1.60	7.68	1.71	26.1	1.27	6.2	3.03
4	Senegal25	1.00	2.37	8.61	1.90	44.1	2.75	12.1	7.56
4	Senegal26	1.00	2.17	10.56	2.30	44.6	2.79	13.1	8.20
4	Senegal31	1.00	1.89	10.10	1.70	34.7	2.17	8.8	5.53
4	Sind07	0.60	0.77	12.88	3.00	8.0	0.30	2.1	0.80
4	Sind08	0.55	1.18	5.55	1.67	8.3	0.28	1.8	0.62
4	Sudan11	0.90	2.34	11.71	1.56	43.3	2.43	12.5	7.06
5	Burkina03	1.00	2.05	8.65	1.55	35.9	2.24	9.4	5.88

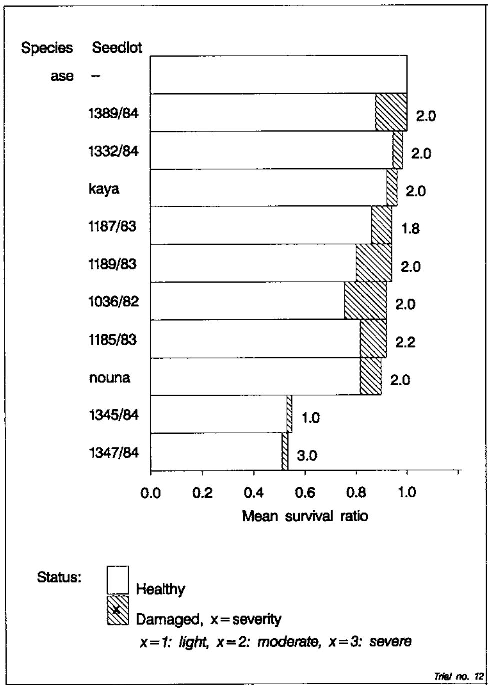
Super-block	Provenance	Survival	Height	Crown area	Number of stems	Basal area of the mean tree	Total basal area	Dry weight of the mean tree	Total dry weight
		proportion	m	m^2 $tree^{-1}$	no. $tree^{-1}$	cm^2 $tree^{-1}$	m^2 ha^{-1}	kg $tree^{-1}$	ton ha^{-1}
5	Burkina13	1.00	2.17	11.87	1.90	40.4	2.53	10.9	6.81
5	Senegal23	0.89	2.10	10.85	1.63	44.5	2.47	12.3	6.86
5	Senegal24	0.80	2.00	11.54	1.75	38.4	1.92	10.6	5.30
5	Senegal25	0.80	2.78	11.37	2.13	54.4	2.72	15.5	7.73
5	Senegal26	0.90	1.99	8.32	2.11	32.4	1.82	8.5	4.78
5	Senegal31	1.00	2.33	11.79	1.33	45.8	2.86	13.0	8.10
5	Sind07	0.70	0.60			0.0	0.00	0.0	0.00
5	Sind08	0.44	1.43	8.72	2.67	22.2	0.62	5.5	1.52
5	Sudan11	1.00	2.31	9.38	1.33	32.1	2.01	8.2	5.15

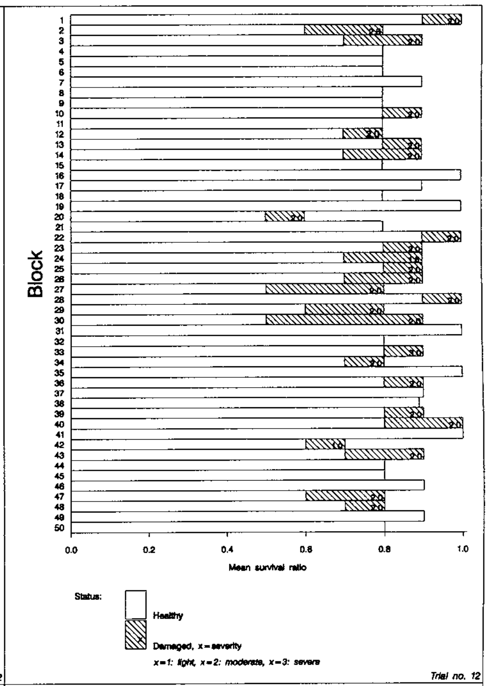
Annex 5. Graphical presentation of the health data

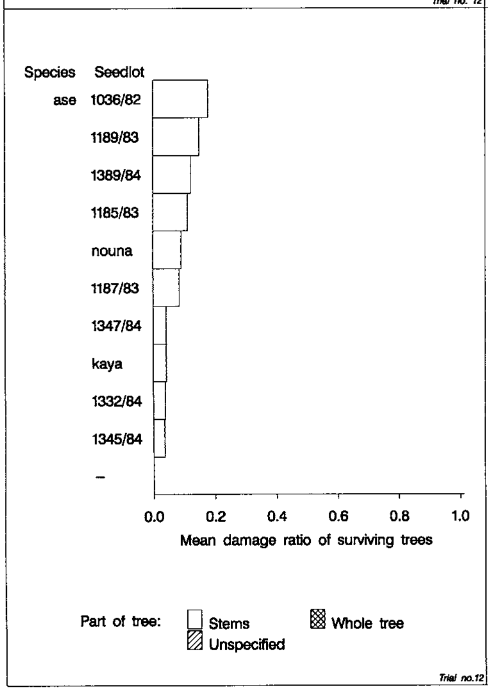
The health status of the trees were evaluated on a scale from 0 to 3, where 0 indicates no damage, and 1, 2 and 3 indicates light, moderate and severe damage, respectively. The health status code is named SCSEV in the diagrams on the following pages.

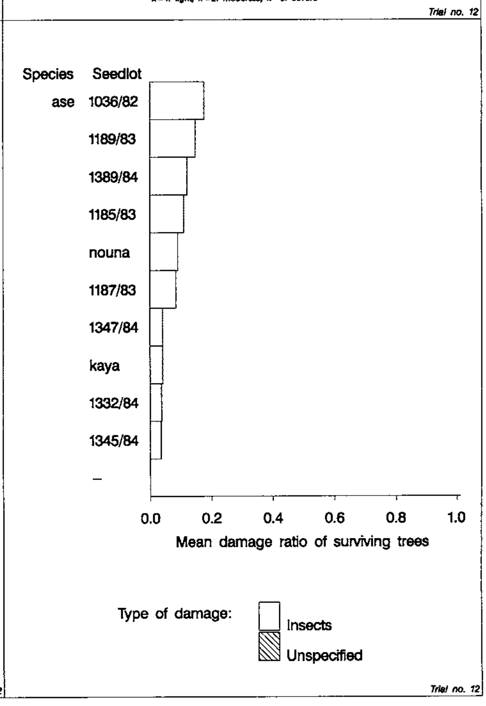
The diagrams present the mean survival ratios, the damage ratios of the surviving trees and the average damage scores for the damaged trees. They also indicate the distribution of the damage on the trees and the cause of the damage. The damage scores are presented according to plots, blocks and seedlots.

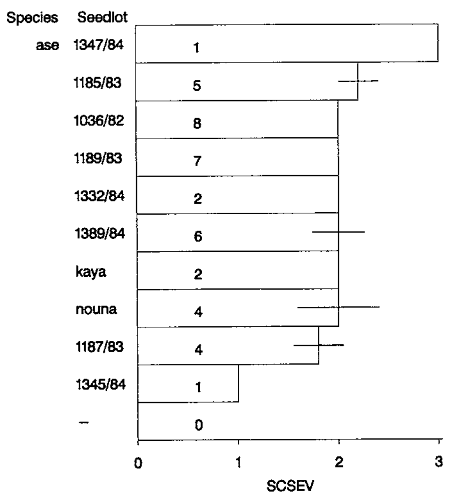
Please note that the seedlot codes correspond to the numbers given in annex 2.





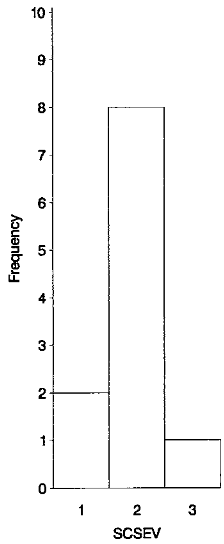






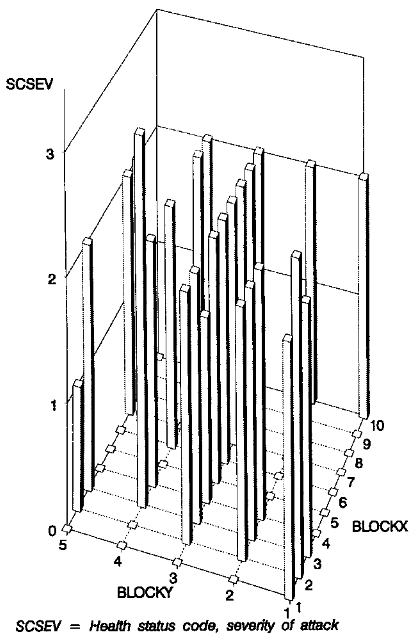
Mean SCSEV of seedlot with error bar line (+/− standard deviation of the mean) and the average number of assessed (living) trees per seedlot.

Trial no. 12



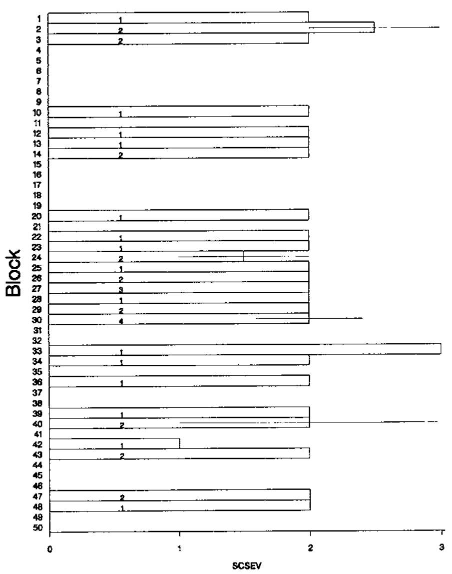
Frequency distribution of seedlot mean values

Trial no. 12



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

Trial no. 12



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. 12