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Evaluation of a provenance trial of *Prosopis juliflora* at Petrolina - PE, Brazil

Trial no. 4 in the arid zone series

by

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Diagram showing vertical height in the *P. juliflora* provenance. See Figure 3.

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

Preface

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

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

This trial was established and maintained by the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) / Centro de Pesquisa Agropecuária do Trópico Semi-Arido (CPATSA), Petrolina, Pernambuca, in Brazil. The assessment team consisted of Paulo César Fernandes Lima, João Claro de Souza, Pedro José Alves, José de Assis Amaral de Lima (EMBRAPA/CPATSA), Agnete Thomsen (FAO) and Lars Graudal (DFSC).

The authors thank the personnel at EMBRAPA/CPATSA for help with the establishment, maintenance and assessment of the trials, and 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, and Luiz Balbino Morgado, researcher at Embrapa Semi-Árido.

Abstract

This report describes results from a trial with four provenances of *Prosopis juliflora*, coming from Brazil, Honduras, Mexico and Senegal. The trial was established with spacing of 6 x 6 metres at Petrolina - PE, Brazil in 1988 and assessed at an age of 5 years in 1992. Different growth parameters were measured and subjected to analyses of variance and multivariate analyses.

The fastest growing provenances had increment rates in basal area of 0.3 m^2 ha^{-1} y^{-1}, corresponding to a dry weight production of approximately 1.1 t ha^{-1} y^{-1}. Though having only a moderate survival, the Brazilian provenance had the fastest growth together with the provenance from Senegal. The provenance from Honduras had a creeping growth habit, and in the multivariate analysis, the provenances from Honduras and Mexico were clearly separated from the land-races from Brazil and Senegal, as well as from each other. The differences between the provenances were significant for all the analysed variables.

Contents

1. Introduction

This report describes the results from trial no. 4 in a large series of provenance trials within the 'International Series of Trials of Arid and Semi-Arid Zone Arboreal Species'. The main goals of the series were to contribute to the knowledge on the genetic variation of woody species, their adaptability and productivity and to give recommendations for the use of the species. The species included in this series of trials are mainly of the genera *Acacia* and *Prosopis*. A more detailed introduction to the series is given by DFSC (Graudal *et al.* 2003).

The species *P. juliflora* was introduced with certainty to Brazil in 1942 and is at present found in the entire north-eastern region and other parts of the country (Silva 1988). Seed were brought in from United States, Peru and Sudan, but only four trees survived these introduction trials, and it is believed that today's population of *P. juliflora* are descendants of these trees (Pires *et al.* 1988). There is concern therefore that the trees are of narrow genetic origin, and in trials differences between offspring are difficult to find (Pires & Kageyama 1988, Pires *et al.* 1988). According to Pasiecznik *et al.* (2001) it is possible that the species was introduced earlier, but the dominant form in Brazil is believed to origin from the introductions in the 1940s.

The species is cultivated through large parts of the tropics and origin in South America. Due to its widespread cultivation, however, the exact origin is not known, but is believed to include the Western part of the Andes, the Caribbean and Central America. It should be noted that the taxonomy of *Prosopis* species native to these areas is highly complex, and that *P. juliflora* especially in Peru hybridises with *P. pallida* (Pasiecznik *et al.* 2001). This trial includes four provenances of the species, including the local land race, two provenances from Honduras and Mexico and a land race from Senegal. Lima (1998) gives a detailed description of the background for the trial.

2. Materials and methods

2.1 Site and establishment of the trial

The trial is located at Bebedouro, Petrolina (9°9′S, 40°22′W) in Pernambuco state, Brazil at an altitude of 366 m. The mean annual temperature is 27 °C, and the mean annual rainfall is 553 mm (DFSC 1994). The dry period is approximately 7 months. Further information is given in the assessment report (DFSC 1994) and summarised in annex 1.

Seed were sown in December 1987, and the trial was established in May 1988.

2.2 Provenances

The trial includes 4 provenances of *P. juliflora*, one from each of the countries Mexico, Brazil, Honduras and Senegal (Table 1). For convenience, the provenances have been given identification numbers relating to their geographical origin (name of country followed by a number). The original seedlot numbers are provided in annex 2.

2.3 The experimental design

The experimental design is a randomised complete block design with 5 blocks. Within each block, each provenance is represented by 20 trees in a plot, planted in a rectangle of 4 × 5 trees. The trees have a spacing of 6×6 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 October 1992 EMBRAPA/CPATSA, FAO and DFSC undertook a joint assessment. The assessment included the following characters:

- Survival
- Health status
- Vertical height
- Diameter at 0.3 m
- Number of stems at 0.3 m
- Crown diameter

A detailed account of the assessment methods is given by DFSC (Graudal *et al.* 2003). The provenance Honduras3 was characterised by a creeping growth habit, and it was impossible to determine where to measure the diameter. Therefore diameter was not measured for this provenance. The 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.

Table 1. Species and provenances of *Prosopis juliflora* tested in trial no. 4 at Petrolina - PE, Brazil.

Provenance identification	Seed collection site	Country of Origin	Latitude	Longitude	Altitude (m)	Rainfall (mm)	No. of mother trees
Brazil2	Bebedouro	Brazil	9°9'S	40°22'W	365.5	553	15
Honduras3	Comayagua	Honduras	14°21'S	87°37'W	680	880	30
Mexico6	Cananez	Mexico	24 13 N	104 28 W	890		
Senegal37	Thies	Senegal					

3. Statistical analyses

3.1 Variables

In the report the following variables are analysed:

- Survival
- 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
- Biomass of the mean tree
- Total biomass
- Health

Survival was analysed as the rate of surviving trees to the total number of trees per plot, whereas height, crown area, number of stems, health and basal area and biomass of the mean tree were analysed as the mean of surviving trees for each plot. Total basal area and total biomass were calculated as the sum of the variable for each plot and then related to the growth space of the trees, expressing the values on the basis of unit area.

For five small trees, no assessment of number of stems was made. This means that the analysis and the mean values for number of stems are biased. Since this applies only to a small proportion of the trees, the implications of this are likely to be small. The provenance Honduras3 is not included in the analyses of basal area and biomass, because no diameter was measured (see above).

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 *P. juliflora* the regression is

$$TreeDW = e^{(2.466 \times \ln(basalarea) - 2.036)}$$

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 analysis included a test of differences between all provenances, performed 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 residualof plot *jk* which is assumed to follow a normal distribution $N(0, \sigma_e^2)$.

In order to complement blocks in adjusting for uneven environments, a co-variate related to the plot position was included in the initial model. This co-variate was distance along the first axis of the trial, plotx. The distance along the second axis, ploty, was not included because it was confounded with the block effect. In the cases where plotx was not significant at the 10% level, it was excluded from the model.

Standard graphical methods and calculated standard statistics were applied to test model assumptions of independence, normality and variance homogeneity (Snedecor & Cochran 1980, Draper & Smith 1981, Ræbild *et al.* 2002). In all cases the assumptions of the models were fulfilled, and no further reference is made to this.

The P-values from the tests of provenance differences were corrected for the effect of multiple comparisons by the sequential tablewide Bonferroni method (Holm 1979). The tests were ranked according to their P values, and the test corresponding to the smallest P value (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. Kjaer & Siegismund 1996). In this case the number of tests was set to nine, 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. Note that in the calculation of BLUPs it is assumed that the provenances represent a random selection.

A multivariate analysis providing canonical variates, and Wilks lambda and Pillais trace statistics, complemented the univariate analyses (Chatfield & Collins 1980, Afifi & Clark 1996, Skovgård & Brockhoff 1998).

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

4. Results

4.1 Survival

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

The average survival varied between 44 and 80 % (Fig. 1). The differences between provenances were significant, also when correcting for the effect of multiple tests (The Bonferroni P-value, Table 2). The co-variate plotx was not significant and was not included in the model. The provenance from Honduras had the highest survival, and the provenances from Brazil and Mexico had the lowest survivals, both with 44 %. Senegal37 was intermediate. The predicted genetic values by choosing the provenance with the highest survival in stead of the Brazilian provenance are considerable (Fig. 2).

Table 2. Results from analysis of variance of provenance differences of survival in trial 4.

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	3	0.162	7.2	0.005	**
Blocks	4	0.015	0.7	0.62	
Error	12	0.023			

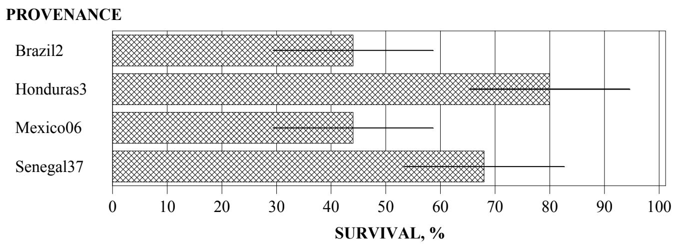

Figure 1. Survival in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are least square means with 95 % confidence limits.

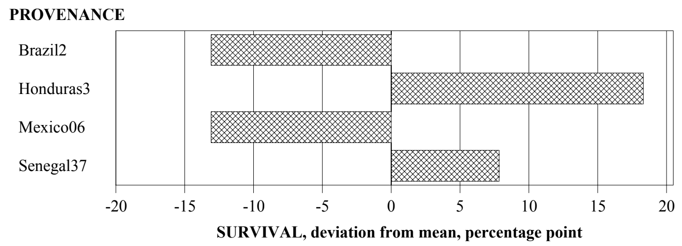

Figure 2. Best linear unbiased predictors (BLUPs) for survival in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are deviations from the mean value in percentage point.

4.2 Height

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

The average vertical height varied from 1.5 m in the provenance from Honduras to more than 4 m in the local Brazilian provenance (Fig. 3). The provenances from Mexico and Senegal attained average heights of 2 and 3.9 m, respectively. According to the analysis of variance, the differences between provenances were highly significant (Table 3). Therefore the predicted genetic gains by choosing the best provenance are quite considerable (Fig. 4). The co-variate plotx was significant.

Table 3. Results from analysis of variance of provenance differences of height in trial 4.

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	3	7.3	97.4	<0.0001	***
Blocks	4	0.1	1.5	0.28	
Plotx	1	1.1	15.4	0.002	
Error	11	0.1			

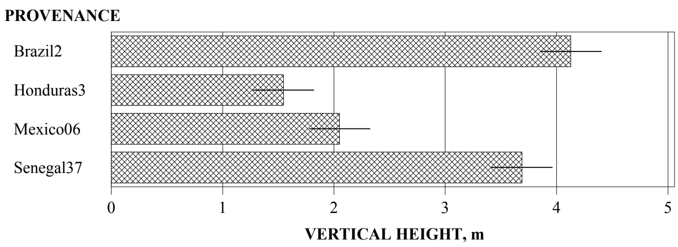

Figure 3. Vertical height in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are least square means with 95 % confidence limits.

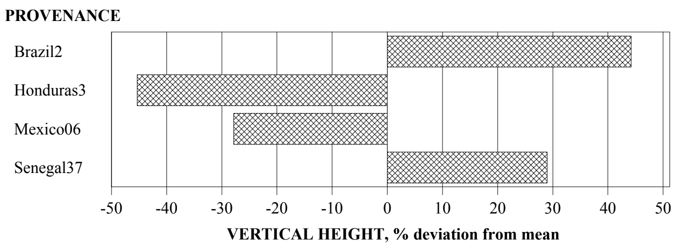

Figure 4. Best linear unbiased predictors (BLUPs) for vertical height in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values are presented as deviations in percent of the mean value.

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.

The average crown area for the provenances varied between 8 m^2 $tree^{-1}$ (Mexico06) and 28 m^2 $tree^{-1}$ (Brazil2) (Fig. 5). Since the growth space in the trial is 36 m^2 $tree^{-1}$, the trees of Brazil2 would be close to covering the area had the survival of the provenance been higher. Honduras3 and Senegal37 had intermediate crown areas of 19 and 26 m^2 $tree^{-1}$, respectively. The differences between provenances were again highly significant (Table 4), and there were considerable genetic gains by choosing the best provenances (Fig. 6). The covariate plotx was significant.

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

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	3	381	37.1	<0.0001	***
Block	4	3	0.3	0.85	
Plotx	1	70	6.9	0.02	
Error	11	10			

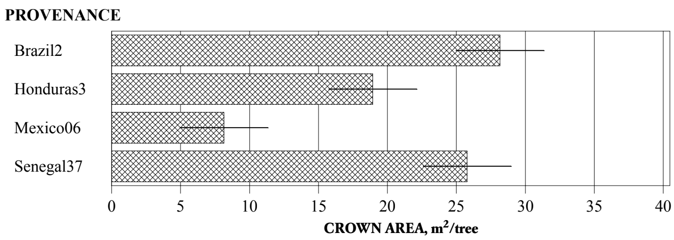

Figure 5. Crown area in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are least square means with 95 % confidence limits.

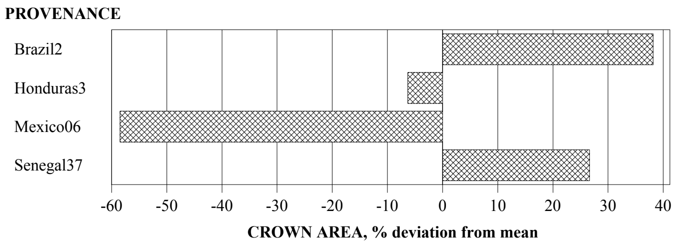

Figure 6. Best linear unbiased predictors (BLUPs) for crown area in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.4 Number of stems

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

Senegal37 had the lowest average number of stems with values just below 2 stems tree^{-1}. Honduras3 and Mexico06 both had approximately 3.5 stems tree^{-1}, whereas Brazil2 was intermediate with 2.5 stems tree^{-1} (Fig.7). This corresponds with the visual impression that Senegal37 and Brazil2 had the most tree-like growth, and that Honduras3 and Mexico06 were more bushy. Note, however, that the analysis and the estimates are biased since five of the smallest trees were not assessed (see section 3.1). The differences between the provenances were highly significant (Table 5), and the predicted gains by provenance selection for number of stems are subsequently high (Fig. 8). The co-variate plotx was not significant.

Table 5. Results from analysis of variance of provenance differences of number of stems in trial 4.

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	3	4.03	32.9	<0.0001	***
Block	4	0.76	6.2	0.006	
Error	12	0.12			

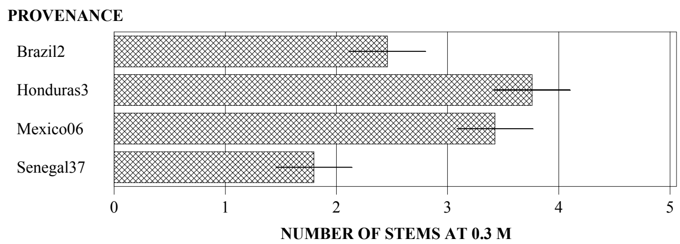

Figure 7. Number of stems in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are least square means with 95 % confidence limits.

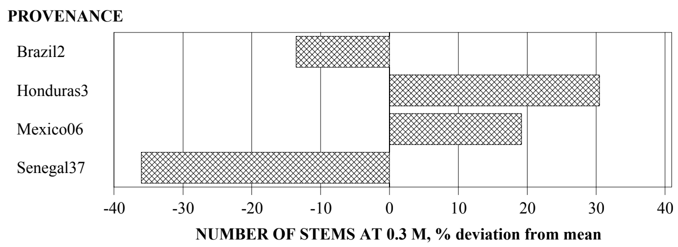

Figure 8. Best linear unbiased predictors (BLUPs) for number of stems in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values are presented as deviations in percent of the mean value.

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.

Note that the provenance from Honduras was not included in the diameter measurements. Basal areas for this provenance are therefore included neither in the analysis nor in the estimates. However, there were highly significant differences between the provenances included in the measurements (Table 6), and the co-variate plotx was significant.

The mean trees of Mexico06 had basal areas of 20 cm^{-2} $tree^{-1}$, whereas Senegal37 and Brazil2 had values of 78 and 94 cm^{-2} $tree^{-1}$, respectively (Fig 9). Consequently, the predicted genetic gain by provenance selection varies from almost -70 % in Mexico06 to 45 % in Brazil2 (Fig. 10). The differences between Brazil2 and Senegal37 did not seem to be significant. One may note that in the five years following sowing of the trees, the trees of the Brazilian provenance have on the average increased with almost 20 cm^{-2} $tree^{-1}$ annually.

Table 6. Results from analysis of variance of provenance differences of basal area of the mean tree in trial 4.

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	2	7064	57.1	<0.0001	***
Blocks	4	454	3.7	0.06	
Plotx	1	1790	14.5	0.0007	
Error	7	124			

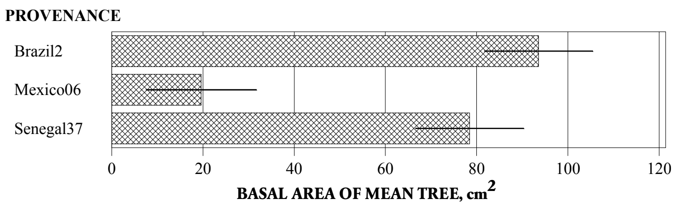

Figure 9. The basal area of the mean tree in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are least square means with 95 % confidence limits.

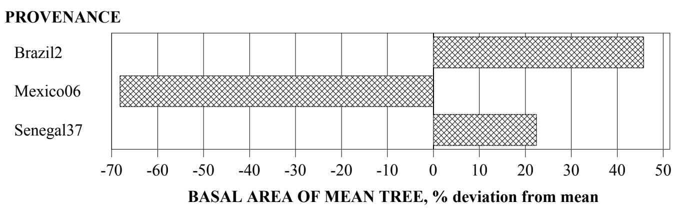

Figure 10. Best linear unbiased predictors (BLUPs) for the basal area of the mean tree in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.6 Total basal area

In comparison to the basal area of the mean tree, the total basal area is expressed per hectare and is thus a better measure of the actual production on the site.

Note again that there are no data for the provenance from Honduras. The average total basal areas varied from below 0.3 m^2 ha^{-1} in Mexico06 to 1.3 and 1.4 m^2 ha^{-1} in Brazil2 and Senegal37, respectively. For Senegal37 this corresponds to an average annual increment of approximately 0.3 m^2 ha^{-1} (Fig. 11). In the analysis of variance the provenance effect was highly significant (Table 7), but plotx was not significant.

The predicted values for the deviations from the mean value ranged from below –60 % in Mexico6 to almost 50 % in Senegal37 (Fig. 12). The differences between Senegal37 and Brazil2 were not significant.

Table 7. Results from analysis of variance of provenance differences of total basal area in trial 8.

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	2	1.71	20.7	0.0007	***
Block	4	0.18	2.15	0.17	
Error	8	0.08			

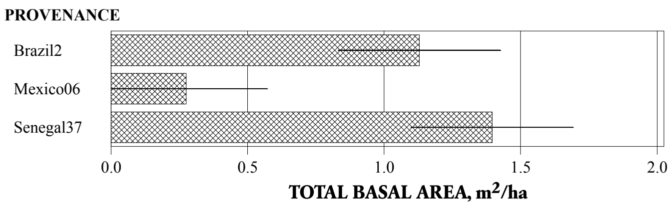

Figure 11. Total basal area for the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are least square means with 95 % confidence limits.

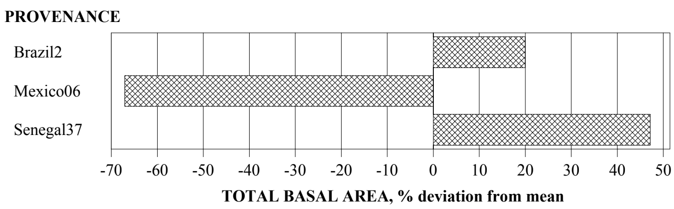

Figure 12. Best linear unbiased predictors (BLUPs) for total basal area in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values are presented as deviations in percent of the mean value.

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 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.

The dry weight of the mean tree varied from only 5 kg tree^{-1} in Mexico06 to 30 and 38 kg tree^{-1} in Senegal37 and Brazil2, respectively (Fig. 13). This corresponds to an average annual growth of approximately 5 kg tree^{-1} for the Brazilian provenance. The differences between the provenances were highly significant (Table 8), even though the difference between Senegal37 and Brazil2 was not large enough to become significant. Plotx was also significant. The resulting predicted values for dry weight of the mean tree varied from almost −80 % for Mexico06 to +55 % for Brazil2 (Fig. 14).

Table 8. Results from analysis of variance of provenance differences of dry weight of the mean tree in trial 4.

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	2	1332	53.0	<0.0001	***
Block	4	131	5.2	0.03	
Plotx	1	420	16.8	0.005	
Error	7	25			

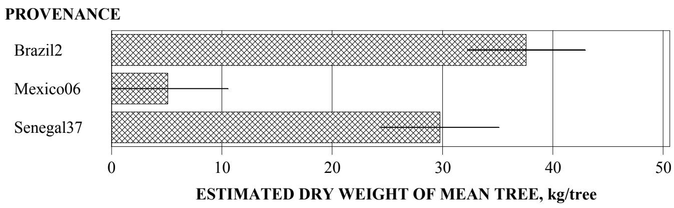

Figure 13. Dry weight of the mean tree in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are least square means with 95 % confidence limits.

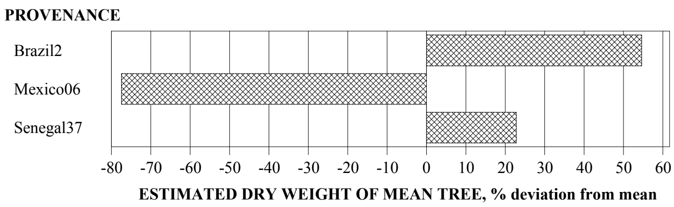

Figure 14. Best linear unbiased predictors (BLUPs) for dry weight of the mean tree in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.8 Total dry weight

In parallel with the total basal area, the total dry weight is expressed on a unit area basis and gives the best measure of the actual production of biomass at the site.

Mexico06 had the lowest production with only 0.6 t ha^{-1}. The ranking between the two other provenances was opposite to what was observed in the dry weight of the mean tree, Brazil2 having a dry weight of 4.7 t ha^{-1} and Senegal37 having a dry weight of 5.3 t ha^{-1} (Fig. 15). This amounts to an average annual production of approximately 1.1 t ha^{-1} from the time of sowing to the assessment. The differences between provenances were highly significant (Table 9), but again the differences between Brazil2 and Senegal37 were too small to become significant. Plotx was significant. The predicted gains varied from −80 % for Mexico06 to +50 % for Brazil2 (Fig. 16).

Table 9. Results from analysis of variance of provenance differences of total dry weight in trial 4.

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	2	30.8	32.0	0.0003	***
Block	4	4.2	4.4	0.04	
Plotx	1	6.1	6.3	0.04	
Error	7	1.0			

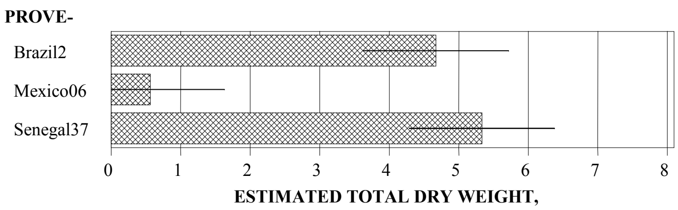

Figure 15. Total dry weight in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values presented are least square means with 95 % confidence limits.

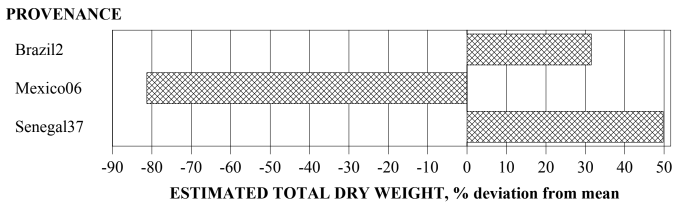

Figure 16. Best linear unbiased predictors (BLUPs) for total dry weight in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Values are presented as deviations in percent of the mean value.

4.9 Damage score

The damage score of the surviving trees is important in the sense that it gives an account of the present health status. In this particular case insects attacked the trees, and the susceptibility of the different provenances to the attack is analysed.

The damage score was scored on a scale from 0 to 3, where 0 means that the tree is perfectly healthy; 1 - slight damage: 2 - moderate damage and 3 - severe damage. It should be noted that the analysis of variance is problematic in the sense that there is no guarantee that the scale is equidistant – the distance in terms of severity may be larger between the scores 2 and 3 than between the scores 0 and 1. However, this is not accounted for in the present analysis.

Overall the health status was quite good, the mean of all provenances being 0.5 on the scale from 0 to three. Note that the scale is reversed in the sense that low values mean that the trees are healthy (Fig. 17). Nevertheless there were highly significant differences between the provenances (Table 10). Plotx was not significant. The provenances Honduras3 and Mexico06 were hardly damaged at all, whereas the provenances Brazil2 and Senegal37 on average were slightly damaged with damage scores of approximately 1.

An extra analysis was made on the proportion of damaged trees to the total number of surviving trees (not presented). Again there were highly significant differences between the provenances, and the provenances had almost the same ranking. In Honduras3 and Mexico06 only 3 and 16 % of the trees were damaged, whereas 70 and 79 % of the trees were damaged in Brazil2 and Senegal37, respectively. This indicates that the damages in Brazil2 and Senegal37 were spread out on a large number of trees that were only slightly damaged, rather than being concentrated on few trees with severe damages.

In accordance with the above results the predicted damage score values indicate that there are considerable gains by choosing between the provenances. The deviations from the mean ranged from –0.45 (Honduras3) to +0.45 (Brazil2) (Fig. 18). Note again that negative values denote a better than average health, and that the values are presented on the scale of the health score.

Table 10. Results from analysis of variance of provenance differences of damage score in trial 4.

Effect	DF	MS	F-value	P-value	Bonferroni sequential table-wide correction
Provenance	3	1.15	17.7	<0.0001	***
Block	4	0.17	2.6	0.09	
Error	12	0.07			

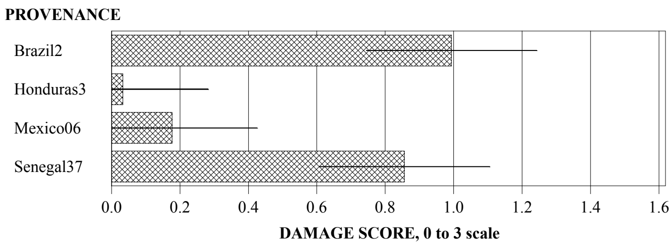

Figure 17. Damage score in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Damage was scored on a scale from 0 to 3, where 0 means no damage and 3 means severe damage. Values presented are least square means with 95 % confidence limits.

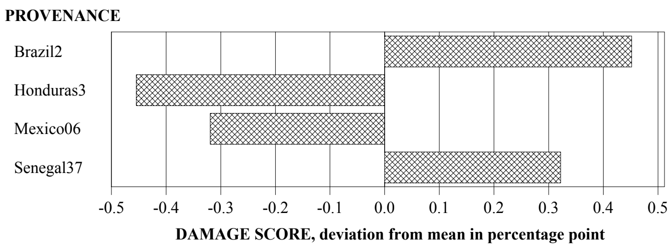

Figure 18. Best linear unbiased predictors (BLUPs) for damage score in the *P. juliflora* provenances in the trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). Note that the values are presented as deviations from the mean, and that the units are units on the damage score. Negative deviations denote a better-than-average health, and vice versa.

4.10 Multivariate analysis

The multivariate analysis included the variables survival, height, crown area, number of stems and health, but since diameter was not measured on the provenance Honduras3, basal area and biomass variables were not included. All the variables were used without transformations.

All three canonical variates were significant, meaning that the variation is best explained in three dimensions (Table 11). The three variates account for all the variation in the data, but the first was the most important since it explained 71 % of the variation. The differences between provenances were highly significant (P-value for Wilk's lambda and Pillai's trace both below 0.0001).

In order to present the data, the scores on the canonical variates were plotted. Since three variates were significant, the plots of can2 versus can1 and can3 versus can1 present all information from the three dimensions (Fig. 19). Apart from the scores, the mean values for the provenances are given together with their approximate 95 % confidence regions.

In the diagrams, provenances that are far apart are interpreted as being very different, and if the confidence regions do not overlap, it is likely that the provenances have different properties. It appears that the provenances from Senegal and Brazil were quite close together. The provenances from Honduras and Mexico, on the other hand, were far apart, both from each other and from the provenances from Senegal and Brazil.

Table 11. Results from the canonical variate analyses for the three canonical variates in trial 4.

Canonical variate no.	1	2	3
Proportion of variation accounted for	0.71	0.26	0.03
Significance, P-value	<0.0001	<0.0001	0.03

	Raw canonical coefficients			**Standardised canonical coefficients**			**Canonical directions**		
Canonical variate no.	1	2	3	1	2	3	1	2	3
Survival	-1.4	2.7	-1.2	-0.3	0.6	-0.3	-0.3	0.6	-0.6
Height	3.4	-2.0	0.35	3.7	-2.2	0.4	2.9	1.3	2.2
Crown area	-0.22	0.40	0.08	-1.8	3.1	0.7	11.4	29.0	32.5
Number of stems	-0.88	-1.7	2.2	-0.8	-1.7	2.1	-2.1	-1.6	2.9
Health	2.1	-1.2	1.7	1.1	-0.6	1.0	1.2	0.7	0.8

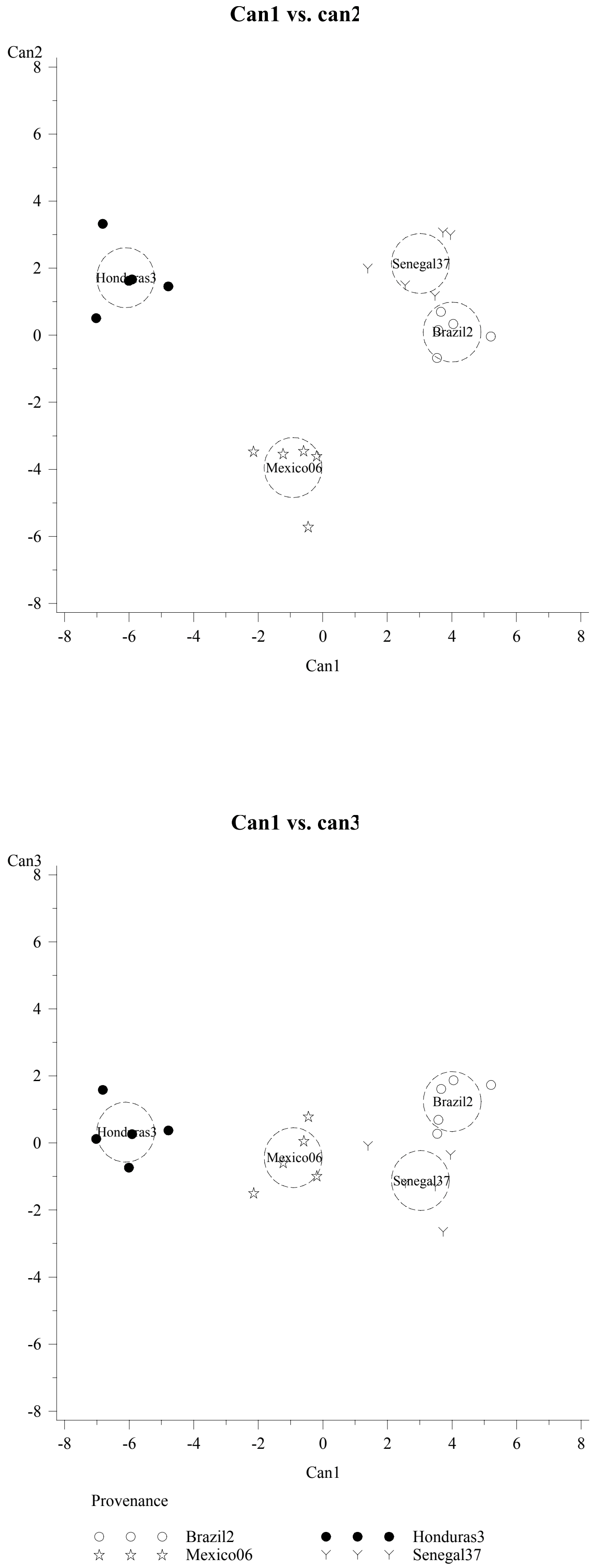

Figure 19. Score plots of the first and the second canonical variates (upper figure) and the first and the third canonical variates from the canonical variate analysis for the provenances in the *P. juliflora* provenance trial at Petrolina - PE, Brazil (Trial no. 4 in the arid zone series). The variables survival, height, crown area, number of stems and health were included. Each provenance is marked at the mean value and surrounded by a 95 % confidence region.

5. Discussion and conclusions

Productivity

The dry weight production of the best provenances in the trial (Senegal37 and Brazil2) was 1.0-1.1 t ha^{-1} y^{-1}. In the trials no. 1, 2 and 3 in this series , also located at Petrolina, the best provenances had higher production of biomass, up to 2.1 t ha^{-1} y^{-1}. However, it seems that this is an effect of the micro-site of this trial rather than an inherent low production of *P. juliflora* in comparison with other species. The provenance Brazil2 was also included in the trials no. 2 and 3 and had a production of 1.7 t ha^{-1} y^{-1} in both trials.

Provenance differences

There were significant or highly significant differences between the four provenances in all variables analysed. The provenances Honduras3 and Senegal37 had the highest survival, but with respect to height, crown area, basal area and production of biomass the provenances Brazil2 and Senegal37 were the leaders. In the number of stems Honduras3 and Mexico06 had the highest values.

Bearing in mind that the trial was relatively young at the assessment, the conclusion from the trial was clearly that the best producers of biomass were Brazil2 and Senegal37. There were no major differences between these two provenances, and even in the multivariate analysis they were quite close to each other. Probably these provenances should be recommended for future plantings. However, the development in insect attacks should be followed closely as the two provenances were more prone to damage caused by insects than the provenances from Mexico and Honduras. It should also be noted that the Brazilian land race may be of narrow genetic origin (Lima 1998, see introduction).

P. juliflora is closely related to a number of other *Prosopis* species, and the taxonomy of the species is not completely clarified. The species is believed to have originated in Peru but having spread into Central America and the Southern North America (Pasiecznik *et al.* 2001). Pasiecznik et al. distinguishes three major races on the basis of geographical regions and leaf morphology: The Peruvian-Ecuadorian race, the Columbian-Caribbean race and the Central American race.

From the data it seems that the provenances from Brazil and Senegal behave similarly. The provenance from Brazil is believed to have Peruvian ancestors (Lima 1998), but according to Pasiecznik *et al.* (2001) the origin of the provenance from Senegal is uncertain. If it is correct that the Brazilian provenance has a Peruvian origin, it would belong to the Peruvian-Ecuadorian race of Pasiecznik et al. One could then speculate on whether the two provenances belong to the same race, but this would need further verification.

The provenances from Honduras and Mexico were distinctly different from Brazil2 and Senegal37. Honduras3 had a creeping growth habit, whereas Mexico06 was tree-like, but with a very slow growth. In the multivariate analysis the two provenances were clearly separated from each other as well as from Brazil2 and Senegal37. This could support the hypothesis of a Central American race (Pasiecznik *et al.* 2001), but also indicate that there is a wide variation within this race. An alternative interpretation is that the two provenances represent another species, as discussed by Lima (1998). On the basis of phenological characters in the same trial, he raised the possibility that the provenances from Central America are of a different species than the Brazilian and Senegalese land races.

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Annex 1. Description of the trial site

Name of site:	Bebedouro, Petrolina Latitude: 9°9'S Longitude: 40°22'W Altitude: 365.5 m
Meteorological stations:	Local (5 km (Establishment Report 1988)) Petrolina (9°23'S, 40°29'W, 370 m (FAO 1985))
Rainfall:	Annual mean (period): 553 (11 years - period not given (Establishment Report 1988))
Rainy season:	November-April (Establishment Report 1988) Type: Intermediate (FAO 1985) Length (days): 60 (FAO 1985)
Dry months/year:	(Establishment Report 1988): No. of dry months (<50 mm): 7 No. of dry periods: 1
Temperature:	(°C (Establishment Report 1988)): Annual mean: 27 Coldest month: 18 (minimum) Hottest month: 40 (maximum)
Wind:	Speed: 1.4 (FAO 1985)
Topography:	Flat/gentle
Soil: **Type:** **Depth:**	 Latosols, low water holding capacity, low organic matter (Lima 1986) and stony Shallow (Lima 1986)
Climatic/agroecological zone:	Semi-arid
Dominant natural vegetation:	'Caatinga', deciduous woodland
Koeppen classification:	BSh

Annex 2. Seedlot information

Species and provenances of *Prosopis juliflora* tested in trial no. 4 at Petrolina - PE, Brazil. The plot numbers refers to the seedlot in the map of the trial, see Annex 3.

Seedlot numbers				**Provenance information**						
Provenance	**DFSC**	**Country of origin**	**Plot**	**Origin**	**Country of origin**	**Latitude**	**Longitude**	**Altitude (m)**	**Rainfall (mm)**	**No. of mother trees**
Brazil1			4	Bebedouro	Brazil	9°9'S	40°22'W	365.5	553	15
Honduras3		OFI 49/83	1	Comayagua	Honduras	14°21'S	87°37'W	680	880	30
Mexico6	1214/83		3	Cananez	Mexico	24 13 N	104 28 W	890		
Senegal05			2	Thies	Senegal					

Annex 3. Layout of the trial

Layout of blocks and plots in the field. The numbers correspond to the seedlots given in Annex 2.

y					
5	3	1	2	4	BLOCK 5
4	1	3	4	2	BLOCK 4
3	4	2	1	3	BLOCK 3
2	3	4	2	1	BLOCK 2
1	1	2	3	4	BLOCK 1
	1	2	3	4	x

Individual tree positions in each plot (each tree indicated by its local tree number):

y						
4	1	2	3	4	5	
3	10	9	8	7	6	
2	11	12	13	14	15	
1	20	19	18	17	16	
	1	2	3	4	5	x

Annex 4. Plot data set

Trees damaged denote the number of trees with damage scores of 1 or higher related to the number of live trees on the plot.

Block	Plotx	Ploty	Provenance	Survival	Height	Crown area	Number of stems	Basal area of mean tree	Total basal area	Dry weight of mean tree	Total dry weight	Damage score	Trees damaged
				Proportion	m	$m^2\ tree^{-1}$	no. $tree^{-1}$	$cm^2\ tree^{-1}$	$m^2\ ha^{-1}$	kg $tree^{-1}$	t ha^{-1}	0-3 scale	Proportion
1	4	1	Brazil2	0.45	3.61	28.1	2.8	67.3	0.84	24.6	3.08	1.44	1.00
1	1	1	Honduras3	0.85	1.68	19.8	4.2					0.00	0.00
1	3	1	Mexico06	0.30	1.77	8.9	3.7	19.6	0.16	5.8	0.48	0.33	0.33
1	2	1	Senegal37	0.60	3.37	22.5	2.2	73.6	1.23	27.1	4.52	1.00	0.92
2	2	2	Brazil2	0.35	4.21	29.0	2.6	92.2	0.90	35.5	3.45	1.00	0.71
2	4	2	Honduras3	0.60	1.10	14.7	3.3					0.17	0.17
2	1	2	Mexico06	0.60	2.68	11.2	3.7	33.1	0.55	10.4	1.73	0.00	0.00
2	3	2	Senegal37	0.55	3.20	21.2	1.8	62.4	0.95	22.2	3.39	0.91	0.91
3	1	3	Brazil2	0.50	4.38	29.8	2.2	123.9	1.72	54.2	7.53	1.60	1.00
3	3	3	Honduras3	0.90	1.53	16.7	4.0					0.00	0.00
3	4	3	Mexico06	0.65	1.73	6.3	3.2	13.3	0.22	3.3	0.55	0.38	0.31
3	2	3	Senegal37	0.55	4.48	33.3	1.6	122.3	1.87	51.2	7.83	1.00	0.91
4	3	4	Brazil2	0.50	4.16	24.6	3.0	93.7	1.30	38.5	5.35	0.30	0.30
4	1	4	Honduras3	0.85	1.87	26.0	4.4					0.00	0.00
4	2	4	Mexico06	0.30	2.18	7.6	4.2	32.3	0.22	10.4	0.72	0.17	0.17
4	4	4	Senegal37	1.00	3.66	23.2	1.7	65.2	1.81	23.2	6.46	0.80	0.70
5	4	5	Brazil2	0.40	3.94	26.7	1.8	79.6	0.88	29.7	3.29	0.63	0.50
5	2	5	Honduras3	0.80	1.89	20.1	2.9					0.00	0.00
5	1	5	Mexico06	0.35	2.23	9.4	2.4	22.1	0.22	6.6	0.64	0.00	0.00
5	3	5	Senegal37	0.70	3.40	26.2	1.7	57.5	1.12	19.7	3.82	0.57	0.50