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Evaluation of a provenance trial of *Acacia nilotica* at Khor Donia, Sudan

Trial no. 25 in the arid zone series

by

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Results and Documentation no. 29

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Cover photo: A stump of *Acacia nilotica* in the trial. Due to ongoing illegal logging, it was impossible to measure the diameter at 0.3 m on many of the trees. Instead the diameter was measured at 0.05 m and a regression between the basal areas at the two heights esablished. Phot. Holger E. Nielsen 1994.

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From 1st January 2004, Danida Forest Seed Centre (DFSC) is part of the Danish Centre for Forest, Landscape and Planning, which is an independent centre under the Royal Veterinary and Agricultural University (KVL), in short *Forest & Landscape Denmark*.

Forest & Landscape is a merger between DFSC, the Danish Forestry College, the Danish Forest and Landscape Research Institute and the Department of Economics and Natural Resources at the Royal Veterinary and Agricultural University of Copenhagen (KVL).

Results and documentations are publications of analyses of e.g. provenance trials, carried out between DFSC and other institutions. DFSC publications are distributed free of charge.

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 originally published by the Danida Forest Seed Centre. The series has served as a place for publication of trial results for the Centre itself as well as for our collaborators. With the integration of DFSC into the Danish Centre for Forest, Landscape and Planning, the series will be taken over by *Forest & Landscape* publication series.

The reports are available from the *Forest & Landscape* 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 reports will allow a more detailed documentation than is possible in scientific journals.

This report presents results of a trial within the framework of the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species', initiated by the FAO. Following collection and distribution of seed between 1983-87, a large number of trials were established by national institutions during 1984-1989. An international assessment of 26 trials took place from 1990 to 1994. DFSC was responsible for the reporting of this assessment.

This trial was established and maintained by the Forest Research Centre (FRC), Soba in collaboration with Agricultural Research Corporation (ARC), Gezira Research Station, Forestry Research Section, Medani, in Sudan. The assessment team consisted of Kamal Hamad El Amin, El Amin Yosif A/Raddad, Mohamad Adam Burma, Farog Mohammed Ahmed, Adb El Bagi El Shami, Ramadan El Nour (FRC/ARC), Agnete Thomsen (FAO), and Holger Nielsen (DFSC).

The authors wish to acknowledge the help of the personnel at FRC/ARC with the establishment, maintenance and assessment of the trials, and thank the personnel of DFSC for their help with the data management and preliminary analyses. Drafts of the manuscript were commented on by Marcus Robbins, consultant to FAO.

Abstract

This report describes results from a trial with 15 provenances of *A. nilotica* and one provenance of each of *E. microtheca* and *A. seyal.* The provenances of *A. nilotica* originated in India, Senegal and Sudan, whereas the provenances of the other species were from Sudan. The trial was established with a spacing of 3 x 3 metres at Khor Donia, Sudan, in 1984 and assessed after 10 years in 1994. Different growth parameters were measured and subjected to analyses of variance and multivariate analyses.

The fastest growing provenances (*A. nilotica* and *A. seyal*) had increment rates of 0.55 m^2 ha^{-1} y^{-1}, which for *A. nilotica* corresponded to a dry weight production of 1.5 t ha^{-1} y^{-1}. *E. microtheca* had a poor survival. Only in total basal area was there convincing evidence of differences between the provenances of *A. nilotica*, the largest provenance being from Senegal. There were no clear differences between subspecies. or groups with similar geographical origin.

Contents

1. Introduction

This report describes the results from trial no. 25 in a large series of provenance trials within the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species'. The main goals of the series were to contribute to the knowledge on the genetic variation of woody species, their adaptability and productivity and to give recommendations for the use of the species. The species included in this series of trials are mainly of the genera *Acacia* and *Prosopis*. A detailed introduction to the series is given by DFSC (Graudal *et al.* 2003).

This trial includes 15 provenances of *A. nilotica* and two Sudanian provenances of the species *A. seyal* and *Eucalyptus microthera*. Thus emphasis will be on *A. nilotica*, which is a very variable species with a natural distribution covering large tracts of tropical and subtropical Africa and Asia. Nine subspecies or varieties are recognised (Brenan 1983, Ross 1979) and in this trial three to five subspecies. (depending on the taxonomy) from India, Senegal, Sudan and Yemen are represented: subsp. *adansonii*, subsp. *adstringens*, subsp. *indica* var. *jaquemontii*, subsp. *nilotica* and subsp. *tomentosa*. According to Brenan (1983), subsp. *indica* var. *jaquemontii* from India is now considered a separate species, *A. jaquemontii*, and subsp. *adansonii* and subsp. *adstringens* are united under the name *adstringens*. Thus there is some confusion as regards the taxonomy. In this report we continue to use the terminology applied by the seed collectors.

There appears to be two distinct ecological preferences in the African subspecies (Fagg & Barnes 1990). Subsp. *adstringens* (and thus *adansonii*) is found predominantly in wooded grassland, on deep sandy-loamy soils such as fossil dunes, and on lateritic and calcareous sites. Subsp. *tomentosa* and subsp. *nilotica* tolerates inundation and appear to be restricted to habitats along rivers and seasonally flooded areas, on clay or alluvial soils (von Maydell 1986, Ross 1979, Fagg & Barnes 1990).

The trial is noteworthy in that most of the provenances originate from areas where the precipitation is considerably less than at the trial site.

2. Materials and Methods

2.1 Site and establishment of the trial

The trial was located at Khor Donia (11°47′N, 34°23′E) in Sudan at an altitude of 470 m. The mean annual temperature is 28.1 °C, and the mean annual precipitation is 736 mm with a dry period of approximately eight months. Further site information is given in the assessment report (DFSC 1994) and summarised in annex 1. Seed were sown in February 1984, and the trial was established in July 1984.

2.2 Species and provenances

Three species (*Acacia nilotica*, *A. seyal* and *E. microtheca*) are represented with a total of 17 provenances (Table 1). 15 of the provenances are *A. nilotica:* Two are from India (subsp. *jaquemontii*), seven are from Senegal (subsp. *tomentosa* and subsp. *adansonii*), five are from Sudan (subsp. *tomentosa*, *nilotica* and *adstringens*) and one is from Yemen (subspecies not specified). Please note the comments on taxonomy in the introduction. The provenances have been given identification numbers relating to their geographical origin (name of province or country followed by a number), and the original seedlot numbers are provided in annex 2. Two provenances, Senegal16 and Senegal18, appear to be exactly the same and collected at the same site, the only thing differing being the seedlot number.

The precipitation data for the provenances from Senegal are debatable. Coming from the northwestern part of Senegal, they origin in areas with a low rainfall, but according to Pélissier (1983) the average precipitation does not fall below 300 in any part of the country. Thus the 200 mm stated in table 1 may be an underestimate.

2.3 The experimental design

The experimental design is a block design with four blocks. However, the design is neither complete nor randomised. Five of the provenances (Senegal16, Senegal17, Senegal18, Senegal19 and Senegal20) are only replicated two times, and they are located in two clusters in block 3 and 4. The other provenances are replicated four times and this part of the trial in itself constitutes a randomised complete block design. This has implications for the analysis of the data (see later).

In each block the provenances are represented by 16 trees in a plot, planted in a square of 4×4 trees. The trees are placed with a spacing of 3×3 m. The layout of the design is shown in annex 3, and further details are given in DFSC (1994).

2.4 Assessment of the trial

In February 1994 FRC/ARC, FAO and DFSC undertook a joint assessment. The assessment included the following characters (DFSC 1994):

- Survival
- Health status
- Vertical height
- Diameter of the three largest stems at 0.05 and 0.3 m
- Number of stems at 0.3 m
- Crown diameter

Raw data from the assessment are documented in DFSC (1994), and the plot data set on which the statistical analyses in this report are performed is shown in annex 4. This data set includes directly observed values as well as derived variable values.

Table 1. Provenances of tested in trial no. 25 at Khor Donia, Sudan.

Provenance identification	Species	Seed Collection Site	Country of origin	Latitude	Longitude	Alti-tude (m)	Annual rainfall (mm)	No. of mother trees
Ahmedabad1	*A. nilotica* subsp. *indica* var. *jaquemontii*	Kutch (Bhuj)	India	23°50' N	69°48' E	80	349	25
Andhra Pradesh2	*A. nilotica* subsp. *indica* var. *jaquemontii*	Anantapur	India	14°41' N	77°37' E	350	562	.
Senegal12	*A. nilotica* subsp. *tomentosa*	F.C. Richard-Toll	Senegal	16°28' N	15°42' W	4	300	31
Senegal13	*A. nilotica* subsp. *tomentosa*	F.C. Donaye	Senegal	16°39' N	14°52' W	5	300	30
Senegal16	*A. nilotica* subsp. *adansonii*	Keur Samba Kane, St. Louis	Senegal	16°30' N	15°30' W	-	200	
Senegal17	*A. nilotica* subsp. *tomentosa*	Podor, St. Louis	Senegal	16°40' N	15°08' W	-	200	
Senegal18	*A. nilotica* subsp. *adansonii*	Keur Samba Kane, St. Louis	Senegal	16°30' N	15°30' W	-	200	
Senegal19	*A. nilotica* subsp. *tomentosa*	Richard-Toll, St. Louis	Senegal	16°40' N	15°42' W	-	200	
Senegal20	*A. nilotica* subsp. *tomentosa*	Nianga, St. Louis	Senegal	16°37'N	15°05' W	-	200	
Sudan01	*A. nilotica* subsp. *tomentosa*	Khartoum	Sudan	15°33' N	32°32' E	330	165	
Sudan02	*A. nilotica* subsp. *tomentosa*	Hariri, Sennar	Sudan	13°16' N	33°52' E			
Sudan03	*A. nilotica* subsp. *tomentosa*	Lambewa, Sennar	Sudan	13°22' N	33°40' E			
Sudan04	*A. nilotica* subsp. *nilotica*	Khartoum	Sudan	15°33' N	32°32' E	330	165	
Sudan05	*A. nilotica* subsp. *adstringens*	Sherkila	Sudan	12° 50' N	31°20' E			
Yemen1	*A. nilotica*	Beihan	Yemen	14°52' N	45°45' E	900	100	10
Sudan13	*A. seyal*	Soba	Sudan	15°27' N	32°40' E	330	165	
Sudan24	*Eucalyptus microtheca*	Greenbelt, Khartoum	Sudan	15° 33' N	32°32' E	330	165	

3. Statistical analyses

3.1 Variables

In this report the following eight variables are analysed:

- Survival
- Vertical height
- Crown area
- Number of stems at 0.3 m
- Basal area of the mean tree at 0.3 m
- Total basal area at 0.3 m
- Dry weight of the mean tree
- Total dry weight

The values were analysed on a plot basis, i.e. ratio, mean or sum as appropriate. Survival was analysed as the rate of surviving trees to the total number of trees per plot. Height, crown area and number of stems were analysed as the mean of surviving trees on a plot, as were the basal area and the dry weight of the mean tree. The total basal area and the total dry weight represent the sum of all trees in a plot, expressed on an area basis. Note that the calculations of basal area are based on measurements of the three largest stems per tree.

A large proportion of the trees was damaged either by fire, water stress and attack from insects or by cutting off branches for firewood. However, as the initial graphical analysis gave no indications of provenance differences in susceptibility to damage, no statistical analysis of this character was performed. The interpretation of such analysis would have been difficult as the damage was due to several different causes. Instead a graphical presentation of the health scores is given in annex 5.

Due to illegal cutting, it was impossible to measure the diameter at 0.3 m for approximately 200 trees of the 928 trees in the trial. However, since trees were cut at some distance above the ground, it was possible to measure the diameter at 0.05 m. By comparing basal area at 0.05 m and 0.3 m for the trees that were not cut, it was possible to establish a regression between basal areas for the two heights and thus calculate the basal area at 0.3 m for the trees that were cut. This is possible because the trees were cut recently or even as the assessment was made, meaning that cut trees would not have lost increment as compared to living trees. The reason that the analysis of basal area is not performed for values that were measured at 0.05 m (which would undoubtedly be simpler) is to enable comparison with other trials in the arid zone series. The regressions are of the type

$$ba30 = a + b \times ba05$$

where *ba05* and *ba30* are the basal areas measured at 0.05 and 0.3 m respectively, and *a* and *b* are constants specific for each provenance. The constants appear in Table 2.

Table 2. Constants used in the regression between basal area measured at 0.05 and 0.3 m.

Provenance	a	b
Ahmedabad1	0.2	0.78
Andhra Pradesh2	-3.1	0.81
Senegal12	-0.8	0.80
Senegal13	-3.2	0.86
Senegal16	6.1	0.61
Senegal17	-6.2	1.02
Senegal18	14.9	0.55
Senegal19	-2.9	0.83
Senegal20	-1.9	0.81
Sudan01	-1.9	0.80
Sudan02	-5.1	0.93
Sudan03	-1.9	00.80
Sudan04	-1.7	0.77
Sudan05	-3.5	0.91
Yemen1	3.9	0.66
Sudan13	-6.9	0.85
Sudan24	-2.1	0.76

Obviously it was not possible to measure height and crown area for the trees that were cut, and these trees are therefore omitted from the analyses of these variables. Even for the trees where diameter was measured at 0.3 m, there were some which had no measurements of crown diameter and vertical height, presumably because of cutting at a point higher than 0.3 m. No correction was made for this.

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. nilotica* the regression is

$$TreeDW = e^{(2.582 \times \ln(basalarea) - 2.518)}$$

where *TreeDW* expresses the dry weight of the tree in kg tree^{-1}, and *basalarea* expresses the basal area (at 0.3 m) of the tree in cm^{-2}.

No such regressions were available for *A. seyal* and *E. microtheca*.

3.2 Statistical model and estimates

In order to extract as much information as possible from the trials, a total of five tests were performed. The first three tests were performed on data with all provenances included, whereas the next two tests were performed on data excluding the two provenances of *A. seyal* and *E. microtheca*. By excluding these provenances one obtains a picture of the variation within *A. nilotica*.

Unfortunately the design of the trial makes the analysis quite complex. The fact that five provenances are replicated only two times and furthermore are clumped in one end of the two blocks means that the trial is not properly randomised and that the provenance and environmental effects become confounded (see plot layout in annex 3). In other words, if the mean values for the two parts of the trial are different, it could be either because the provenances are different, or because of differences in the environment (e.g. soil properties) between the two parts. It is impossible to exclude one reason in favour of the other.

Therefore, in an ideal situation, all provenances cannot be analysed together but should be analysed in two groups: One with the twelve provenances that are replicated four times and one with the five provenances that are replicated only two times. However, since it is tempting to compare all provenances despite the reservations mentioned above, we have also made an analysis of all provenances together. Of course the results of the latter should be taken with reservation. Thus, for each variable the following tests were performed:

1. All provenances, both parts of the trial
2. All provenances, large part only
3. *A. nilotica* provenances, both parts of the trial
4. *A. nilotica* provenances, large parts only
5. *A. nilotica* provenances, small part only

Since the small part of the trial was only consisting of *A. nilotica*, it was not necessary to make an analysis of the small part for all provenances.

All tests were based on the model:

$$X_{ij} = \mu + provenance_i + block_j + \varepsilon_{ij}$$

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

To complement blocks in adjusting for uneven environments, co-variates related to the plot position were included in the models. In the initial models, the co-variates were distances along the two axes of the trial, plotx and ploty, and squared values of these, plotx2 and ploty2. The co-variates were excluded successively if they were not significant at the 10% level.

Standard graphical methods and calculated standard statistics were applied to test model assumptions of independence, normality and variance homogeneity (Snedecor & Cochran 1980, Draper & Smith 1981, Ræbild *et al.* 2002). 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, and where appropriate, excerption of outliers were performed to fulfil basic model assumptions (ibid.; Afifi & Clark 1996).

P-values from the tests of provenance differences were corrected for the effect of multiple comparisons by the sequential table-wide Bonferroni method (Holm 1979). The tests were ranked according to their P values. 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 (c.f. Kjær & Siegismund 1996). In this case the number of tests was set to six or eight, according to the number of variables analysed. In the analyses of all provenances, the number was six because neither dry weight of the mean tree nor total dry weight were available for all provenances, but for the analyses of *A. nilotica* provenances, all variables were present and the number was set to eight. The significance levels are indicated by (*) (10%), * (5%), ** (1%), *** (1 ‰) and N.S. (not significant).

Finally the model was used to provide estimates for the provenance values. Two sets of estimates are presented: The least square means (LS-means) and the Best Linear Unbiased Predictors (BLUPs) (White & Hodge 1989). In brief, the LS-means give the best estimates of the performance of the chosen provenances at the trial site, whereas the BLUPs give the best indication of the range of variation within the species.

For the calculation of BLUPs it is assumed that the provenances represent a random selection. In order to avoid bias the estimates were calculated separately on the two parts of the trial.

BLUP-values are usually presented as deviations from the mean value. In this case, where the BLUP values are calculated on two different data sets, this gives some obvious problems in the interpretation (the mean values of the two parts of the trial are different, see above). This should be borne in mind when consulting the graphs.

Finally, 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 climatic extremes and conditions that may be experienced during the life-span of a tree in the field. Trees that had been cut recently were counted as living in this trial. Survival therefore does not involve anthropogenic factors.

Statistical analysis

The analysis of this variable proceeded without complications. No co-variates were significant. Since the differences between *A. nilotica* provenances were far from being significant in the large part of the trial, it was not possible to calculate BLUP-estimates for these provenances.

Results

The survival varied from almost 25% to 80%. Sudan24, the provenance of *E. microtheca*, had the lowest survival, but Senegal20 of *A. nilotica* also was at the low end (Fig. 1). The other provenances of *A. nilotica* and *A. seyal* had moderate to high survival. When Sudan24 was included in the analyses of variance, the provenance differences were significant (Table 3). However, when only the provenances of *A. nilotica* were analysed, the significance disappeared. In the large part of the trial, differences between *A. nilotica* provenances were insignificant and no BLUP values are available. In the test of the small part of the trial (also only *A. nilotica*) the provenance effect was significant, but not when the correction for multiple comparisons was made. In this part of the trial, the BLUP values indicated that the expected gains by provenance selection could reach 20 % (the provenance Senegal16).

Table 3. Results from analysis of variance of provenance differences of survival in trial 25.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances (*A. nilotica*, *A. seyal* and *E. microtheca*)					
Both parts of the trial included					
Provenance	16	913	2.1	0.03	*
Block	3	100	0.2	0.88	
Error	38	438			
Test of the large part of the trial only					
Provenance	11	935	3.0	0.007	*
Block	3	617	2.0	0.14	
Error	33	311			
Test of differences in *A. nilotica*					
Both parts of the trial included					
Provenance	14	492	1.1	0.37	n.s.
Block	3	48	0.1	0.95	
Error	**32**	**435**			
Test of the large part of the trial					
Provenance	9	224	0.8	0.63	n.s.
Block	3	542	1.9	10.15	
Error	27	284			
Test of the small part of the trial					
Provenance	4	904	12.5	0.02	n.s.
Block	1	4515	62.5	0.001	
Error	4	72			

Figure 1. Survival in the provenance trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are least square means with 95 % confidence limits.

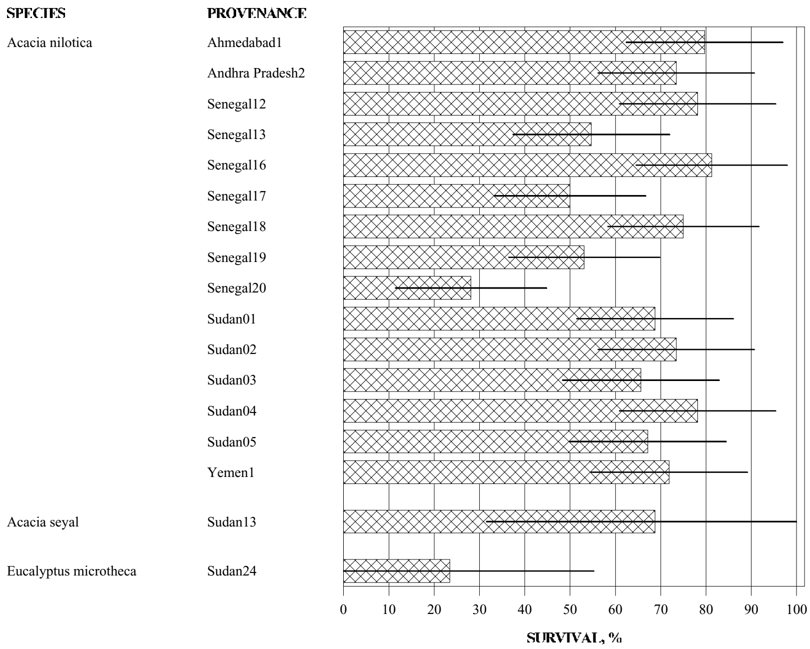
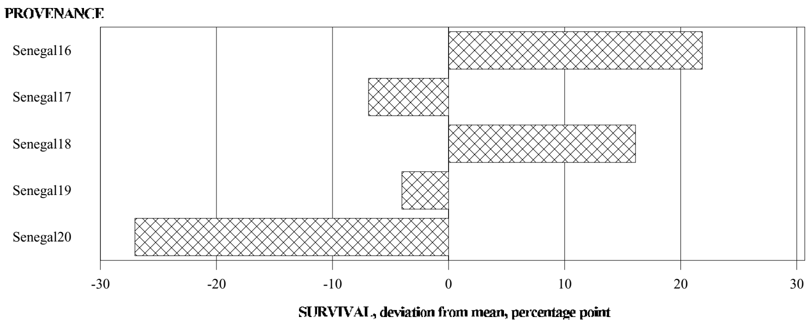


Figure 2. Best linear unbiased predictors (BLUPs) for survival in the *A. nilotica* provenance trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are deviations from the mean value in percentage point.



4.2 Height

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

Statistical analysis

There were signs of variance heterogeneity in the data, and in all analyses but the analysis of the small part of the trial the data were weighted. The co-variates were not significant, except for ploty2 in the test of differences between all provenances of the large part of the trial. Note that cutting of trees from the trial mean that a number of trees are not included.

Results

The average heights varied between 2.6 m (Sudan24, *E. microtheca*) and 4 m (Senegal16 of *A. nilotica* and Sudan13 of *A. seyal*). The differences between provenances were significant when all provenances were included, but when considering only *A. nilotica*, the differences were no longer significant (Table 4). The data thus indicate that there is not much difference between the provenances of this species, and the predicted values for provenance selection vary from -9 % to +7 %.

Table 4. Results from analysis of variance of provenance differences of height in trial 25.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances (*A. nilotica*, *A. seyal* and *E. microtheca*)					
Both parts of the trial included					
Provenance	14	3.6	3.3	0.002	**
Block	3	2.5	2.3	0.09	
Error	34	1.1			
Test of the large part of the trial only					
Provenance	11	3.0	2.8	0.01	*
Block	3	1.5	1.4	0.27	
Ploty2	1	7.9	7.2	0.01	
Error	30	1.1			
Test of differences in *A. nilotica*					
Both parts of the trial included					
Provenance	12	2.6	2.4	0.03	(*)
Block	3	1.8	1.6	0.20	
Error	30	1.1			
Test of the large part of the trial					
Provenance	9	1.8	1.8	0.12	n.s.
Block	3	2.3	2.2	0.11	
Error	27	1.0			
Test of the small part of the trial					
Provenance	4	0.14	2.5	0.30	n.s.
Block	1	0.008	0.15	0.74	
Error	2	0.06			

Figure 3. Vertical height in the provenance trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are least square means with 95 % confidence limits.

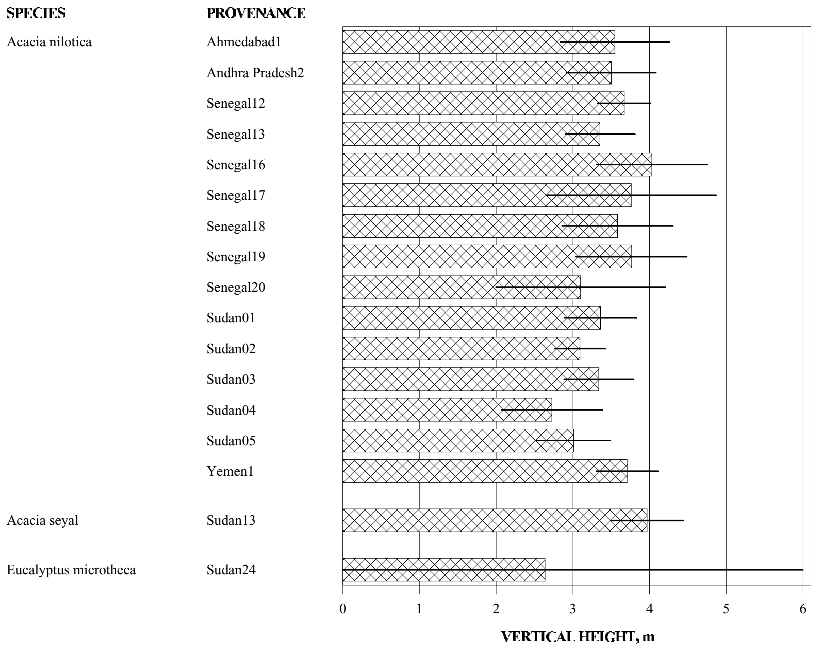
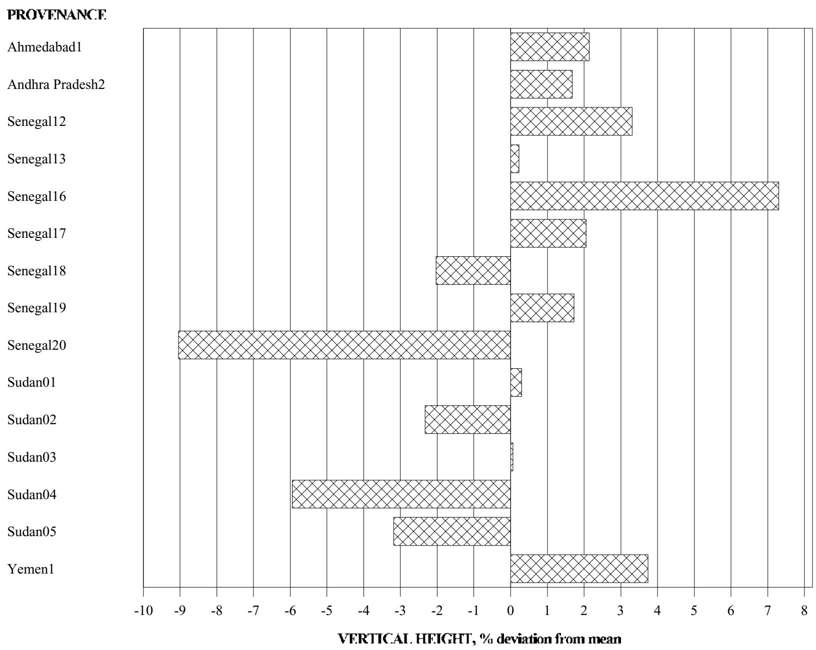


Figure 4. Best linear unbiased predictors (BLUPs) for vertical height in the *A. nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values are presented as deviations in percent of the mean value. Note that the mean values for the two parts of the trial are not the same.



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

It was not possible to measure the crown area on cut trees, and they are therefore not included in the analyses. Due to variance heterogeneity the data were weighted in all analyses but the analysis of provenance differences in the small part of the trial. No co-variates were significant.

Results

Sudan24 (*E. microtheca*) had the smallest crown area with only 2.5 m^2 $tree^{-1}$, whereas Sudan13 (*A. seyal*) was the largest with 14 m^2 $tree^{-1}$. In *A. nilotica*, most provenances had crown areas around 5 m^2 $tree^{-1}$, but Senegal16 and Senegal18 took the lead with 8 and 10 m^2 $tree^{-1}$, respectively (Fig. 5). Considering that the trees were planted at 3×3 m, the canopy was just about to close for provenances with high survival and large crown areas.

Again the differences between provenances were significant when all provenances were included (Table 5), but when only *A. nilotica* was analysed, the differences were no longer significant. Nevertheless the BLUP values indicated that the gain by selection of the provenances with the largest values was up to 40 % (Senegal18). In the provenances of *A. nilotica* in the large part of the trial, the variation was small, and the BLUP values are therefore almost zero for these provenances (Fig. 6).

Table 5. Results from analysis of variance of provenance differences of crown area in trial 25.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances (*A. nilotica*, *A. seyal* and *E. microtheca*)					
Both parts of the trial included					
Provenance	14	5.3	5.3	<0.0001	***
Block	3	4.8	4.8	0.007	
Error	34	1.0			
Test of the large part of the trial only					
Provenance	11	4.2	4.4	0.0006	**
Block	3	3.5	3.6	0.02	
Error	31	1.0			
Test of differences in *A. nilotica*					
Both parts of the trial included					
Provenance	14	8.6	1.9	0.07	n.s.
Block	3	5.8	1.3	0.29	
Error	30	4.4			
Test of the large part of the trial					
Provenance	9	4.4	1.0	0.47	n.s.
Block	3	4.0	0.9	0.45	
Error	27	4.4			
Test of the small part of the trial					
Provenance	4	14.8	4.1	0.21	n.s.
Block	1	10.4	2.9	0.23	
Error	2	3.6			

Figure 5. Crown area in the provenance trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are least square means with 95 % confidence limits.

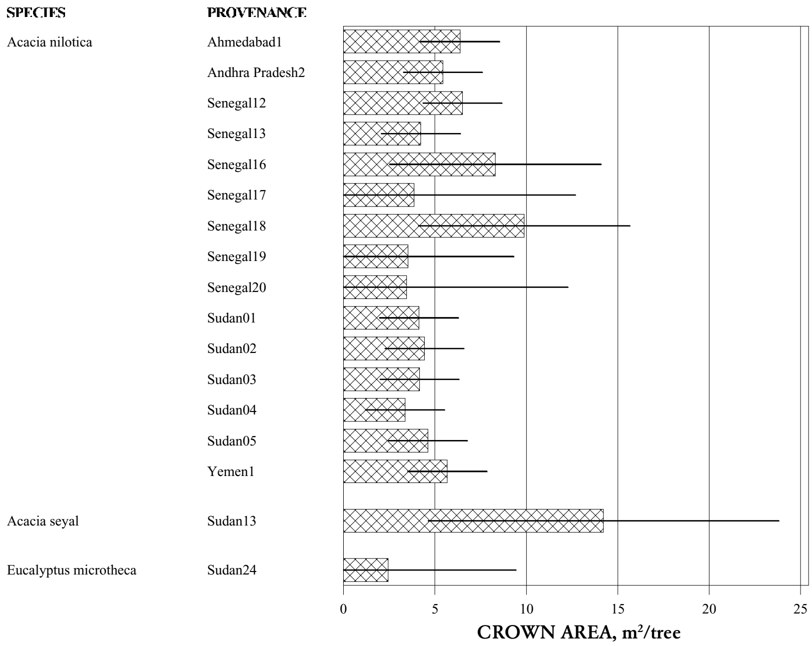
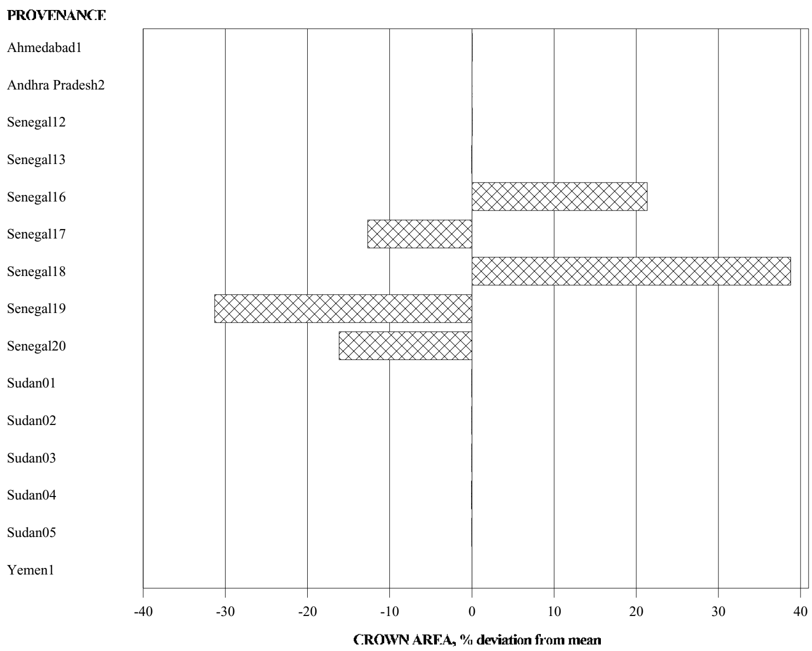


Figure 6. Best linear unbiased predictors (BLUPs) for crown area in the *A. nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values are presented as deviations in percent of the mean value. Note that the mean values for the two parts of the trial are not the same.



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 tree-like growth.

Statistical analysis

Again a number of trees had to be excluded due to cutting and thus lack of data. Variance heterogeneity made it necessary to weight the data in all but the analysis of the small part of the trial. No co-variates were significant. Due to missing values in the small part of the trial it was necessary to base the estimates for these provenances on simple means. For some reason the software did not permit calculation of the BLUP-estimates for the large part of the trial. In this case it does not necessarily imply that there is no difference between the provenances.

Results

The number of stems varied from just one in many provenances to 1.75 in the provenance Senegal16 of *A. nilotica* (Fig. 7). The differences between provenances were significant when all provenances were included (Table 6). When *A. nilotica* was analysed alone and both parts of the trial were analysed together, the differences were still significant, but the significance disappeared when the two parts were analysed separately. The BLUP values from the small part of the trial indicated that there were from -12 to 40 % difference from the mean in the provenances (Fig. 8).

Table 6. Results from analysis of variance of provenance differences of number of stems in trial 25.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances (*A. nilotica*, *A. seyal* and *E. microtheca*)					
Both parts of the trial included					
Provenance	14	1732	3.5	0.001	**
Block	3	2395	4.8	0.007	
Error	34	495			
Test of the large part of the trial only					
Provenance	11	1.85	2.1	0.05	*
Block	3	0.03	0.04	0.99	
Error	31	0.87			
Test of differences in *A. nilotica*					
Both parts of the trial included					
Provenance	12	2.65	3.2	0.005	*
Block	3	0.08	0.1	0.96	
Error	30	0.83			
Test of the large part of the trial					
Provenance	9	2.29	2.6	0.02	n.s.
Block	3	0.01	0.01	1.0	
Error	27	0.87			
Test of the small part of the trial					
Provenance	4	0.21	6.8	0.13	n.s.
Block	1	0.10	3.3	0.21	
Error	2	0.03			

Figure 7. Number of stems in the provenance trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are least square means with 95 % confidence limits. Values above 2.5 were truncated.

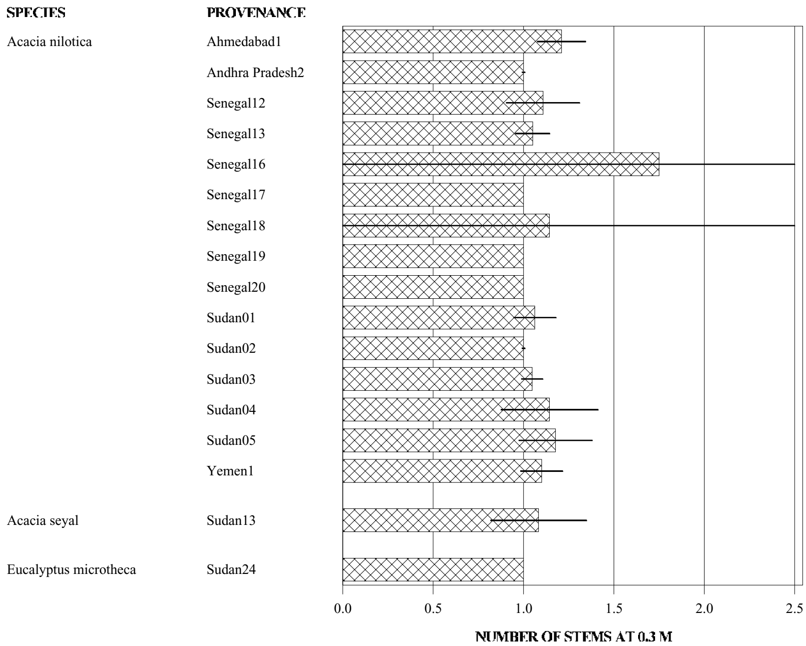
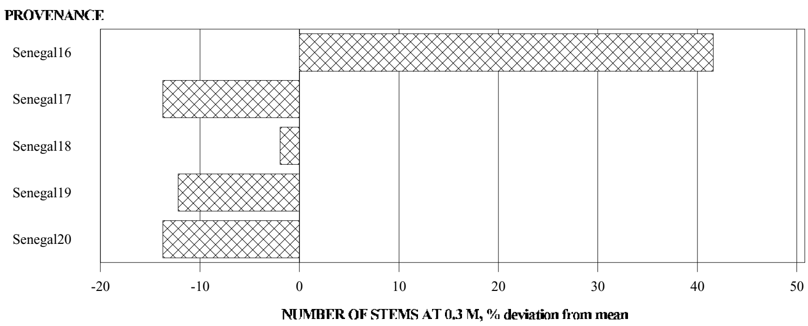


Figure 8. Best linear unbiased predictors (BLUPs) for number of stems in the *A. nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values are presented as deviations in percent of the mean value.



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 gives an account of the potential basal area production of the provenance provided that all trees survive.

Statistical analysis

The test of residuals revealed one outlier (Sudan24 in block 1). Since there was only one tree on this plot, it was deleted from the data set. It was necessary to apply weight statements in the analyses of *A. nilotica* differences, both when the two parts of the trial were analysed together and when the large part of the trial was analysed alone. Ploty2 was significant in three of the tests.

Results

Sudan24 (*E. microtheca*) and Sudan13 (*A. seyal*) had the largest basal areas per tree with approximately 85 and 70 cm^2 $tree^{-1}$. Senegal16 of *A. nilotica* was the largest provenance of this species with 60 cm^2 $tree^{-1}$, whereas the smallest was Sudan04 with only 15 cm^2 $tree^{-1}$ (Fig. 9).

With all provenances included, the differences between provenances were highly significant, but for the *A. nilotica* provenances, the difference was on the edge of significance. When the two parts of the trial were analysed together, the differences were significant, but not when they were analysed separately (Table 7). Nevertheless the BLUP-values indicated that the potential gains by provenance selection varied between ±35 %, the best provenances being Senegal16 and Yemen1 (Fig. 10).

Table 7. Results from analysis of variance of provenance differences of basal area of the mean tree in trial 25.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances (*A. nilotica*, *A. seyal* and *E. microtheca*)					
Both parts of the trial included					
Provenance	16	1197	5.3	<0.0001	***
Block	3	756	3.4	0.03	
Ploty2	1	1012	4.5	0.04	
Error	34	224			
Test of the large part of the trial only					
Provenance	11	1584	6.6	<0.0001	***
Block	3	710	3.0	0.05	
Error	31	1161			
Test of differences in *A. nilotica*					
Both parts of the trial included					
Provenance	13	3.0	2.8	0.01	*
Block	3	6.2	5.7	0.003	
Ploty2	1	12.5	1.1	0.002	
Error	30	1.1			
Test of the large part of the trial					
Provenance	9	3.2	3.1	0.01	(*)
Block	3	7.0	6.7	0.002	
Ploty2	1	22.2	21.2	<0.0001	
Error	26	1.0			
Test of the small part of the trial					
Provenance	4	403	6.3	0.08	n.s.
Block	1	318	5.0	0.11	
Error	2	64			

Figure 9. The basal area of the mean tree in the provenance trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are least square means with 95 % confidence limits.

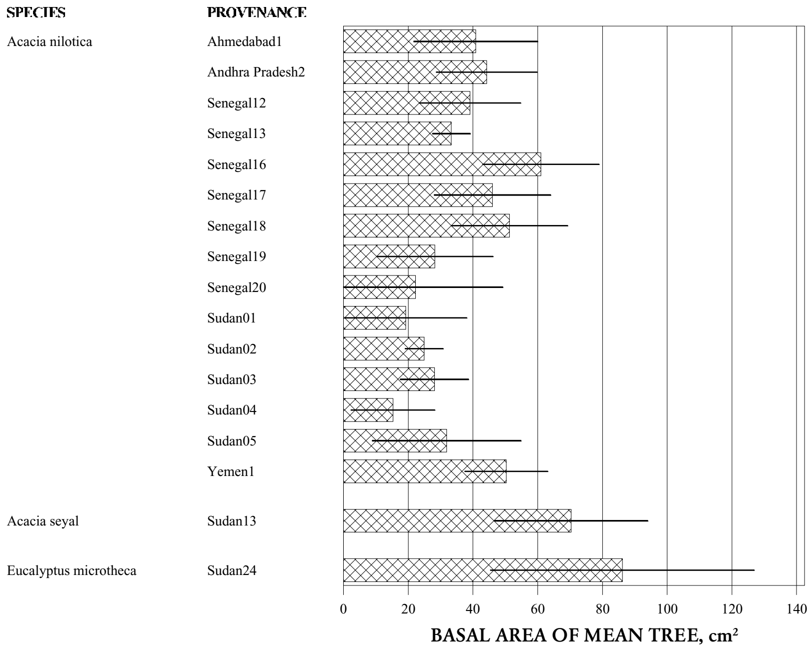
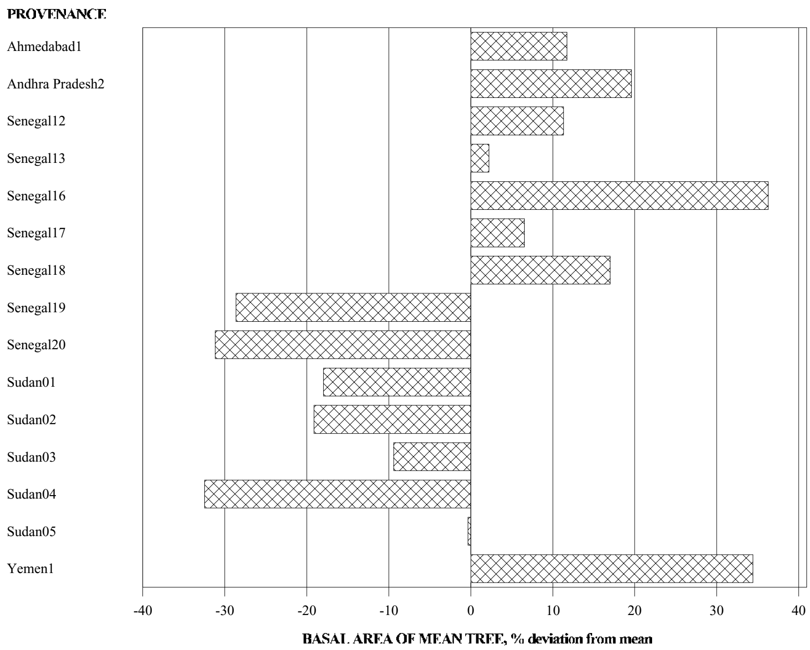


Figure 10. Best linear unbiased predictors (BLUPs) for basal area of the mean tree in the *A. nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values are presented as deviations in percent of the mean value. Note that the mean values for the two parts of the trial are not the same.



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

Since there was variance heterogeneity, weight statements were applied in all but the analysis of *A. nilotica* differences in the small part of the trial. Ploty2 was significant in the same analyses.

Results

The lowest basal area was found in Senegal20 with a total basal area of just below 1 m^2 ha^{-1}. Sudan13 (*A. seyal*) and Senegal16 (*A. nilotica*) were the largest with approximately 5.5 m^2 ha^{-1}, corresponding to a growth rate of 0.55 m^2 ha^{-1} y^{-1}. The provenance of *E. microtheca* had a basal area of 2.2 m^2 ha^{-1} (Fig. 11). The differences between provenances were significant or almost significant, irrespective of whether all provenances were included or not (Table 8). Thus there seems to be rather certain evidence of differences within *A. nilotica.* This was also indicated by the BLUP values, predicting deviations from the mean basal area ranging from almost -75 % to +70 % (Fig. 12).

Table 8. Results from analysis of variance of provenance differences of total basal area in trial 25.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of all provenances					
Both parts of the trial included					
Provenance	16	3.5	3.3	0.001	**
Block	3	5.3	5.0	0.005	
Ploty2	1	22.5	21.3	<0.0001	
Error	37	1.1			
Test of the large part of the trial only					
Provenance	11	3.3	3.2	0.005	*
Block	3	5.5	5.4	0.004	
Ploty2	1	19.0	18.6	<0.0001	
Error	32	1.0			
Test of differences in *A. nilotica*					
Both parts of the trial included					
Provenance	14	4.8	4.7	0.0002	**
Block	3	3.9	3.8	0.02	
Ploty2	1	35.2	34.1	<0.0001	
Error	31	1.0			
Test of the large part of the trial					
Provenance	9	3.1	3.0	0.01	(*)
Block	3	3.4	3.3	0.03	
Ploty2	1	26.2	25.6	<0.0001	
Error	26	1.0			
Test of the small part of the trial					
Provenance	4	7.3	19.6	0.007	(*)
Block	1	18.1	48.2	0.002	
Error	2	0.4			

Figure 11. Total basal area in the provenance trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are least square means with 95 % confidence limits.

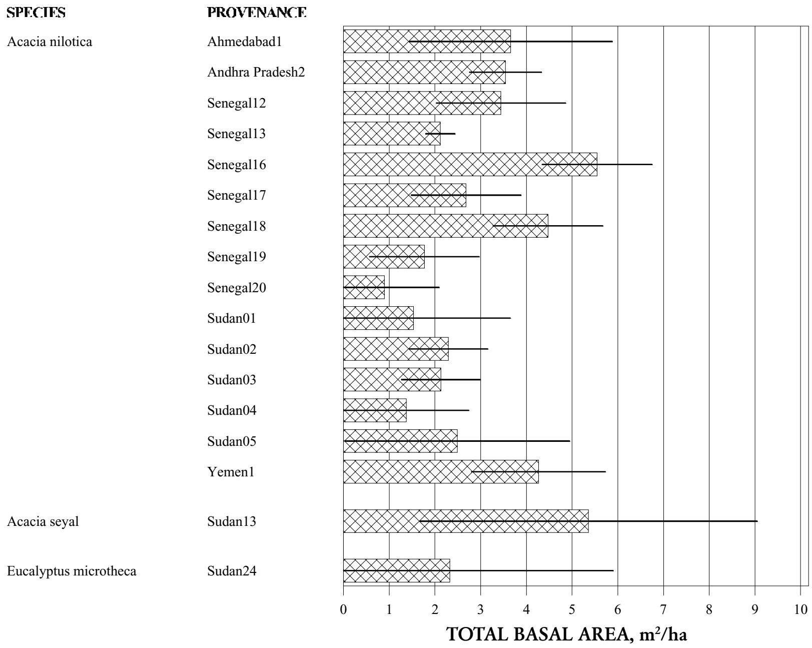
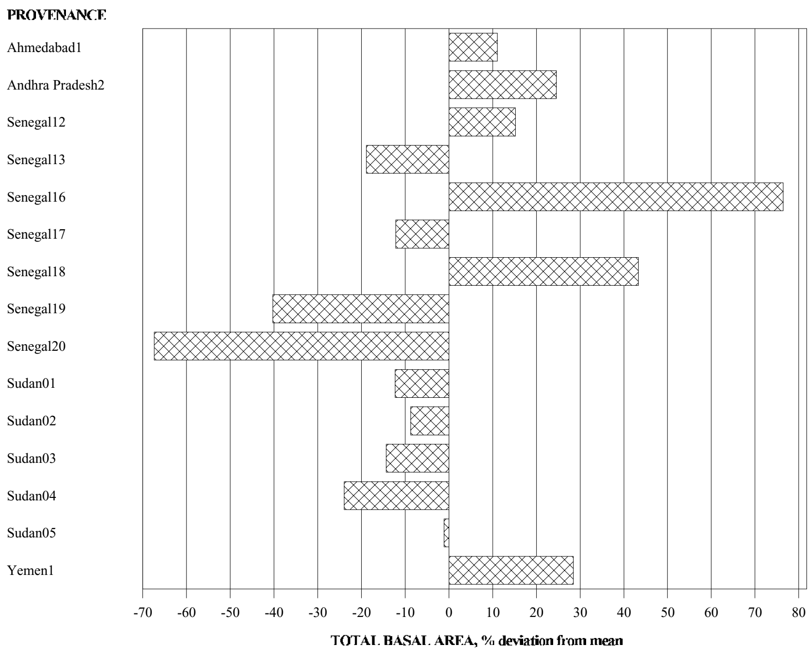


Figure 12. Best linear unbiased predictors (BLUPs) for total basal area in the *A. nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values are presented as deviations in percent of the mean value. Note that the mean values for the two parts of the trial are not the same.



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 as the basis for estimation of the dry weight is the basal area. However, an important difference is that the dry weight include a cubic term (in comparison to basal area having only a square term), meaning that large trees with a large dry mass are weighted heavily in this variable. The dry weight of the mean tree is thus the best estimate for the production of biomass at the site.

Statistical analysis

For this variable, data are available only for *A. nilotica*, hence only three tests appear. Weight statements were applied in the analysis of both parts of the trial and in the analysis of the large part only. Ploty2 was significant in the same two analyses.

Results

The mean dry weight ranged from 3 to 17 kg tree^{-1}, again with Senegal16 taking the lead (Fig. 13). Interpretation of the results from the analysis of variance is difficult, as the results are not consistent. When all provenances (of *A. nilotica*) are included, the differences are significant, but when the two parts of the trial are analysed separately, the significance disappears, at least after the correction for multiple comparisons is made (Table 9). The corresponding BLUP values ranges from -35% to +45% (Fig. 14).

Table 9. Results from analysis of variance of provenance differences of dry weight of the mean tree in trial 25.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of differences in *A. nilotica*					
Both parts of the trial included					
Provenance	13	3.8	3.4	0.003	*
Block	3	7.5	6.8	0.001	
Ploty2	1	13.7	12.4	0.001	
Error	30	1.1			
Test of the large part of the trial					
Provenance	9	2.4	2.4	0.04	n.s.
Block	3	8.3	8.0	0.0006	
Ploty2	1	20.8	20.2	<0.0001	
Error	26	1.0			
Test of the small part of the trial					
Provenance	4	40.9	5.8	0.09	n.s.
Block	1	31.3	4.5	0.13	
Error	2	7.0			

Figure 13. Dry weight of the mean tree in the *Acacia nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are least square means with 95 % confidence limits.

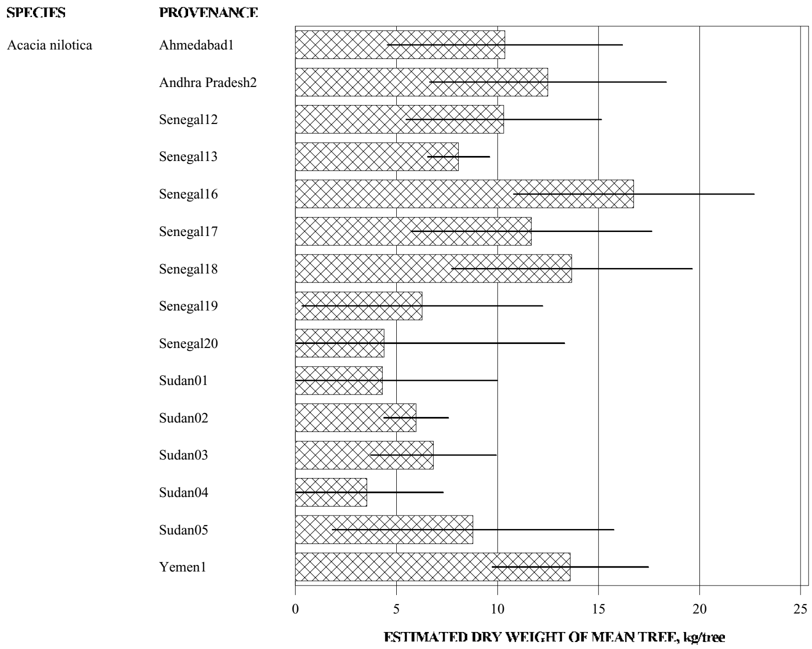
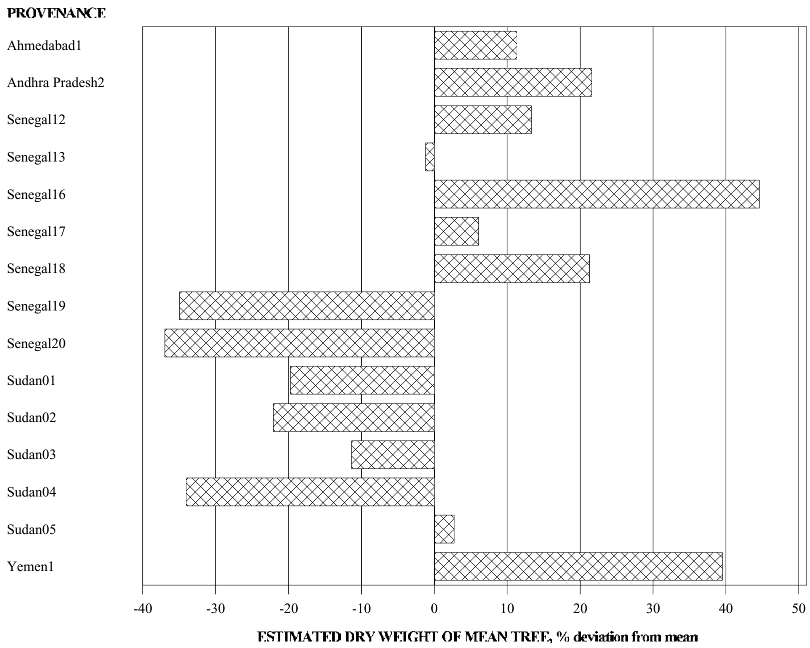


Figure 14. Best linear unbiased predictors (BLUPs) for dry weight of the mean tree in the *A. nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values are presented as deviations in percent of the mean value. Note that the mean values for the two parts of the trial are not the same.



4.8 Total dry weight

As 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

Again the data are only available for the *A. nilotica* provenances. Weight statements were applied in all analyses except for the analysis of the small part of the trial.

Results

Senegal20 had the lowest total dry weight with 2 t ha^{-1}, and Senegal16 was again the highest with 15 t ha^{-1} (Fig. 15). This corresponds to a maximum production of 1.5 t ha^{-1} y^{-1}. In the analysis of all provenances, the provenance effect was significant, but when the two parts of the trial were analysed separately, the picture was not as clear. For both parts the provenance effect was significant, but the correction for multiple comparison moved the P-values into the non-significant area, indicating that the results should be interpreted cautiously (Table 10). Irrespective of this the predicted values indicated that there were substantial gains by provenances selection, the BLUP values ranging from -70% to +80% (Fig. 16).

Table 10. Results from analysis of variance of provenance differences of total dry weight in trial 25.

Effect	DF	MS	F-value	P-value	Bonferroni sequential tablewide correction
Test of differences in A. nilotica					
Both parts of the trial included					
Provenance	14	4.1	3.9	0.0007	**
Block	3	8.5	8.2	0.0004	
Ploty2	1	28.7	27.2	<0.0001	
Error	31	1.0			
Test of the large part of the trial					
Provenance	9	2.4	2.4	0.04	n.s.
Block	3	5.8	5.8	0.004	
Ploty2	1	22.7	22.7	<0.0001	
Error	26	1.0			
Test of the small part of the trial					
Provenance	4	61	12.4	0.02	n.s.
Block	1	130	26.5	0.007	
Error	2	5			

Figure 15. Total dry weight in the *Acacia nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values presented are least square means with 95 % confidence limits.

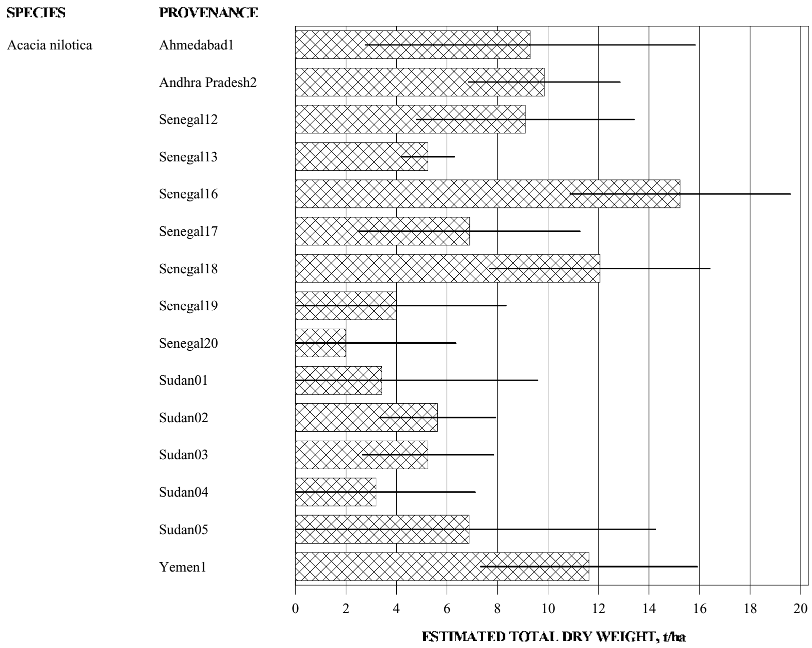
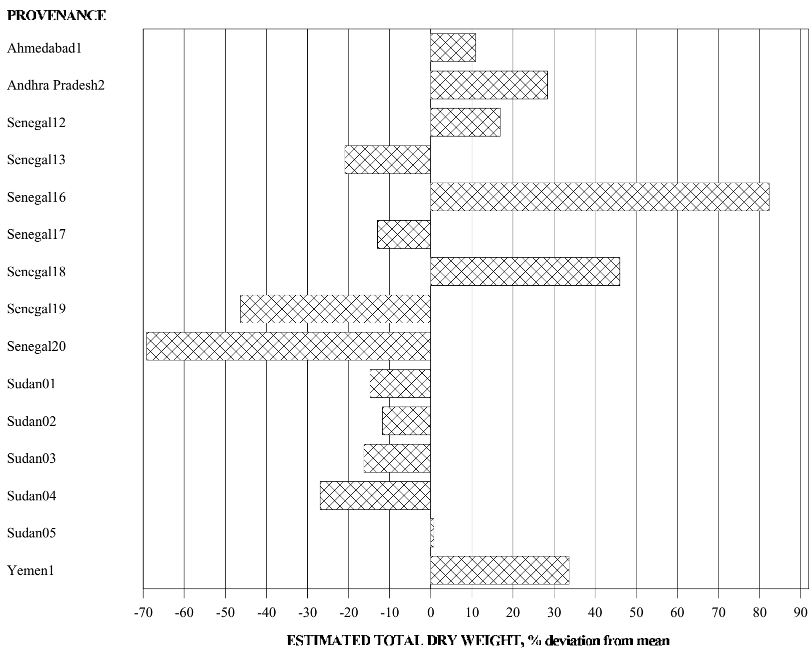


Figure 16. Best linear unbiased predictors (BLUPs) for total dry weight in the *A. nilotica* provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). Values are presented as deviations in percent of the mean value. Note that the mean values for the two parts of the trial are not the same.



4.9 Multivariate analysis

Due to the imbalanced design, the same number of analyses should be performed in the multivariate part of the analyses as in the univariate part. However, it was not possible to perform the multivariate analysis on the small part of the trials. Only the analyses of the two parts analysed together are presented, but the results were confirmed by extra analyses referred to in the text. When the analyses and especially the figures are interpreted, the imperfections of the design and the implications this has for the interpretation should be borne in mind. Another reservation is that the multivariate analysis does not account for the variance heterogeneity observed in many of the univariate analyses, which imposes further restrictions on the interpretation.

Analysis of all provenances

This analysis included all variables analysed in the univariate analyses, except for the dry weight of the mean tree and the total dry weight.

The first canonical variate was highly significant, whereas the second was only significant at the 5 % level (Table 11). In total, the two variates accounted for 67 % of the variation, leaving a fairly large proportion of the variation unexplained. Differences between the provenances were highly significant (P-value for Wilk's lambda=0.0006, P-value for Pillai's trace=0.003). An analysis of the large part of the trial alone confirmed these results, the P-value for Wilk's lambda being 0.0008 and for Pillai's trace being 0.009 (analysis not presented).

The plot of scores for the two first canonical variates is given in Fig. 17. Apart from the scores, the mean values for the provenances are given together with their approximate 95 % confidence regions. The confidence regions have been calculated on the assumptions that there were four replicates. Thus, for the provenances of the small part of the experiment (where there were only two replicates) the confidence regions should be larger than depicted. In the diagram, provenances that are far apart are interpreted as being different, and if the confidence regions do not overlap, it is likely that the provenances have different properties. It appears that the provenances Sudan24 of *E. microtheca* and Sudan13 of *A. seyal* are more or less separated from the group of *A. nilotica* provenances, which would also be expected considering that they represent different species with a different growth habit. In the group of *A. nilotica* provenances there is less variation, but a more profound analysis of this is made in the next section.

Table 11. Results from the canonical variate analyses for the first two canonical variates in trial 25.

Canonical variate no.	**1**	**2**
Proportion of variation accounted for	0.37	0.30
Significance, P-value	0.0006	0.03

	Raw canonical coefficients		**Standardised canonical coefficients**		**Canonical directions**	
Canonical variate no.	**1**	**2**	**1**	**2**	**1**	**2**
Survival	-0.032	-0.032	-0.63	-0.65	184.5	-154.1
Height	-0.61	0.28	-0.37	0.17	5.5	4.6
Crown area	0.55	-0.01	2.01	-0.03	64.0	48.1
Number of stems	-0.24	-2.34	-0.047	-0.46	0.87	-0.59
Basal area of the mean tree	-0.13	0.07	-2.9	1.49	110.5	386.9
Total basal area	1.17	-0.03	2.4	-0.06	19.7	20.7

Figure 17. Score plot of the first and the second canonical variate from the canonical variate analysis for the provenances in the trial at Khor Donia, Sudan (Trial no. 25 in the arid zone series). The variables survival, height, crown area, number of stems, basal area of the mean tree and total basal area were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.

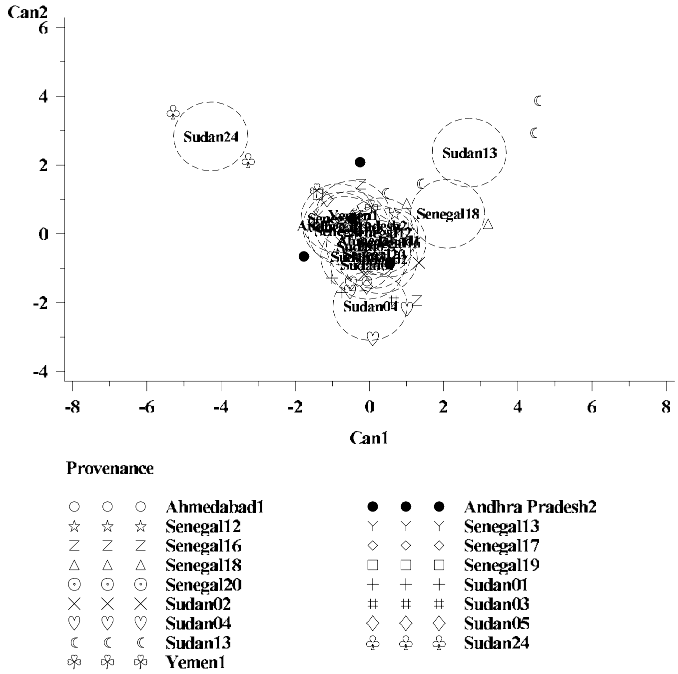
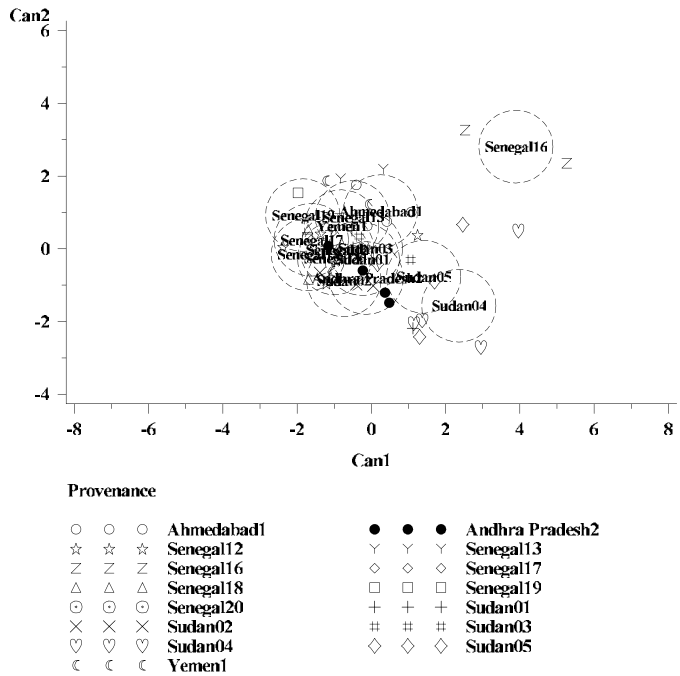


Figure 18. Score plot of the first and the second canonical variate from the canonical variate analysis for the *A. nilotica* provenances in the trial at Khor Donia, Senegal (Trial no. 25 in the arid zone series). The variables survival, height, crown area, number of stems, basal area of the mean tree, total basal area, dry weight of the mean tree and the total dry weight were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.



Analysis of *A. nilotica* provenances

In this analysis, only the first canonical variate was close to significance (Table 12), accounting for no more than 41 % of the variation. Similarly, the differences between the provenances were only at the limit of significance (P-value for Wilk's lambda=0.06, P-value for Pillai's trace=0.09). When the large part of the trial was analysed alone, the significance disappeared completely (P-value for Wilk's lambda=0.19, P-value for Pillai's trace=0.20, results not shown). The lack of significance despite the significance observed in some of the univariate analyses could indicate that variance heterogeneity distort the results.

As there were no clear signs of significant differences, the interpretation of the plots of scores (Fig. 18) should be cautious. However, the figure seem to support that there are not much difference between the provenances, most of them being placed in a massive cluster. The only provenance that possibly differs from the others is Senegal16, placed a bit away from the cluster.

Table 12. Results from the canonical variate analyses for the first two canonical variates in trial 25. Analysis of *A. nilotica* provenances only.

Canonical variate no.	1	2
Proportion of variation accounted for	0.41	0.22
Significance, P-value	0.06	0.40

	Raw canonical coefficients		Standardised canonical coefficients		Canonical directions	
Canonical variate no.	**1**	**2**	**1**	**2**	**1**	**2**
Survival	0.053	-0.043	0.9	-0.8	0.053	-0.043
Height	-1.5	0.93	-0.8	0.5	-1.5	0.9
Crown area	-0.27	-0.13	-0.6	-0.3	-0.27	-0.13
Number of stems	9.6	4.0	1.9	0.8	9.6	4.0
Basal area of the mean tree	-0.42	0.12	-7.7	2.2	-0.42	0.12
Total basal area	4.2	4.2	8.0	8.0	4.2	4.2
Average dry weight	2.0	-0.16	11.3	-0.9	2.0	-0.16
Total dry weight	-2.2	-1.6	-12.1	-8.8	-2.2	-1.6

5. Discussion and conclusions

Productivity

Sudan13 (*A. seyal*) and Senegal16 (*A. nilotica*) were the largest provenances with basal areas of approximately 5.5 m^2 ha^{-1}, corresponding to a growth rate of 0.55 m^2 ha^{-1} y^{-1}. Dry weight data are available only for *A. nilotica*, and Senegal16 was again the largest with 15 t ha^{-1}, corresponding to a production of 1.5 t ha^{-1} y^{-1}. This is similar to the maximum dry weight production in the other trial at Khor Donia (trial no. 26 in this series, including provenances of *A. tortilis*), and within the range observed for the trials in Burkina Faso. However, compared to the series as a whole, the production is only moderate when considering that the precipitation is the highest of the 26 trials. This may indicate that some factor other than rainfall is limiting growth at the site.

Species and provenance differences

The analyses were somewhat hampered by the imperfections of the design. In general, when both blocks were analysed together, significance was higher than when analysed apart. This could be because the provenances in the two parts have different growth potentials, but could also be due to differences in the environment - the small part of the trial being more fertile than the large part. Thus it is difficult to compare provenances in the two groups.

The provenance of *E. microtheca* behaved quite clearly differently from the other provenances, having lower survival, height and crown area and higher basal area of the mean tree. The provenance of *A. seyal* had the largest crown area, but in many respects did not differ from the provenances of *A. nilotica*. In the multivariate analysis, however, it came out separately.

Within *A. nilotica*, convincing significant differences were found only in total basal area. Though the analyses of all provenances often were significant, the splitting up of the trial increased the P-values and moved the differences away from significance. Even in the multivariate tests, the differences were only at the limit of significance. The provenance separating the most from the others was Senegal16, which had the largest production of dry weight. Senegal18, which was collected at the same site, had a somewhat lower production, but was also among the best.

As regards variety differences within *A. nilotica*, the trial did not bring any clarification – the subspecies were mixed between each other and differences seemed small. It is worth noting, on the other hand, that none of the provenances of the subspecies *tomentosa* were among the best performers. The site may not be ideal for this variety, which prefers moist soils. No clear signs of geographical variation were found either.

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Annex 1. Description of the trial site

Name of site:	Khor Donia (Ed Damazin) Latitude: 11°47'N Longitude: 34°23'E Altitude: 470 m
Meteorological stations:	Damazin (FAO 1984)
Rainfall:	Mean: 736 mm (FAO 1987)
Rainy season:	May-October Type: Normal with dry period (FAO 1984) Length (days): Intermediate 43, Wet 80 (FAO 1984)
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: 16.2 Hottest month: 39.5
Wind:	Prevailing directions: Northern dry winter wind December-February, Southern summer wind June-October (Mustafa 1986). Speed at 2 m: 1.6 m/s (FAO 1984)
Topography:	Flat
Soil:	Type: Neutral, black cracking clay soil Depth: Deep
Climatic/agroecological zone:	Semi-arid
Dominant natural vegetation:	*Acacia seyal*, *Balanites aegyptiaca*, *Compretum spp*., rarely *Acacia senegal*.
Koeppen classification:	BSh

Annex 2. Seedlot codes for provenances tested in trial 25

The plot numbers correspond to the location of the provenances in the field (see annex 3). Species codes: ani: *A. nilotica*, aniada: *A. nilotica* subsp. *adansonii*, aniads: *A. nilotica* subsp. *adstringens*, aniinja: *A. nilotica* subsp. *indica* var. *jaquemontii*, anini: *A. nilotica* subsp. *nilotica*, anito: *A. nilotica* subsp. *tomentosa*, asey: *A. seyal*, emi: *Eucalyptus microtheca*.

Seedlot numbers					Provenance information						
Provenance identification	DFSC	Country of origin and CTFT	Plot	Species code	Seed collection site	Country of origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
Ahmedabad1	1076/82		1076	aniinja	Kutch (Bhuj)	India	23° 50' N	69° 48' E	80	349	25
Andhra Pradesh2	1080/82		1080	aniinja	Anantapur	India	14° 41' N	77° 37' E	350	562	.
Senegal12	1037/82	82/625 (ISRA)	1037	anito	F.C. Richard-Toll	Senegal	16° 28' N	15° 42' W	4	300	31
Senegal13	1038/82	82/624 (ISRA)	1038	anito	F.C. Donaye	Senegal	16° 39' N	14° 52' W	5	300	30
Senegal16		80/2820N (CTFT), 79/55 (ISRA)	2820	aniada	Keur Samba Kane, St. Louis	Senegal	16° 30' N	15° 30' W	-	200	
Senegal17		80/2821N (CTFT), 79/57 (ISRA)	2821	anito	Podor, St. Louis	Senegal	16° 40' N	15° 08' W	-	200	
Senegal18		80/3245N (CTFT), 79/55 (ISRA)	3245	aniada	Keur Samba Kane, St. Louis	Senegal	16° 30' N	15° 30' W	-	200	
Senegal19		80/3246N (CTFT), 79/64 (ISRA)	3246	anito	Richard-Toll, St. Louis	Senegal	16° 40' N	15° 42' W	-	200	
Senegal20		80/3247N (CTFT), 80/219 (ISRA)	3247	anito	Nianga, St. Louis	Senegal	16° 37' N	15° 05' W	-	200	
Sudan01		0.697	697	anito	Khartoum	Sudan	15° 33' N	32° 32' E	330	165	
Sudan02		0.692	692	anito	Hariri, Sennar	Sudan	13° 16' N	33° 52' E			
Sudan03		0.693	693	anito	Lambewa, Sennar	Sudan	13° 22' N	33° 40' E			
Sudan04		0.698	698	anini	Khartoum	Sudan	15° 33' N	32° 32' E	330	165	
Sudan05		0.724	724	aniads	Sherkila	Sudan	12° 50' N	31° 20' E			
Yemen1	1064/82	(3)	1064	ani	Beihan	Yemen	14° 52' N	45° 45' E	900	100	10
Sudan13		0.717	717	asey	Soba	Sudan	15° 27' N	32° 40' E	330	165	
Sudan24		0.752	752	emi	Greenbelt, Khartoum	Sudan	15° 33' N	32° 32' E	330	165	

Annex 3. Layout of blocks and plots in the field

Each provenance is indicated by the code given in annex 2. A bold line separates the two parts of the trial.

y	BLOCK 4				BLOCK 3			
11		17 (3247)	16 (3246)			17 (2821)	16 (2820)	
10	15 (2821)	14 (3245)	13 (2820)		15 (3247)	14 (3246)	13 (3245)	
9	12 (693)	11 (1037)	10 (697)		12 (1080)	11 (1076)	10 (692)	
8	9 (698)	8 (724)	7 (1038)		9 (698)	8 (1037)	7 (697)	
7	6 (1064)	5 (692)	4 (717)		6 (752)	5 (1038)	4 (724)	
6	3 (752)	2 (1080)	1 (1076)		3 (1064)	2 (717)	1 (693)	
5	BLOCK 2				BLOCK 1			
4	12 (717)	11 (1080)	10 (752)		12 (752)	11 (717)	10 (698)	
3	9 (692)	8 (697)	7 (693)		9 (1080)	8 (1038)	7 (693)	
2	6 (1064)	5 (1037)	4 (1038)		6 (1037)	5 (1076)	4 (1064)	
1	3 (698)	2 (724)	1 (1076)		3 (692)	2 (697)	1 (724)	
	1	2	3	4	5	6	7	x

Individual tree positions in each plot:

y					
4	+	+	+	+	
3	+	+	+	+	
2	+	+	+	+	
1	+	+	+	+	
	1	2	3	4	x

Annex 4. Plot data set

Block	Plot	Plotx	Ploty	Provenance	Species	Survival	Height	Crown area	Number of stems	Basal area of the mean tree	Total basal area	Dry weight of the mean tree	Total dry weight
						%	m	m^2 $tree^{-1}$	no. $tree^{-1}$	cm^2 $tree^{-1}$	m^2 ha^{-1}	kg $tree^{-1}$	t ha^{-1}
1	1	7	1	Sudan05	aniads	94	3.66	7.21	1.38	70.5	7.34	20.7	21.53
1	2	6	1	Sudan01	anito	38	3.20	4.06	1.00	18.4	0.77	4.0	1.67
1	3	5	1	Sudan02	anito	94	3.53	4.99	1.00	49.0	5.10	13.5	14.04
1	4	7	2	Yemen1	ani	81	4.36	7.89	1.20	65.4	5.91	18.1	16.37
1	5	6	2	Ahmedabad1	aniinja	75	3.24	4.54	1.10	31.3	2.61	7.4	6.13
1	6	5	2	Senegal12	anito	75	3.55	7.95	1.00	55.8	4.65	15.2	12.68
1	7	7	3	Sudan03	anito	63	3.13	4.50	1.10	17.4	1.21	4.0	2.75
1	8	6	3	Senegal13	anito	44	3.48	5.86	1.00	39.2	1.90	9.6	4.66
1	9	5	3	Andhra Pradesh2	aniinja	56	4.36	9.60	1.00	65.0	4.06	21.2	13.25
1	10	7	4	Sudan04	anini	69	2.05	1.26	1.00	4.6	0.35	0.7	0.57
1	11	6	4	Sudan13	asey	63	3.60	10.82	1.00	62.3	4.33		
1	12	5	4	Sudan24	emi	6	4.00	2.99	1.00	41.3	0.29		
2	1	3	1	Ahmedabad1	aniinja	69	2.90	5.58	1.09	32.9	2.51	8.1	6.18
2	2	2	1	Sudan05	aniads	69	2.87	5.09	1.33	22.1	1.69	5.3	4.04
2	3	1	1	Sudan04	anini	88	2.33	3.36	1.00	14.7	1.43	3.2	3.13
2	4	3	2	Senegal13	anito	56	3.34	4.13	1.20	31.0	1.94	7.3	4.58
2	5	2	2	Senegal12	anito	94	3.74	7.38	1.00	32.0	3.33	7.8	8.12
2	6	1	2	Yemen1	ani	81	3.42	5.12	1.20	54.1	4.89	14.8	13.37
2	7	3	3	Sudan03	anito	81	3.29	5.31	1.09	20.5	1.85	4.6	4.12
2	8	2	3	Sudan01	anito	81	2.59	2.62	1.00	6.7	0.61	1.2	1.06
2	9	1	3	Sudan02	anito	44	2.74	2.68	1.00	7.0	0.34	1.1	0.53
2	10	3	4	Sudan24	emi	6				68.5	0.48		
2	11	2	4	Andhra Pradesh2	aniinja	69	3.13	5.22	1.00	30.0	2.29	7.5	5.72
2	12	1	4	Sudan13	asey	100	4.33	15.60	1.00	79.5	8.84		
3	1	7	6	Sudan03	anito	31	3.00	2.09	1.00	30.0	1.04	7.1	2.47
3	2	6	6	Sudan13	asey	44	3.96	22.06	1.00	85.8	4.17		
3	3	5	6	Yemen1	ani	63	3.63	5.41	1.00	38.7	2.69	10.2	7.08
3	4	7	7	Sudan05	aniads	44	2.94	4.96	1.00	46.1	2.24	13.3	6.46
3	5	6	7	Senegal13	anito	44	2.80	3.58	1.00	25.2	1.22	5.4	2.63

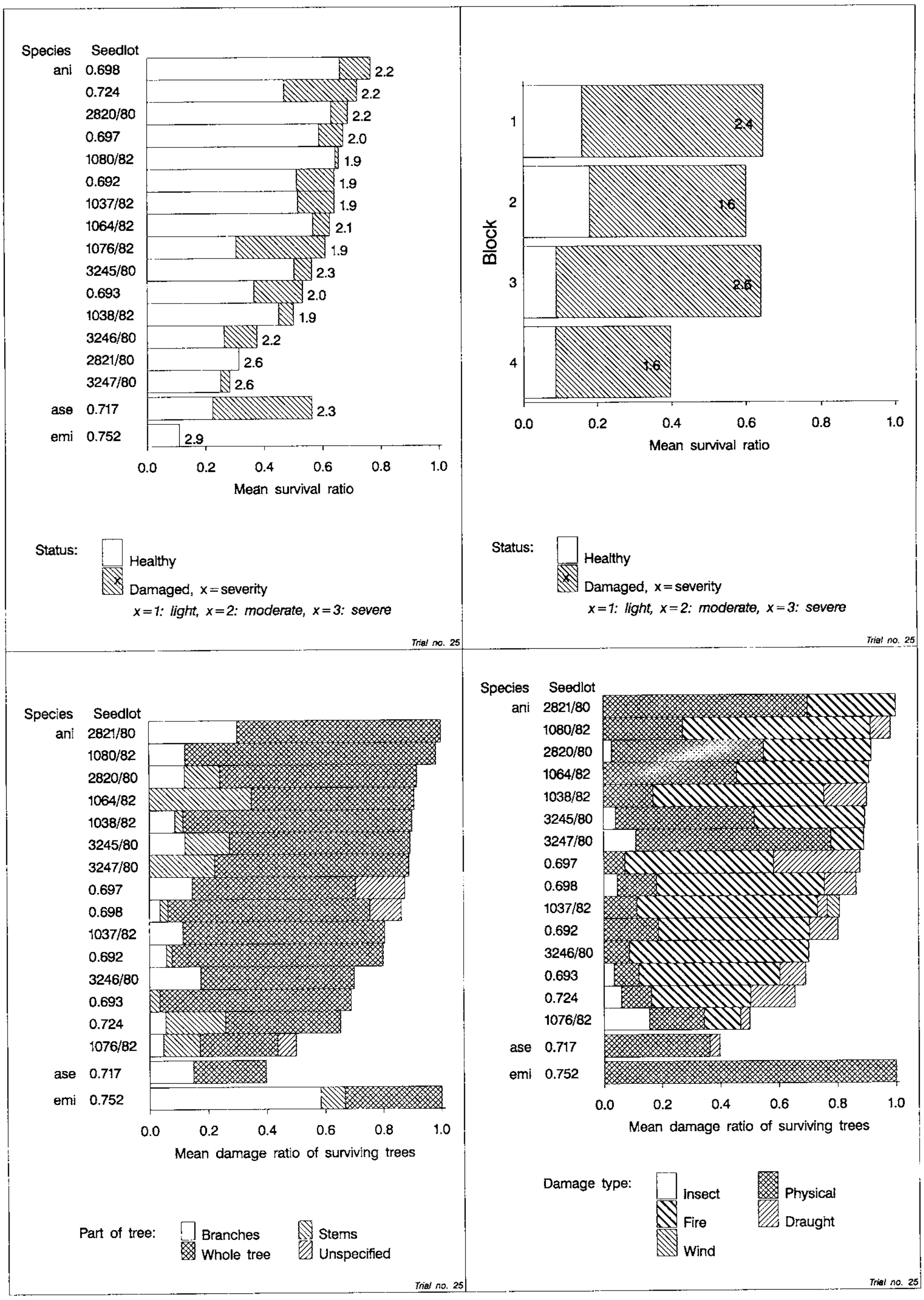
Block	Plot	Plotx	Ploty	Provenance	Species	Survival	Height	Crown area	Number of stems	Basal area of the mean tree	Total basal area	Dry weight of the mean tree	Total dry weight
						%	m	m^2 $tree^{-1}$	no. $tree^{-1}$	cm^2 $tree^{-1}$	m^2 ha^{-1}	kg $tree^{-1}$	t ha^{-1}
3	6	5	7	Sudan24	emi	44	1.28	1.89	1.00	89.2	4.33		
3	7	7	8	Sudan01	anito	63	3.74	2.33	1.00	18.6	1.29	3.8	2.37
3	8	6	8	Senegal12	anito	56	3.41	4.71	1.00	22.6	1.42	5.2	3.26
3	9	5	8	Sudan04	anini	81	3.50	7.21	1.57	36.0	3.25	9.4	8.46
3	10	7	9	Sudan02	anito	81	2.73	6.89	1.00	39.2	3.54	9.5	8.54
3	11	6	9	Ahmedabad1	aniinja	81	4.62	8.90	1.40	59.1	5.34	16.0	14.42
3	12	5	9	Andhra Pradesh2	aniinja	81	3.52	2.10	1.00	38.0	3.43	9.7	8.75
3	13	7	10	Senegal18	aniada	88	3.69	12.35	1.29	65.8	6.40	18.4	17.89
3	14	6	10	Senegal19	anito	75	3.92	5.18	1.00	32.5	2.71	7.4	6.19
3	15	5	10	Senegal20	anito	56	3.14	4.76	1.00	28.5	1.78	6.4	3.98
3	16	7	11	Senegal16	aniada	100	3.88	8.14	2.00	62.8	6.98	17.3	19.21
3	17	6	11	Senegal17	anito	75	3.80	5.17	1.00	50.5	4.21	13.2	10.96
4	1	3	6	Ahmedabad1	aniinja	94	3.43	6.47	1.25	51.1	5.32	13.4	13.98
4	2	2	6	Andhra Pradesh2	aniinja	88	2.99	4.83	1.00	24.9	2.42	5.8	5.65
4	3	1	6	Sudan24	emi	38				100.9	4.20		
4	4	3	7	Sudan13	asey	69	3.98	8.38	1.33	53.7	4.10		
4	5	2	7	Sudan02	anito	75	3.37	3.13	1.00	12.5	1.04	2.3	1.95
4	6	1	7	Yemen1	ani	63	3.43	4.30	1.00	25.5	1.77	6.0	4.14
4	7	3	8	Senegal13	anito	75	3.80	3.34	1.00	24.8	2.06	6.0	5.01
4	8	2	8	Sudan05	aniads	63	2.55	1.18	1.00	4.5	0.31	0.6	0.45
4	9	1	8	Sudan04	anini	75	3.02	1.61	1.00	6.3	0.53	1.0	0.80
4	10	3	9	Sudan01	anito	94	3.91	7.51	1.25	48.8	5.08	13.0	13.54
4	11	2	9	Senegal12	anito	88	3.97	5.98	1.43	58.4	5.68	16.8	16.36
4	12	1	9	Sudan03	anito	88	3.93	4.71	1.00	30.1	2.93	7.3	7.05
4	13	3	10	Senegal16	aniada	63	4.18	8.46	1.50	59.2	4.11	16.2	11.25
4	14	2	10	Senegal18	aniada	63	3.48	7.41	1.00	36.7	2.55	9.0	6.22
4	15	1	10	Senegal17	anito	25				41.5	1.15	10.2	2.83
4	16	3	11	Senegal19	anito	31	3.60	1.89	1.00	23.8	0.83	5.1	1.78
4	17	2	11	Senegal20	anito	0					0.00		0.00

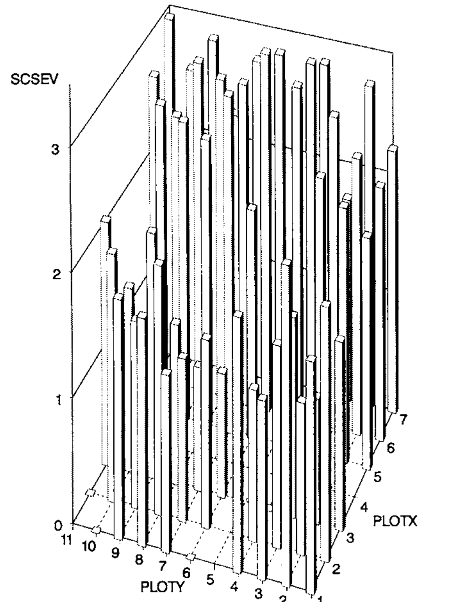
Annex 5. Graphical presentation of the health data

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

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

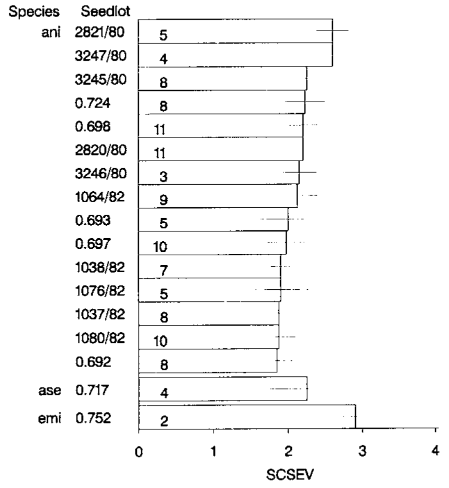
Please note that the seedlot codes correspond to the numbers given in annex 2.





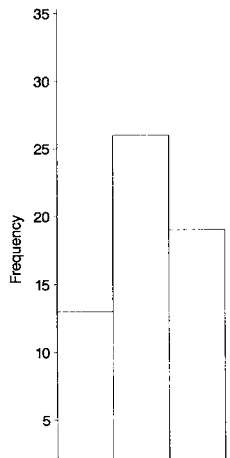
SCSEV = Health status code, severity of attack
Scatter of plot mean values

Trial no. 25



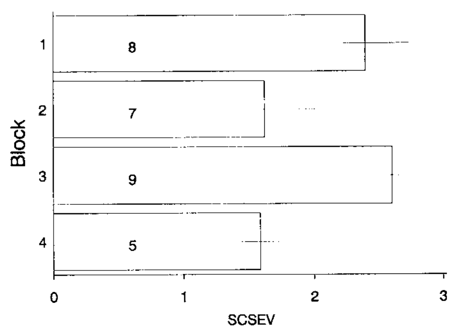
Mean SCSEV of seedlot with error bar line (+/− standard deviation of the mean) and the average number of assessed (living) trees per plot for each seedlot.

Trial no. 25



Frequency distribution of plot mean values

Trial no. 25



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

Trial no. 25