LEGUME TREES IN SEMI-ARID AND ARID AREAS

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ABSTRACT - A review of the research and development activities on nitrogen fixing trees for semi-arid regions is presented. In the period from 1980 through 1983 much new information on pod productivity, on natural stand nitrogen fixation and on greenhouse mineral nutrition has become available. Early results from small plot plantation work indicate a biomass productivity of 10-13 dry metric tons per hectare per year. Clones have been made of promising individual trees and research on rooting of cuttings is rapidly approaching commercialization. Tissue culture propagation of semi-arid nitrogen fixing trees has only just begun. Procedures have been developed employing subsoiling and herbicides that yield more than 90% survival on sites receiving 500 mm annual rainfall.

A tabular review is presented of the major research organizations and donors involved in semi-arid nitrogen fixing trees. Major technical constraints are coping with semi-arid soils that are generally low in available phosphorus, iron, zinc and manganese, range in soil texture from cracking clays to high bulk density sands or rocky desert pavement, and that vary in pH from 6.5 to 9.5. Pest management issues (insects and diseases) have not yet been studied in semi-arid nitrogen fixing trees and should be addressed before large scale plantations are undertaken.

The excellent progress made from 1980 through 1983 suggests a very bright future for semi-arid nitrogen fixing trees.

Index terms: N_2 fixation, nodules, saline soils.

LEGUMINOSAS ARBÓREAS PARA ÁREAS SEMI-ÁRIDAS E ÁRIDAS

RESUMO - Foi feita uma revisão da pesquisa sobre leguminosas arbóreas para áreas semi--áridas. No período compreendido entre 1980 e 1983, muita informação sobre produção de vagens, fixação de N_2 em condições naturais e nutrição mineral tornou-se disponível. Os resultados iniciais obtidos em pequenas parcelas indicam uma produção de biomassa de *Prosopis* entre 10-13 toneladas de peso seco por hectare/ano. Propagação vegetativa por cultura de tecidos é uma área de pesquisa recém-iniciada para as árvores fixadores de N_2 de regiões semi-áridas. Por outro lado, clonagens de árvores individuais mais promissoras foram feitas, e a pesquisa sobre o enraizamento de estacas está rapidamente chegando ao nível comercial. Técnicas de manejo já foram desenvolvidas, empregando subsolagem e herbicidas, as quais permitem mais que 90% de sobrevivência de mudas em localidades com cerca de 500 mm anuais de chuvas.

As principais instituições de pesquisa e financiadoras envolvendo árvores fixadoras de N_2 para o semi-árido são listadas. Os maiores problemas técnicos a enfrentar são os solos do semi-árido que, geralmente, são deficientes em fósforo disponível, ferro, zinco e manganês, além de apresentarem ampla variação de textura, desde os argilosos aos are-

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nosos e rochosos, e variação de pH de 6,5 a 9,5. O manejo das pragas e doenças não tem sido ainda objeto de estudo, e deve ser investigado antes que plantações em grande escala sejam estabelecidas. Entretanto, o excelente progresso obtido no período de 1980/83 sugere um futuro brilhante para as árvores fixadoras de nitrogênio, adaptadas às regiões semi-áridas.

Termos para indexação: fixação de N_2, nódulos, solos salinos.

INTRODUCTION

Excellent reviews on tree legume in semi-arid regions have become available as for example on *Prosopis cineraria* in the Indian desert (Leakey & Last 1980, Mann & Saxena 1980), on utilization of mesquite in the United States (Parker 1982), on *Prosopis tamarugo* in the Chilean salt deserts (Habit et al. 1981), the utilization of *Prosopis* in Latin America (Mendes 1982), and a review of tree legumes in semi-arid regions (Felker 1980). This review will primarily deal with *Prosopis* since this genus seems to be the one receiving the most attention in semi-arid regions.

In recent years substantial new information on tree legumes has become available in areas as diverse as tissue culture propagation, animal feeding with *Prosopis* pods, nitrogen cycling studies, new silvicultural techniques, and selection of superior genetic planting stock. The first part of this paper will review some of these developments, while the second part will examine unresolved issues with impact on further developments.

PROSOPIS POD PRODUCTION AND UTILIZATION

Some of the most innovative work on *Prosopis* pod utilization has come from Meyer et al. (1982) and Becker (1982) at the USDA laboratory in Berkely, California. These workers have devised commercial scale milling equipment (500 kg/h) and procedures for separating *Prosopis* pods into four fractions consisting of: (1) exo-mesocarp (31% sucrose, 35% dietary fiber, 11% protein, 0% galactomannan); (2) endocarp (5% sucrose, 61% dietary fiber, 6% protein, 0% galactomannan); (3) endosperm splits (0% sucrose, 0% dietary fiber, 8% protein, 60% galactomannan); and (4) the colydenon (0% sucrose, 0% dietary fiber, 56% protein, 0% galactomannan). Thus, *Prosopis* pods can be fractionated into a high sugar fraction, a high fiber fraction, a high protein fraction, and a high galactomannan or gum fraction (similar to guar gum).

The mill used by Meyer et al. (1982) can be adjusted to produce nearly 100% unbroken but mechanically scarified seeds from *Prosopis*.

Cattle feeding was examined in five levels of substitution for wheat bran by ground *Prosopis* pods (Silva 1982). A randomized complete block design with four animals per replicate and four runs was used. No significant differences in weight gain were observed, but the *Prosopis* ration was the least costly. A study of the progressive substitution of *Prosopis* pods for sugar cane molasses in the diets of sheep was carried out by Barros (1981). As *Prosopis* pods were so high in sugar, this study was designed to test the usefulness of *Prosopis* pods as an energy ration. The ration which substituted 50% of the molasses by *Prosopis* pods had the greatest daily gain, but the lowest conversion coefficient efficiency. Another Brazilian study (Nobre 1982) examined the effect of substituting *Prosopis* pods for whole wheat flour on the milk production of Holstein-Zebu cows, and reported that rations with 20, 40, and 60% substitution of wheat flour by *Prosopis* flour were not significantly ($P = 0.05$) different from each other, but yielded significantly greater milk fat and total solid productions than the ration without *Prosopis* pods.

A feeding trial in the Sudan attempted to determine whether a diet consisting solely of *Prosopis* pods could maintain body weight of desert goats (Abdelgabbar 1983). The *Prosopis* pods were finely ground and fed to goats in confinement at 55%, 70%, 85% and 100% of the diet respectively. Cotton seed cake and wheat bran were used to fill out the remainder of the diet. The goats lost weight when mesquite pods constituted 85% and 100% of the diet; however, gains of 0.17 kg/week and 0.27 kg/week were observed when mesquite pods accounted for 70% and 55% of the diets, respectively. Little differences in the digestibility of dry matter, crude protein, crude fiber or ether extract occurred between the rations. The major shortcoming of the 100% *Prosopis* pod diet seemed to be lack of palatibility of the finely ground pods. Additional studies should probably examine pods which have been coarsely chopped to break the seeds rather than grind them finely.

A comparison of pod production of North and South American, Hawaiian, and African *Prosopis* accessions in young California plantations is in press (Felker et al. 1984). This study examined 13 species and over 30 *Prosopis* half-sib families over a period of four years. In one field study pod production was stimulated at the expense of total biomass production when irrigation was withheld from the trees in a winter rainfall climate. *P. velutina* accessions from southern California and northern Mexico consistently out produced other species such as *P. alba, P. chilensis, P. pallida, P. Tamarugo, P. glandulosa* var. *torreyana* etc., at 2 to 3 years of age on all three sites. However, many Arizona *P. velutina* accessions had little or no pod production during this study indicating the necessity of field tests for progeny from southern Arizona to identify superior pod producers.

NITROGEN FIXATION/NITROGEN CYCLING STUDIES

Some excellent quantitative data on nitrogen cycling in a *Prosopis* dominated desert ecosystems have been published by a multi-disciplinary team of ecologists and soil scientists (Shearer et al. 1983, Sharifi et al. 1982, Virginia & Jarrell 1983, and Rundel et al. 1982). These studies were conducted in a hot (47°C maximum summer temperatures) dry (60 mm annual rainfall) region where *Prosopis* uses a groundwater source 3.5 to 5 m below the soil surface. *Prosopis* accounted for 90% of the total plant cover at the site, but still had a canopy cover of only 30% of the total area (Sharifi et al. 1982). In spite of the low canopy cover, *Prosopis* had a pod production of 3,650 $kg/ha^{-1}/yr^{-1}$ which is very high for this low rainfall (Sharifi et al. 1982). Rundel et al. (1982) measured the nitrogen compartmentalization of the biomass productivity of leaves, branches, trunk and reproductive tissues, and estimated that 23-36 kg/ha^{-1} N/yr^{-1} were fixed on a stand basis of 33% canopy cover, and Rundel et al. (1982) suggested that approximately 150 kg/ha N/yr could be fixed if 100% stand cover were achieved.

Due to the difficulties in sampling 3.5 m to 5 m deep root systems for nodule observations, Shearer et al. (1983) made nitrogen fixation estimates based on determinations of natural abundance $^{15}N/^{14}N$ ratios. This technique is based upon the principle that the nitrogen fixation process does not discriminate between the ^{15}N and ^{14}N isotopes and thus a plant which fixes all its nitrogen should have the same $^{15}N/^{14}N$ ratio as the atmosphere. On the other hand, soil denitrifying organisms discriminate between ^{15}N and ^{14}N leading to "high" soil $^{15}N/^{14}N$ ratios. Thus, plants which take their nitrogen from the soil should have higher $^{15}N/^{14}N$ ratios than plants which fix their own nitrogen. Using this technique and carefully pairing nitrogen fixing and non-nitrogen fixing plants, Shearer et al. (1983) estimated that *Prosopis* fixed approximately 43 to 61% of its nitrogen on 6 of the 7 sites they examined. These authors also demonstrated significant differences in natural abundance N isotopes between legumes and non-legumes on 7 different sites. Although $^{15}N/^{14}N$ determinations are costly, these determinations yield an integrated indicator of nitrogen fixation for deep rooted perennial trees that is not possible to obtain by other methods.

A comparison of soil properties under the *Prosopis* canopy with those between the *Prosopis* rows was carried out by Virginia & Jarrell (1983). These authors observed significantly higher total N, nitrate N, ammonium N, organic C, and sodium bicarbonate extractable phosphorus under the trees. There was also lower salinity under the trees evidently because *Prosopis* excludes sodium during mineral uptake at the leaf and root surfaces. The water infiltration was also greater under the canopy of *Prosopis* than between the trees. When the results of this multi-disciplinary study are taken together, they indicate considerable potential for productivity for either food or fuel, for nitrogen fixation, and for soil improvement.

In addition to work at the ecosystem level on nitrogen fixation of semi-arid tree legumes, some useful greenhouse experiments have also been published. Felker & Clark (1981a) added another nitrogen fixing tree to the list of arid adapted trees: *Olneya tesota* (desert ironwood), and failed to observe nodulation on *Cercidium floridium* and *Acacia greggi. Cercidium* occurs on vast areas in North and South America and its lack of nodulation on infertile soils seems out of place. Also in greenhouse experiments it was found that *Prosopis articulata* and *P. tamarugo* grow in sand culture (albeit very slowly) at salinities equivalent to sea water (3.6% NaCl) on a nitrogen free medium (Felker et al. 1981). Soybeans and beans (*Phaseolus* spp.) tolerate salinities of 0.1% with difficulty and the most salt tolerant common legume, alfalfa, tolerates 0.6% with difficulty.

Nodules are seldom found on tree legumes in semi-arid regions despite the fact that many of these tree legumes have been shown to nodulate in the lab or greenhouse. Felker & Clark (1982) simulated a phreatophytically grown semi-arid tree legume by growing it in a 3 m long column in the greenhouse. With only one watering from the top and all subsequent waterings (1½ years) from below, the *Prosopis* developed all of its nodules at least 2.75 m from the soil surface. Furthermore, this legume fixed nitrogen at leaf air temperatures of 47°C and leaf xylem water potentials of minus 3.3 MPa (Felker & Clark 1982). These environmental parameters are clearly more extreme than can be tolerated by annual legumes.

MINERAL NUTRITIONAL REQUIREMENTS OF TREE LEGUMES

There are millions of hectares of tree legumes growing unmanaged in the semi-arid regions of the world (Felker 1980). The two major management practices for improving the productivity are: (1) to correct mineral nutrient deficiencies affecting nitrogen fixation and growth; and (2) to improve the stand by eliminating inferior trees and replacing them with genetically superior stock. Before removing existing trees it would be useful to have a method for assessing nutrient deficiencies, for example, via foliar analyses.

Reyes & Felker (manuscript in preparation) recently examined the growth of *Leucaena leucocephala* K8 in a lime, phosphate, micronutrient factorial greenhouse experiment designed to optimize biomass production. Leaf tissue macro and micronutrient analyses were significantly correlated with plant dry weights. For P levels this correlation was positive and for Na levels negative. Biomass production was also negatively correlated with soil pH (over the range of 4.9 to 7.2). Leaf nitrogen content was not correlated with biomass production indicating that these plants were fixing sufficient nitrogen. Table 1 lists the optimum leaf tissue parameters we observed for *Leucaena* biomass production. These values may prove useful in diagnosing mineral deficiencies in the field.

Due to the importance of phosphorus for legume growth and nitrogen fixation, one would expect mycorrhizae to benefit tree legumes on semi-arid soils since they are typically neutral to alkaline in pH with low phosphorus levels.

Major nutrient imbalances occurred with leaf sodium levels of 0.005 to 0.011% and greater, and when leaf phosphorus levels were below 0.07%. Leaf manganese levels were sensitive to pH and were typically 40-50 μg/g at pH values greater than 7.

Preliminary results of a field trial with *Leucaena leucocephala* K67 at 0, 60 and 120 kg/ha P with and without VA mycorrhizal (*Glomus fasiculatus*) inoculation revealed that phosphorus fertilization had little effect on growth while mycorrhizal inoculation nearly doubled the growth of three month old transplanted seedlings (Mbugua & Rhodes, unpublished observations). No differences in leaf tissue phosphorus concentrations were observed, but almost double the quantity of phosphorus occurred in the mycorrhizal seedlings (Mbugua & Rhodes, unpublished obs.). A poor soil (white clay with very low water infiltration) was chosen for this trial and perhaps mycorrhizae will have no benefit on better soil types. This preliminary experiment needs to be repeated on several sites over a period of years.

FIELD PRODUCTIVITY STUDIES

A. Natural stands

As mentioned earlier, Sharifi et al. (1982) have reported the pod productivity of a native *Prosopis glandulosa* var. *torreyana* stand in the California desert to be 3,650 kg/ha for 30% coverage. These authors suggested that higher productivities would be possible since the stand density is primarily limited by establishment rather than water availability from the 4 meter deep water table.

TABLE 1. Leaf tissue nutrient concentrations associated with optimum biomass production of *Leucaena leucocephala* K8 in the greenhouse (data from Reyes & Felker manuscript in preparation).

Nutrient	Leaf concentration
phosphorus	0.16%
nitrogen	4.3%
potassium	1.5%
magnesium	0.18%
sodium	0.001%
calcium	0.76%
iron	58 μg/g
zinc	22 μg/g
manganese	95 μg/g
copper	2.2 μg/g

In contrast to this high productivity, Braun et al. (1978) estimated a net primary pod productivity of 1,60 $kg/ha^{-1}/yr^{-1}$ for a *Prosopis flexuosa* dominated community in a 260 mm annual rainfall region of Mendoza, Argentina. This was a mature climax vegetation site and perhaps greater yields would have been obtained in younger growth stages.

B. Plantations

A comparison of the biomass production of 32 *Prosopis* accessions representing North and South American, Hawaiian and African germplasm, under three different irrigation regimes, has just been published (Felker et al. 1983). The *Prosopis* accessions were watered when the soil water potential at the 30 cm depth reached either 60, 200 or 500 kPa. After three seasons growth there was little difference in biomass production among irrigation treatments for the fast growing accessions of *P. chilensis* and *P. alba.* However, there were large differences in dry matter productivity between the accessions of *P. chilensis* from Argentina, showing the highest yield (40 $t/ha^{-1}\cdot^{-3}/yr^{-1}$), and the leafless *P. kuntzei* also from Argentina, the lowest.

The total irrigation plus precipitation received during the three seasons was 1,390 mm and therefore a water use efficiency of 345 kg per kg of dry matter was calculated (Felker et al. 1983), which compares very favorably with C-4 grasses like sorghum. A similar yield (14 $t/ha^{-1}/yr^{-1}$) was estimated for *Prosopis* leaf and woody biomass production irrigated at 30% of pan evaporation in the California Imperial Valley (Felker et al. 1983). A screening trial of 55 tree legume accessions carried out in the Imperal Valley showed a 100 fold range in biomass production among the accessions.

The cold tolerance of *Prosopis* selections representing high biomass producing lines, such as *P. chilensis, P. alba* and *P. articulata,* were compared to mesquite native to California, Arizona, New Mexico and Texas (Felker et al. 1982). *Prosopis juliflora* from West Africa and *P. pallida* from Hawaii were observed to be truly tropical species tolerating maximally - 1.5°C. Most *P. alba, P. chilensis* and *P. articulata* accessions had greater biomass productivity, but less cold tolerance than species in native North America. However, sufficient variability existed to substantially improve *Prosopis* biomass production in the United States.

Practical field management techniques are being developed which avoid irrigation using the promising clones identified in California field trials (Felker et al. 1984). A heavy duty mechanical transplanter was modified from a subsoiler to plant 38 cm long seedling containers entirely below ground level. Five herbicides at a high and a low rate were examined for use in transplanting *Leucaena* and *Prosopis.* Oryzalin (2.8 kg active ingredient per hectare) gave a 3-4 fold increase in biomass production of *Leucaena* and *Prosopis,* and increased seedling survival from 75 to 95%. This experiment was carried out with only 150 mm rainfall within 110 days after transplant and illustrates the importance of weed control in semi-arid systems (Felker et al. 1984).

A field trial was recently conducted to compare growth and survival of *Prosopis* and *Leucaena* seedlings using two seedling containers (Felker & Smith, unpublished observations). A 20 cm long by 3.8 cm wide plastic dibble tube that is removed prior to transplanting was compared to a 38 cm long cardboard container that was not removed prior to transplanting. An adverse site with a clay soil that had a low water infiltration rate was chosen.

The survival was 100% with cardboard containers and 73% and 46% with plastic dibble tubes for *Prosopis* and *Leucaena,* respectively. However, the *Leucaena* seedlings, which survived when transplanted without a surrounding container, had much greater biomass than seedlings which still had the container around the root system. The contrast, *Prosopis* seedlings had greater biomass production when the cardboard containers were still left on. These differences may be due to the fact that *Prosopis* has a tap root while *Leucaena* has a fibrous root system that is close to the soil surface.

Our observation has been that the most expensive planting system that excludes partial or full irrigation is approximately ten times cheaper than the most inexpensive irrigation system. Thus, we have chosen to use long (38 cm) seedling containers, disking, subsoiling, herbicides and mechanical transplanters capable of rapidly planting long root systems. Using these techniques our *Prosopis* planting survival was greater than 90% on each of the five sites we planted in the last 2 years.

VEGETATIVE PROPAGATION

The breeding mechanisms of semi-arid tree legumes dictate whether or not they will propagate true to type from seed. *Leucaena leucocephala* is a self-fertile, highly inbred plant that produces copious quantities of seed at one to two years of age (Brewbaker & Hutton 1979). Thus, isolated seed orchards of *Leucaena* are the method of choice for providing bulk quantities of *Leucaena* propagules.

In contrast, *Prosopis* and many *Acacia* species are self-incompatible (Simpson 1977) and are therefore obligate outcrossed species that cannot propagate true to type from seed. In addition, some of the best biomass producing *P. chilensis* species do not begin to produce seed until they are five years of age (Felker et al. 1984).

Thus, rapid (and hopefully inexpensive) vegetative propagation techniques that produce true to type seedlings are required. Six of the tested species sometimes rooted well if young greenhouse grown stockplants were used (Felker & Clark 1981b). However, these workers noted that mature field trees yielded 1% or less rooted cuttings and that even greenhouse grown stock plants yielded 10% or less rooted cuttings in the winter. Thus, the effect of environmental parameters on the rooting of cuttings was examined with the use of growth chambers. Klass (manuscript in preparation) found that cuttings would not root at 20°C, they would root poorly at 27°C and the optimum temperature was approximately 35°C. The rooting percentage was 6 to 9% at 9,000 lumens/m^2 (900 ft candles) and 70% at 25,000 lumens/m^2 (2,500 ft candles) when fluorescent lights were used. Photoperiods (8, 12, 18, 24 h) did not exert a marked influence on the rooting percentages, although the 12 and 18 h photoperiods were slightly better than the 8 and 24 h photoperiods.

When the optimal light, temperature and photoperiod were achieved indolebutyric acid and napthaleneacetic acid powders, in the range of 0,3% to 3,6%, did not significantly increase the percentage rooting over a control although they did increase the number of roots per cutting (Klass manuscript in preparation). This indicates that environmental factors have more influence on rooting of cuttings than do exogenously supplied auxins.

Another alternative to vegetative propagation is to produce plantlets via tissue culture propagation. In order to ensure the exact reproduction of the desired parental type, the plantlets should be derived from lateral or apical meristems rather than undifferentiated callus. While it is often relatively easy to produce tissue cultured plantlets from seedling hypocotyls it is obviously not possible to clone desirable field trees from hypocotyl explants.

The laboratory with the most experience to date on tissue culture of semi-arid tree legumes is that of Dr. H.S. Arya of the Botany Department at the University of Jodhpur, India. Dr. Arya's laboratory has worked on the tissue culture of *Acacia, Prosopis, Tecomella* and *Zyzphus.*

Research on the tissue culture propagation of *Prosopis alba, P. tamarugo* and *Leucaena leucocephala* at Texas A & I University developed for initial axillary bud explant sterilization, and hormone formulations have identified that routinely yield leaf proliferation. In about 15% of the cases single shoots of 2 cm maximum length have been produced. Multiple shoots have not yet been produced nor have any of the shoot explants been successfully subcultured. As tissue cultured plantlets can be produced over 1,000 times more rapidly than cuttings once good techniques have been developed, it is mandatory to continue this line of research. However, one must be very patient, for results in this area do not come quickly.

Wood technology and harvesting

Some of the arid/semi-arid tree legumes species have superb wood qualities. Both desert ironwood (*Olneya tesota*) and Texas ebony (*Pithecellobium flexicauli*) are more dense than water and possess an almost black colored heartwood. Wood supplies of these trees are very limited and are in considerable demand by wood carvers, custom furniture makers and hobbyists.

Fine furniture craftsmen in both Argentina and the United States have come to appreciate the excellent technical qualities of *Prosopis* wood. In a recent *Prosopis* workshop, Rogers (1983) compared mesquite wood properties with five other hardwoods and found in to have 25% of the volumetric shrinkage of the other hardwoods and a hardness 50% greater than any of the other hardwoods.

The semi-arid lands are somewhat unique in their potential to produce large scale firewood plantations because of the low population density and extensive areas that are suitable to biomass farming. With advanced technical packages yields of 10-15 metric tons of wood per hectare per year have been obtained. Felker (1984) estimated that wood produced from semi-arid energy farms might cost as little as US$ 28 per dry metric ton or US$ 1.40 per GJ (US$ 1.48 per million Btu).

Technical constraints to further development

Since genotypes with good biomass productivity and water use efficiency have been identified, it is important to develop field management techniques that will enhance nitrogen fixation of the farm or in the plantation.

Soil physical properties may exert profound influences over the growth of nitrogen fixing trees. Low productivity is to be expected on shallow (30 cm) soils over clay or calcium carbonate hard pans, on gravel soils, on clay soils with low water infiltration rates, and on sandy soils that have not been subjected to deep plowing to reduce bulk density and increase root penetration. Sandy soils often appear to the inexperienced observer as though roots should have little difficulty penetrating them, but sands have the greatest bulk density of all soil types. In an excellent monograph, Charreau & Nicou (1971) have demonstrated for millet and groundnuts linear regressions between crop yield, root density and soil bulk density in the sandy soils of West Africa. There is no reason to believe that root development (and above ground biomass) of nitrogen fixing trees would not also be restricted by high soil bulk density in semi-arid sandy soils.

Soil chemical properties profoundly influence nitrogen fixation in annual legumes and would also be expected to influence nitrogen fixation in trees. In contrast to the wet tropics, the soils of semi-arid regions of the tropics have pH values generally greater than seven with high base saturation (Dregne 1976). Under these conditions, phosphorus, iron, zinc and manganese could all be expected to limit crop production. While considerable data are available on soil fertility levels of rainfed cultivated agriculture sites, which have generally received some fertilizer amendments, there is virtually no fertility data base for the non-cultivated soils supporting mixed *Acacia/Prosopis* stands in the semi-arid regions of Africa, India, North America or Latin America. Recent reviews of African soils (Dregne 1976, Ahn 1977) gave no values or references for sodium bicarbonate extractable phosphorus levels which are generally recognized as the most useful soil phosphorus test for alkaline soils (Olsen et al. 1954). Sodium bicarbonate extractable phosphorus levels for three non-fertilized rangeland sites in the United States were less than 2 μ g/g (El-Ghonemy et al. 1978, Black & Wight 1972, Virginia & Jarrell 1983) and thus considerably below the 10 μg/g value to which a response to phosphate fertilization is certain for annual crops (Olsen et al. 1954). The responses of native stands and plantations of *Acacia* and *Prosopis* to phosphorus and trace element fertilization need to be measured and related to leaf tissue levels. Baseline data (maps) on soil phosphorus, pH and trace element concentration throughout the non-cultivated semi-arid lands also need to be established.

Given the low concentrations and low availabilities of key nutrients for nitrogen fixation it is critical to use them as efficiently as possible. Mycorrhizae enhance uptake of immobile plant nutrients, as discussed earlier, stimulates the growth of young *Leucaena* seedlings. As various species and strains of mycorrhizae occur naturally it would be useful to screen various sources for their ability to stimulate growth at low soil nutrient concentrations.

CONCLUSIONS

Much progress has been made since 1980 to develop the resources of nitrogen fixing trees in semi--arid regions. Seed cleaners have been identified that produce 100% unbroken seed from pods fed at the rate of 500 kg/h; firm ecosystem nitrogen fixation data have become available demonstrating 30-40 kg N/ha^{-1}/yr^{-1} fixed in the California desert; halophilic nitrogen fixing trees have been identified that grow on 50% sea water, and clones have been identified that produced 50 kg of dry pods/tree in two seasons. Vegetative propagation of *Prosopis* by rooting of cuttings is approaching commercialization, and tissue culture propagation is seriously underway.

A very refreshing increased awareness of the problems and potentials of nitrogen fixing trees in semi-arid systems is now evident from university researchers, national forestry directors and international donors.

Semi-arid nitrogen fixing-tree species possessing adequate nitrogen fixation and biomass production have been identified on selected sites and reasonably good stand establishment procedures that avoid irrigation at transplant are now available. Research is now required to determine the long term productivity of the selected strains and to determine the growth responses on a variety of soil types with and without fertilization and with and without mycorrhizal inoculation.

Very exciting genetic material for woodfuel and pod production has been identified. Great technical strides have been made in the last few years and more people than ever before are engaged in research and development of these trees, and funding agencies are looking more and more favorably upon requests for research and development in this area. The future for semi-arid nitrogen fixing trees looks very bright indeed.

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APPENDIX

ORGANIZATIONS PRIMARILY INVOLVED IN SEMI-ARID TREE LEGUME WORK

Key Contact	Address	Major area of interest	Primary species
Dr. J. Alon Aronson	Research & Dev. Auth. Ben-Gurion Univ. of Negev. Beer-Sheva 84110 POB 1025, Israel	Plant introduction	*Prosopis, Acacia*
Dr. Arya	Dept. Botany, Univ. Jodhpur-Jodhpur, India	Tissue culture	*Acacia, Proposis cineraria*
Dr. O. Balboa	Botany Laboratory, Catholic Univ. of Chile Casila 114-D, Santiago, Chile	Laboratory research	*Prosopis, Acacia*
Mr. R. Becker	USDA/WRRC 800 Buchanan St. Berkeley, CA 94710	Nutrition of tree legume fruits	*Geoffrea, Prosopis, Olneya*
Mr. M.D. Benge	U.S. Agency for Int. Development S & T/FNR Dept. of State Washington, D.C. 20523	Donor agency	various
Mr. Neil Branden	Lutheran World Relief 3600 Park Ave. S. New York, N.Y. 10016	Reforestation East & West Africa & India	*Leucaena, Acacia, Prosopis*
Dr. J.L. Brewbaker	Nitrogen Fixing Tree Assoc. P.O. Box 680 Waimanalo, HI 96795	Research coordination	*Leucaena*
Dr. Luis Marcano Coello	Fusagri Francisco de Miranda, Cruce Av. los Palos Grandes, Edif. Cavendes Caracas, 1062 - Venezuela	Field research	*Leucaena, Prosopis*
Dr. Yvon Dommergues	Centre ORSTOM B.P. 1386 Dakar, Senegal	*Mycorrhizae & Rhizobia*	*Casuarina, Acacia*
Dr. P. Felker	Texas A & I University, Campus Box 218 Kingsville, TX 78363	Field & lab. research	*Prosopis, Leucaena*
Dr. A. Paulo M. Galvão	EMBRAPA - Ed. Super Center Venâncio 2000 SCS - Q. 8 - Bloco B, Nº 60 70333 Brasília, DF, Brasil	Plantation forest research	*Prosopis, Acacia, Leucaena*
Mr. J. Gorse	World Bank 1818 H. Street N.W. Washington D.C. 20433	Donor agency	various
Dr. M. Greene	National Academy of Sciences 2101 - Constitution Ave. Washington, D.C. 20418	Research grants	various
Mr. O. Hamel	Centre National de Recherches Forestières B.P. 2312 Dakar-Hann, Senegal	Plantation establishment	*Acacia*
Dr. A. El Houri	Forest Research Center P.O. Box 658 Khartoum, Sudan	Field trials	*Acacia, Prosopis*
Dr. J.H. Hunziker	Departamento de Ciencias Biologicas Universidad de Buenos Aires 1428 Buenos Aires, Argentina	Taxonomy cytology	*Prosopis*
Dr. Peter Huxley	ICRAF P-O - Box 30677 - Nairobi, Kenya	Advisor, research coordinator	various
Dr. W. Jarrell	Dept. Soil & Env. Sci., Univ. Cal. Riverside Riverside, CA 94710	Nitrogen cycling measurents	*Acacia, Cercidium, Prosopis*
Mr. John Michael Kramer	Renewable Nat. Res. CARE 660 First Ave. New York, NY 10016	Plantation establishment in Somalia, Sudan	*Acacia, Prosopis*
Mr. L.G. Lessard	International Devlp. Res. Centre Box 8500 Ottawa, KIG3H9 - Canadá	Donor agency	various
Dr. S.P. Malhotra	Central Arid Zone Research Institute Jodhpur, India	Applied field research	*Acacia, Prosopis*
Dr. M. Mounir	Plant Introduction Dept. Desert Institute Mataria, Cairo, Egypt	Field trials in arid regions	*Prosopis, Acacia*
Dr. B.V. Nimbkar	Nimbkar Agric. Res. Institute Phaltan 415523 Dist. Satara, Maharashtra, India	Breeding/field trials tissue cultures	*Prosopis*
Ms. C. Palmberg	Forestry Dept. FAO Via delle terme di Caracalla 00100 Rome, Italy	Research coordination germplasm collection	various
Mr. K. Rogers	Texas Forest Prod. Lab. Lufkin, TX	Wood technology	*Prosopis*
Ing. J. Salinas	National Florestal, Encargado Ministério de Agricultura & Ganaderia Casilla 2919 - Quito, Ecuador	Plantation work	*Prosopis*
Mr. Ron Smith	Operation Double Harvest, P.O. Box 673 Port-au-Prince, Haiti	Plantantion establishment	*Cassia, Leucaena, Prosopis*
Ing. Agr. Enrique Pardo Tejeda	INIREB, Av Avila Camacho 112 - Xalapa Veracruz, Mexico	Laboratory & field research	*Acacia, Prosopis*
Ing. Tomas Tello R.	E.E. Vista Florida Aptdo. 116 - Chiclayo	Management existing stands	*Prosopis, Acacia, Leucaena*
Ms. M.E. Torres	INTEC Casilla 667 - Santiago, Chile	*Rhizobia*	*Prosopis tamarugo, Prosopis alba*
Dr. J.W. Turnbull	CSIRO Division Forest Res. P.O. Box 4008 Canberra A.C.T. 2600 - Australia	Seed collection & inventory	*Acacia, Casuarina*
Dr. Salome Valdivia	Universidad de Lima - Lima, Peru	Large plantations	*Prosopis*
Ing. Pedro Eduardo Valls	Departamento de Ciencias Agrarias Universidad Nacional de Catamarca Republica 350 CC189 4700 - Catamarca, Argentina	Seed collection	*Prosopis*
Dr. G.E. Wickens	Royal Botanic Gardens, Kew Richmond Survey England TW9 3AB	Literature review of arid land plants	various
Dr. Peter J. Wood	Commonwealth Forest Institute of Oxford Oxford 0X1 3RB - England	Seed collection, field evaluation	*Acacia, Prosopis*
Ing. Luis Zalada G.	Casilla 2916 - CORFO - Santiago, Chile	Tamarugo plantation	*Prosopis tamarugo*