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FINAL REPORT

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Exploiting unique germplasm resources of leguminous trees:
Prosopis, Leucaena and Acacia.

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Executive Summary

The grant covers two basic types of research. The first phase consisted of greenhouse and lab research at Texas A&I University to develop tissue culture propagation systems for tree legumes, to identify leaf tissue levels that indicate mineral disorders in mature field trees and to screen tree legumes for growth potential at seawater salinity levels. The second phase involved field trials of semi-arid adapted tree legumes in Haiti for multipurpose use and developing clonal propagation systems in Haiti to propagate elite trees.

The greenhouse fertility experiment identified leaf diagnostic criteria that would indicate mineral nutrient deficiencies in field trees. This work also found the importance of micronutrients especially zinc in permitting growth in high pH (9.0) soils. We had a collaborating scientist from India for 4 months (funded independently) for this work.

A most interesting discovery was the identification of Prosopis seedlots capable of growing at 3.2 % NaCl which is equivalent to seawater. This is the first legume reported to grow in full seawater. There is the potential of irrigating nitrogen fixing Prosopis with seawater irrigation along coastal deserts such as Mauritania and Somalia where fuelwood and pod production is urgently required. In contrast the growth of common annual legumes i.e. soybeans, peas and beans is severely depressed at salinities of 0.4 % NaCl. Some of these clones are currently being evaluated in saline environments in Pakistan. We have independently developed collaborative projects with Pakistani scientists.

The tissue culture work was successful with Leucaena but not Prosopis. As 4 other world labs have been unsuccessful with Prosopis tissue culture, we submitted a proposal with Indian colleagues to the NSF/India program to understand the basic mechanisms for the failure of Prosopis tissue culture.

Prosopis is the main fuelwood species in Haiti. Therefore a country wide collection of Prosopis germplasm was made and compared in a field trial to Leucaena and Prosopis from the United States, Argentina, Chile and Peru. The Peruvian species were the fastest growing and a few individual trees were thornless, erect and non-browsed by goats that broke through the fence and ate all other thornless Prosopis and Leucaena. Clones of 4 elite trees were brought to the United States before the coup of 1990 and have been distributed to Pakistan and Brazil. A solar powered mist system was developed in Haiti to asexually propagate elite trees where the electrical power is erratic.

Research Objectives

(1) To develop leaf diagnostic criteria for tree legumes.

The expense and difficulty in establishing new plantations of tree legumes in semi-arid or arid regions is difficult due to lack of water, heavy browse pressure and a general poor infrastructure. Thus it could be much more cost effective to improve the growth of established trees rather than establish new plantations. Since nitrogen fixation and growth of tree legumes is usually most severely limited by soil phosphorus, it would be useful to be able to assess whether tree growth was limited by phosphorus. Since N/P ratios are often 12 or greater, it makes sense to apply P rather than N. Similarly many semi-arid soils tend to be alkaline in nature where the micronutrients Fe, Zn, Mn and Cu can be limiting. If the growth of trees could be greatly stimulated by applications of only a few kg/ha of a trace element, this would be a very cost effective technique to improve wood or forage production in semi-arid lands.

(2) To identify tree legumes capable of growing at near seawater salinity.

As there are many deserts adjacent oceans i.e. Mauritania, Somalia, Israel it would be most advantageous if plants could be grown using seawater for irrigation. By screening the world barley collection for high salt tolerance, Epstein et al., (1979) found a selection that could be grown with seawater irrigation along the coast of northern California. Since our previous work (Felker et al., 1981) found that *P. tamarugo* could grow at full seawater salinity, it would be useful to screen a broad based genetic collection for growth at full seawater salinity levels.

(3) To develop tissue culture techniques to rapidly propagate Prosopis.

Since *Prosopis* is self-incompatible it is obligately outcrossed. As a result great heterozygosity exists in the species and progeny are so variable in economically useful characters, that the economic viability of commercial plantings is greatly reduced. Thus some form of asexual propagation is necessary for *Prosopis*. While asexual propagation techniques by rooted cuttings have been worked out, it would be advantageous to develop tissue culture propagation techniques (1) because of the very much faster multiplication rate and (2) because of sterile environment that facilitates transfer across international borders.

(4) To identify superior Prosopis for use in Haiti as a source of fuelwood and as a source of animal feed.

Several scholarly but unpublished AID reports(see references in Lee et al., 1992), examining the rural lifestyle of the Haitian people have noted that Prosopis juliflora (bayahonde in French) is the most important fuelwood in Haiti. This is because Prosopis coppices from the stump and grows in the harsh sites in semi-arid northwestern Haiti on steep mountainsides where little else will grow. Despite this fact none of major AID forestry contracts in Haiti i.e. CARE, PADF have used Prosopis in their programs. In private Felker has been told that this is because there is little experience on the part of the ex-patriot community in semi-arid sites or the the propagation and establishment of Prosopis. Due to fact that some Prosopis species produce large quantities of high energy content pods, development of Prosopis species with more abundant pod production and pods with greater nutritional value would be of substantial benefit to the poor people of Haiti's semi-arid regions.

(5) To develop asexual propagation techniques capable of use in remote field locations.

Due to the failure of Prosopis species to propagate true-to-type, techniques for asexual propagation are required. While mass clonal propagation by rooted cuttings is possible, it is difficult to obtain the first clonal propagule of proven elite mature field trees by rooted cuttings. Thus we examined grafting scionwood of mature field trees onto greenhouse grown stockplants to capture the first asexual propagule.

When about 70 greenhouse stock plants in 5 gallon containers are obtained, about 1,500 rooted cuttings/month can be obtained using rooting under mist. However this assumes a continuous supply of electrical power, since failure to provide mist to unrooted cuttings in the middle of the day will cause most of the cuttings to die in a matter of hours. To avoid the problems with unreliable or intermittent power availability in developing countries, we investigated development of a solar powered mist system.

Methods and Results

As can be seen in the list of 21 papers published wholly or partially with the support of this grant, it would be redundant to repeat the materials and methods, results of all 21 papers. Rather we will summarize results of the key papers described for the 5 research objectives listed above.

(1) To develop leaf diagnostic criteria for tree legumes.

A greenhouse pot experiment was conducted with Prosopis alba and P. glandulosa var glandulosa as a function of increasing pH, phosphorus additions and micronutrient additions. The pH was increased by adding graded levels of lime to vary the pH from 6 to 9. At each lime level a factorial experiment with and without phosphorus and micronutrient additions was used. The shoots were harvested after 26 weeks of growth, dried at 43 C, weighed and analyzed for tissue levels of N, P, K, Ca, Na, Mg, Mn, Fe, Zn, and Cu. The soil pH at the termination of the experiment was also measured. Dry biomass was related to leaf tissue nutrient levels with regression techniques.

The biomass, leaf phosphorus and leaf sodium concentrations in this experiment are presented in Figure 1. Clearly the major influence was due to the presence or absence of P in the soil. However at the highest pH of 9.0, micronutrient addition was crucial to maintaining growth. It appears as if there is a relationship between leaf sodium levels and addition of micronutrients (Figure 1). Here when micronutrients are added, the sodium levels are low for both P. alba and P. glandulosa, but when the micronutrients are withheld, leaf sodium levels dramatically increase and biomass is substantially decreased.

Table 1 shows the leaf composition of both species at the highest pH with and without micronutrient additions. Clearly the major increases in leaf micronutrients at the highest pH occur with Zn and Cu. The empirical experience with growing Prosopis in high pH soils (10.4) in India is that Zn additions are very helpful in promoting growth(Singh et al., 1989). As opposed to sodium secreting halophytes such as Atriplex, Prosopis is a sodium excluder as can be seen by the low leaf sodium concentrations. It is tempting to speculate that Zn mediates a sodium excluding biochemical pump in Prosopis.

As a further example of the kind of data generated, Figure 2 shows the quadratic fits for growth of both P. alba and P. glandulosa as a function of leaf tissue P. The optimum leaf tissue levels for growth for both species occur at about 0.2 % P. Using similar statistical techniques we estimated the minimum leaf tissue concentrations for the 10 nutrients examined here.

(2) To identify tree legumes capable of growing at near seawater salinity.

Knowing that there is great variation among Prosopis progeny from the same tree as well as significant variation between progeny from different trees, it was important to screen many individuals per tree. We chose 9 seed sources of Prosopis

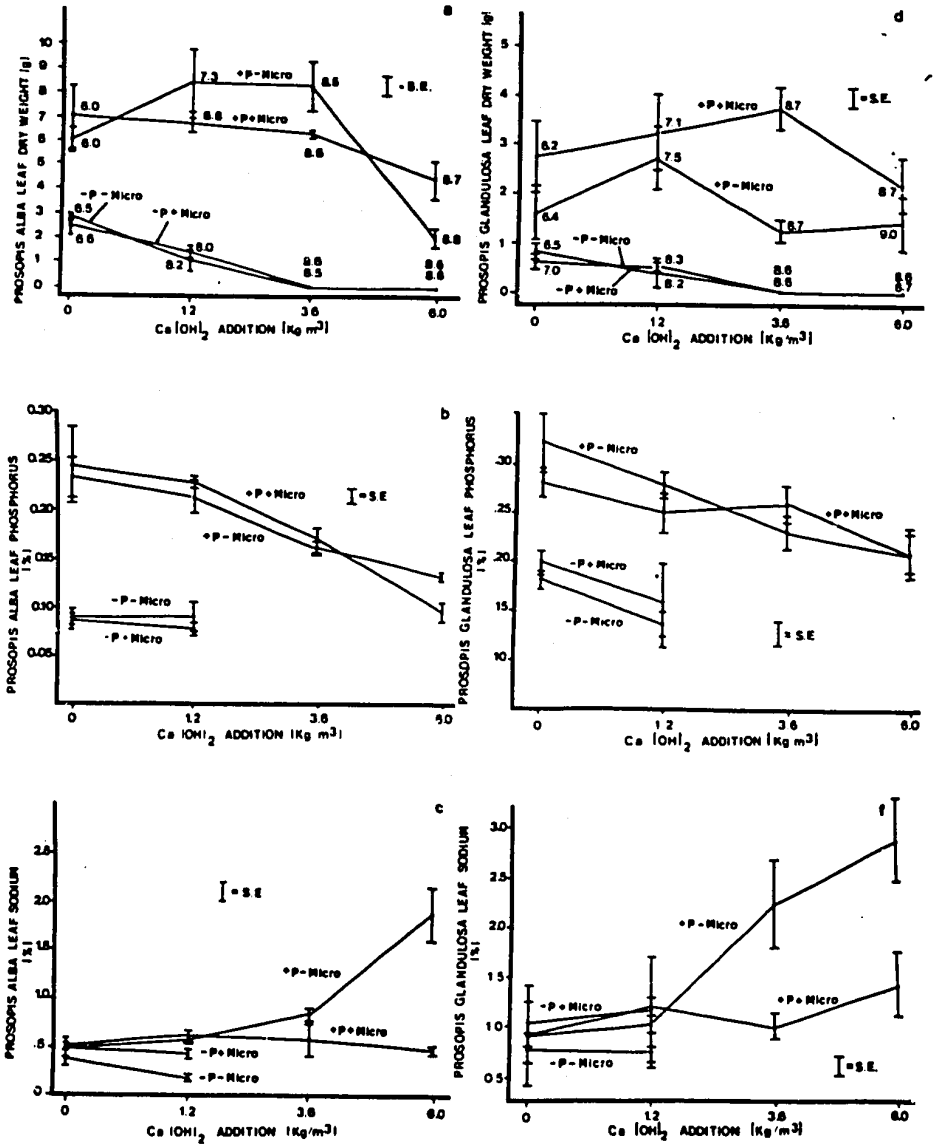


Fig. 1. Influence of increasing lime ($Ca(OH)_2$) additions on leaf dry matter for *Prosopis alba* (a), and *P. glandulosa* (d); leaf tissue phosphorus concentrations for *P. alba* (b) and *P. glandulosa* (e); and leaf tissue Na concentrations for *P. alba* (c) and *P. glandulosa* (f). The vertical bars represent the standard errors (n=4). Final soil pH values are adjacent to the data points. No leaf production occurred at the 3.6 and 6.0 kg m^{-3} lime levels without phosphorus amendments.

TABLE 1

Comparison of *Prosopis alba* and *P. glandulosa* leaf tissue nutrients with and without addition of micronutrients with high lime 6.0 kg m^{-3} additions

	Prosopis alba		*Prosopis glandulosa*	
	– micronutrients (Mean ± SE)	+ micronutrients (Mean ± SE)	– micronutrients (Mean ± SE)	+ micronutrients (Mean ± SE)
Dry weight	2.1 ± 0.3	4.5 ± 0.8	1.4 ± 0.6	2.2 ± 0.5
Soil pH	8.8 ± 0.04	8.8 ± 0.2	9.0 ± 0.02	8.7 ± 0.1
Zn (mg/kg)	13 ± 1	29 ± 6	23 ± 0.9	38 ± 6
Mn (mg/kg)	59 ± 10	49 ± 3	94 ± 26	74 ± 3
Fe (mg/kg)	63 ± 2	63 ± 4	200 ± 40	146 ± 20
Cu (mg/kg)	17 ± 5	29 ± 8	26 ± 3	34 ± 9
K (%)	1.1 ± 0.3	1.3 ± 0.1	1.2 ± 0.1	1.1 ± 0.2
Na(%)	1.9 ± 0.3	0.46 ± 0.03	3.3 ± 0.4	1.9 ± 0.3
Ca (%)	1.4 ± 0.1	0.92 ± 0.1	0.66 ± 0.08	1.0 ± 0.1
Mg (%)	0.24 ± 0.03	0.19 ± 0.03	0.14 ± 0.02	0.16 ± 0.02
P (%)	0.13 ± 0.003	0.09 ± 0.009	0.16 ± 0.02	0.16 ± 0.02
N (%)	2.7 ± 0.3	3.0 ± 0.03	3.2 ± 0.3	3.6 ± 0.4

All of the above values were supplemented with triple superphosphate at 333 g m^{-3}. SE = Standard error of the mean, n=4.

TABLE 2

Percentage tree legumes seedlings surviving after solution culture at various salinities

Species/accession/ origin	Seedling survival (%)					
	NaCl conc. (%)					
	0.0	1.2	1.8	2.4	3.0	3.3
Leucaena leucocephala K67 Hawaii	82	0	0	0	0	0
Prosopis chilensis (0009)/Argentina	96	27	24	23	20	19
P. articulata (0016) Baja Mexico	5	5	5	5	4	4
P. juliflora (0044) Senegal, W. Africa	35	29	29	29	26	26
P. alba (0166) California	100	74	70	50	36	21
P. nigra/flexuosa (1012) Salar de Pipinaco, Argentina	85	63	63	61	56	45
P. glandulosa var *glandulosa* (1115) Kingsville, Texas	100	47	46	25	3	0
P. alba/nigra (1117) Pampa del Tamarugal, Chile	99	86	83	77	68	54

Each accesssion contained 5 replicates of 20 trees per replicate. The trees were held at each salinity level for 3 weeks. One hundred seedlings of *Prosopis tamarugo* were started but they died due to a stem fungal disease. A *P. pubescens* accession from the California Salton Sea had 68% survival at the end of the 0.0% NaCl treatment but died in the 1.2% NaCl treatment, presumably from fungal diseases.

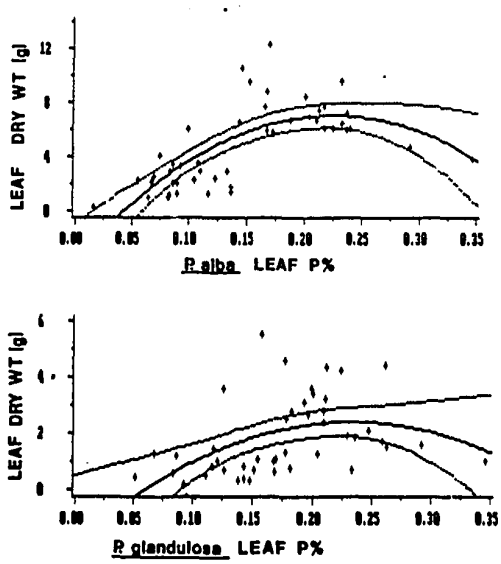


Fig. 2. Leaf tissue phosphorus concentrations as a function of leaf dry weight for *Prosopis alba* (a) and *P. glandulosa* (b), respectively. The center line is a plot of the quadratic equation providing the best fit of the data. The remaining curves delimit the 95% confidence intervals for the quadratic regression equation.

from saline environments and Leucaena leucocephala K67 for comparative purposes.

In searching for tree legumes with potential for growth at high salinity, it is useful to examine trees that grew in highly saline environments. In South America, there is a landform known as a "Salar" in Spanish that has no equivalent in English. The salars are located in the bottoms of large valleys. The salars are the result of water run-off from the mountains moving to the center of the valley followed by evaporation under high temperatures to leave a salt crust. There is a gradient of increasing salinity as one leaves the foothills of the mountains to the edge of the Salar. In the Salar de Pipinaco in Argentina, the salt crust is only several millimeters thick, while the Salar de Pintados in Chile's Pampa del Tamarugal is often half a meter thick. In Chile there are both algarrobos (P. alba/P.flexuosa/P.nigra types) as well as tamarugos (P. tamarugo) while in Argentina there are only algarrobos. Felker had collected seed of these algarrobos and tamarugos in Chile and Argentina in previous visits. While NAS publications have touted the virtues of P. tamarugo it has only been successfully grown in Chile despite attempts by our group and others to grow it in other parts of the world. P. articulata and P. juliflora were also chosen for this experiment since prior work (Felker et al., 1981) found that P. articulata and P. pallida (which is very closely related to P.juliflora) had individual trees which grew at full seawater.

The experiment was set up as a randomized complete block design with 10 treatments (seed sources) and 5 replicates of 20 seedlings per replicate. Thus 1,000 seedlings were screened. The seedlings were grown in a hydroponic sand culture apparatus in the greenhouse in which the salinity increased from 0.0 to 1.2, 1.8, 2.4, 3.0 and 3.3 % NaCl(Seawater). As can be seen in Table 2, the leucaena seedlings all died at the lowest salinity level. It can be observed that 6 accessions had seedlings which survived full seawater. It is also to be noted that P. articulata, P. juliflora, P. nigra/flexuosa from Argentina, and P. alba/nigra from Chile all had greater than 50 % survival.

While survival is important, it is also important to have significant growth. In Table 3 it can be seen that P. chilensis, P. articulata, P. juliflora, and P. alba all had seedlings which grew in the full seawater treatment. Some of the surviving seedlings were repotted in 5 gallon containers and are still being maintained in the Texas A&I greenhouse.

While these seedlings grew in full seawater it was not known if they fixed nitrogen at full seawater or if nodules and/or mycorrhizal associations could be formed at these high salinities. It would also be most useful to field test these

TABLE 3

Effect of salinity on stem elongation (height increase, cm) in *Prosopis* species which survived solution culture in 3.3% NaCl

Species/ accession	NaCl conc. (%)						Number surviving
	0.0	1.2	1.8	2.4	3.0	3.3	
Prosopis chilensis (0009)							
replicate 1	9.1	8.0	8.2	−3.8*	−0.7	1.2*	10**
replicate 2	8.1	3.7	8.1	1.6	2.5	5.5*	3
Prosopis articulata (0016)							
replicate 1	7.5	4.7	7.6	0.4	−2.6*	0.8*	1
replicate 2	5.6	1.6	6.0	1.5	2.6	1.4*	2
Prosopis juliflora (0044)							
replicate 1	9.0	4.7	10.6	0.5	−2.1*	5.4*	5
replicate 2	7.7	3.6	7.0	7.3	9.6	3.1	6
Prosopis alba (0166)							
replicate 1	8.2	6.2	4.4	−1.1*	2.3*	2.0*	5
replicate 2	6.4	3.9	3.7	1.1	0.3	2.3*	11
Prosopis nigra/ flexuosa (1012)							
replicate 1	11.0	8.1	5.5	−4.9*	−1.4*	−0.6*	9
replicate 2	8.2	8.1	—	9.5*	−2.0*	−1.7*	11
Prosopis alba/ nigra (1117)							
replicate 1	9.9	7.7	6.9	−3.5*	−0.1*	−0.7*	12
replicate 2	8.4	9.2	6.0	−1.9*	−0.9*	−0.4*	13

*Tip die-back caused by a fungal pathogen.
**Number of surviving trees in a replicate at the end of the 3.3% NaCl treatment.
The height increases reported above were otained by subtracting height at beginning of 3-week-long salinity treatment from the height at the end of the treatment.

clones along a sandy coastal environment where they could be irrigated with seawater. A proposal to examine these possibilities was submitted to the Science Advisors Office Proposal #9.087 and recommended by the PSTC for funding. Unfortunately, Albert Merkel, the AID Chief of Party in Pakistan (who had 3 Winrock Chief of Partys to resign) declined to have the proposal conducted in Pakistan because too much of the funds were to be expended in the United States. This was when the AID forestry component in Pakistan was several million dollars per year. It is rumored that Merkel sent the proposal to researchers at the atomic energy plant lab near Faisalabad and asked them to conduct the research using local AID funds.

Fortunately the local collaborator, Dr. Rafiq Ahmad was able to obtain funds from a US/Pakistan program to test some of these clones and other salt tolerant Prosopis in Pakistan. In the fall of 1992 Felker delivered budwood of these clones and demonstrated grafting techniques for the genetic materials.

(3) To develop tissue culture techniques to rapidly propagate Prosopis.

This work was primarily conducted by Dr. Yashpal Goyal, from Jodhpur, India who was working in a Postdoctoral capacity. Dr. Goyal completed his PhD on tissue culture of P. cineraria native to the Indian Thar desert. This was our major "official" linkage with this program.

The basic techniques for propagation of mature trees lies in the aseptic culturing of axillary buds. While adventitious shoots can arise from undifferentiated cell cultures as well as from many differentiated tissues, adventitious shoots often have genetic aberrations resulting from loss of chromosomes. In contrast, the induction of multiple shoots from preformed meristems in axillary buds has shown to yield plants that are much more true-to-type.

After the buds were obtained, they were surface sterilized with a series of detergent, mercuric chloride, chlorox and sterile water as described in the attached publications. The resulting sterile bud cultures were grown on a variety of media to induce multiple shoot proliferation. In general the auxins; indoleacetic acid, indolebutyric acid, and napthleneacetic acid stimulate root growth and the cytokinins; kinetin, benzylaminopurine, zeatin and isopentyladenine stimulate shoot proliferation.

In addition to identifying the proper hormone concentrations for shoot proliferation, it is necessary to identify the correct inorganic nutrient composition to stimulate growth without harming the cultures. For leucaena we found that a benzylaminopurine (BA) concentration of 3 mg/l combined with a

napthaleneacetic acid concentration of 0.05 mg/l gave the most shoot proliferation. A shoot multiplication rate of 22 shoots per bud explant was obtained in 150 days.

An example of shoot and root development in Leucaena leucocephala K67 is shown in Figure 3.

In addition to the tissue culture work on Leucaena, we also spent considerable effort on the tissue culture of Prosopis alba clone B2V50. This clone was examined partially because it was a high biomass producing clone and partially because it had been shown to be relatively easy to propagate by rooted cuttings. Both before and after the AID funded work on tissue culture of Prosopis we conducted many man-years of research on tissue culture of Prosopis. Unfortunately despite all the effort we were not successful.

While we could achieve production of 15-30 mm long shoots on the majority of the explants in 6-9 weeks, these shoots eventually senesced starting from the tip back. We examined the major cytokinins in factorial combination with the major auxins at ranges in concentration from 0.01 mg/l to 50 mg/l, most of the major mineral salt basal media i.e. Schenk and Hildebrandt, Gamborg B5, Murashige and Skoog, Woody Plant Media, anti-phenolic oxidants such as ascorbate, charcoal, polyvinylpyrrolidone, and coconut milk. None of these treatments overcame the senescence.

As described in one of our recent reviews (Felker, 1992) we have discovered that laboratories in Chile, England, and India have had similar results. We now have evidence to suggest that gummy exudates secreted by tree legumes (such as gum arabic) may prevent the uptake of nutrients required for growth. Dr. Vibha Dhawan of the Tata Energy Research Institute in Delhi and Felker jointly submitted a proposal to the India/USA bilateral NSF program to measure uptake of radio labeled organic N, organic C and inorganic nutrients. While the proposal was declined initially most of the reviews were very favorable and we have been encouraged to resubmit.

(4) To identify superior Prosopis for use in Haiti as a source of fuelwood and as a source of animal feed.

In a program to genetically improve Haiti's major source of energy, which is from Prosopis juliflora, it was essential to know if there was know if there was sufficient genetic variation in Prosopis in Haiti to not require exotic introductions. Thus with the assistance of Peace Corps Volunteers and CARE foresters we traversed the major routes of Haiti to collect as much diverse genetic material as possible. On many of the major routes in Haiti, such as the route from Bombardopolis to Molle St. Nicholas, it is only possible to maintain average speeds of 12-15 mph when in a 4 wheel drive

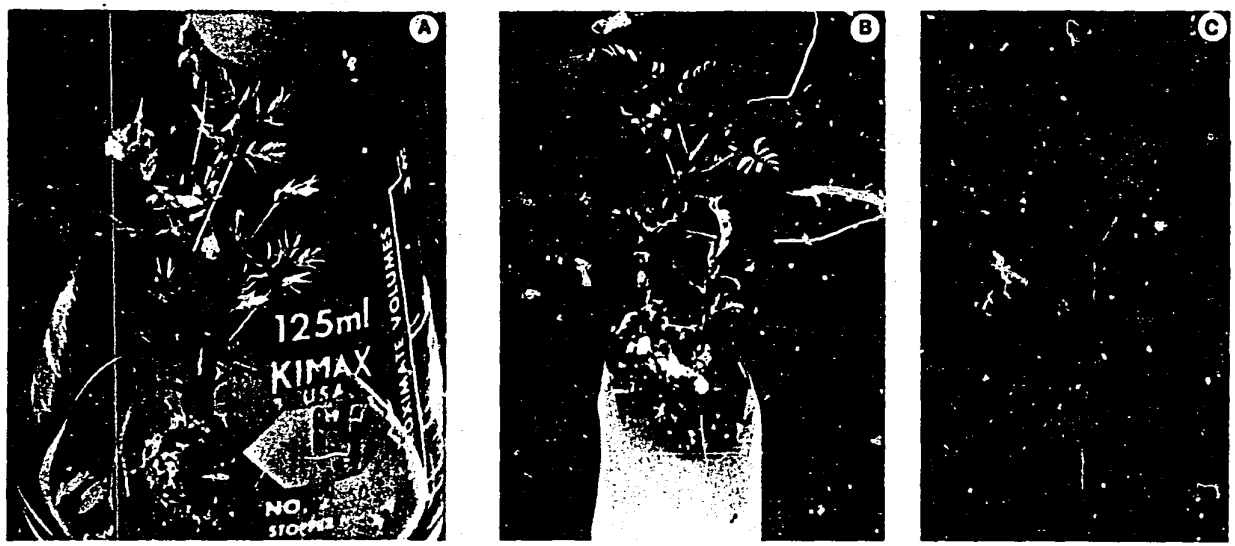


Figure 3. (1A) Multiple shoot differentiation in the culture of *L. leucocephala* K67 on MS medium + BA 3.0 mg l^{-1} + NAA 0.05 mg l^{-1} after 5 weeks. (1B) Multiplication of shoot propagules on half strength MS medium + BA 3.0 mg l^{-1} + NAA 0.05 mg l^{-1} after 140 days. (1C) Root formation at the cut end of shoot propagules on ½MS medium + IBA 3.0 mg l^{-1} + kinetin 0.05 mg l^{-1} after 15 days.

vehicle. Some large trees (> 1 m in diameter) were collected as well as small trees in harsh sites.

Haitian Prosopis from 44 representative regions and size classes were selected to be incorporated into 2 field trials. In addition to the 44 Haitian Prosopis, 12 Prosopis accessions representing major regions in Peru, several accessions from Argentina, Chile, southwestern United States and a single Leucaena pulverulenta were included in this trial.

A nursery was established in northern Haiti near Bassin Bleu and in the Cul-de-Sac area near Thomazeau. Unfortunately, militant Priests completely destroyed the nursery in the north leaving only the site in the south. No irrigation water or tractors were available. Thus after the 2 ha site was cleared of brush and cacti with hand tools, no-till water conserving techniques were employed the season before planting to ensure adequate water was in the profile. Using long (12 inch) cardboard plant bands, left on at transplant and planting within minutes of having the holes dug, we obtained an overall seedling survival of 93 % without irrigation at any phase of the trial (Lee et al., 1992). At the end of 4 years growth, the tallest 6 seed sources were of Peruvian origin. Some of these Peruvian trees were thornless, had erect habit and were non-browsed by goats, unlike other thornless P. alba families from South America. Scions of the tallest, spineless and most erect trees were transported in August 1990 from Haiti to Texas A&I where they were successfully grafted onto P. alba rootstock. Scions from these grafts have been subsequently taken to Pakistan and are scheduled to be taken to Brazil in mid-summer of 1993.

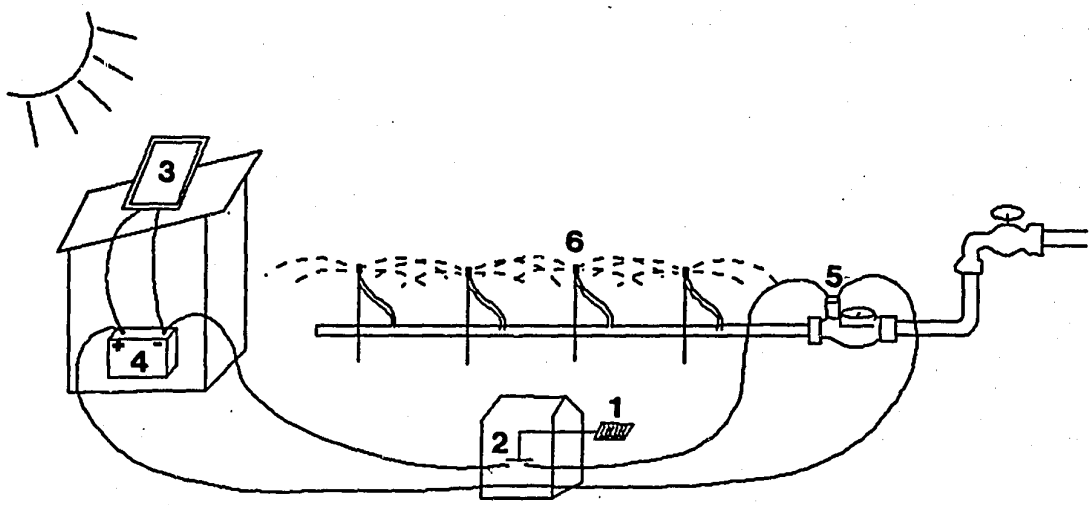
(5) To develop asexual propagation techniques capable of use in remote field locations.

The heterozygosity, outcrossing nature and long generation time of many tree species makes rapid genetic improvement through sexual processes quite slow. In contrast many of the asexual propagation techniques are so involved technically that they are difficult to implement in developing countries.

While traditional mist systems are widely used for eucalyptus propagation in Brazil, they are difficult to maintain where electrical power, used to control the timers is erratic.

We thought about using hydraulically driven timers for clocks, but the best design appeared to be use of a solar panel to charge a car battery that would power low voltage (24 volt) solenoid valves. We worked with a Texas engineer to match the power requirements of the solar panel, car battery and solenoids. The schematic for the solar powered mist system is shown in Figure 4. In normal operation the solenoid operates on 24 volt AC but we found that it worked satisfactorily on 12

Figure 4. Solar powered mist system schematic.



1 Mechanical leaf

2 Mercury tilt switch

3 Solar panel

4 Car battery

5 Valve operated by mercury tilt switch

6 Misters over cuttings.

volt DC. The valve required 0.3 amps to open and 0.19 amps to stay open. Since the 5 0 Watt solar panel provided 0.3 amps this was quite sufficient for long term operation. Since the solenoid is only active for a very small percentage of time, many solenoid valves could be used at one time.

The solar powered mist system was set up in Haiti 0.5 km from the field site where the missionaries lived. The nearest electricity was 4 miles away. Pressurized water was provided from a reservoir filled by a windmill.

When using a mist system, it is critically important to have a rooting media that allows good drainage. This is because the large volumes of water continually used to keep the leaves hydrated, would soon cause anoxic conditions to build up in the root zone if good drainage were not achieved. In the United States, perlite/vermiculite mixtures are used, but these are not available in developing countries. Thus it was necessary to find a local substitute for perlite/vermiculite. In Table 4 we compare the performance of a perlite/vermiculite mixture used commercially to propagate Prosopis in the United States with a porous volcanic gravel common in Haiti and local compost. We were especially pleased that a locally available material i.e. volcanic gravel was found that both in numbers of roots and in percentage of rooted cuttings was equal or better to the imported rooting media.

The high percentages of rooted cuttings in Table 4 also show that the entire solar powered mist system performed admirably in Haiti.

In addition to development of rooting of cutting techniques, it would be useful if grafting techniques could be developed to combine rootstocks resistant to adverse conditions with scions producing beneficial tops. Thus we surveyed a number of techniques for grafting including; budding, whip and tongue, cleft grafting, and side-veneer. The percentage survival of these grafts were as follows; T-bud 0%, side-veneer 47 %, cleft 67 %, and whip and tongue 67 %.

Having developed efficient grafting techniques, we wished to know what graft compatibility problems would be encountered among the major economically important Prosopis species. This is important since some species i.e. P. articulata are highly resistant to salinity and water logging but are very thorny and have pods with low forage quality. Thus grafting thornless, high pod producing scionwood of a different species onto P. articulata rootstock could be quite beneficial.

Table 5 shows that 5 Prosopis species representing North American, South American and tropical germplasm all had excellent survival when used either as a rootstock or as a scion. There was a substantial P. alba rootstock effect in

Table 4. Mean number of roots, longest root and rooting percentage of *Prosopis juliflora* cuttings under mist in 3 different rooting media

Rooting Medium	Number of Roots Mean Std. Dev.	Longest Root (cm) Mean Std. Dev.	Percentage of Cuttings Rooted Std. Dev.
Perlite/ Vermiculite	11.65 a 3.81	11.80 a 1.39	90% ab 11.55
Volcanic Gravel	18.20 a 4.55	10.15 a 2.03	100% a 0.0
Compost	2.80 b 0.82	4.20 b 1.47	60% b 16.33

Means in columns followed by same letter are not significantly different ($P > 0.05$) by Tukey's HSD test.

Table5: Survival and mean fresh weight results for Prosopis section Algarobia species graft combinations.

	SCIONS				
ROOTSTOCK	P. alba	P. articulata	P. chilensis	P. glandulosa	P. juliflora
P. alba					
% Survival	92	83	100	100	75
MFRWT g. (STD)	46.5 (12.0)	28.7 (6.7)	44.2 (6.7)	19.3 (4.4)	41.1 (8.7)
P. articulata					
% Survival	100	83	75	100	75
MFRWT g. (STD)	13.8 (1.9)	11.4 (2.5)	17.0 (3.9)	12.8 (4.3)	21.6 (4.5)
P.chilensis					
% Survival	100	100	92	92	83
MFRWT g. (STD)	35.3 (3.4)	21.0 (4.2)	33.1 (8.8)	12.4 (2.7)	39.3 (9.2)
P. glandulosa					
% Survival	83	83	67	92	67
MFRWT g. (STD)	18.2 (4.1)	12.8 (2.7)	13.5 (3.7)	9.7 (1.9)	19.6 (4.9)
P. juliflora					
% Survival	100	92	75	83	83
MFRWT g. (STD)	14.6 (2.9)	16.1 (4.5)	12.0 (3.3)	4.3 (0.9)	20.8 (4.9)

Values are based on 12 replications of each combination that are pooled results from the spring and fall experiment.
MFRWT = mean fresh weight, STD = standard deviation

which nearly all scions grafted onto P. alba rootstock had greater biomass even when grafted onto its own rootstock.

Impact, Relevance and Technology Transfer

The third of the earths surface that is semi-arid/arid contains some of the most destitute people on earth. For example several hundred million people live in the semi-arid regions of the Indian subcontinent, famine resulting from droughts are routine in the semi-arid areas of Somalia, Chad, Burkina Faso and Senegal, and some of the poorest people in Latin America depend on Prosopis in Haiti, northeastern Brazil, Peru and Ecuador. Thus the need for improved fuelwood and forage for animals in semi-arid regions is of the highest international priority.

The opportunity to partially alleviate the fuelwood and forage needs of these people with thornless, erect non-browsed, high forage Prosopis species is comparable to the impact that short statured, non-lodging wheat had on food supplies of Mexico and India.

Thus these materials need to be distributed around the world. Unfortunately there appears to be no mechanism to accomplish this distribution. CIFOR is apparently only going to concern itself with long term basic research. The AID fuelwood programs are so driven by local missions who do not keep up with technical developments that it is unlikely that these new materials will be evaluated at the request of AID missions. Most governmental forestry support staff in Europe and the United States have been trained in temperate forestry schools and really have no appreciation for the problems and opportunities in semi-arid lands.

The only hope is to build on the informal network of excellent third world scientists and development officers working in the semi-arid regions. For instance in India Dr. Nandini Nimbkar, President of an NGO, has been hybridizing Prosopis species, Dr. Gurbachan Singh of the federal Soil Salinity Lab has been testing species that grow in high pH (10.4) soils, Dr. Vibha Dhawan at TERI has been working on tissue culture and Dr. L.N. Harsh at the federal dryland research lab has been testing several hundred species for the Rajasthan desert. In Africa, Dr. Michael Burke of CARE has reported that Prosopis is one of their most successful tree species, in Mauritania Lutheran World Relief has been very successful using Prosopis for sand dune stabilization, in Peru, researchers at the University of Piura have developed many new human food uses of the pods, in Chile Prosopis has been planted on 20,000 ha by the government, in Argentina there is an outstanding industry based on Prosopis furniture and flooring and in Brazil the head of the Federal Forestry Department is initiating a national program using Prosopis for animal feed.

What is critically needed is (1) a satellite based E-mail network to bring these researchers and development specialists into daily communication and (2) a modest budget for processing and distributing improved germplasm.

Project Activities/Outputs

The following publications were partially supported by AID funding under this grant. This publication list is about half of the tree legume publications that occurred during this period that were mainly supported by the U.S. Department of Energy Short Rotation Woody Biomass Program and the Meadows Foundation.

Peter Felker. (1984) Legume trees in semi-arid and arid areas. In: Symposium on nitrogen fixing trees for the tropics. Pesq. Agropec. Bras. Brasilia 19: 47-59.

Yashpal Goyal, R.L. Bingham, and Peter Felker 1985. Propagation of the tropical tree, Leucaena leucocephala K67 by in vitro bud culture. Plant Cell Tissue and Organ Culture 4:3-10.

Edward Glumac, Peter Felker, Yashpal Goyal, Sharon Klass, Charles Wisman, Gary Cline, Isidro Reyes, Tom Tabone, and Sonia De Souza. 1985. Aridland plant research at the Caesar Kleberg Wildlife Research Institute. U.S. Forest Service General Technical Report RM-135: 109-113.

Gary Cline, Peter Felker, and Dwight Rhodes 1986. Micronutrient, phosphorus and pH influences on growth and leaf tissue levels of Prosopis alba and Prosopis glandulosa. Forest Ecology and Management 16:81-93.

Tabone, T.J., Peter Felker, R. Bingham, I. Reyes, and S. Loughery. 1986. Techniques in the shoot multiplication of the leguminous tree Prosopis alba clone B_2V_{50}. Forest Ecology and Management 16:191-200.

Oduol, Peter, A. Peter Felker, Craig R. McKinley and C.E. Meier. 1986 Variation among selected Prosopis families for pod sugar and pod protein contents. Forest Ecology and Management 16:423-431.

E.L. Glumac, Peter Felker and I.Reyes. 1987. Correlations between biomass productivity and soil and plant tissue nutrient concentrations for Leucaena leucocephala growing in calcareous soils. Forest Ecology and Management. 18: 241-250.

Peter Felker (Editor). 1986. Tree plantings in semi-arid regions. Proceedings of a symposium held at Texas A&I April 1985 containing 38 papers. Forest Ecology and Management 16:444 pp.

Dwight Rhodes and Peter Felker.1987. Mass screening Prosopis (mesquite) seedlings for growth at seawater salinity. Forest Ecology and Management 24:169-176.

Lee, Scott G., Russell, E, and Felker, P. 1992. Discovery of thornless, non-browsed, erect tropical Prosopis in Haitian progeny trials. Forest Ecology and Management 46:189-200.

Gathaara, G., Glumac, E., and Felker, P., 1991. Three year growth studies of Leucaena leucocephala (1094) and Leucaena pulverulenta (1001) at 2 spacings in Texas. Forest Ecology and Management. 40: 189-198.

Felker, P., Chamala, R., Glumac, E., Wiesman, C., and Greenstein, M., 1992 Forage production of Leucaena leucocephala and L. pulverulenta in mechanized farming systems in a semiarid region of Texas. Tropical Grasslands 25:342-348.

Felker,P. Prosopis spp. 1990. In: "Useful trees of tropical North America". Russell M. Burns Technical Coordinator, Menanera Mosquera, Editor Spanish Version. North American Forestry Commission Compendium Publication No.3. USDA Forest Service, Washington DC Publishers. English version 13 pp, Spanish version 15 pp.

Felker, P. 1990. Prosopis- Opportunities for genetic improvement and management of existing trees. In: International Symposium on natural resources management for a sustainable agriculture. Delhi India 6-10 February 1990

Bassala, P., Felker, P., and Swakon, D.H.D. 1991. A comparison of Leucaena leucocephala and Leucaena pulverulenta leaf and stem age classes for nutritional value. Tropical Grasslands.25:313-316

Lee, S.G. and P. Felker 1992 Influence of water/heat stress on flowering and fruiting of mesquite (Prosopis glandulosa var. glandulosa) Journal of Arid Environments in press.

Felker, P. 1991. Prosopis in Latin America- Genetic conservation and economic development for the 21st Century. A paper presented at the Prosopis germplasm workshop, 3-6 December 1991, Mendoza Argentina.

Wojtusik, Timothy, Peter Felker, Edward J. Russell, and Michael D. Benge. Cloning of erect, thornless, non-browsed nitrogen fixing trees of Haiti's principal fuelwood species (Prosopis juliflora). Agroforestry Systems. In press.

Timothy Wojtusik and Peter Felker. 1992 Inter-species graft incompatability in Prosopis. Forest Ecology and Management. in press.

Timothy Wojtusik, Michael T. Boyd and Peter Felker 1992. Development of solar powered mist system for vegetative propagation of Prosopis in under-developed countries. Forest Ecology and Management. in press.

P. Felker. 1992. Capturing and managing the genetic variation in Prosopis for use in fuelwood, luxury quality lumber, pods and soil improvement. In: Tropical Trees: The Potential for Domestication. Institute for Terrestrial Ecology Publishers, Edinburg, Scotland.

Project Productivity. With the exception of the inability to tissue culture Prosopis alba,(which is the subject of a new major initiative), all of the original goals and objectives were met and surpassed. Through frugal use of funds and matching with other grants it was possible to extend the $150,000 + $80,000 for nearly 10 years resulting in 20 publications, numerous international consultancies and conferences.

Future Work. As partially described above we have many new funding initiatives in the works to continue this project including; A joint NSF/India proposal to work on tissue culture, a joint NSF/Argentina project to explore genetic improvement of Prosopis in field trials in Argentina and the USA, a joint Texas A&I/ University of Karachi project to test Prosopis clones under very high salinity, a request from the Brazilian government to assist with Prosopis development for animal feed on an industrial scale, work with a Texas oilman planting 1 million leucaena trees per year for cattle forage, work with U.S. hardwood moulding companies to develop high value added processes for converting small diameter, short logs into high value tongue and grooved flooring, and management techniques for existing Prosopis to provide revenue from firewood while grooming high value trees for the future and maximizing nitrogen fixation at the stand level for enhanced soil development.

Unfortunately none of the most needed follow-on projects fit the aims of the PSTC modules. With all due respect, the modules to which PSTC proposals can be submitted appear to have been developed by a distinguished panel of U.S. scientists with very little third world development experience. These modules are too confining to solve some of the critical economic development problems, especially in semi-arid regions.

We should be first asking what are the truly important problems related to development in the third world and then

how can science be of assistance. PSTC has the process backwards in developing techniques such as biotechology first and then going looking for problems to solve.

Felker's physical chemistry text defined physical chemistry as "anything in science that is interesting". I believe PSTC should take the same approach. As long as the observations are replicated and measured, any proposal should be considered that is relevant to development.

In conclusion there are many excellent scientists in the very poor regions of the third world who could make a substantial contribution to semi-arid lands through their knowledge and research on Prosopis. Due to the horrendous mail and phone situation in the third world they are essentially isolated. The greatest priority must be to bring these researchers together on an electronic mail network along with modest funds to share newly developed elite germplasm and clonal propagation techniques. The tools are now available to create a green revolution for fuelwood in the semi-arid regions. This investigator hopes that somehow, someway, there will be a light through the international donor community to allow it to happen.

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Felker, P., P.R. Clark, A.E. Laag, and P.F. Pratt. 1981. Salinity tolerance of the tree legumes mesquite (Prosopis glandulosa var. torreyana, P. velutina, and P. articulata), algarrobo (P. chilensis), kiawe (P. pallida) and tamarugo (P. tamarugo) grown on sand culture on nitrogen free media. Plant and Soil 61: 311-317.

Singh, G., I.P. Abrol, and S.S. Cheema. 1989. Effects of gypsum application on mesquite (Prosopis juliflora) and soil properties in an abandoned sodic soil. Forest Ecology and Management 29: 1-14.

Felker. P. 1992. Capturing and managing the genetic variation in Prosopis for use in fuelwood, luxury quality lumber, pods and soil improvement. In: Tropical Trees: The potential for domestication. R.R.RB Leakey (Ed) Institute for Terrestrial Ecology, Edinburg Publishers. In press

Lee, S.G., E. Russell, and P. Felker. 1992. Discovery of thornless, non-browsed, erect tropical Prosopis in Haitian progeny trials. Forest Ecology and Management 46: 189-200.