Prosopis Genetic Improvement Trials in Cape Verde

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ABSTRACT

In the Republic of Cape Verde, an ambitious afforestation programme was begun after independence in 1975, making extensive use of *Prosopis juliflora*. In this study, the relative performance of *P. juliflora* and other *Prosopis* species introduced from Oman, India and Argentina, and from collections provided by P. Felker of Texas A&M University-Kingsville, was evaluated.

In one preliminary trial *P. juliflora* exhibited a higher survival than *P. cineraria* and eight non-*Prosopis* drought-tolerant species after 4.5 years under conditions of extreme aridity and heavy browsing. In another trial, *Prosopis tamarugo* suffered 100% mortality after 6 months, while 100% survival of *P. juliflora* was recorded after 4 years.

In a trial planted in 1992, including five *Prosopis* species, Argentinean provenances of *P. alba*, *P. chilensis*, *P. flexuosa* and *P. nigra* showed high survival after 2.5 years. Survival of Indian *P. cineraria* provenances was only 20% to 44%. *P. nigra* 333 was the most promising provenance overall, with high branch length and stem-base diameter, high survival, an acceptable growth habit, and very small thorns.

In a trial planted in 1993, at two sites in the arid agroecological zone, 20 provenances had survivals of at least 90%, including all four *P. juliflora* provenances tested, seven out of the nine *P.* sp. 'Peru', and one or more provenance of *P. alba, P. articulata, P. caldenia, P. chilensis, P. glandulosa,* and *P. velutina*. All of these species are in the section *Algarobia*. Provenances of species such as *P. pubescens* and *P. cineraria* from outside of section *Algarobia* showed poorer survival and *P. tamarugo* failed to survive. Overall, in terms of biomass production, *P. juliflora* and *P.* sp. 'Peru', likely to be *P. juliflora* or a *P. juliflora* hybrid, were the most promising. Further collection and evaluation of the Peruvian provenances is recommended. *P. juliflora* 737, from trees naturalised in Cape Verde and widely used in local afforestation programmes, ranked approximately third for biomass production and was the least thorny of the *P. juliflora* provenances.

Reasonable success with vegetative propagation was obtained only with *P. juliflora*, and grafting was largely unsuccessful. Therefore, low-cost vegetative propagation does not appear promising and there is a need to consider conventional programmes of germ plasm collection, selection, breeding, and seed production.

Introduction

Many developing countries in arid and semi-arid zones suffer from serious environmental degradation. Climatic changes and human activities have resulted in overgrazing, soil erosion, loss of fertility, and a predisposition to periodic drought and famine. A key factor in developing such areas is widely considered to be appropriate sustainable forestry and agroforestry, aimed at environmental stabilization and soil improvement, and the provision of fuelwood, fodder, human food, and other locally important products. Legume trees and shrubs play a potentially vital role in such developments.

The Republic of Cape Verde is made up of nine inhabited islands and a number of small islets located 620 km off the West African Coast. The islands are of volcanic origin and have been eroded by wind and rain. Some of the oldest islands, such as Sal, are very low lying, flat and arid with virtually no agriculture, little settlement, and scarce water. Other islands, such as Santiago, are mountainous with larger populations and considerable agriculture (Sandys-Winsch and Harris, 1992).

The climate of the islands has always been dry with periods of severe drought recorded at intervals over the past five centuries. From the mid-1970s until 1987 Cape Verde experienced a devastating drought. Since then, rains have been variable and in 1989 parts of the islands received less than 75 mm of rain, with some forestry-trial sites receiving no rain between September 1988 and August 1990. The Cape Verde Islands are not only extremely dry but also have probably the most variable rainfall in the world. Wetter years can have 75 times as much rain as the driest years and the entire year's rainfall is usually received in a few days or weeks.

The islands were uninhabited before being discovered by the Portuguese in 1462. No description of the original vegetation exists, but 50 years after their discovery some islands were reported to be well-forested. It has been deduced from early recordings that, at the time of their discovery, the Cape Verde Islands probably supported a fairly continuous cover of perennial grasses and small shrubs with trees becoming dominant only in the wetter interiors and valley bottoms of the mountainous islands.

Centuries of intense exploitation for fuel, construction, the introduction of goats leading to overgrazing, and agriculture have vastly altered the character of the natural vegetation destroying much of it and exposing the soil to erosion by wind and rain. The climate and topography of the islands leave little land suitable for agriculture. The main food crops are maize and beans. These crops are rain fed and yields can be minimal in dry years. Much of this subsistence agriculture is carried out on the steep sides of deep valleys leading to serious erosion. Virtually all the remaining areas are utilized for grazing, or are stripped for fuel and fodder. At independence, tree cover was virtually absent.

Since independence great importance has been attached to the country's forestry programme (Spaak, 1990). From the mid-1970s the FAO coordinated a project which they describe as a "unique experiment in ecological stabilization." In this programme, very large areas of some of the islands, ranging from farmland to seriously degraded wastelands were designated for forestry, agroforestry, or silvopastoral use. The initial aims of the project were to afforest vast areas of the islands and to develop managed plantations for soil stabilization, watershed protection, firewood production, and dry-season browse. By the end of 1993, an impressive 12% of the entire surface area of the country had been planted, with an estimated overall survival of 70%. Over 60% of the trees planted were *P. juliflora*, and forests now cover many of the more arid lowlands.

Planting programmes, not only in Cape Verde, that include the genus *Prosopis* are currently utilising only a small fraction of the genetic resource available in the genus (Hughes, 1991). Historically, most introductions have been of *P. juliflora*, often poorly documented and identified, and usually from a narrow genetic base. Having become naturalised, and spread widely in many areas, the genetic

material available there is likely to be suboptimal, referred to as "genetic garbage" by some Sahelian foresters (Hughes, 1991). Although still providing the local population with a tree tolerant to drought, poor site conditions and repeated cutting, the narrow genetic base often means that the trees are thorny, shrubby in form and habit, and aggressively invasive by nature. Bad impressions then develop, which can hamper the acceptance of further plantings of such a potentially useful tree, but this could be overcome by successful selection and breeding programmes, supplemented by some further introductions as required.

There have been many trials including *Prosopis* species over the years, and in many parts of the world, but relatively few that aim to directly compare the performance of many different species and/or provenances of the genus, and no worldwide programme of field testing of selected genotypes. These trials were aimed to fill some of these gaps in knowledge, and provide a basis for larger programmes, by elucidating some of the most promising, and some unsuitable, species and provenances.

From the Cape Verdean perspective, this project aimed to increase the diversity of species and quality of stock available for wide scale planting, concentrating on *Prosopis*. The need for alternative and/or improved plant material for out-planting has been realised and the superior performance of *P. juliflora* over all other species had been shown repeatedly. It was therefore decided to concentrate on this genus, with investigations into the relative field performance of as many species and provenances as possible, and methods of genetic improvement, by the selection of superior lines and their subsequent multiplication by simple vegetative propagation techniques.

General Materials and Methods

Seed for the Praia Formosa and Santa Cruz trials was obtained from commercial suppliers. *P.cineraria* seed accessions are the bulked collections from several trees in a locality. Argentinian provenances used in the Lapa Cachorro trial were from collections made by the University of Cordoba. Seeds used in the Agostinho Alves and Achada Ponta field trials were from a variety of sources and many were single-tree selections from the collection of Peter Felker, Texas A&M University, Kingsville, USA. For convenience, all seed collections are referred to as provenances. Details of the seed origin are given in Table 1.

All nursery work was carried out at the Instituto Nacional de Investigação e Desenvolvimento Agrário (INIDA) Agricultural Station, São Jorge, Santiago, Republic of Cape Verde. Seed was pretreated, most commonly by immersion in boiling water, and left to cool and soak for 24 h before sowing. Manual, mechanical scarification was undertaken only when very small quantities of seed were available. Sowing took place in April or May, with seed sown three to a bag, into standard black polythene bags (6 x 22 cm when full), filled with the standard nursery mix (8:1:1; terrace soil, coarse river sand and composted cow manure), to a depth of 1 cm, and covered with a layer of moistened dried grass.

Field-trial sites were fully mapped, systematic soil sampling carried out, and climatic records from the nearest meteorological station collected All five sites planted are in the arid or semi-arid coastal zone, with Santa Cruz, Lapa Cachorro and Achada Ponta all within 1 km of the sea and affected by persistent salt-laden winds. Praia Formosa and Agostinho Alves were 3 km and 5 km inland, respectively. Low sand contents characterised all of the soils, and sites were at low altitudes (50-180 masl), gently sloping (0-15%) and with a north east aspect. Mean minimum and maximum air temperatures were 18 °C and 28 °C. Mean annual rainfall ranged from 184 to 241 mm but was highly variable from year to year. All sites were 2 ha except Lapa Cachorro which was 5 ha.

The sites were then subdivided into blocks and plots. Site preparation consisted of holes being dug to 40 x 40 x 40 cm, either in crescent-shaped microcatchments (caldeiras) normally at 5 x 5 m spacing, or at 5 m spacing along contour ridges (banquetta), 30 cm high and 30 cm wide at 5 m to 15 m intervals on the slope. Guards were employed from nearby villages as required. Planting took place from July to September, after a rainfall event greater than 50 mm when possible. No post-planting treatment was carried out.

Field evaluation was carried out at 3 months, 6 months, and 12 months, and at 6 or 12 month intervals thereafter. Survival was assessed, a plant being classified as dead when no trace of living tissue could be found. The main growth parameter monitored was maximum branch length (MBL), from the base of the stem to the terminal bud or point of highest living stem where dieback had occurred. These, along with general health, were recorded at every evaluation. At 12 months and thereafter, assessment was made of vertical height, stem-base diameter (SBD) and maximum thorn length for each tree. Where more than one stem existed at ground level, the SBD was the sum of the diameters. Habit ratio was calculated from the MBL and vertical height data. The habit ratio (height to branch-length ratio) is interpreted as 0.20 to 0.50 = spreading; 0.50 to 0.70 = shrubby; 0.70 to 0.90 = semi-erect and 0.90 to 1.00 = erect. In the final evaluations, the number of stems at ground level was recorded, as a measure of form.

Praia Formosa Trial

Acacia brachystachya, A. caven, A. salicina, A. sclerosperma, A. tortilis, A. tumida, Balanites aegyptiaca, Olneya tesota, Prosopis cineraria and *P. juliflora* were planted in September 1990 at Praia Formosa in the arid zone of Santiago island, Republic of Cape Verde (15°03′N; 23°31′W). The site was approximately 2 ha, slightly sloping, 3 km from the sea, and at an altitude of 80 m. The mean annual rainfall was 184 mm (1978S1992). Four replicate plots of each species were normally used in a completely random design, although the number of plants per plot varied between 16 and 36. Half of the *P. juliflora* included in the trial was inoculated with fresh, species-specific *Rhizobium*, NifTAL three-strain mix, incorporated into the potting compost at sowing. The plants were initially protected from grazing by guards but this was abandoned after 6 months. Final survival and height of remaining plants were assessed after 4.5 years.

A. brachystachya, A. salicina, A. sclerosperma and *A. tumida* all suffered high losses, mainly between six and twelve months after planting, and at 30 months recorded 100% mortality. *P. cineraria* also suffered high initial losses and none persisted after 4.5 years. The survival data for remaining species is shown in Table 2. *P. juliflora* exhibited the highest survival of all species, and as reported previously (Sandys-Winsch and Harris, 1992), appears particularly well adapted to these harsh conditions. Inoculation with *Rhizobium* did not significantly effect survival of *P. juliflora*. The two species indigenous to Sahelian Africa, *A. tortilis* and *B. aegyptiaca* survived with 55% and 48%, respectively, while the two American species, *A. caven* and *O. tesota* showed poorer survivals of 23% and 17%, respectively. Although all these latter four species are renowned for their drought tolerance, it would appear here that climatic conditions may be harsher than in their native ranges. Trees were planted with 68 mm of rain in October 1990, followed by ten months without rain, and with a mean annual rainfall of 150 mm recorded from 1991 through 1994 with nine-month dry periods. Other factors such as the browsing by stock would also have influenced survival, as during the long dry seasons little vegetative matter is available, and goat grazing pressure on perennials is high.

Growth data for the remaining species is given in Table 3. In terms of both MBL and SBD, *P. juliflora* outperformed all other species significantly. There was also a significant difference between the performances of inoculated and uninoculated stock. Paradoxically, the uninoculated *P. juliflora* performed better, having a MBL of 203 cm and SBD of 35 mm, over 30% more than the inoculated *P. juliflora* and twice that of any other species. Cape Verde has many indigenous legumes and presumably indigenous *Rhizobia* also. *P. juliflora*, that has been introduced for several decades, is known to form a symbiosis with native *Rhizobia* in the nursery. No investigations of the root systems of the trees in this trial were conducted, but it may be that the uninoculated *P. juliflora* are benefiting

from a symbiotic relationship with native *Rhizobia*, and that these are more effective than the NifTAL mix employed with the other trees.

On land that is under such intensive grazing, the planting of palatable forage species must be questioned, unless protection methods or rotational grazing are to be considered, both of which are fairly impractical in Cape Verde. All species apart from *P. juliflora* underwent browsing, and it may be significant that only the thorniest of these species survived to any extent. Only *P. juliflora* appears to have the potential to produce useful amounts of firewood at this site and should eventually bear fruits which would provide valuable forage.

Santa Cruz Trial

In August 1987, *Acacia bivenosa*, *A. holosericea*, *Prosopis juliflora*, and *P. tamarugo* were planted at Biacurta, an arid site on the east coast of Santiago Island, Republic of Cape Verde (15°09′N; 23°33′W) at an altitude of 50 m. Rainfall was 321 mm in 1987, 228 m in 1988, 111 mm in 1989, and 282 mm in 1990. Mean annual minimum and maximum temperatures are 18.6°C and 27.7°C, respectively. The soil type was a silty clay loamwith poor drainage. A Latin-square design was used with four plots of each species and 36 trees per plot in a 6 x 6 lattice. Trees were transplanted at 5 x 5 m spacing into microcatchments. Four years after transplanting, height, stem-base diameter, and crown diameters of surviving trees from the inner 16 of each plot were measured.

***Prosopis tamarugo* suffered 100% mortality after 6 months, while after three years 78% survival was recorded for *Acacia bivenosa* and 100% survival for both *P. juliflora* and *A. holosericea*. Four years after planting, *P. juliflora* trees were taller than either of the two *Acacia* species and had a larger crown than *A. holosericea* (Table 4). *A. holosericea* appears to be poorly adapted to the prevailing conditions although it grows well in the interior of the island. Previous studies have indicated that *A. holosericea* suffers greatest from leaf loss and that its growth may be limited by the soil salinity and persistent sea winds at this site (Sandys-Winsch and Harris 1991).**

Lapa Cachorro Field Trial

The trial site was located at Lapa Cachorro (15°15′45" N; 23°42′10" E) at an altitude of 110 m in northern Santiago Island, Republic of Cape Verde. It is less than 1 km from the coast in an area exposed to persistent salt-laden winds. The site is within the arid-coastal agroeclogical zone. Mean annual rainfall (1983S1992) was 241 mm and mean monthly minimum and maximum temperatures in 1993 were 20°C and 28°C, respectively. The soil type was silty clay loam with poor drainage.

The area is utilized as agricultural land for the cultivation of maize and beans followed by extensive livestock grazing. The area, divided into two blocks, is flat to gently sloping. Trees were planted on the up-slope side of the banquettes to provide an approximate planting distance of 4 x 10 m between individual trees. A randomized complete-block design consisted of two blocks each with 24 plots of 25 seedlings. With the wide spacing and early growth stage of the trial data was recorded from all of the trees without employing guard rows.

The results after 30 months are shown in Tables 5 and 6. Survival of the Argentinean provenances (*P. alba*, *P. chilensis*, *P. flexuosa* and *P. nigra*) was high (Table 5). *P. nigra* 334 showed the highest survival of 96%, and with *P. nigra* 333 also having a very high survival of 92%, this species appears well adapted to local conditions. *P. chilensis* provenances also generally survived well. The *P. alba* and *P. flexuosa* provenances had survivals ranging from 62% to 82%, with the exception of *P. alba* 329, which had a survival of 94%. Survival of all of the Indian *P.cineraria* provenances, at 20% to 44%, was significantly lower than all the Argentinean provenances, except *P. chilensis* 332 and *P. flexuosa* 335. The high mortality of *P. cineraria* occurred mainly during the first year, with few subsequent losses in the following 18 months. It is possible that the survival of *P. cineraria* could be increased with

improvements in nursery and transplanting procedures, and with better care taken of the trees in the early establishment period.

The growth of the provenances, as indicated by mean maximum branch length (MBL) and stem-base diameter (SBD) are shown in Table 6 and the morphology, as indicatd by habitat, thorniness, and number of stems in Table 7. *P. nigra* 333 and 334 and *P. chilensis* 332 were the most promising provenances in terms of growth, with MBLs significantly higher than all other provenances except *P. flexuosa* 336. Of these, *P. nigra* 333 was the superior provenance overall, with a high survival (92%), an acceptable habit ratio (0.71) and a low number of stems (1.4), indicating a more erect tree form, and very small (5 mm) thorns. *P. nigra* 334 although having a very high survival (96%), had the poorest habit ratio (0.49) of all provenances, a greater number of stems (1.7) and much longer (27 mm) thorns. *P. chilensis* 332 had a significantly higher SBD (56 mm), but a much lower survival (62%), and although it had an acceptable habit ratio (0.67), it had a high number of stems (3.0) and a profusion of long (42 mm) thick thorns that make this a less desirable provenance.

***P. flexuosa* 336 was intermediate in terms of MBL, and was seen to have many morphological characteristics of *P. nigra*, with larger and more grey-green leaves and leaflets, and some pubescent young shoots. It can also be seen, in terms of growth and habit, to be quite different from the other two provenances of *P. flexuosa*, and more like *P. nigra*. The taxonomic status of this provenance requires further investigation. The other two *P. flexuosa* provenances, 335 and 337, were similar, with moderate growth, erect habit, and small thorns.**

***P. cineraria* provenances all showed less growth than the Argentinean species from the section *Algarobia*, with most individuals also damaged by browsing. All had <50% survival, MBLs below 60 cm and SBDs below 20 mm. In terms of survival, the species can be seen to be unsuited to the conditions prevailing at this site. All *P. cineraria* provenances exhibited the low growth rates which characterise this species, even in its natural range.**

Overall, it would appear that *P. nigra* is certainly worthy of further introductions, with very high survivals and excellent growth rates, though provenance testing would be advantageous in identifying more erect and smaller-thorned varieties. *P. chilensis*, although showing good growth, has large thorns and a multistemmed nature making this species less desirable for widespread planting. *P. flexuosa*, along with *P. nigra*, is another species that has not previously been planted in Cape Verde, and considering the strong desire to diversify the species used in the national afforestation programme, would also merit further attention, having acceptable growth, survival and morphological traits. *P. alba* may also benefit from further provenance testing to identify provenances with high survivals and more erect forms, though, generally, they performed less well. All provenances of *P. cineraria* exhibited their poor adaptability to local conditions.

Agostinho Alves and Achada Ponta Field Trials

Achada Ponta is in the arid coastal agroecological zone of eastern Santiago Island at 15°06′45" N; 23°31′15" W. The site is approximately 2 ha in area and very gently sloping (maximum gradient 5%) at an altitude of 60 m (55 m to 70 mm). Positioned on a flat portion of the northeastern coast and less than 1 km from the sea, the area receives strong, saline persistent northeast trade winds. The mean annual rainfall (1983S1992) was 191 mm. This site suffered persistent goat browsing, especially in the dry season.

Agostinho Alves is also in the arid agroeclogical zone on a valley side bordering the semiarid zone at 14°58′15″ N; 23°30′50″ W in southeastern Santiago Island. The site was prepared with the construction of micocatchments at 5 m by 5 m spacing. The site of about 2 ha is on the side of a valley with a mean slope of 15% (0% to 25%). The altitude of the site is 180 m (170 to 190 m). At

5 km from the sea, salinity is not a limiting factor to growth. The mean annual rainfall (1985S1992) was 229 mm. The site was well protected from grazing animals.

Planting of the two sites was carried out on August 30 and 31, 1993. For each provenance, 20 plants were planted at each of the two sites, with the exception of the *P.* sp.'Peru' (but not *P.* sp. 382) provenances, *P. pubescens* 505 and *P. tamarugo* 561, where only 10 of each were planted at each site. Two provenances of *P. africana* exhibited very low germination with only a few individuals remaining after 3 months. *P. africana* was, therefore, excluded from the field trial and exhibited 100% mortality after 6 months in the nursery. The rainfall over the 13 months post planting were equivalent; Achada Ponta received 131 mm in 9 rainy days, and Agostinho Alves received 123 mm in 10 rainy days. Achada Ponta is a coastal site, and plants suffered in the early summer from salt wind burn, killing off the leading shoots and leading to dieback. The "habit ratio" is the ratio of the actual vertical height divided by the maximum branch length, which is calculated individually for each plant. In this trial, a ratio of 1.00, implying a fully erect form, almost invariably indicates that the plants have been grazed down.

Table 8 shows the survival at the two sites over 18 months calculated on a "species" basis. At the Agostinho Alves site there was no significant difference among the *Algarobia* species which all had greater percentage survival than *P. cineraria, P. pubescens* and *P. tamarugo*. A similar result was obtained at the browsed Achada Ponta site, except that *P. juliflora* had a greater percentage survival than *P. caldenia, P. chilensis, P. nigra* and *P. articulata.*

Provenances of *P.* sp. 'Peru' and *P. juliflora* showed greatest mean maximum branch length (Table 9). There was considerable variation in the growth of individual trees within provenances of *P.* sp. 'Peru' with some exceeding 2.5 m after only 12 months with a little over 100 mm rainfall. At Achada Ponta, branch length of *P. juliflora* 737, from seed collected from trees naturalised in Cape Verde was exceeded, though not significantly, only by *P.* sp. 'Peru' 423 and *P. juliflora* 739 and 738, the latter two provenances being from West African naturalised stands in Burkino Faso and Senegal, respectively. The three West African-sourced *P. juliflora* provenances and *P.* sp. 'Peru' had significantly greater branch lengths than all provenances of *P. glandulosa, P. velutina, P. alba, P. nigra, P. chilensis, P. caldenia, P. articulata* or *P. cineraria* at the Achada Ponta site. At Agostinho Alves, *P. juliflora* 738, and *P.* sp. 'Peru' 423, 397 and 381 had significantly greater branch lengths than the naturalised *P. juliflora* 737 provenance.

Where differences between sites were significant, the branch lengths of *P. juliflora, P.* sp. 'Peru' and *P.* sp. were greater at the browsed Achada Ponta site, with the exception of *P.* sp. 'Peru' 381 and *P.* sp. 'Peru' 397, which performed worse at the Achada Ponta site. In contrast, where significant differences occurred, *P. chilensis, P. caldenia, P. articulata, P. cineraria* and *P. alba* all had lower branch lengths at the browsed Achada Ponta site. These data are interpreted as indicating a more favourable environment for *Prosopis* growth at the Achada Ponta site, but with mainly the unpalatable *P. juliflora* and *P.* sp. 'Peru' provenances being able to benefit from this, against a background of potential browsing. Some *P.* sp. 'Peru' grew less well at Achada Ponta but this was presumed to be due to salt wind burn. *P. alba* provenances, except the almost thornless 350, showed only small overall decreases, but suffered grazing down of selected, mainly thornless, individuals. These observations are of particular importance for species choice in areas where livestock is abundant and firewood is the desired end product and, in this instance, thornlessness appears disadvantageous where browsing was prevelent.

Data for stem-base diameters are shown in Table 10 and generally correspond to branch length data. At Achada Ponta, stem-base diameter of *P. juliflora* 737, from seed collected from trees naturalised in Cape Verde was exceeded significantly, only by *P.* sp. 'Peru' 423. At Agostinho Alves, *P. juliflora* 738, and *P.* sp. 'Peru' 423 (PF 0550, Sullana), and 381 (PF 0417, Trujillo) had significantly greater

stem-base diameters than the naturalised *P. juliflora* 737 provenance. Overall, in terms of biomass production, *P. juliflora* and *P.* sp. 'Peru', likely to be *P. juliflora* or a hybrid including *P. juliflora*, stood out as the most promising germplasm. *P.* sp. 'Peru' provenances performed exceptionally well at both sites. It is also interesting that *P. juliflora* 737, from trees naturalised in Cape Verde and widely used in local reafforestation programmes, ranked approximately third overall for biomass production of all provenances tested in these trials, and was the least thorny of the *P. juliflora* provenances tested.

The habit ratio (Table 11) for *P. juliflora* 737 showed this provenance to be semierect at the Agostinho Alves site with no provenance having a greater habit ratio. Most provenances tested in these trials formed a proportion of multistemmed trees, averaging close to two stems per plant for virtually all provenances. All of the species giving good biomass production were thorny with few significant differences among the top ten provenances. There were significant differences in thorn length among provenances of the same species as seen in the difference between *P. juliflora* 685, with 25 mm to 41 mm thorns, and *P. juliflora* 737, with 8 mm to 13 mm thorns.

Conclusions

***Prosopis* species show remarkable drought tolerance when tested in field trials such as those in Cape Verde, usually outperforming other legume trees tested in terms of both survival and growth. In Cape Verde, existing and new field trials with *Prosopis* allowed detailed comparisons of the survival, growth, growth form, and phenology over a good range of species within the genus. In particular, the field trials indicate the tolerance of *P. juliflora* provenances to the conditions of sometimes extreme drought prevailing in Cape Verde, and their rapid biomass production. Similar results were obtained with *P.* sp. from Peru, thought to be *P. juliflora* or a hybrid with this species. Provenances from the same Peruvian collection were also the best performing species in field trials in Haiti (Wojtusik et al., 1993) and in Rajasthan, India (L. Harsh, pers. comm.). Further taxonomic investigation of these accessions and further collections from their native range are strongly recommended.**

The field trials in Cape Verde allow the choice of *Prosopis* for planting in different agroecological zones, with varying degrees of drought tolerance combined with differing inherent biomass production characteristics, growth forms, thorniness, and palatability of leaves and fruit. Although in other climates and situations, the slower growing but more palatable *P. cineraria* or *P. tamarugo* may be preferred, under the extreme conditions of the Cape Verde Islands, *P. juliflora* and *P.* sp. 'Peru' offer the best prospects for fuelwood, watershed protection, and possibly pod production for dry season fodder. If the desire for increased diversity in Cape Verde is taken into account, *P. nigra*, *P. flexuosa*, *P. alba* and possibly *P. chilensis* also have the capacity to provide positive benefits to the forestry programme.

Experiments on the vegetative propagation of *Prosopis* by shoot cuttings and by grafting, carried out as part of this study were only partially successful. Although rooting of shoot cuttings of *P. alba*, *P. articulata*, *P. chilensis*, *P. cineraria*, *P. flexuosa*, *P. glandulosa*, *P. juliflora*, *P. nigra*, *P. velutina*, and *P.* sp. 'Peru' was achieved, rooting percentages were generally low and highly variable. Rooting of only *P. juliflora* and *P.* sp. 'Peru' cuttings exceeded 50% at any of the times and with any of the treatments tested (Harris et al., 1996). Thus, it is possible to root cuttings in small amounts, for germplasm collections or for seed orchards, but mass multiplication of elite clones for outplanting, using simple methods, would be difficult without further work. There was complete failure of the grafting of juvenile nursery stock (Harris et al., 1996). Therefore, low-cost vegetative propagation does not appear promising and there is a need to consider conventional programmes of germplasm collection, selection, breeding, and seed production.

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Table 1. Origin Of *Prosopis* Seeds Used In Field Trials

(All provenances with four-figure numbers under seed-origin are originally from the collection of Peter Felker, Texas A&M University, Kingsville, Texas, USA. The numbers are his own accession numbers, while those following in parentheses denote the mother tree from which seed of that accession was collected.)

Species	HDRA No.	Seed Source
P. alba	328	J.V. Gonzalez, Argentina (493 masl, 550 mm/y)
	329	Rio Dulce, Sgo del Est, Argentina (168 masl, 168 mm/y)
	330	Rio Dulce, Sgo del Est, Argentina (100 masl, 550 mm/y)
	350	0591 (0039), Kingsville, Texas, USA
	362	0465 (0032), Riverside Row, California, USA
	441	0166, Thermal, California, USA
	513	0751 (0032), UCR, California, USA
	555	0900 (0137), UCR, California, USA
P. articulata	349	0593 (0016), Kingsville, Texas, USA
P. caldenia	650	Santa Luis, Argentina (600 masl, 600 mm/y)
	651	Santa Luis, Santa Rosa, Argentina (500 masl, 350 mm/y)
	652	Santa Luis, Santa Rosa, Argentina (500 masl, 350 mm/y)
P. chilensis	163	Setropa (Commercial seed supply; origin unknown)
	331	Talampaya, La Rioja, Argentina (1000 masl, 200 mm/y)
	332	Guandacol, La Rioja, Argentina (1200 masl, 150 mm/y)
	338	Talampaya, La Rioja, Argentina (1670 masl, 150 mm/y)
	339	San Blas, Argentina (1150 masl, 200 mm/y)
P. cineraria	313/1	Hisar, Haryana, India (400-500 mm/y)
	313/2	Sirsa, Haryana, India (400-500 mm/y)
	313/4	Ganga Nagar, Rajasthan, India (200-300 mm/y)
	313/9	Jaisalmer, Rajasthan, India (150 mm/y)
	313/12	Jalore, Rajasthan, India (300-400 mm/y)
	313/14	Sikar, Rajasthan, India (300-400 mm/y)
	313/17	Nagaur, Rajasthan, India (150-200 mm/y)
	313/20	Jasrasar, Rajasthan, India (150-200 mm/y)
	313/22	Himmat Nagar, Gujarat, India (500-700 mm/y)
	313/24	Vishnagar, Gujarat, India (500-750 mm/y)
	313/25	Bhuj, Gujarat, India (300-400 mm/y)
	313/27	Ankleshwar, Gujarat, India (750-1000 mm/y)
	320	Bowslar, Muscat, Oman
	676	Nizwa, Oman (1000 masl, 250 mm/y)
	677	Bilad Bani Bu Hassan, Oman (<50 masl, 80 mm/y)
	678	Sur, Oman (14 masl, 95 mm/y)

Species	HDRA No.	Seed Source
	679	Adam, Oman (15 masl, 70 mm/y)
	680	Suweig, Oman (1000 masl, 200 mm/y)
P. flexuosa	335	Copacabana, Catamarca, Argentina (1040 masl, 173 mm/y)
	336	La Arcadia, Salta, Argentina (1820 masl, 81 mm/y)
	337	Fiambala, Argentina (1150 masl, 193 mm/y)
P. glandulosa	369	0475 (0001), Whitehavens, California, USA
	374	0933 (0001), Riverside Row, California, USA
	459	0385, Whitehavens, California, USA
	463	0392, Imperial County, California, USA
P. juliflora	737	Säo Jorge, Cape Verde (400 masl, 350 mm/y)
	738	Richard Toll, Senegal
	739	Doli, Burkina Faso
	685	Comayagua, Honduras (630 masl)
P. nigra	333	San Rafael, Salta, Argentina (1600 masl, 350 mm/y)
	334	J.V. Gonzalez, Argentina (493 masl, 550 mm/y)
	517	0774 (0133), UCR, California, USA
P. pubescens	505	0627 (0245), BBP, California, USA
P. tamarugo	564	1116, Chile
	683	La Hualca, Pampa del Tamarugo, Chile
P. velutina	355	0454 (0020), Riverside Row, California, USA
	361	0464 (0020), Riverside Row, California, USA
	378	0943 (0031), Riverside Row, California, USA
	500	0520 (0080), UCR, California, USA
P. sp 'Peru'	381	0417, Trujillo, Peru (60 masl)
	382	0418, Trujillo, Peru (60 masl)
	394	0431, Trujillo, Peru (40 masl)
	395	0432, Trujillo, Peru (40 masl)
	396	0433, Trujillo, Peru (40 masl)
	397	0434, Trujillo, Peru (40 masl)
	398	0435, Trujillo, Peru (40 masl)
	422	0549, Sullana, Peru
	423	0550, Sullana, Peru

Table 2. Survival of Multipurpose Trees in the Praia Formosa Trial in the Arid Zone of Cape Verde after 54 Months.
(Means not followed by the same letter differ significantly (χ^2, p=0.01). (+) inoculated with *Rhizobium*; (-) uninoculated.)

Species	Number Planted	Survival (%)
Prosopis juliflora (+)	117	82 a
Prosopis juliflora (-)	94	79 a
Acacia tortilis	130	55 b
Balanites aegyptiaca	30	48 b
Acacia caven	130	23 c
Olneya tesota	80	17 c

Table 3. Growth of Multipurpose Trees in the Praia Formosa Trial in the Arid Zone of Cape Verde after 54 Months.
(Means not followed by the same letter differ significantly.) (ANOVA, Tukey's t, p=0.05). (+) inoculated with *Rhizobium*; (-) uninoculated.)

Species	Maximum Branch Length (cm)	Stem-Base Diameter (mm)
Prosopis juliflora (-)	203 a	35 a
Prosopis juliflora (+)	156 b	25 b
Acacia tortilis	99 c	17 c
Balanites aegyptiaca	93 cd	17 c
Acacia caven	64 cd	13 c
Olneya tesota	35 d	14 c

Table 4. Tree Growth after Four Years in the Santa Cruz Trial in the Arid Coastal Zone of Cape Verde.
(Means not followed by the same letter differ significantly (ANOVA, Tukey's t, p=0.05)

Species	Number	Height (cm)	Stem-Base Diameter (cm)	Mean Maximum Crown Diameter (cm)
Prosopis juliflora	64	254 a	7.55 a	403 a
Acacia bivenosa	61	123 c	not taken	371 a
Acacia holosericea	64	160 b	4.66 a	154 b

Table 5. Survival of 24 *Prosopis* Provenances in the Field at Lapa Cachorro in the Arid Coastal Zone of Cape Verde, over 30 Months.
(Means not followed by the same letter differ significantly, ($\div^2$, p=0.05).)

Species	HDRA No.	Survival (%)	Species	HDRA No.	Survival (%)
P. nigra	334	96 a	*P. cineraria*	313/2	44 ef
P. alba	329	94 ab	*P. cineraria*	313/27	40 ef
P. nigra	333	92 ab	*P. cineraria*	313/22	38 ef
P. chilensis	339	90 abc	*P. cineraria*	313/12	38 ef
P. chilensis	338	88 abc	*P. cineraria*	313/9	30 f
P. alba	330	82 abcd	*P. cineraria*	313/14	28 f
P. chilensis	331	80 abcd	*P. cineraria*	313/17	28 f
P. flexuosa	336	78 bcd	*P. cineraria*	313/1	26 f
P. alba	328	76 bcd	*P. cineraria*	313/20	26 f
P. flexuosa	337	72 cd	*P. cineraria*	313/24	22 f
P. chilensis	332	62 de	*P. cineraria*	313/25	20 f
P. flexuosa	335	62 de	*P. cineraria*	313/4	20 f

Table 6. Mean Maximum Branch Length (MBL) and Stem-Base Diameter (SBD) of *Prosopis* Provenances in the Field at Lapa Cachorro in the Arid Coastal Zoneof Cape Verde, after 30 Months.
(Means for each parameter not followed by the same letter differ significantly, (ANOVA, Tukey's t, p = 0.05). Ranked in decreasing order of maximum branch length after 30 months.)

Species	HDRA No	MBL (cm)	SBD (mm)	Species	HDRA No	MBL (cm)	SBD (mm)
P. nigra	333	158 a	33 cd	*P. cineraria*	313/9	55 fg	8 gh
P. chilensis	332	158 a	56 a	*P. cineraria*	313/27	55 fg	18 efgh
P. nigra	334	149 a	38 bc	*P. cineraria*	313/2	53 fg	10 gh
P. flexuosa	336	135 ab	33 c	*P. cineraria*	313/14	52 fg	13 fgh
P. chilensis	339	125 bc	48 ab	*P. cineraria*	313/25	43 g	10 gh
P. chilensis	331	123 bc	39 bc	*P. cineraria*	313/4	41 g	10 gh
P. chilensis	338	106 cd	39 bc	*P. cineraria*	313/12	36 g	8 h
P. flexuosa	335	106 cd	19 efgh	*P. cineraria*	313/20	36 g	13 fgh
P. alba	329	105 cd	23 def	*P. cineraria*	313/22	35 g	10 gh
P. flexuosa	337	104 cd	21 efg	*P. cineraria*	313/1	33 g	8 gh
P. alba	328	87 de	29 cde	*P. cineraria*	313/24	32 g	9 gh
P. alba	330	74 ef	21 efg	*P. cineraria*	313/17	29 g	10 gh

Table 7. Habit Ratio, Mean Thorn Length, and Mean Number of Stems of *Prosopis* Provenances in the Field at Lapa Cachorro in the Arid Coastal Zone of Cape Verde, after 30 Months

Species	HDRA No.	Habit Ratio	Thorn Length (mm)	No. of Stems	Species	HDRA No.	Habit Ratio	Thorn Length (mm)	No. of Stems
P. nigra	333	0.71	5	1.4	*P. cineraria*	313/9	0.84	4	1.7
P. chilensis	332	0.67	42	3.0	*P. cineraria*	313/27	0.82	5	2.7
P. nigra	334	0.49	27	1.7	*P. cineraria*	313/2	0.85	4	2.0
P. flexuosa	336	0.55	5	2.2	*P. cineraria*	313/14	0.74	5	2.4
P. chilensis	339	0.79	10	2.1	*P. cineraria*	313/25	0.71	4	2.0
P. chilensis	331	0.76	30	1.9	*P. cineraria*	313/4	0.85	4	2.1
P. chilensis	338	0.77	23	2.1	*P. cineraria*	313/12	0.80	4	1.6
P. flexuosa	335	0.79	5	1.7	*P. cineraria*	313/20	0.81	5	3.1
P. alba	329	0.55	12	1.7	*P. cineraria*	313/22	0.80	5	2.4
P. flexuosa	337	0.85	10	1.5	*P. cineraria*	313/1	0.84	4	1.6
P. alba	328	0.65	4	1.9	*P. cineraria*	313/24	0.88	4	1.8
P. alba	330	0.54	5	1.9	*P. cineraria*	313/17	0.81	4	2.1

Table 8. Survival of *Prosopis* Species after 18 Months at Agostinho Alves (unbrowsed) and Achada Ponta (browsed) in the Arid and Arid Coastal Zones of Cape Verde.
(Means within each column not followed by the same letter differ significantly.)

(ANOVA, Tukey's t, p=0.05). Ranked in decreasing order of survival at Achada Ponta.)

Species	Survival at Agostinho Alves (%)	Survival at Achada Ponta (%)
Prosopis juliflora	89 a	93 a
Prosopis sp.	95 a	90 ab
Prosopis velutina	80 a	90 ab
Prosopis glandulosa	84 a	90 ab
Prosopis sp. 'Peru'	90 a	89 ab
Prosopis alba	89 a	83 ab
Prosopis caldenia	82 a	75 b
Prosopis chilensis	75 a	75 b
Prosopis nigra	100 a	70 b
Prosopis articulata	95 a	70 b
Prosopis cineraria	32 b	26 c
Prosopis pubescens	0 c	0 d
Prosopis tamarugo	0 c	0 d

Table 9. Mean Branch Length (MBL) of *Prosopis* Provenances after 18 Months at Agostinho Alves (AA) and Achada Ponta (AP) in the Arid and Arid Coastal Zones of Cape Verde.
(LSD values (ANOVA, Tukey's t, p = 0.05) are given for each site. Species are ranked in decreasing order of branch length at Achada Ponta.)

Species	HDRA No.	AA MBL (cm)	AP MBL (cm)	Species	HDRA No.	AA MBL (cm)	AP MBL (cm)
P. sp. 'Peru'	423	196 ab	197 a	*P.* sp.	500	54 ij	71 cde
P. juliflora	739	70 fghij	179 a	*P. velutina*	361	55 ij	64 cde
P. juliflora	738	161 bc	177 a	*P. glandulosa*	369	59 hij	63 cde
P. juliflora	737	107 def	167 a	*P. alba*	362	55 ij	61 cde
P. sp. 'Peru'	395	94 defghi	160 ab	*P. alba*	513	52 ij	61 cde
P. sp. 'Peru'	398	106 defg	152 abc	*P. nigra*	517	56 ij	60 de
P. sp. 'Peru'	396	79 defghij	150 abc	*P. alba*	555	51 ij	58 de
P. sp.'Peru'	394	93 defghi	149 abc	*P. chilensis*	163	122 d	58 de
P. sp. 'Peru'	422	124 cd	138 abcd	*P. caldenia*	651	47 ij	40 de
P. sp. 'Peru'	382	98 defgh	131 abcd	*P. caldenia*	652	114 de	35 e
P. sp. 'Peru'	381	235 a	108 abcde	*P. chilensis*	338	49 ij	34 e
P. juliflora	685	61 hij	108 abcde	*P. articulata*	349	87 defghi	32 e
P. sp. 'Peru'	397	193 ab	97 abcde	*P. caldenia*	650	69 fghij	26 e
P. glandulosa	463	76 efghij	89 bcde	*P. cineraria*	677	20 j	25 e
P. velutina	355	77 efghij	87 bcde	*P. alba*	350	54 ij	20 e
P. alba	441	66 ghij	83 bcde	*P. cineraria*	678	-	16 e
P. glandulosa	374	62 hij	74 cde	*P. cineraria*	680	25 j	13 e
P. velutina	378	64 ghij	73 cde	*P. cineraria*	676	22 j	8 e
P. glandulosa	459	77 defghij	73 cde				

Table 10. Stem-Base Diameter (SBD) of *Prosopis* Provenances after 18 Months at Agostinho Alves (AA) and Achada Ponta (AP) in the Arid and Arid Coastal Zones of Cape Verde
(LSD values (ANOVA, Tukey's t, p=0.05) are given for each site. Species are ranked in decreasing order of maximum branch length at Achada Ponta.)

Species	HDRA No.	AA SBD (mm)	AP SBD (mm)	Species	HDRA No.	AA SBD (mm)	AP SBD (mm)
P. sp. 'Peru'	423	25 ab	28 a	*P.* sp.	500	8 fg	10 efghij
P. juliflora	739	8 efg	14 defg	*P. velutina*	361	7 fg	11 efghij
P. juliflora	738	27 a	22 ab	*P. glandulosa*	369	8 fg	10 fghij
P. juliflora	737	16 cd	21 bc	*P. alba*	362	8 fg	10 efghij
P. sp. 'Peru'	395	9 efg	12 defghij	*P. alba*	513	7 fg	8 ghij
P. sp. 'Peru'	398	11 defg	18 bcd	*P. nigra*	517	10 defg	8 ghij
P. sp. 'Peru'	396	10 defg	12 defghij	*P. alba*	555	7 fg	11 defghij
P. sp. 'Peru'	394	10 defg	15 cdef	*P. chilensis*	163	22 abc	12 defghij
P. sp.'Peru'	422	16 cde	12 defghij	*P. caldenia*	651	6 fg	6 ij
P. sp. 'Peru'	382	13 defg	16 cd	*P. caldenia*	652	14 de	7 ij
P. sp. 'Peru'	381	27 a	14 defg	*P. chilensis*	338	8 fg	9 fghij
P. juliflora	685	7 fg	13 defgh	*P. articulata*	349	15 de	7 hij
P. sp. 'Peru'	397	18 bcd	10 defghij	*P. caldenia*	650	11 defg	5 j
P. glandulosa	463	9 efg	13 defghij	*P. cineraria*	677	4 g	4 j
P. velutina	355	12 defg	13 defg	*P. alba*	350	13 def	6 j
P. alba	441	12 defg	16 cde	*P. cineraria*	678	-	5 j
P. glandulosa	374	8 fg	11 defghij	*P. cineraria*	680	5 g	4 j
P. velutina	378	8 fg	11 defghij	*P. cineraria*	676	5 g	3 j
P. glandulosa	459	8 fg	9 fghij				

Table 11. Habit Ratio and Thorn Length of *Prosopis* Provenances after 18 Months at Agostinho Alves (AA) in the Arid and Arid Coastal Zones of Cape Verde.

Species	HDRA No.	Habit Ratio	Thorn Length (mm)	Species	HDRA No.	Habit Ratio	Thorn Length (mm)
P. sp. 'Peru'	423	0.60	18	*P.* sp.	500	0.74	12
P. juliflora	739	0.63	17	*P. velutina*	361	0.89	11
P. juliflora	738	0.63	16	*P. glandulosa*	369	0.85	15
P. juliflora	737	0.87	8	*P. alba*	362	0.81	11
P. sp. 'Peru'	395	0.69	12	*P. alba*	513	0.77	10
P. sp.'Peru'	398	0.70	15	*P. nigra*	517	0.73	6
P. sp. 'Peru'	396	0.72	17	*P. alba*	555	0.80	9
P. sp. 'Peru'	394	0.71	16	*P. chilensis*	163	0.65	23
P. sp. 'Peru'	422	0.73	16	*P. caldenia*	651	0.75	7
P. sp. 'Peru'	382	0.92	6	*P. caldenia*	652	0.49	9
P. sp. 'Peru'	381	0.64	13	*P. chilensis*	338	0.87	12
P. juliflora	685	0.45	25	*P. articulata*	349	0.56	16
P. sp. 'Peru'	397	0.53	16	*P. caldenia*	650	0.60	8
P. glandulosa	463	0.93	18	*P. cineraria*	677	1.00	3
P. velutina	355	0.80	15	*P. alba*	350	0.55	6
P. alba	441	0.76	14	*P. cineraria*	678	-	-
P. glandulosa	374	0.85	14	*P. cineraria*	680	0.91	4
P. velutina	378	0.80	14	*P. cineraria*	676	0.98	3
P. glandulosa	459	0.89	16				