Prosopis:

Semiarid Fuelwood and Forage Tree
Building Consensus for the Disenfranchised

An Oulof woman in Dakar, Senegal, with mesquite pods from a roadside planting to take to her landless urban home to feed her sheep

Two-year-old, erect, thornless *Prosopis* with sweet pods cloned in Indian Rajasthan Desert trials

A Workshop
13S15 March 1996
U.S. National Academy of Sciences Building
Washington, D.C.

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For Two Years of Planning, Organization, and Logistics

Nancy Patch and John Parish, Graduate Students
Texas A&M University-Kingsville

Table of Contents

Workshop Rationale and Objectives

The 3.4 billion hectares of the world's drylands constitute 25% of the earth's surface and harbor 500 million people. The people of these drylands belong to some of the world's poorest communities, with problems of food security, inadequate access to drinking water, and inadequate access to sanitation facilities. Examples of poor economic conditions in drylands can be found in major areas of India, sub-Saharan Africa, Haiti, Mexico, Brazil, Argentina, and Peru. In the United States, some areas with the greatest unemployment and greatest health problems are located in semiarid regions of southern Texas.

The diversity of plant communities declines rapidly with increasing aridity. Thus, the availability of plants capable of producing food, firewood, cash flow, and soil fertility without irrigation also decline rapidly with increasing aridity. Multipurpose genera that are very biologically diverse, resulting from multiple interbreeding species, and are widely adapted to the world's semiarid regions are rare. *Acacia*, *Casuarina*, *Eucalyptus*, *Tamarisk*, and *Prosopis* are the principal genera with great biological diversity and ecological plasticity that have been used worldwide in arid regions. *Prosopis* has a significant advantage over *Eucalyptus* and *Tamarisk* in being a nitrogen fixer. *Prosopis* has a significant advantage over *Acacia* and *Casuarina* in that only *Prosopis* has great historical precedence for providing food for humans and domestic livestock.

The nitrogen-fixing genus *Prosopis* has more than 40 species native to North and South America, Africa, and Asia that range from 1-m-tall shrubs to 18-m-tall trees. Hundreds of hectares of *Prosopis* occur naturally in Death Valley, California, the hottest location in the Western Hemisphere. Other *Prosopis* species have become naturalized to harsh semi-arid areas of Haiti, Sahelian Africa, and India. *Prosopis* pods, which are high in sugar (30%), with moderate levels of protein (12%), have been used for human and animal food by indigenous people for millennia. In Mexico, Argentina, and Brazil, *Prosopis* pods are a critically important source of animal feed. In Peru, pods of especially sweet varieties are used for human food. In North America, soils under the canopy of *Prosopis* have 1,000 kg/ha more soil nitrogen and 8,000 kg/ha more soil carbon than soils outside the canopies of the trees. In *India, Prosopis* has been used to reclaim high-pH (10.4) soils. *Prosopis* strains have been found that will grow in salinities equal to ocean water. In Somalia, *Prosopis* has been used for sand dune control. In many places of Sahelian Africa, it is important for fuelwood and forage. In western India and Haiti, *Prosopis* provides more firewood than any other species. Although the reddish/brown lumber of *Prosopis* is usually less than 2 m in length and 0.4 m in width, it finishes very well, is harder than oak, and is more dimensionally stable (lower volumetric shrinkage) than any lumber measured to date. Thus production of flooring, fine furniture, and artisanal products is a very active growth industry in the United States and Argentina.

It is useful to cite illustrative economic data:

In the Chaco Province of northwestern Argentina, 140,000 tons/year of *Prosopis* logs are harvested for furniture and flooring.

In the state of Texas, 15,000 tons of *Prosopis* chips and chunks are processed yearly for sale in retail stores across the United States. Also, in the United States, a small but fast-growing *Prosopis* lumber, flooring, and furniture market has developed.

In Peru, 180,000 tons of *Prosopis* pods are used annually for livestock feed.

In Mexico in 1970, 40,000 tons of *Prosopis* pods were used annually for livestock feed.

In Gujarat state of India, 300,000 30-kg bags of *Prosopis* charcoal are produced each year for sale in large cities.

In Haiti in 1991, the total value of the charcoal industry (principally resulting from *Prosopis*) was $50 million, and the charcoal industry supported 150,000 people.

In the Sahel, about 16 million cubic meters of firewood are required per year. Senegal imports 50,000 cubic meters of wood each year from neighboring countries. *Prosopis* is a major provider of firewood for Senegal.

It is most unfortunate that one of the world's finest furniture lumbers, currently being sold in Argentina and the United States for $800 per cubic meter (about $900 per ton) is being manufactured into charcoal at $200 per ton to satisfy basic living requirements.
Using sawmills currently producing lumber for pallets, fine furniture and flooring production from short *Prosopis* logs could be developed into significant industries in arid lands. Small furniture and flooring components could be integrated into fine furniture. However, large increases in the quality of sanding, joinery, and finishing would be required to meet international standards.

Despite the significant economic impact of *Prosopis* in many regions, at this writing, no country had a national development plan for *Prosopis*. Among development agencies, only the Food and Agriculture Organization (FAO) and Overseas Development Authority (United Kingdom) had *Prosopis* programs in their portfolios.

Great progress has been made in the last six years in identifying *Prosopis* that are rapidly growing (2 meters per year), erect, and thornless and produce sweet pods that can be used in human or animal food. As noted in this volume, researchers in coastal areas of Haiti, arid regions of Cape Verde, and interior Rajasthan deserts of India have all found *Prosopis* seed sources from Peru to have grown the tallest and be erect and thornless. With pod utilization techniques reported in this volume for both human and livestock food, and with identification of superior genetic materials for tropical arid regions, the route is paved for commercial investments into arid lands.

In 10 years, great strides have also been made in reducing the weedy nature of *Prosopis* by thinning and pruning, promoting intraspecific competition, and incorporating *Prosopis* in agroforestry practices.

Despite the widespread importance of *Prosopis* for firewood and forage for very poor people in arid regions of Mexico, Haiti, Sahelian Africa, and India, there has been little international awareness of the problems and potential for *Prosopis* because of very limited communication between these poor people. With recently improved genetic strains, soil management techniques, native stand management techniques, and marketing efforts, great opportunity exists to rapidly improve the lives of very poor people in some of the world's harshest ecosystems.

Given the fact that one third of the earth's land surface is semiarid or arid, when the local experiences with *Prosopis* are aggregated on a worldwide scale, *Prosopis* is a significant worldwide resource.

It was the intent of this workshop to stimulate awareness of the worldwide magnitude of the contribution that *Prosopis* has already made and to outline immediate concrete steps to rapidly improve the lives, economies, and ecosystems of some of the world's poorest people.

Workshop Summary and Recommendations

There was excellent participation in the workshop from nearly all sectors related to arid-land management. Excellent press coverage was provided by Mr. Kurt Kleiner from *New Scientist*, Ms. Elizabeth Pennisi from *Science*, and Mr. Bob Sivak from Voice of America.

In addition to the participants discussed below, Dr. Barbara Dugelby and Dr. Shirley Keel attended from The Nature Conservancy, Mr. Bruce Rich and Mr. Ken Walsh attended from the Environmental Defense Fund, and Mr. Larry Williams attended from the International Section of the Sierra Club. Dr. Greg Ruark from the U.S. Forest Service and Dr. Philip Simms, the USDA National Program Leader for Range, also participated in the conference. We were indeed fortunate to have excellent representation from the World Bank, including Mr. Eduardo Loayza, Dr. Bill Beattie (economist, Latin America), Dr. Norman Jones (forester, India), Dr. Bob Kirmse (forester, Latin America), Dr. Christian Taupiac (forester, East Africa), and Dr. Peter Dewees(forester, Horn of Africa).

The reception at the National Academy of Sciences on Tuesday evening provided an excellent opportunity for participants to become acquainted before the workshop. The 20% *Prosopis* flour cookies brought by Mr. Jose Inacio da Silva from Brazil were served and most appreciated.

Upon registration, each participant was given a 4-inch-square finished mesquite piece with the laser-engraved Los Amigos del Mesquite logo.

The Wednesday program began with an acknowledgment of the workshop sponsors and an informative welcome by Agency for International Development (AID) agroforester Mr. Mike Benge.

A very colorful and appropriate welcome message was provided by Ms. Betty Alberts of the President's office at the National Academy of Sciences. Ms. Alberts related that when she was about 10 years old and living in Hawaii, she earned spending money by collecting *Prosopis* pods that were fed to cattle. She received only $0.50 per 25-pound bag of pods, but, during World War II, this was important when they were cut off from the mainland. She also recounted getting a large thorn in her foot from collecting pods one day. Clearly, she was very familiar with the good and bad points of *Prosopis*. When she was visiting India, she saw *Prosopis* in many places, but the foresters accompanying her insisted the trees were *Acacias*. Finally, a specialist from the Central Arid Zone Research Institute confirmed that what she saw was indeed *Prosopis*.

Also on Wednesday, Mr. David Miller, past President of Los Amigos del Mesquite, set up his exhibit of flooring, furniture, and lumber. This exhibit was much appreciated, as it was the first time that many *Prosopis* scientists outside Texas or Argentina had seen fine *Prosopis* furniture and flooring. Several international foresters commented that the wood was similar in color and figure to sissham or Indian Rosewood.

Other U.S. industry participants at the meeting included Mr. Jerry Lawson of W.W. Woods and Mr. Bob Colberts, the new owner of Lazzari Fuels in San Francisco. Lazzari Fuels is the oldest and largest mesquite charcoal importing company in the U.S. Several years ago, Lazzari Fuels began a policy of purchasing only mesquite charcoal made from pruned branches and cull trees. This has opened up the stands to complete clearing of the land at no additional cost.

It was also very significant that Dr. Carlos Rodriguez Franco, the Forestal Vocal Ejectivo of INIFAP (Director of the research branch, Mexican Forest Service), gave a presentation and moderated a session. He was interested in volume tables for mesquite and stand-management techniques.

Drs. Rafiq Ahmad from Pakistan, Gurbachan Singh from India, and Ousman Diagne of Senegal opened the workshop session on land reclamation and soil stabilization with comprehensive reviews of the use of *Prosopis* for sand-dune reclamation in the Arab Gulf States, use of *Prosopis* for reclamation of high-pH (10.4) soils resulting from irrigation mismanagement in India, and nitrogen fixation and utilization of *Prosopis* in Senegal.

Following lunch, Dr. Stephen Bristow of the NGO SOS Sahel presented the results of 10 years using *Prosopis* in controlling sand-dune movements on the upper branch of the Nile in Sudan. *Prosopis* has been the most successful species used to control sand dune movements near the irrigated areas along the Nile, where dunes have drifted to cover entire villages. This effort was supported by Rotary clubs in the United Kingdom. Dr. Zach Lea and Mr. Henri Valles of Haiti then illustrated the fact that *Prosopis* was the number one fuelwood species in Haiti. Mr. Valles reported on his progress in establishing 13 *Prosopis* pod collection / grinding sites in Haiti. The *Prosopis* is being ground for animal feed. Dr. Rebecca Butterfield of CARE surveyed the approximately 15-year project of tree planting in Niger, West Africa. *Prosopis* was usually an important component of these planting efforts. However, she reported that farmers did not like the trees because of the thorns. She felt that *Prosopis* was useful for stream-bank control but would not be useful in farmers' fields unless thornless varieties were available. She also stressed the need for utilization projects for *Prosopis* in Niger.

At the coffee break in the pod utilization session, Mr. Jose Inacio da Silva provided pastries with 20% *Prosopis* flour, coffee made with 50% coffee and 50% roasted *Prosopis* flour, and finely ground *Prosopis* flour for samples. He brought 35 kg of *Prosopis* cookies to be distributed to guests at the workshop.

The session on human and animal uses of *Prosopis* pods was superb. Ms. Michelle Silbert began this session by discussing her research on the *Prosopis*-pod cooperative in central Mexico. In some years this cooperative processed several thousand tons of pods that were purchased from people in the area. An electric hammermill was used to grind the pods into various rations for animal feed. Ms. Silbert reported on her interviews with farmers to determine the extent of utilization and the prices paid for *Prosopis* pods.

Mr. Inacio da Silva then reported on his 3,000-ha *Prosopis* plantation in northeastern Brazil and his system for drying (with wood-fired coffee driers) and grinding the pods. Each year he usually processes about 4,000 tons of pods, which are sold to the people in the surrounding area.

As the current President of the International Prosopis Association, an organization that has had several international conferences in South America, he stressed the need for cooperative efforts between any new organization and existing *Prosopis* organizations.

Ing. Nora Grados of the University of Piura in Peru described the historical uses of *Prosopis* pods for human food and reviewed the program at the University of Piura for drying and fractionating pods into products for human use. The frost-sensitive *Prosopis* in Peru are especially sweet, with very little bitter aftertaste. A number of excellent products are already being marketed for human use in Peru.

The mesquite barbecue reception hosted by the Texas A&M Research Foundation on Wednesday evening was most helpful in introducing Texas Congressional aides to both the Texas and the international dimensions of *Prosopis* (mesquite). Texas barbecue manufacturer Jerry Lawson explained the Texas Beef Council / Texas mesquite barbeque-producers initiative. Mr. David Miller, who is the largest mesquite sawmill producer in Texas, explained his perspectives, and Mr. Bob Colbert of Lazzari Fuels discussed U.S. / Mexican mesquite-charcoal sustainable-harvest initiatives. The extensive international dimension of the workshop participants helped portray the international dimension of the problems and opportunities of *Prosopis* to the Texas Congressional delegation.

The presentations on Thursday morning provided an excellent overview of the genetics and management opportunities for *Prosopis*. Dr. Phil Harris of the Henry Doubleday Research Association in Great Britain reported on the use of *Prosopis* in their trials in India and Cape Verde. The trials in Cape Verde examined over 100 seed sources of *Prosopis* from all the world's major regions. The Peruvian *Prosopis* were the tallest, straightest, and fastest growing in these trials. The Indian *Prosopis cineraria* was one of the slowest growing of all the species. *Prosopis africana*, native to West Africa, was very poorly adapted and did not survive the nursery.

Dr. Harsh from the Central Arid Zone Research Institute in Jodhpur, India, reported on their replicated trial of over 110 *Prosopis* families from Argentina and Peru. While some of the multistemmed *Prosopis alba* had the highest biomass, the Peruvian *Prosopis* were the tallest and straightest, and some had no thorns. Elite selections from this trial have been grafted and distributed to other research stations in India.

Dr. Peter Felker and Ms. Nancy Patch reported on results of 10-year-old field trials designed to alleviate weedy aspects of mesquite by managing it in a savannah ecosystem. This work included research on pruning, thinning, and techniques designed to eliminate poor genetic stock and graft superior materials onto the rootstock. They also reported on Haitian progeny trials in which the Peruvian *Prosopis* of the same lineage as in Cape Verde and India were, once again, the tallest and straightest, with no thorns.

Ing. Mariano Cony of Argentina reported on progeny trials for two of the major arboreal *Prosopis* in Argentina. He examined about 70 families of *Prosopis* from about eight regions in Argentina. He reported that no geographic region was superior as a seed source. The geographic region with the greatest mean biomass contained some of the best- and worst-performing individual families (mother trees). This clearly pointed to the need for cloning superior individual trees and establishing clonal seed orchards of superior trees.

The high-value-added utilization sessions featured former Los Amigos del Mesquite President David Miller and Mr. Jerry Lawson, President of one of the largest mesquite barbeque-wood manufacturers in Texas. Mr. Miller stressed the need for all segments of the mesquite industry to work closely together. The exhibit of mesquite veneer, flooring, furniture, and kitchen cabinets in the entrance was the clearest demonstration of the high-value-added potential of mesquite. This was perhaps the first time that people outside United States or Argentina had observed the superb quality of mesquite's capabilities. Indeed, a notable National Academy of Sciences personality purchased the mesquite writing stand for her husband.

Mr. Jerry Lawson described the marketing approaches that allowed him to be successful in developing a mesquite barbeque-wood business. The fact that his retail packages are sold in about 8,000 retail outlets throughout the United States was a very powerful tribute to the potential market demand for mesquite products. Many of the multilateral foreign-aid agencies were impressed with the commercialization potential presented by Mr. Lawson and Mr. Miller. Their concrete examples of successful *Prosopis*-based businesses in semiarid regions were indeed refreshing.

Dr. Peter Wood, Past Chairman of the Commonwealth Forestry Association, gave a presentation on the role of value-added products in developing countries. He stated that colored woods, both red and dark, were highly valued, were in very short supply because they were obtained from tropical rain forests, and were available only in short, narrow pieces. Accordingly, the reddish color of *Prosopis* would appear to be very appropriate for this high-value international market.

Ing. Judith Ochoa of Argentina followed with a historical review of *Prosopis* in her country. Before Europeans arrived, extensive *Prosopis* forests provided pods for human food. After the immigration of Europeans began, *Prosopis* pods were used extensively for livestock forage. Privately owned British railroad companies destroyed much of the extensive forests for railway cross ties and fuel for steam locomotives. Currently *Prosopis* is used extensively for furniture. While there are many universities with programs in botanical and ecological studies, there is no current national program to integrate all aspects of *Prosopis* utilization in Argentina.

Dr. Sabine Bruns of the International Foundation for Science in Sweden provided an overview of their grants program for beginning scientists in developing countries. Dr. Bruns particularly encouraged applications from scientists from arid regions.

Dr. Carlos Rodriguez Franco, the INIFAP Vocal Ejectivo for Forestry from Mexico, reviewed forestry programs in Mexico and stated that about 50% of Mexico is semiarid or arid. No major *Prosopis* programs exist in Mexico, but he hopes to initiate mesquite-management programs in the near future.

For the banquet address, we were most fortunate to have Mr. Kurt Mann, Minority Agriculture Staff for Research Titles of the U.S. House of Representatives. Mr. Mann discussed difficulties in funding arid-land projects and stressed the importance of keeping legislators informed of the progress and results in economic-development activities.

The program on Friday morning began with a shared presentation by Dr. Dah Salihi of FAO and Dr. Ikar of the German foreign-aid project. They discussed their respective sand-dune reforestation programs with *Prosopis* in Mauritania.

Dr. Russell Greenburg of the Smithsonian Institution reported on the importance of *Acacias* for migratory-bird habitats in Mexico. Dr. Greenburg felt that other leguminous trees, such as *Prosopis*, might also be useful to migratory birds in arid regions.

Dr. El Hadje Sene, Chief of Forest Conservation of FAO, surveyed the many excellent FAO programs in arid-zone forestry. He pointed out the very successful FAO reforestation project in Cape Verde and mentioned the difficulties in managing the social consequences of successful arid-zone reforestation projects where land tenure issues were not resolved.

Ms. Lene Poulsen of the United Nations Development Program (UNDP) gave a clear presentation of how The Convention to Combat Desertification emerged from Agenda 21 of the Rio Summit and has since been ratified by many UN countries.

We were most fortunate to have had Dr. Walter Lusigi of the Global Environment Facility (GEF) provide an overview of the GEF structure and potential projects. The GEF fund of about $1 billion arose from contributions following the Rio Summit. While the four areas of global climate change, international waters, ozone issues, and biodiversity are the only areas that can be funded, Dr. Lusigi suggested that arid-land reclamation was critical to biodiversity and global climate change, thus, proposals to GEF could be supported for arid-land reclamation. Most critical to GEF funding was support of the Finance Minister or Agriculture Minister of the country submitting a proposal. Dr. Lusigi suggested that a network with *Prosopis* as a model species for arid-land reclamation using other species could be an interesting proposal for GEF.

At lunch on Friday, a very interesting announcement was made by Mr. David Miller of Los Amigos del Mesquite and Ms. Betty Alberts of the President's office of the U.S. National Academy of Sciences. Mr. Miller kindly offered to install a mesquite floor in the anteroom of the U.S. National Academy of Sciences as a gesture of thanks for their support of the workshop. Ms. Alberts stated that she would be pleased to recommend approval of this project to the art board and executive committee. It is hoped that a piece of *Prosopis* from each of the countries where *Prosopis* is grown could be used to make this floor.

The afternoon program was devoted to discussions of how to continue this important initiative. A panel briefly expressed their views for the future of an international collaborative effort. This panel included Dr. Sabine Bruns of the IFS; Dr. Gurbachan Singh of India; Mr. Michael Benge of U.S. AID; Mr. Larry Williams, International Director of the Sierra Club; Dr. Rebecca Butterfield of CARE; Dr. El Hadge Sene of FAO; Dr. Carlos Rodriguez Franco of INIFAP/Mexico; Ms. Lene Poulsen of UNDP; and Dr. Peter Wood of the Commonwealth Forestry Association.

After considerable discussion, several courses of action were developed:

The first need seen was to advocate the importance of arid-zone environmental and economic-development issues. It was recommended that individual countries should prepare materials about these issues for use in schools and that countries should share these materials. Use of the e-mail network for this purpose was highly encouraged.

Second, it was considered critically important to maintain the excellent dialogue that occurred as a result of this meeting. Initially this dialogue would continue through the *Prosopis* e-mail network. Several participants suggested that a similar workshop should be convened in several years. Representatives from each country should begin to seek travel funds to participate in such a workshop.

Third, it was decided to submit a proposal to GEF for an international *Prosopis* network. Dr. Peter Felker was designated the coordinator to compile requests from individual countries. These requests would, in turn, be submitted to Lene Poulsen of the UNDP for her review, editing, and submission to GEF. The following volunteered to coordinate individual country requests: Dr. Ousman Diagne (Senegal), Dr. Dah Sahili (Mauritania), Dr. Zach Lea

(Haiti), Dr. Singh and Harsh (India), Ing. Ochoa and Cony (Argentina), Ing. Rodriguez (Mexico), Ing. Grados (Peru), Dr. Rafiq Ahmad (Pakistan), and Ing. Jose Inacio da Silva (Brazil).

Subsequent discussions with Dr. Lusigi confirmed his interest in developing a proposal for submission to GEF. Letters of approval from each country desiring to participate need to be obtained from their respective Ministers of Finance or Agriculture.

After discussion with numerous individuals, it was decided to publish the proceedings by inexpensive desktop publishing so that all NGOs would have the resources to purchase them. In addition the proceedings will also be placed in their entirety on the World Wide Web, providing access to everyone. We hope this will be agreeable to all participants.

At the conclusion of the workshop on Friday, the participants felt confident that, as a minimum, this fine exchange of information would continue at the level of the e-mail network. The many excellent contacts made at the workshop will doubtless produce many exciting results over the coming years. We are all very hopeful that with hard work we will succeed in establishing a *Prosopis* network with significant resources to serve the people of arid lands.

Performance of *Prosopis* Species in Arid Regions of India

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Introduction

In dry tropical regions of India, woody species have key roles in environmental protection vis-a-vis rural economy. From time immemorial they have been a main energy source in addition to providing food and medicine (Hoking 1993). Despite all developmental efforts, the dependence on woody vegetation is not likely to shift for many years to come, especially for fuelwood and fodder.

To satisfy the need for fuel, fodder, and timber, the local vegetational resources have been exploited ruthlessly in the last four decades. This is primarily because of the tremendous increase in human and livestock populations during this period. Inhospitable climatic conditions do not support much required natural regeneration and subsequent growth of the vegetation. Consequently, vegetation in the area has become sparse and consists of scattered trees, shrubs and grasses (Tewari et al., 1993). The prominent tree species of the region are *Prosopis cineraria, Tecomella undulata*, *Capparis decidua*, *Calligonum polygonoides*, *Acacia jaquemontii, A . senegal*, etc. (Satyanarayan, 1963)

In view of the availability of limited number of very slow growing woody species and the high requirement of fuel, fodder, and timber, especially in arid tracts of India, we decided to introduce fast-growing exotics from other isoclimatic regions of the world. *Prosopis juliflora* is one of the species which was introduced in India in 1877 (Muthana and Arora, 1983). Owing to its tremendous capacity of seed production and excellent coppicing ability, this species has spread to almost all parts of arid and semiarid tracts of India and, in fact, it has now become naturalised. This species often provides as much as 80% to 90% of the fuel needs of population of arid and semiarid parts of the country (Saxena and Ventakeshwarlu, 1991). *Prosopis* pods have also been processed for use as cattle feed and the gum of the plant has been used in industry (Sharma, 1995). In recent years, due to recurrent droughts in vast stretches of arid and semiarid region, *Prosopis* is gradually becoming an important alternative to annual crops in marginal areas.

Status of *P. juliflora* in Arid Tracts

P. juliflora was introduced in Indian arid tracts about 1877 owing to its fast-growth features and drought hardiness (Muthana and Arora, 1983). Mass-scale aerial seeding of this species was done by the ruler of the erstwhile Marwar state during the 1930s. In 1940, the species was declared a "Royal Tree" and instruction was given to all the officials to plant and protect this tree species (Muthana and Arora, 1983). Due to its rapid colonizing and fast growth, the species has spread over large areas of arid and semiarid tracts.

The ecological amplitude this species is very high. It has been grown in highly saline areas, such as Rann of Kutch in Gujarat State, as well as the sand dunes of the Thar Desert (Saxena and Venkateshwarlu, 1991). In Rann of Kutch, it is the only tree species which has grown naturally and that has been exploited for gum, fuelwood, and fodder (pods). It has been estimated that in the Kutch district more than 200,000 ha are covered with *P. juliflora* (Varshney, 1993). At the moment, *P. juliflora* is the main source of fuelwood in larger parts of arid and semiarid regions of the country (Saxena and Venkateswarlu, 1991).

The Present Study

In view of the wide ecological amplitude and multiple uses of *P. juliflora* , recently, a number of other *Prosopis* species have been introduced into the arid tract of India.

The objective of the introduction was to study the production potential of *Prosopis* , especially in terms of pods and biomass. In 1991, more than 200 accessions of five *Prosopis* species, mainly of Latin American origin were introduced at Central Arid Zone Research Institute at Jodhpur. These *Prosopis* accessions were examined for their adaptability and growth potential in the environmental conditions of the Indian arid tract.

Setting of Trial Region

The Indian arid region, lying between 24 and 29 N latitude and 70 and 76 E longitude, covers an area of 317,909 sq. km and is spread over seven states viz., Rajasthan, Gujarat, Punjab, Haryana, Maharashtra, Karnataka, and Andhra Pradesh. Of these seven states, Rajasthan alone accounts for 61% of the Indian arid tract. The arid tract of western Rajasthan is better known as the Thar Desert, and is located between the Aravalli ranges on east and the Sulaiman Kirthar range on the west (Rode, 1964).

The climate of the regions is characterized by extremes of temperatures ranging from below freezing in winter (mid-December to February) to as high as 48 C in summer (April to June). Rainfall is precarious and erratic, ranging from 150 mm in extreme west (Jaisalmer area) to 375 mm in eastern part (Jodhpur and parts of Pali district). The mean monthly wind speed ranges from 7.3 km/hr (December) to 20 km/hr (May). However, in the summer, the wind often suddenly increases to 100 km/hr, resulting in severe dust storms (Pramanik and Harisharn, 1952).

The soils in the region are generally sandy to sandy loam in texture. The consistency and depth vary according to topographic features of the area. In general, they are poor in organic matter (0.04- 0.02%) and low to medium in phosphorus content (0.05 to 0.10%). The nitrogen content is mostly low, ranging between 0.02% and 0.07%. The infiltration rate is very high (7 to 15 cm/hr) (Kaul, 1965; Gupta, 1968).

Materials and Methods

The experimental site was located in silvatum of CAZRI, Jodhpur. The seeds of more than 200 single tree selections of five *Prosopis* species, mainly of Latin American origin, were procured from Texas A&M University-Kingsville, USA. The *Prosopis alba*, *P. chilensis*, *P. flexuosa*, and *P. nigra* accessions were collected by E. Marmillion of Cordoba, Argentina. The Peruvian *Prosopis* were collected by A. Sagastegui of the Universidad Nacional de Trujillo, Peru. They were selected on the basis of earlier performance. The seeds were sown in 10" x 4" polyethylene bags perforated at the base in February 1991. Of these, more than 200 accessions seedlings of only 106 accessions were obtained in numbers to conduct a replicated field trial. These 106 accessions of five *Prosopis* species were out-planted in the field during July 1991. These included: *P. nigra* (12), *P. flexuosa* (23), *P. alba* (30), *P. chilensis* (19) and *Prosopis* spp.-Peruvian (22). One accession of local *P. juliflora* was taken as a control.

To establish the experiment on the field, a block design with four replicates was employed. Each replicate consisted of a row of five trees with a spacing of 4.0 x 2.5 m. Seedlings were planted in pits of 45 x 45 x 45 cm size. After planting, each seedling was irrigated with 10 liters of water at monthly intervals during first year of establishment. Percentage survival, height increment, and collar diameter was recorded at the beginning of winter season, i.e., at the end of growing season each year up to 1994 (in the month of December). The diameter at 30 cm above the ground of the single largest stem was taken to be the collar diameter. For computation of biomass from multistemmed trees, all stems originating below 30 cm in height were measured. The biomass of individual stems was estimated from basal diameter measurements using the regression equation described below. The biomass of all these stems were summed to obtain biomass per tree.. The biomass was estimated in the third year using the prediction equation (Felker et al.,1989):

$$\log_{10} \text{Dry Weight (kg)} = 2.1905\,[\log_{10} \text{stem diameter (cm)}] - 0.9811$$

after verifying it by selective destructive sampling. Biomass data were also subjected to Duncan's multiple-range analysis following the procedure as given in Gomez and Gomez (1983). Pod production during the study period was also measured. The pods were subjected to nutritive-value analysis (carbohydrate determinations where conducted according to Yemn and Willis (1954) and protein content was measured by the Kjeldahl technique). Vegetative propagation studies on some of these introduced species were also conducted.

Results and Discussion

Field out-planting and survival

Nursery-raised seedlings of 106 accessions of procured exotic *Prosopis* species and one accession of local *P . juliflora* (total 107) were out-planted in the field after the first effective monsoon rain, i.e., in July 1991. Species survival after five months was maximum (95%) in case of *P. nigra*, followed by *P. juliflora* (91%). The species varied from 87% to 88% survival.

The percentage survival was again recorded in March 1992 (8 months after initial out-planting).The survival among the species ranged from 74% to 90%, maximum being for *P. nigra* and minimum for *P. flexuosa*.

Within the species, great variation in survival percentage was noticed for different accessions. Accessions 158, 161, and 219 of *P. nigra*, and accession 144 of *P. alba* had 100% survival. The greatest survival in the other species were 94% for accessions 51 and 195 of *P. flexuosa*, and 94% for accession 30 of *P. chilensis*. Accession 421 of the Peruvian species had maximum survival for this group. Early results indicated that although all the introduced species/accessions were fairly adaptable to environmental conditions of the Indian arid tract, *P. nigra* had better survival than the other species.

General growth performance of different Prosopis species

A wide range of variability for plant height and collar diameter was found among species and in different accessions of same species. Only few accessions within species have shown consistently better performance across all four years.

Among species, the best performance for plant was noticed for *Prosopis* spp.-Peruvian(276 cm / plant) followed by *P . alba* (251 cm / plant) and *P. chilensis* (238 cm / plant) (Table.1). In contrast, for growth in collar diameter, *P. alba* (4.13 cm / plant) was found best, followed by *Prosopis* spp.-Peruvian (3.80 cm / plant) and *P. chilensis* (3.55 cm / plant).The mean annual increment (MAI) for collar diameter was maximum in *P . alba* (1.09 cm / tree) followed *Prosopis* spp. - Peruvian and *P. chilensis*. *P. nigra* had the lowest MAI among all the species.

In general, the coefficient of variation for collar diameter was greater than for plant height in all the *Prosopis* species under study. It was also observed that within accessions of same species, there was a great deal of variation in height and collar diameter. The variability for any character is determined to a great extent by the natural and human selection sieves through which population had passed during its phylogenetic history (Swaminathan, 1969).

The *P. nigra* , accessions were not significantly different from each other for plant height for all four years. In contrast, they were significantly different for collar diameter in first two years. Different accessions showed variable growth pattern and accession 219 from San Javier, north of Cordoba, exhibited comparatively better performance(over means i.e., means of all the accessions)across all the four years for both plant height and collar diameter (Table 2). The maximum plant height was recorded in accession 222 from Guemes in Salta Province, accession 119 from Villa Angela in Chaco Province 179 and 219 (each having 218 cm / plant), while maximum collar diameter was found in accession 179 (3.63 cm / plant). While accession 219 had a smaller collar diameter than 179, it had nearly twice the biomass of 179.

The collar diameter was measured from the single largest stem at 30 cm height while the biomass was computed by summing all the stems below 30 cm in height. Because accession 179 had more and larger stems, it had the greatest biomass. The parent trees for these accessions were located at the points of a triangle, each more than 500 km distant from the other. Thus, there was no apparent good geographical source for *P. nigra*.

The *P. flexuosa*, accessions were significantly different for plant height in the second and third year. Collar diameter was not significantly different among the accessions for any of the years. Accessions 51 (La Puntilla, Catamarca), 64 (Anilaco, Catamarca), 181 (Catamarca)and 197 (from Valle Calcha in Salta Province) have shown consistently better performance across all four years (Table 3). Plant height and collar diameter maximum in accession 64 (plant height 329 cm / plant; collar diameter 4.87 cm / plant) followed by accession 52 (plant height 322 cm / plant; collar diameter 4.80 cm / plant).

The *P. chilensis* , accessions were significantly different for plant height in years 1, 3, and 4 (Table 4). For collar diameter, they were significantly different only in the fourth year. *P. chilensis* accessions 30, 85, 100, 105, 108 and 118 had consistently better performance for all four years (Table 4). The maximum plant height (305 cm / plant) was recorded in accession 108, followed by accession 105 (297 cm / plant). The maximum collar diameter was in accession 30 (5.03 cm / plant),followed by accession 105 (4.86 cm / plant). Accessions 108, 105, and 30 were from Catamarca Province.

In *P. alba* , the accessions were significantly different for plant height in all four years (Table 5). However, for diameter they did not show any significant differences. Accessions 28, 65, 78, 120, 147, and 151 performed consistently better for all four years (Table 5). Plant height was maximum in accession 67 (386 cm / plant), followed by accession 73 (339 cm / plant), both from La Rioja Province, while collar diameter was maximum in accession 78 (5.55 cm / plant), a special tree whose seed was supplied by Ula Karlin, closely followed by accession 73 (5.31 cm / plant).

In *Prosopis* spp. - Peruvian, the accessions were significantly different in the first two years for both plant height and collar diameter. Accessions 418, 420, and 424 had consistently good growth rates across all four years (Table 6). Plant height was maximum in accession 442 (387 cm / plant), followed by accession 424 (373 cm / plant). The collar diameter was maximum in accession 424 (6.05 cm / plant), followed by accession 442 (5.35 cm / plant). Accessions 418 and 420 were collected in the Procedencia El Nino and Procedencia Porota of Departmento La Libertad of the province of Trujillo. Accession 424 was collected in Procedencia Algorrobal (Distro San Benito) Departmento Cajamarca of Province Contumaza. Accession 442 was collected in Procedencia Huancaco (Viru). Departmento La Libertad in Province of Trujillo.

It is significant that the Argentine trees with the greatest height and collar diameter originated from the most arid (western) provinces of La Rioja, Catamarca, and Salta.

Provenance trials conducted on native *P. cineraria* by Kackar (1988) in Indian arid tracts found similar trends in growth behaviour of provenances collected from different locations. Jindal et al. (1991) also reported similar genetic variation in a progeny trial of Tecomella undulata , an important arid-zone timber species of India.

Fuelwood production

The fuel production from all 107 accessions of all the *Prosopis* spp. under study was estimated approximately at four year's age.

It is important to recognize that substantial differences in ranking of biomass and collar diameter are attributable to the fact that the collar diameter is the diameter of the single largest stem at 30 cm height, while the biomass is the sum of all the branches. Thus multistemmed trees had greater biomass than single-stemmed trees of the same collar diameter. The mean biomass production for the species (across the accessions) was greatest in *P. alba* (4.34 kg / individual) (Table 5) followed closely by *P. chilensis* (4.11 kg / individual) (Table 6). Minimum biomass occurred (1.90 kg / individual) in *P. nigra* . In the case of local *P. juliflora* (control species) the biomass accumulation during the study period was 1.47 kg / plant. Although *Prosopis* spp.-Peruvian, attained the maximum height during this period, its mean biomass production as a group ranked third, primarily due to straight-bole characteristic of the species. Only very few branches originated from the base or from the lower part of tree trunk of the Peruvian species accessions. The straight-bole characteristic of the Peruvian species may be of greater economic significance than use as fuel because it can be used in high-value timber applications.

The production of fuelwood within the different accession of same species was also assessed. The early results revealed considerable variation in fuelwood production among different accessions of the same species.

In *P. nigra*, accession 219 of this species gave maximum (3.01 kg / individual) average dry fuelwood per plant (Table 2). The minimum (0.99 kg / individual) fuelwood production was recorded in accession 42. The multiple-range analysis of fuelwood production data showed that accessions 168, 165, and 159 belonged to the same group, while accessions 158, 43, and 167 belonged in another distinctive group. In the rest of the accessions, no clear trends were observed, rather, they exhibited overlapping.

There was significant variation in dry fuelwood production among different accessions of *P. flexuosa.* The average wood production was maximum im accession 197 (3.67 kg/individual) and minimum in accession 183 (0.73 kg/individual) (Table 3). The multiple-range analysis of fuelwood production data of different accessions exhibited presence of three distinctive groups. Accessions 198, 183, 119, 194, 103, 133, 195, 111, 180, 196, 52, and 51 belonged to the same group. Similarly, accessions 186, 192, 112, and 117 belonged to another group. Further, accessions 106, 107, and 110 belonged to a third group showing similarity in fuelwood production. In the remaining accessions, viz., 181, 64, and 197, no clear trend was discernible.

Of the 19 accessions of *P. chilensis*, accession 257 gave average maximum (7.81 kg/individual) fuelwood production, followed closely by accession 30 (7.63 kg/individual) (Table 4). The minimum average fuelwood (1.34 kg/individual)was recorded in the accession 226. The fuelwood production in different accessions varied significantly. The multiple-range analysis of the data revealed the presence of two distinctive groups as far as fuelwood production is concerned. Accessions 100, 228, 108, 29, and 118 belonged to one group, while accessions 95, 99, and 241 belonged to another group. In the remaining accessions, the patterns were not as distinct.

Of the 30 total accessions of *P. alba* introduced, the maximum fuelwood production (7.84 kg/individual) was recorded in accession 146 and minimum (1.84 kg/individual) in accession 74 (Table 5). Statistically, the variation in values was quite significant. On the basis of multiple-range analysis, three distinct groups were identified. Accessions 74, 153, and 152 belonged to the first group, showing similar range biomass production in terms of fuelwood yield. Similarly, accessions 149, 233, 67, 135, 120, and 144 belonged to the second group. In accessions 128, 66, 28, 147, 126, 71, 151, 65, and 72, the values exhibited more or less similar trends, but these accessions also exhibited overlapping of values and, thus, it roughly forms a fourth distinctive homogeneous group. In the remaining accessions, trends were not clear.

In the different accessions of *Prosopis* spp.-Peruvian, the fuelwood yield ranged between 8.77 kg/individual (accession 424) to 1.17 kg/individual (accession 432) (Table 6). On the basis of multiple-range analysis, three groups can be identified. While accessions 420, 431, 440, and 439 belonged to the first homogeneous group, accessions 442, 435, and 438 formed the second homogeneous group. Accessions 430, 446, 428, 434, 441, and 443 also form more or less one homogeneous group, but the trend was not as distinctive as in the case of earlier two groups.

Pod production and their nutritive value

Pod production of the introduced species/accessions was initiated in the fourth year after initial field transplantation. In *Prosopis* spp.-Peruvian, 6 of 22 accessions exhibited flowering and produced pods. Only one accession of each *P. chilensis* (105), *P. flexuosa* (69), *P. alba* (70), and *P. nigra* (158) produced pods. The maximum quantity of pods occurred in accession 423 of *Prosopis* spp.-Peruvian (2.059 kg/plant). The minimum was produced by *P. chilensis* (7.8 g/plant).

The maximum carbohydrate content (40%) was found in the pulp of *P. nigra*, followed by *P. alba* (38%), and *P. chilensis* (37.5%). While the average carbohydrate content of *Prosopis* spp.-Peruvian was 30%, its variability between accessions was very high, ranging from 18% to 37%. The crude protein content in *Prosopis* spp.-Peruvian was also quite variable, ranging from 5.11% to 11.55%, with an overall average of 8.44%. The protein content of *P. alba*, *P. chilensis*, and *P. nigra* pods was 8.8%, 4.48%, and 5.99%, respectively. Further investigations in this regard are in progress.

Vegetative propagation

Raising seed orchards through seeds leads to heterogeneity in the population due to out crossing in the species. In order to propagate good germ plasm both for thornlessness and high nutritive value, the cleft grafting technique was followed (Wojtusik et al., 1993).

Nonthorny grafts from superior *Prosopis* spp.-Peruvian were grafted on the local thorny *P. juliflora*, both on one-year-old field-transplanted saplings and five-month-old nursery seedings. About 70% success was obtained on both field-outplanted saplings, as well as in nursery seedlings. The nursery-raised grafted seedlings were supplied to different institutions in India to evaluate their performance in different agroecological zones. Moreover, *P. chilensis*, *P. alba*, and *P. nigra* have also been grafted successfully on local *P. juliflora*. The success rate with these species of these species was about 50%. In addition to grafting, all five exotic *Prosopis* species have also been propagated using stem cuttings in the mist chamber.

Conclusions

The species of genus *Prosopis* have the capacity for thriving on poor fertility soils and in hot dry climates (Vasquez et al., 1985). Currently, between 36% and 43% of the earth's area is rated as desertic. According to modern historians, the origin of civilization in the Nile, Indus, and Tigris- Euphrates valleys could be linked to the increasing aridity of the surrounding areas, which forced the population of steppes and savannas to move to these valleys where they had to irrigate and cultivate the land (Habit, 1985). Now, vast areas of the world are threatened by desertification. According to conservative estimates, arid zones and their advance affect approximately 384 million people directly or indirectly. This population accounts for 12% of the world's total population, most of which belongs to the Third World (Duhart, 1985).

In India, more than 0.3 million square kilometers are categorised as hot arid and the western part of Rajasthan state, commonly known as the Thar Desert, accounts for 61% of the total arid zone of the country. Beside the native *Prosopis* species, *P. cineraria*, vast stretches of tropical arid and semiarid parts of the country have been covered by *P. juliflora*.

The present study has shown that all the introduced *Prosopis* species are highly adaptable to environmental conditions of the Indian arid tract. The study of Sharma (1995) further substantiated this fact that, although all the newly introduced *Prosopis* species in 1991 have performed well, but among them, *Prosopis* spp.-Peruvian has performed much better. Lee et al., (1992) also reported the excellent performance of this species from Haiti. Harris et al. (This volume) have also found the Peruvian *Prosopis* to have superior biomass and survival. Thus, the Peruvian genetic stock is near the top in evaluations in three distinctly different environments: Haiti, Cape Verde, and the interior deserts of India.

Early results of the present study indicated that the introduced species of multipurpose utility of genus *Prosopis* (mainly of Latin American origin) has tremendous capacity for biomass and pod production in inhospitable soil and climatic conditions of the Indian arid tract. All these features make them highly suitable candidates for plantation and agroforestry activities in arid and semiarid tracts of the country.

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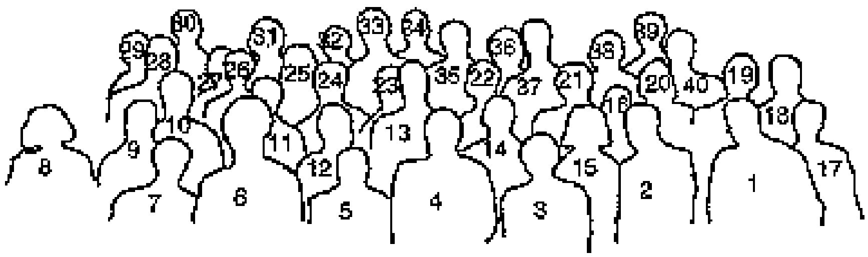
Table 1. Average Performance of *Prosopis* Species in Different Years

Species	Plant Height (cm)				Collar Diameter (cm)			
	1991	1992	1993	1994	1991	1992	1993	1994
P. nigra	39	79	134	188	0.60	1.17	1.79	2.45
P. chilensis	53	100	183	238	0.92	1.79	2.86	3.55
P. flexuosa	58	100	169	229	0.69	1.23	2.22	3.20
P. alba	47	90	189	251	0.92	1.78	3.14	4.13
Prosopis spp.-Peruvian	89	159	210	276	0.88	2.16	3.02	3.80
P. juliflora (check)	40	50	167	204	0.40	0.88	2.82	3.34

Table 2. Mean Values of Plant Height and Collar Diameter of 12 Accessions of *P. nigra* at Four Growth Stages

US No.	Accession No.	Plant Height (cm)				Collar Diameter (cm)				Biomass (kg)
		1-year	2-year	3-year	4-year	1-year	2-year	3-year	4-year	
42	EC 308027	32	60	99	142	0.61	0.94	1.62	2.14	0.99
43	EC 308028	45	90	121	182	0.71	1.27	1.26	1.58	1.85
44	EC 308029	39	73	147	196	0.56	0.84	1.51	2.34	1.03
158	EC 308034	38	76	114	173	0.47	0.92	1.45	2.25	1.65
159	EC 308035	48	86	126	175	0.71	1.64	1.56	2.19	1.19
161	EC 308037	32	86	152	187	0.63	1.17	2.26	2.67	2.47
165	EC 308041	45	79	98	153	0.53	0.86	0.96	1.66	1.30
167	EC 308043	34	79	140	213	0.58	1.20	2.02	2.39	1.91
168	EC 308044	32	75	109	176	0.53	0.91	1.54	1.99	1.67
179	EC 308045	39	73	171	218	0.60	1.21	2.66	3.63	1.98
219	EC 308046	43	90	164	218	0.67	1.95	2.33	3.08	3.01
222	EC 308047	38	83	166	218	0.55	1.14	2.33	3.45	2.55
	Mean	39	79	134	188	0.60	1.17	1.79	2.45	1.90
	±SE	6.88	9.41	25.94	34.21	0.11	0.22	0.45	0.67	0.63
	Range	32-48	60-90	98-171	142-228	0.47-0.71	0.91-1.95	0.96-2.66	1.58-3.63	0.99-4.16
	CV %	25.1	16.8	27.4	25.7	26.2	26.9	35.2	3.86	46.88
	CD 5%	-	-	-	-	0.45	0.92	-	-	1.28
	CD 1%	-	-	-	-	0.61	-	-	-	1.73



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The Role of Prosopis in Reclaiming High-pH Soils and in Meeting Firewood and Forage Needs of Small Farmers

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Introduction

With an annual growth rate of about 2.3%, the human population in India will cross the one billion mark by 2000 AD, leading to a concomitant increase in demand for food, fuel, and timber. Similarly, the livestock population has increased from 292 million in 1951 to 416 million in 1982 and is estimated to exceed 500 million by the end of the century. Projected fodder requirement is estimated as 850 million tonnes in 2000 AD as against 573 million tonnes in 1980 (Singh et al., 1993). On the other hand, forest cover declined from 22% in 1952 to 14.1% in 1982 as against the 33% recommended as the minimum for ecological security. Recent surveys have indicated that good forests with more than 30% cover are hardly 11% of the geographical area (Yadav, 1990). Continued deforestation at an alarming rate has created a wide gap between the supply and demand of fuelwood, industrial wood, timber, and other forest products. Availability of fuelwood in India in 1980 was 17 million m^3 as against the requirement of 184 million m^3 (Yadav, 1990). The demand is expected to increase further to 225 million m^3 by 2000 AD. This gap in fuelwood supply is being filled with alternative energy sources, such as animal dung and agricultural wastes. It has been estimated that about 73 million tonnes of animal dung and 41 million tonnes of agricultural wastes out of the respective total annual production of 324 and 204 million tonnes are burnt as substitutes for firewood (Singh et al., 1993). The amount of nutrients thus lost exceeds the amount of fertilizers used in the country. This calls for extensive plantation drives on wastelands constituted to cover nearly 93.6 million ha (SPWD, 1984). Of this, 8.11 million ha are salt affected (Singh, 1992).

Large tracts of salt-affected soils in India are confined to villages as community lands (Figure 1), as public properties near cities, along the railway tracks and roads, and government land reserved for specific purposes. Today, these marginal lands contribute least to the national output and present a picture of desolation. There is a need to revegetate these wastelands and prevent their further degradation. Establishment of permanent vegetative cover of suitable trees and grasses is an option of great promise for the use of such lands in view of the growing demand for fuelwood and fodder as well as environmental considerations.

Workers at the Central Soil Salinity Research Institute at Karnal have found that trees of the genus *Prosopis* (mesquite) can be used for afforestation of salt lands in the country (Singh and Singh, 1993). The tree is highly salt tolerant and an excellent biomass producer. Standard technology has been developed for its cultivation in salt lands. This paper deals with various aspects of mesquite cultivation, such as tolerance to high pH, cultural practices, reclaiming effects, compatibility with grasses and agricultural crops, and socioeconomic impacts on rural inhabitants.

Nature of Salt-Affected Soils

Soils containing soluble salts in the root zone in quantities large enough to adversely affect plant growth are called salt affected. Such soils differ from normal soils in soil reaction (pH) and soluble-salt content. Visually, they are recognized by the presence of a white or greyish-white efflorescence of salts on the surface during dry months. Commonly, they are devoid of good natural vegetation. Being poorly drained, water stagnates over their surface for long periods. Indicator plants of these soils include trees, bushes, and grasses, such as *Prosopis juliflora*, *Acacia nilotica*, *Capparis aphylla*, *Salvadora persica*, *Butea monosperma*, *Sporobolus* spp., *Desmostachya bipinnata*, *Suaeda maritima*, *Kochea indica*, *Leptochloa fusca*, *Cynodon dactylon*, and *Bracharia mutica*.

Estimates of the area of salt-affected soils in India vary a great deal owing to variations in the mode and source of information. According to recent estimates, there are about 8.11 million ha of salt-affected soils in India (Singh, 1992). At the global level, 952 million ha of land are affected by salt problems (Szabolcs, 1977). Broadly, these are classified into groups of alkali or saline soils. Soluble salts in alkali soils comprise measurable amounts of carbonate and bicarbonate of sodium. The exchangeable sodium percentage (ESP) of these soils often exceeds 15%. In barren alkali soils, the exchange complex may be largely occupied by sodium ions. The presence of a large amount of exchangeable Na disperses the soils, resulting in their poor physical condition. The presence of sodium carbonate and hydrolysis of exchangeable Na increases the soil pH, which, in highly deteriorated soils, may be as high as 10.5. In the literature, alkali soils are also referred to as sodic soils. In local parlance, these are known as Usar in Uttar Pradesh and Kallar in the states of Punjab and Haryana. The factors inhibiting tree growth in alkali soils are:

- High pH throughout the profile causes problems of nutrient availability.
- Alkali soils exhibit highly deteriorated soil structure. Poor water-transmission characteristics lead to water stagnation and reduced aeration of roots.
- Presence of a hard $CaCO_3$ layer at about one-meter depth in the profile acts as a physical barrier for vertical penetration of tree roots. The location of this layer in the profile and its thickness varies in different soils. Often compact subsurface horizons also restrict root penetration in alkali soils.

The saline soils contain excess neutral soluble salts, generally, chlorides and sulphates of sodium, calcium, and magnesium. Saline soils rich in divalent cations have low ESP and pH and good physical condition. Owing to the flocculating effect of neutral salts, saline soils are very permeable and can be reclaimed by leaching with good-quality water, provided the groundwater table is deep. Factors inhibiting tree growth in saline soils include:

- Salinity-induced high osmotic pressure of soil water
- Toxic effect of specific ions
- Nutritional disorders due to competitive uptake of ions
- High water table/water logging associated with such soils
- Groundwater in saline areas is often of poor quality, while fresh water is scarce.

Prosopis Distribution in India

The most common mesquite species found in India are: *Prosopis juliflora* and *Prosopis cineraria*. *Prosopis cineraria* is believed to be native to India and *P. juliflora* has been introduced from the

southwestern United States, Mexico, and Venezuela (Muthana and Arora, 1983). *P. juliflora* **was introduced into India in 1877 (Sind) (Muthana and Arora, 1983) and, later, into many parts of India, such as Hageri, Bellary, Punjab, Agra, and Delhi. In 1913, it was introduced by the then ruler of Jodhpur state into many arid and semiarid parts of Rajasthan to stabilize sand dunes (Muthana and Arora, 1983). The then state government of Rajasthan declared this species a "Royal Plant" in 1940 and directed the public to protect** *P. juliflora* **plants and also encouraged large-scale plantations of this species. It proved to be a highly useful plant for afforestation of the shifting sand dunes, coastal sands, eroded hills, and riverbeds, saline and alkaline terrains, dry and degraded grasslands, and wastelands where rainfall is scanty and erratic. Although it is an introduced species, it is now well adapted to the dry and salty soil environments in India.**

Tolerance to High pH

Prosopis **is moderately tolerant to alkaline conditions. At very high pH (pH >10.0), its growth may be restricted. In such situations, special site preparation techniques and soil amendments might be needed for raising** *Prosopis* **plantations.**

Yadav and Singh (1970) studied the performance of some tree species in a highly alkali soil (pH 10.3) and reported that all species failed when the soil pH exceeded 10.0 and the soluble salt content in the surface soil was 3.42%. According to them, the safe limits for *Prosopis juliflora* **were 0.54% soluble salts and a pH below 9.5, although this species could tolerate soluble-salt content up to 1% and pH up to 10.0. Studies conducted by Singh et al. (1990) on sodicity tolerance limits of** *Prosopis juliflora* **showed that all** *Prosopis* **saplings died within 3 years of planting at soil pH 10.1 to 10.6 and electrical conductivity (EC) 1.66 to 5.43 dS/m. The organic carbon and available N status of the soil ranged from 0.08% to 0.12% and 48 to 66 kg/ha, respectively (Table 1). They further observed that in soils of pH 9.01 to 9.59 and at a low EC level (0.6 to 1.2 dS/m),** *Prosopis juliflora* **grew satisfactorily without the application of soil amendments or any special site-preparation technique.**

Table 1. Alkali Tolerance of *Prosopis juliflora*

Height Class (m)	Observation Sites	Mean girth (cm)	Average pH*	Average EC* (dS/m)	Organic carbon (%)	Available N (kg/ha)
No growth	16	0.0	10.4	2.84	0.13	56.9
0 - 2	22	6.1	10.2	2.12	0.13	68.0
2 - 4	44	13.8	10.0	1.16	0.21	87.4
4 - 6	19	26.3	9.7	1.14	0.24	114.3
6 - 8	11	38.0	9.3	0.89	0.38	156.8

*** Measured in 1:2, soil:water**

Our recent greenhouse studies showed that the nearly thornless and better tree form, *Prosopis alba* **clone B_2V_{50}, is as tolerant to high-pH soil as** *Prosopis juliflora* **(Table 2). To study the effect of soil pH on growth performance and biomass production of** *P. juliflora* **and** *P. alba* **in comparison to other salt-tolerant woody species, a microplot study was conducted for 28 months at Karnal (Singh et al., 1996a). The tree species planted were:** *Dalbergia sissoo*, *Terminalia arjuna*, *Pongamia pinnata*, *Acacia nilotica*, *Prosopis juliflora* **and** *Prosopis alba*. **Based upon a 28-month study, species were arranged according to their growth response and biomass production in a soil of pH 10.0 in the order:** *Prosopis juliflora* > *P. alba* > *Acacia nilotica* > *Terminalia arjuna* > *Pongamia pinnata* > *Dalbergia sissoo*. **Data in Table 3 clearly show that if soil pH is more than 9.7, the species choices should be limited to** *Prosopis juliflora*, *Acacia nilotica*, **and** *Prosopis alba*.

Table 2. Effect of Soil pH on Survival, Height, and DSH Of *Prosopis* Species Planted in Pots 6 Months after Planting

Soil pH	*P. alba*			*P. juliflora*			*P. glandulosa*			*P. velutina*		
	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)
10.0	100	83.0	0.96	100	94.0	0.70	100	94.7	0.75	100	100.7	0.87
9.4	100	90.7	1.15	100	92.0	0.79	100	96.7	0.85	100	155.3	1.02
8.7	100	114.7	1.17	100	116.7	1.13	100	141.0	1.29	100	173.0	1.31
8.1	100	129.0	1.22	100	126.3	1.17	100	129.7	1.23	100	172.7	1.53

Table 3. Effect of Soil pH on Growth and Biomass Production Of Selected Tree Species 28 Months after Planting

Tree Species	pH Levels											
	8.7			9.3			9.7			10.0		
	Height (m)	DSH (cm)	Biomass (kg)	Height (m)	DSH (cm)	Biomass (kg)	Height (m)	DSH (cm)	Biomass (kg)	Height (m)	DSH (cm)	Biomass (kg)
Prosopis alba	3.7	4.3	9.5	3.3	3.8	2.9	3.4	4.1	3.2	3.4	3.9	2.6
P. juliflora	4.1	3.4	3.9	6.2	6.5	15.9	5.4	6.0	13.9	6.1	7.0	28.10
Terminalia arjuna	4.7	7.0	10.1	3.7	6.8	9.6	3.8	6.9	8.3	3.1	4.7	1.65
Dalbergia sissoo	5.1	7.2	17.1	3.5	5.6	5.4	2.8	4.0	3.0	1.9	2.6	0.39
Pongamia pinnata	5.4	4.2	4.9	3.2	4.1	2.6	2.3	3.3	1.2	1.9	2.9	0.93
Acacia nilotica	3.0	6.2	26.1	5.3	6.2	36.0	4.4	5.7	20.6	4.8	5.7	8.60

DSH = diameter at stump height, 5 cm above ground

Salinity Tolerance

Prosopis can grow in a soil salinity regime equivalent to seawater salinity (Figure 2). Workers at Texas A&M University-Kingsville found that all species of *Prosopis* can tolerate 6,000 mg/l salinity with no reduction in growth (Felker et al., 1981; Rhodes and Felker, 1988). *Prosopis velutina* can tolerate 12,000 mg/l salinity level. *Prosopis articulata*, *Prosopis pallida*, and *P. tamarugo* can be grown successfully in salinity levels between 18,000 to 36,000 mg/1 NaCl. Satisfactory growth of *Prosopis juliflora* can be expected in the soils having electrical conductivity (EC_e) of 27 dS/m. All species that grow in high salinity can fix nitrogen, thus have potential as nitrogen-fixing halophytes. Firmin (1968) reviewed the works on salt tolerance of trees and shrubs in areas with high saline water table in the root zone and reported woody species of the genus *Atriplex*, *Prosopis*, *Tamarix*, *Zizyphus*, *Casuarina*, and *Acacia* as most tolerant to underground saline-water situations.

Cultural Practices for Raising *Prosopis* Plantations in High-pH Soils

Planting technique

To facilitate rooting through the hard subsurface layers, an augerhole technique has been developed for growing *Prosopis* in high-pH soils. This technique involves digging pits (20 to 25 cm in diameter and 100 to 130 cm deep) with tractor-mounted diggers (Figure 3). These pits are refilled with a mixture of original alkali soil, 3 kg of gypsum, and 8 kg of farmyard manure (FYM). About 3-month-old *Prosopis* saplings are planted in these pits. About 20 grams of zinc sulphate and 10 grams of benzene hexachloride (B.H.C.) powder is also mixed into the filling mixture. After planting, four irrigations are given at an interval of 4 to 5 days during the first month. Planting is generally done from July to September. This planting technique has been adopted on a large scale by the State Forest Departments, voluntary organisations, and by others interested in revegetation of alkali lands. This

technique results in mesquite survival rates of 90% to 100% on highly alkaline soils where nothing could be produced earlier. In a long-term field trial (Singh, 1995c), *Prosopis* **growth and biomass production in 6 years was significantly more when planted by the augerhole technique compared to the traditional pit-and-trench planting methods (Table 4).**

Table 4. Response of 8-year-old *Prosopis juliflora*
to Planting Techniques in an Alkali Soil

Planting Technique	Height (m)	DSH (cm)	DBH (cm)	Biomass After 6 Years		
				Lopped (t/ha)	Harvested (t/ha)	Total (t/ha)
Trench (30-cm wide, 30-cm deep, dug across the plots)	8.2	10.0	7.8	4.7	29.6	34.3
Pit (30-cm wide, 30-cm long, and 30-cm deep)	8.4	10.9	8.4	6.0	30.0	36.0
Augerhole (15-cm diameter, 90-cm deep)	9.3	12.0	9.7	6.4	36.2	42.6
LSD (0.05)	NS	1.6	1.4	-	-	-

DSH = diameter at stump height, 5 cm above ground level
DBH = diameter at breast height

The presence of a dense clay or calcium carbonate layer at varying depths in alkali soils inhibits deeper rooting in mesquite. This has been a major cause of either a complete failure or meager growth of the plantation. Therefore, in this experiment, root growth of *Prosopis juliflora* **was studied in relation to different modes of site preparation and amendments used (Figure 4). The mesquite was planted in pits of 30 cm^3; trenches of 30-cm width and 30-cm depth dug across the plots; augerholes of 15-cm diameter and 90-cm depth and 15-cm diameter and 15-cm depth after mixing gypsum in the surface 10 cm of soil in the whole plot area. The root system of mesquite was exposed after 2 years. It was found that mesquite roots were mainly confined to the soil mass amendment mixture in the augerhole. Roots of mesquite that was planted in augerholes and grew beyond the hardpan were close to the water table within 2 years. However, root growth horizontally was less. In trench planting, the majority of roots remained in the amendment-treated trench soil and followed a horizontal path, instead of growing vertically. No root penetrated beyond 30-cm depth. Such a shallow root system can expose the plant to vagaries of strong winds and moisture stress. In the pit-planting method, the whole root system was confined to the pit soil and only one or two roots reached the hardpan short of penetrating it. When gypsum was mixed in the whole surface soil, as is done in growing crops, mesquite roots were spread uniformly in the whole amendment-treated surface soil. Root extension downward was lacking. These root studies showed that site preparation in the vertical direction is more important than the horizontal direction when planting mesquite in alkali soils. The augerhole method allows mesquite roots to circumvent the hard subsurface layers and, as roots reach the lower less deteriorated and coarser soil depths, they proliferate there and boost top growth.**

Amendment Use

The amount of amendment is determined by the volume of soil extracted from the augerhole and the chemical status of the soil. Gypsum, pyrites, farmyard manure, molasses, pressmud (cane filter cake), sulphuric acid, and even rice husk, have been mixed with the alkali soil before refilling the pits or holes. However, maximum survival, height and girth growth, and biomass in *Prosopis* **was**

obtained (Singh, 1995b) when 3 kg gypsum and 8 kg of farmyard manure per augerhole were used (Table 5).

The efficiency of surface application of gypsum for raising *Prosopis* on the pattern of agricultural crops was also studied by Singh et al. (1989a) using 0, 7.5, and 15 t/ha of gypsum mixed in the top 8 to 10 cm of soil. After 2 years, the mortality of *Prosopis* was 48% in the control, 11% with 7.5 t/ha of gypsum, and only 8% with 15 t/ha of gypsum. In one year, the total biomass was 6 to 9 times more under gypsum treatments, compared to the control.

Table 5. Response of 8-Year-Old *Prosopis juliflora* to Amendments in an Alkali Soil

Amendments	Survival (%)	Height (m)	DSH (cm)	DBH (cm)	Biomass After 6 Years (t/ha)
None	44	3.0	2.8	1.7	3.1
Gypsum	75	8.2	10.0	7.8	34.3
Gypsum + Rice husk	85	10.2	13.0	11.2	49.5
Gypsum + FYM	85	10.6	13.8	12.0	52.3
LSD (0.05)	17	2.4	1.6	1.4	

FYM = farmyard manure

Irrigation

Because the bulk of alkali soils in India are confined to arid and semiarid areas, timely irrigation during the dry part of the year is crucial in the initial years when trees are grown on alkali soils. In experiments conducted from 1985 to 1988, Singh et al. (1989b) found that, during the first two years, growth of *Prosopis* was far better when irrigated compared to the plantation which depended on rainfall alone. Within 2 years of planting, 36% of rain-fed *Prosopis* died, while the mortality was only 9% among the irrigated plants. The water use efficiency was also higher under irrigated conditions. Irrigation brought very little change in the chemical composition of different plant parts but significantly decreased soil sodicity.

Spacing and Pruning

The nature and growth habit of tree species and the purpose for which a plantation is raised determine the spacing at the time of planting. Closer plantings cover the risk of mortality so common in salt-affected soils. In a soil of pH 10.4, maximum biomass of mesquite was obtained with 2x2-m planting (Singh et al., 1989c) (Table 6).

Table 6. Biomass Production by *Prosopis* and *Leptochloa* Grass Under Different Spacings in 6 Years on an Alkali Soil

Spacing (m)	Biomass			
	Prosopis			*Leptochloa* Grass (t/ha)
	Lopped (t/ha)	Harvested (t/ha)	Total (t/ha)	
2x2	49.1	112.2	161.3	55.6

3x3	31.6	55.2	86.8	68.7
4x4	25.0	36.1	61.1	80.9

The maximum *Leptochloa* grass yield was obtained at 4x4-m spacing (Table 6). Grass yield from the third year onward was also significantly higher when the *Prosopis* were lopped for fuel. Lopping is a necessary practice in *Prosopis* plantations. At the first lopping, all side branches of mesquite should be removed up to 1 m of stem height, and in the second 2 m, the stem above the ground may be pruned of side branches. As a rule of thumb, about one-third of the stem above ground level should be kept branch free. Mesquite should be lopped only when it is in the dormant stage. In another field trial in a soil of pH 10.0 and exchangeable sodium percentage (ESP) of 90%, Singh et al. (1990) found that high-density plantations (1x1-m and 2x1-m planting geometry) did not affect height and girth of *Prosopis* during the establishment stage. But the oven-dried biomass of 12-month-old plants was almost double with 1x1-m spacing compared with a spacing of 2x1 m. Improvement in soil properties was comparatively more with 1x1-m spacing than with 2x1-m spacing, probably owing to more litter fall and root mass favouring soil improvement. Thirty-three months after planting, 50% of the plants were harvested from the high-density plantation (10,000 plants/ha). The harvested aerial woody biomass shows that firewood needs of rural people could be supplemented through periodic harvests from such high-density plantations. Because of its high coppicing ability, mesquite recovers quickly after harvesting above-ground biomass.

Mesquite-Based Silvipastural Model

Compatibility with crops

A silvipastural model (Figure 5) comprising mesquite and *Leptochloa* grass has been found most promising in terms of firewood and forage production and soil amelioration (Singh, 1995a). *Leptochloa* in association with mesquite planted at a 5x3-m spacing produced 46.5 t/ha of green fodder in 15 cuttings over a 50-month period without fertilizer or soil amendments (Table 7). Mesquite produced about 80 t/ha of air-dried wood in 6 years. This silvipastural system improved the soil to such an extent (Table 8) that it was possible to plough under the *Leptochloa* grass after 4½ years and grow less tolerant, but more palatable, fodder species like *Trifolium resupinatum*, *Trifolium alexandrinum* (Figure 6), and *Melilotus parviflora* along with mesquite trees. The green-forage yield of these inter-crops was comparable to their yields in normal soils. The highest yield of 23.1 t/ha was obtained in *Trifolium resupinatum* and *Trifolium alexandrinum* (Shaftal), followed by 21.3 t/ha in *Trifolium alexandrinum* (Berseem).

Table 7. Green-Forage Yield of *Leptochloa* Grass Grown in Association with *Prosopis juliflora*

Planting Year	Cuttings/Year	Cutting Month	Fresh Forage Yield
First	1	November	2.2
Second	4	May to October	13.1
Third	3	July to September	10.1
Fourth	3	May to October	7.6
Fifth	4	July to October	13.5
Total	15	---	46.5

Table 8. Effect of *Prosopis juliflora* - *Leptochloa fusca* Silvipastural System on Some Properties of the Surface 15 cm of Alkali Soil

Soil Property	Original	After 6 Years	
		Prosopis	*Prosopis* + Grass
pH	10.30	9.3	8.90
EC (dS/m)	2.20	0.46	0.36
Organic carbon (%)	0.18	0.43	0.58
Available N (kg/ha)	79.00	133.00	165.00
Available P (kg/ha)	35.00	36.00	30.00
Available K (kg/ha)	543.00	555.00	486.00

Raising *Prosopis* in Saline Soils

Unlike alkali soils, there is no need to apply amendments and make deep augerholes for raising mesquite in saline soils. In saline soils, channel planting gives better results than flat-planting and ridge-planting methods. In channel planting, mesquite saplings are planted in a 1-foot-deep channel, the same channel is also used for irrigation. This planting technique ensures a better microedaphic environment for the saplings because most soluble salts are deposited at the higher elevations/ridges with evaporation. Frequent irrigations with good-quality canal water help mitigate adverse salinity effects. Applications of phosphorus and zinc help in accelerating mesquite growth in saline soils.

Frequent irrigations with good-quality water are highly beneficial for raising a plantation in saline soils, as these provide a low-salinity environment to the young roots. When good-quality irrigation water is not available, saline groundwater can also be used in conjunction with available fresh water. Mesquite can be raised with saline water of as high electrical conductivity as 20 dS/m. Mesquite trees also have ample scope for *in situ* disposal of saline effluents/water available from drained saline areas.

Biomass Production

Mesquite planted at 1x1-m and 2x1-m spacings in 1985 under irrigated conditions after applying 15t/ha of gypsum is presented in Table 9. The total biomass of bole, branches, and leaves was 39 kg with 5000 plants/ha and 32.2 kg at 10,000 plants/ha.

Table 9. Performance of *Prosopis juliflora* Under High-Density Energy Plantation on Highly Alkali Soil

Growth Parameters	Planting Density	
	5,000 Trees/ha	10,000 Trees/ha
Height (m)	9.2	10.0
DSH (cm)	9.9	8.7
DBH (cm)	7.6	6.8
Bole Weight (kg/tree)	24.8	21.8

Branches + Leaves Weight (kg/tree)	**14.2**	**11.4**

Growth and biomass production of *Prosopis* **was compared with that of** *Acacia nilotica*, *Casuarina equisetifolia*, **and** *Eucalyptus tereticornis* **in a 10-year-old plantation on a soil whose original pH was 10.4. The mean plant height attained in 10 years was maximum in** *Eucalyptus* **followed by** *Casuarina*, *Prosopis*, **and** *Acacia*. **Girth growth was better in** *Prosopis* **and** *Acacia* **plantations. The mean biomass production in 10 years was in the order**: *Prosopis* > *Acacia* > *Casuarina* > *Eucalyptus* **(Table 10). The per-hectare biomass production in 10 years was 260 tonnes in** *Prosopis*, **215 in** *Acacia*, **188 in** *Casuarina* **and 148 in** *Eucalyptus*.

Table 10.Growth Performance and Biomass Production of 10-Year-Old Mesquite and Other Salt-Tolerant Trees in a Soil of pH 10.4

Growth Parameters	Tree Plantations			
	Prosopis juliflora	*Acacia nilotica*	*Casuarina equisetifolia*	*Eucalyptus tereticornis*
Height (m)	12.9	11.6	14.5	14.9
DSH (cm)	15.9	15.4	15.6	13.6
DBH (cm)	12.5	13.6	12.0	11.0
Bole Weight (kg/tree)	112.6	85.4	84.2	65.6
Branches + Leaves Weight (kg/tree)	43.2	43.8	28.4	23.5

Reclaiming Effect

Prosopis trees are known for their beneficial interaction with the surroundings in which they grow. Soil, which is an important natural resource, is influenced by *Prosopis* in many ways. Establishment of *Prosopis* plantations on salt-affected soils sets in amelioration processes by favourably affecting physical, chemical, and biological properties of the soil. The ameliorative effects are mediated through:

- Litter production and nutrient cycling, addition of organic matter, and rise in humus status of the soil

- Initiation of biological activity in the otherwise almost lifeless mass of salt-affected soils. The biological activity produces CO_2 in the soil, which, in combination with water, mobilizes the insoluble calcium carbonate.

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$$
$$(2Na)\ clay + Ca(HCO_3)_2 \rightarrow Ca\ clay + 2NaHCO_3$$

- Reducing salt deposition in upper layers of the soil profile by cutting down evaporation losses of soil water

- The deep and sturdy root system of *Prosopis* opens up the soil and improves water permeability, facilitating leaching of salts

- Exclusion of large amounts of salts through absorption by *Prosopis*

Prosopis litter falling on the ground adds to the humus content of salt-affected soils. The organic acids from the decomposed litter react with native $CaCO_3$ and release Ca, which exchanges with Na on the exchange complex. Thus, mesquite helps in reclaiming alkali soils. A 4- to 6-year-old stand of *Prosopis juliflora* can yield 5 to 8 t/ha of air-dry leaf litter, which contains about 2.2% nitrogen, 0.2% to 0.4% phosphorus, and 1.5% to 1.9% potassium. Sodium content is generally less than 0.2%. The litter also contains sufficient quantities of micronutrients. The annual turnover of nitrogen, phosphorous, and potassium to the soil would be about 88 to 132 kg nitrogen, 8 to 16 kg phosphorous, and 60 to 76

kg potassium per ha per year. Such nutrient additions through litter-fall will raise the fertility status of salt-affected soils that are otherwise deficient in essential plant nutrients.

Mesquite also helps reclaim salt-affected soils more effectively than other trees, such as *Acacia*, *Eucalyptus*, *Terminalia*, **and** *Albizzia* **of the same age and stocking rate. Singh and Gill (1992) studied long-term effects of mesquite growth on highly alkaline soils. The average pH of the 0- to 120-cm soil profile decreased from 10.2 to 9.1 in** *Eucalyptus*, **to 9.03 in** *Acacia*, **to 8.67 in** *Albizia*, **to 8.15 in** *Terminalia*, **and to 8.01 in** *Prosopis* **during their 20 years of growth. Organic carbon content in the soil increased considerably, with the maximum being under** *Prosopis* **and the least under** *Eucalyptus*. **Similarly, phosphorous and potassium were maximum under** *Prosopis juliflora* **(Table 11).**

Table 11. Ameliorating Effects of Mesquite and Other Tree Plantations on an Alkali Soil

Species	Original		After 20 years	
	pH	Organic carbon (%)	pH	Organic carbon (%)
Eucalyptus tereticornis	10.3	0.12	9.18	0.33
Acacia nilotica	10.3	0.12	9.03	0.12
Albizia lebbek	10.3	0.12	8.67	0.47
Terminalia arjuna	10.3	0.12	8.15	0.58
Prosopis juliflora	10.3	0.12	8.03	0.58

The ameliorating effect on the soil appeared to be in the order: *Prosopis* > *Acacia* > *Terminalia* > *Albizia* > *Eucalyptus*. **To know whether agricultural crops, such as wheat and oats, can be grown in alkali soils reclaimed through** *Prosopis* **and other trees, an experiment was conducted in pots after taking soil from under the canopies of the trees listed above (Singh et al., 1996b). Soil was also taken from the adjacent cropland field where alkali soil was reclaimed through amendments. Ten seeds each of wheat and oats were sown in a randomized manner in each pot, and no fertilizers were used. Mean grain and straw yields of both crops were significantly higher in the soil reclaimed through trees than through the application of gypsum (Table 12) Further, yields of both the crops were highest in the soil taken under the** *Prosopis* **canopies, followed closely in the soil under** *Acacia* **canopies (Figure 7). The yields of both crops were in the order**: *Prosopis* > *Acacia* > *Albizia* > *Terminalia* > **cropland.**

Reclaiming Effects of *Prosopis juliflora* Recorded on Village Community Lands

World Bank funded Social Forestry Project in Haryana, the State Forest Department has raised *Prosopis juliflora* **plantations in a number of villages in abandoned high-pH soils between 1982 and 1990. To study the ameliorating role of these plantations on properties of alkali soils, samples were collected under 8-year-old trees from a nearly 100-ha area in four villages, namely Shera, Sutana, Nain, and Bhalsi of Panipat district. The data related to original pH and organic-carbon status and changes that occurred over 8 years is reported in Table 13.**

These studies clearly indicate that within a growth period of 8 years, mesquite may improve an alkali soil to the extent that traditional agricultural crops can be grown without amendment application. Mesquite also improves water intake capacity of the alkali soil, thereby reducing rain-induced surface runoff, which causes floods downstream.

Table 12. Straw and Grain Yields of Wheat and Oats in an Alkali Soil Reclaimed Through Tree Plantations and Through Gypsum Application

Tree Plantations	Wheat		Oats	
	Grain Yield (g/pot)	Straw Yield (g/pot)	Grain Yield (g/pot)	Straw Yield (g/pot)
Prosopis juliflora	**61.7**	**87.5**	**111.1**	**87.9**
Terminalia arjuna	**44.0**	**38.5**	**62.8**	**45.8**
Eucalyptus tereticornis	**32.3**	**25.3**	**58.5**	**42.7**
Albizia lebbek	**45.3**	**43.5**	**66.9**	**52.8**
Acacia nilotica	**55.7**	**68.8**	**67.5**	**61.6**
Cropland	**13.3**	**15.4**	**26.7**	**24.3**
LSD (0.05)	**2.8**	**2.0**	**9.4**	**7.0**

Table 13.Reclaiming Effects of *Prosopis juliflora* Plantations on Village Community Lands

Village	Depth (cm)	Soil Properties			
		pH		Organic Carbon (%)	
		0*	8*	0*	8*
Shera	0-15	10.0	8.8	0.13	0.48
	15-30	10.1	9.6	0.06	0.21
Sutana	0-15	10.2	8.5	0.20	0.40
	15-30	10.6	9.4	0.07	0.09
Nain	0-15	9.7	8.6	0.08	0.45
	15-30	10.2	9.2	0.10	0.12
Bhalsi	0-15	10.0	8.8	0.22	0.65
	15-30	10.5	10.1	0.08	0.12

*** 0 and 8 refer to original and 8 years after planting**

Economics of Raising *Prosopis* Plantations in High-pH Soils

Singh et al. (1993) made rough estimates about the likely benefits of raising *Prosopis* plantations in salt lands. The major expenditure in establishing mesquite plantations on salt-affected soils is for site preparation. Expenditures on site development are more in alkali than in saline soils. In alkali soil, site preparation involves land leveling, making strong bunds [levee or embankment] around the periphery for *in situ* rainwater conservation, digging augerholes, cost of amendments, and providing for a large number of irrigations. In saline soils, preparation involves digging of channels only for planting mesquite and no expenditure is involved in making augerholes and amendment application. Planting one hectare of alkali land using the augerhole technique, at a planting density of 1250 plants/ha, will cost approximately Rs. 12,600 (based on 1990 prices). The net income/ha/annum, based upon 8-year rotation is Rs. 8175 for alkali soils and Rs. 3507 for saline soils (Table 14).

In addition to these monetary gains, mesquite growth on salty soils results in their amelioration to such an extent that many kinds of understory vegetation begin to appear (Figure 8).

Table 14. Economics of Raising Mesquite Plantations in Salty Soils

Expenditure/Income	Alkali soils (Rs.)	Saline soils (Rs.)
Total expenditure in 8 years/ha	32,000	22,400
Gross income after 8 years/ha	98,000	51,000
Net income/ha/year	8,175	3,587

Future Thrust

The presence of strong thorns and bushy growth habit of commonly found *Prosopis* species (*Prosopis juliflora*) in India limits its large-scale adoption by farmers. As a part of the mesquite improvement programme, large-scale collection of seeds of superior mesquite trees is being done within the country and abroad. Superior *Prosopis juliflora* trees have been marked (Figure 9). Mother plants of about 20 mesquite species have been raised in the CSSRI greenhouse. An orchard has been established at the institute which will produce seeds in 3 to 4 years (Figure 10). The species planted in the orchard are: *Prosopis juliflora* (Karnal), *Prosopis juliflora* (Gujarat), *Prosopis juliflora* (Forest Department), *Prosopis alba*, *P. velutina*, *P. chilensis*, *P. articulata*, *P. glandulosa*, *P. tamarugo*, *P*. spp. 1117, *P*. spp. 0450, *P*. spp. 457, and *P. cineraria*.

***Prosopis cineraria* is an ideal plant for rehabilitation of desert lands, but it is very slow growing. There is an urgent need to modify and improve the undesirable features of mesquite to suit different situations. In this context, the following approaches are suggested:**

- **Selection of single-stemmed mother plants in the field, collection of seeds from such desireable plants, and establishment of seed orchards of such mother plants**

- ***Prosopis* does not breed true to seed. Therefore, methods need to be standardised for its multiplication through asexual methods. Workers at Texas A&M University-Kingsville in the United States have standardised techniques for raising *Prosopis* through stem cuttings. More recently, scientists at CSSRI, have successfully grown fast-growing and thornless *P. alba* through soft-wood stem cuttings in shaded microplots without misting.**

- **Inter- and intra-species grafting is possible in mesquite (Peter Felker, pers. comm.). Species can be improved by selecting root-stock-scion wood for planting in different situations. For example, in India,** *Prosopis juliflora* **can be improved by using root stock from salinity/alkalinity-tolerant** *P. juliflora* **and scion wood from faster-growing, less-thorny, and nearly single-stemmed** *Prosopis alba*. **Studies in this direction are under way.**

- **Plant type can also be improved by manipulation of agronomic practices. Planting mesquite at a closer spacing of 2 m between rows and 2 m between plants may help it grow upward instead of spreading out. Periodic removal of side branches also may help it produce a good bole.**

Prosopis **growers and woodworkers in India are not aware of the excellent quality of its wood and the furniture that could be made from** *Prosopis* **wood. All** *Prosopis* **wood is used and sold as firewood. There is an urgent need to create awareness about the wonderful qualities of** *Prosopis* **wood amongst people and woodworkers.**

Socioeconomic Impacts of *Prosopis* on Rural Inhabitants

Meeting fuelwood and fodder demand

Nearly 20,000 ha of salt lands in the country, mostly village community lands, have been revegetated recently with *Prosopis* **(Figure 11). Earlier, these community lands were lying barren and were not contributing in any way to the village economy. Most of these lands now support good plantations of** *Prosopis* **and** *Prosopis* **and grasses. Among the village communities, most beneficiaries of this land-development programme are the small and marginal farmers and landless labourers. Owing to acute firewood and forage shortages, a village woman has to travel many kilometers to collect fuelwood and forage to meet the daily needs of her family. After establishing** *Prosopis* **plantations on the village abandoned community lands affected by salts, two basic needs of low-income groups in the villages have been fulfilled.**

Employment generation

Raising tree plantations generates year-round employment opportunities in villages. About 216 man-days/ha are needed for initial establishment of *Prosopis* **plantation on alkali soil. For raising** *Prosopis* **and grasses together for 8 to 10 years, nearly 900 to 1050 man-days are required. Owing to generation of employment opportunities in the village itself, there is a tremendous decrease in labour flow from the villages to the cities.**

Replacement of cow dung and saving of nutrients

As a substitute for firewood, a large quantity of cow dung is burned as fuel in rural India (Figure 12). It has been estimated (Abrol and Joshi, 1982) that 90 to 120 t of cow dung can be saved by raising one ha of forest plantations. The nitrogen saved in the form of animal dung can meet the demand for this nutrient for about 20 to 26 t/ha. By using saved cow dung in farm fields, nearly 8 tonnes of food grains can be augmented by raising one ha of *Prosopis* **plantations.**

Income generation for village development

In addition to meeting fuelwood and forage needs of less privileged sections in the villages, these plantations generate sufficient income after 8 to 10 years for the village judicial body (Panchayat), to provide for overall development of the village. It was calculated that a one-hectare *Prosopis* **plantation (1250 trees/ha) can generate revenue of about Rs. 64,000 after 8 years. Further, a sensitivity analysis made at CSSRI also showed that afforestation is financially feasible, even when the cost rises 10% and returns remain normal.**

Increase in land value

Tree growth for a certain period of time reclaims the alkali soils to such an extent that the land can be used for growing all kinds of agricultural crops after removing the trees. Therefore, after reclamation, land value increases significantly.

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Figure 1. Salt-affected Village Community Land
(Such lands do not support even a blade of grass.)

Figure 2. Natural Growth of *Prosopis juliflora* **in a Highly Saline Soil**
in Gujarat State of India

Figure 3. A Special Planting Technique (Augerhole Technique) Developed for Planting *Prosopis* in Highly Alkali Soil (It results in nearly 90% *Prosopis* survival when planted in soils of original pH 10.6.)

Figure 4. Root Development of Mesquite (Clockwise from upper left: in a augerbore 15-cm diameter and 90-cm depth; in a pit of 30 cm^3; when gypsum was mixed in the whole surface soil; and in a trench 30-cm wide and 30-cm deep, dug across the plots)

Figure 5. *Prosopis juliflora* **Growing Without (left) and With (right)** *Leptochloa fusca* **Grass in a Soil of Original pH 10.4 (Growing trees and grass together for 52 months results in reclamation of alkali soils to such an extent that normal agricultural crops can be grown after removing the grass.)**

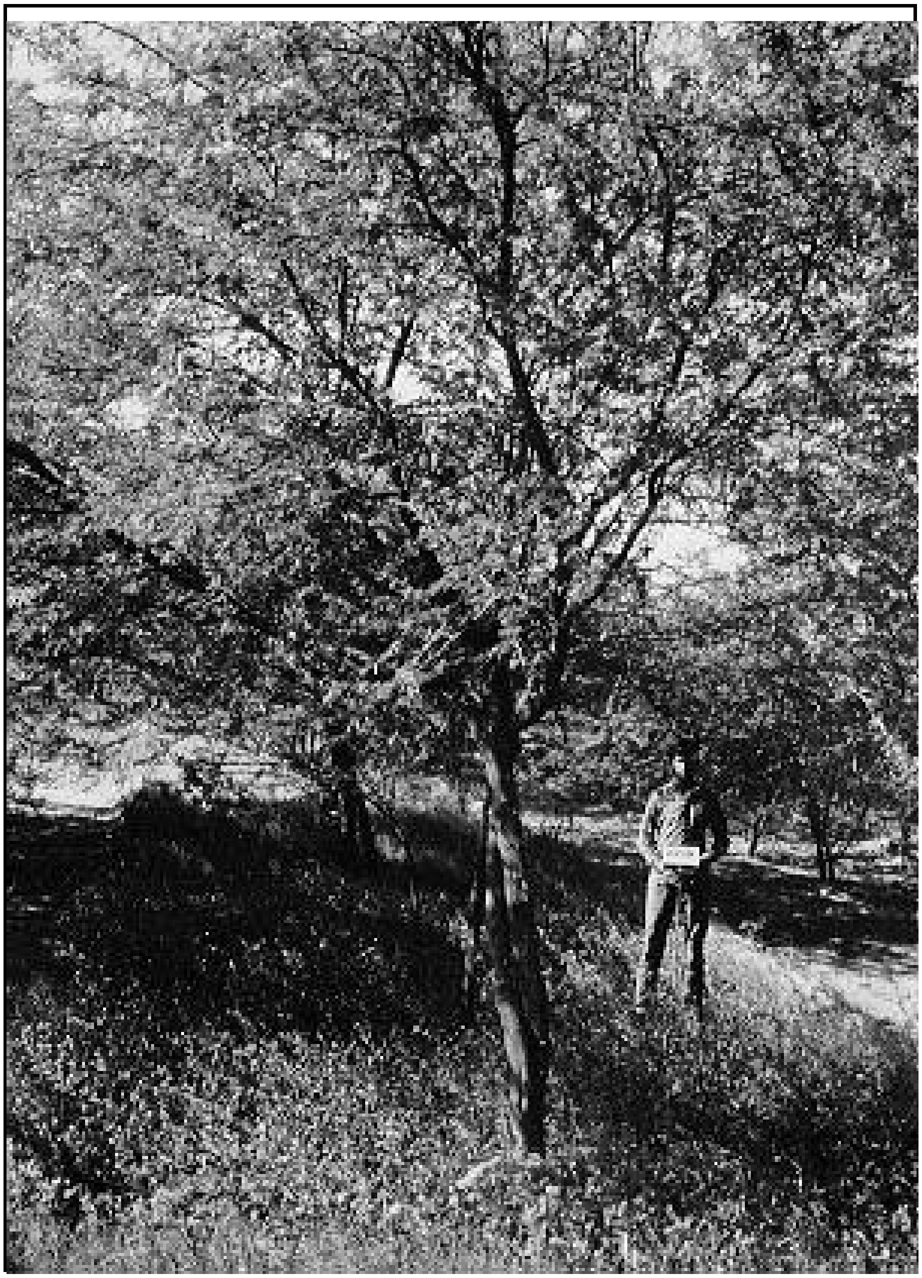

Figure 6. A good crop of *Trifolium alexandrium* **growing along with** *Prosopis juliflora* **(The inter-crop was planted after ploughing under** *Leptochloa* **grass.)**

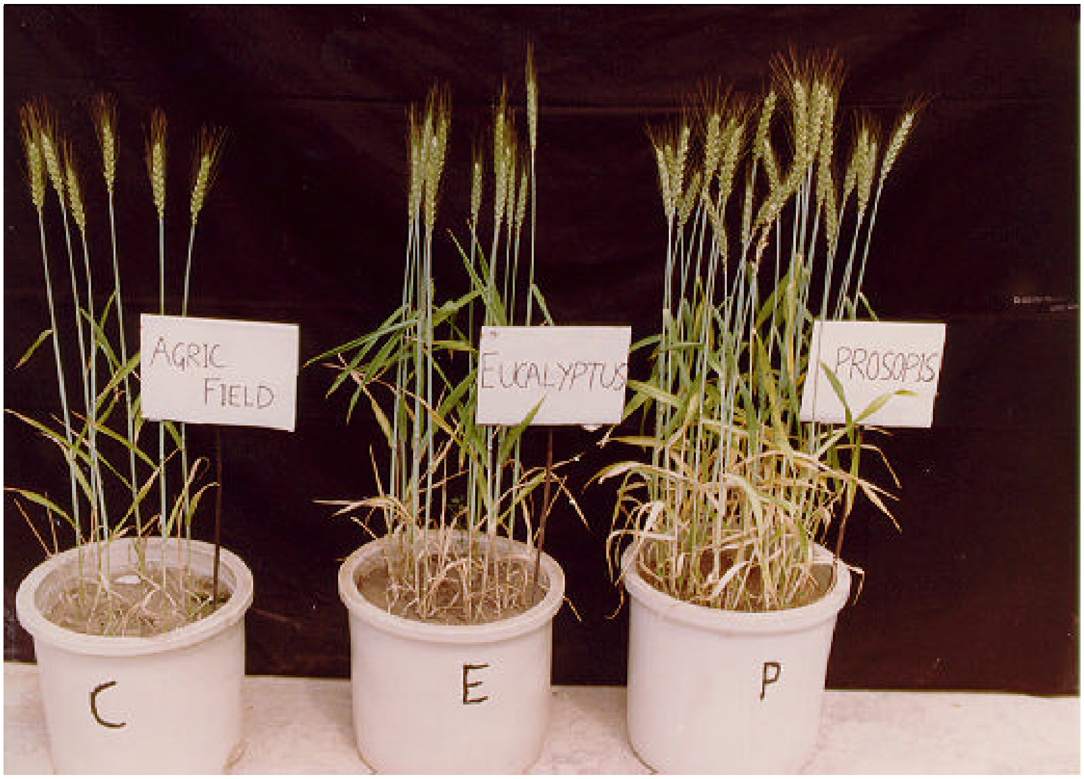

Figure 7. Comparative Growth of Wheat in an Alkali Soil Reclaimed Through *Prosopis* (P) and *Eucalyptus* (E) Plantations and Through Gypsum Application (C)

Figure 8. A View of Understory Vegetation in 8-year-old *Prosopis juliflora* Plantations Raised in an Alkali Soil of Original pH 10.0 (The appearance of salt-sensitive plants under *Prosopis* trees indicates the extent of reclamation.)

Figure 9. A Superior ***Prosopis juliflora*** **Tree (This tree has attained a basal girth of 2.15 m in 25 years. Peter Felker, Nick Pasiecznik from HDRA (UK) and the author are observing the stem girth of this unique tree.)**

Figure 10. Superior Trees of ***Prosopis juliflora*** **Are Being Examined by the** ***Prosopis*** **Experts in a Seed Orchard at Farm of CSSRI, Karnal**

Figure 11. A General View of 6-year-old *Prosopis juliflora* **Raised on Abandoned Alkali Land of Village Gudha, Karnal, India**

Figure 12. Cow Dung Stored for Burning (foreground) and *Prosopis* **Plantations Raised on Village Community Lands to Replace Cow Dung Currently Being Burned as Fuel for Cooking (background)**

Utilization and Nitrogen Fixation of *Prosopis* in Senegal

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ABSTRACT

Prosopis **is one of the best-known trees in Sénégal today. After the loss of several million hectares of forest due to the drought, *Prosopis* is in very high demand to recover the degraded soils. Two *Prosopis* species are widely used in Sénégal: the native *Prosopis africana* growing in the southern part of the country, and *Prosopis juliflora* introduced from Central America.**

The area of *Prosopis africana* extends from Sénégal to East Africa. It characterizes the dry forests, the fallows, and the sandy clay soils. It has an economic value due to its hard and durable wood. Thus, it is overexploited as timber and firewood especially. The pods and leaves of *Prosopis africana* are appreciated as forage. Almost all the tree parts are used in traditional medicine. Like most of the *Prosopis* species, *Prosopis africana* is not affected by pathogenic germs. However, its pods can be overrun by insects. Unfortunately, there is very little microbiological research on this species.

Although it has been introduced in Sénégal, *Prosopis juliflora* is better known and more demanded than *Prosopis africana*. Research activities are mainly conducted on *Prosopis juliflora*. In the Sahel *Prosopis juliflora* usually is found planted with *Acacia* species. In this area, it provides pods and leaves that are very useful to cattle during the dry season. *Prosopis juliflora* is also planted in bare areas as fences and windbreaks. Two of the major problems encountered with *P. juliflora* are lack of techniques to extract the seeds from the pods and to obtain homogenous growth from a lot of seedlings. Fortunately, micropropagation seems promising to multiply *Prosopis* more quickly.

Both species are multipurpose but their great interest is based on their nitrogen-fixing ability. Because of their symbiosis with *Rhizobium*, they can produce nitrogenous substances which play a major role in the poor soils. For this reason, the integration of *Prosopis* into the agroforestry systems is necessary. This benefits not only plant growth but also contributes to soil amelioration. Experiments conducted in the nursery have shown that *Prosopis juliflora* responds positively to inoculation with *Rhizobium*, increasing its biomass and nitrogen-fixing ability. However, the response to inoculation varied markedly according to the provenance of *Prosopis*. The potential of *Prosopis juliflora* to fix significant proportions of nitrogen has been established under seminatural conditions. The amount of N fixed by a tree was approximately 31 g.

INTRODUCTION

The rural populations of the Sahel are mainly farmers in the south or cattle raisers in the north. In the central part, agriculture is associated with sedentary cattle raising. Beside water, their principal needs consist of a wide range of products: firewood, timber, charcoal, food, and gum. However these natural resources are seriously degraded due to long periods of drought, which brought about a loss of several million hectares of forest.

Given the need to tackle this serious situation, several campaigns of reforestation have been launched using the multipurpose, fast-growing and nitrogen-fixing leguminous trees because of their many properties and characteristics. Among these trees, *Prosopis* species appear to be the most promising for the semiarid regions. The importance of *Prosopis* in Sénégal has been underlined previously (Diagne, 1992). The major part of this paper will be focused on the introduction of *Prosopis* species in Sénégal, their biomass production, seed germination, and micropropagation. *Prosopis* microorganisms associations should also be considered because of their role in soil amelioration.

Actually, the microbiological approach has been neglected in the past. The nitrogen fixation of several leguminous trees such as the *Acacia* has been widely studied. However little is known concerning the symbiosis with the *Prosopis* even though the nodulation and nitrogen fixation were proved (Felker and Clark, 1980; Shearer *et al*., 1983; Shoushtari and Pepper, 1985). In this paper, more attention will be given to the quantification of the nitrogen fixed by *Prosopis juliflora*.

UTILIZATION OF *Prosopis*

Biomass Production

Biomass production is very low in the semiarid regions because of the low rainfall. For instance, an experimental field in Bandia, Senegal, produces 1.5 m^3/ha of biomass per year (Freeman *et al*., 1983). According to FAO, more than 13 million people in the arid and semiarid regions and nearly 200 million people in the savanna are essentially dependant on firewood. According to a CILSS (Comité Inter-Etats de Lutte contre la Sécheresse au Sahel) report, the total consumption of firewood in the Sahel is estimated at 16 million m^3 per year, that is, 0.6 m^3 per inhabitant per year.

Given this important consumption of fuel, it is necessary to be interested in fast-growing, nitrogen-fixing trees. They can not only improve the basic economy of the rural populations, but also contribute to decreasing their imported sources of energy. Although the productivity of the Sahel woody lands is low, the nitrogen fixing trees contribute to a great extent to supplying firewood and charcoal to the cities and villages.

An estimation of the productivity in Bambey, Sénégal, has shown that a 17-year-old stand of *Prosopis juliflora* produced 4.2 m^3/ha/y of wood. This production is the best compared to *Acacia seyal* (native species) or to *Racosperma holocericeum* (introduced). When the total biomass harvested was harvested in the same stand at 0.10 m and 1.10 m above ground, 84% and 100% of the trees produced coppiced shoots at the respective cutting heights. A stand of an 8-year-old *Prosopis cineraria* produced 0.7 m^3/ha of wood at Bandia.

The nitrogen-fixing trees (NFT) are used in the craft and building industries. They can also supply timber and pods, whose export constitutes an inflow of currency. Sénégal imports 50,000 to 60,000 m^3 of wood each year from the forestry countries.

Food Production

Before the development of agriculture in the semiarid regions, leguminous trees had played a great role in human food, which was based partly on the gathering and the harvest of leaves and fruits from trees. The sale of the takings from the collection has brought about an improvement in the state of the economy of the populations.

In the Sahel, the leguminous trees are very important as source of food for the nomads who move to pastures with their cattle during the dry season looking for aerial forage, dry fruits and water. During that period, and unlike the annual crops, almost all the NFT keep their vegetative biomass alive and benefit from the underground water until the next rainy season. The aerial biomass is a factor of stability for the populations as it can be produced all year. Unfortunately this equilibrium is not always reached because of the instability of the rains and overgrazing. Thus, the density of the woody plants is tremendously decreasing from the south to the north of the Sahel (Breeman, 1982).

Contrary to the annual crops, the woody legumes have been scarcely studied at the food level. Findings have shown that NFT can play a fundamental role as forage for the cattle in semiarid regions by conditioning their survival in some cases during the long period of drought. In addition, the NFT can provide shade for the grasses. Therefore, it is necessary to associate cattle production with the culture of the NFT. The seeds and pods of some NFT contain an important proportion of proteins, lipids, vitamins, and soluble carbohydrates. The pods of *Prosopis juliflora* are highly edible for the cattle in West Africa because of their fleshy and sweet tissues. They contain 34% to 39% protein and 7% to 8% lipids (NAS, 1980). Leaves and bark of young *P. chilensis* constitute an appreciated food for hares.

Restoration of the Degraded Lands

In the past, the semiarid regions had benefited for a long time from the natural resources that protected the soil against erosion. The present vegetation hardly exists in many cases and the forest services of the concerned countries have launched several campaigns for reforestation. Such actions have faced up to difficulties linked to limited, heterogenous and poor soils. This has led to mass destruction of the natural vegetation to increase the area for mechanized plantings, generating other problems, such as deterioration in soil structure, decline in organic matter level and in biological activity, deterioration in water capacity, and a drop in soil pH (Siband, 1974).

The spreading of such phenomena added to the improper field clearings; the bush fires have been harmful to the ecosystem in the semiarid regions. This deteriorated the vegetation and made the soil sensitive to erosion. According to the World Bank (1978), the forest reserves of the developing countries (estimated at 1,200 million ha) are destroyed at a rate of 15 to 20 million ha per year.

Erosion can cause important losses of nitrogen equivalent to 3.5 kg/ha per year (Pieri, 1982). Thus *P. juliflora* is highly used as windbreak or to stabilize sand dunes (Green Belt in Nouakchott, Mauritania).

Other Utilizations

Even if we carry out a better planning and management of the natural resources, the problem of the degradation of the environment will remain due to the exponential increase of the population and their specific needs. For this reason, several forestry projects have initiated agroforestry trials in which the tree is directly integrated into the activities of the farmer and the cattle raiser. This technique had been practiced in the past by the farmers who kept the NFT such as *A. albida* and *A. senegal* as fallow in their fields.

NFTs also have functioned as ornamental plants in the community groups and, therefore, have contributed to the amelioration of the surroundings of the populations. They form shade in villages or houses, windbreaks, and protective belts. *P. juliflora* has been introduced in most cities in the Sahel along roads and tracts (Figure 1).

Figure 1. *P. africana* near Saboya Village in Senegal (600 to 800 mm annual rainfall)

The curative properties of the leaves, roots, fruits, and bark of most of the NFT have been used in traditional medicine. For example, *P. africana* is frequently used as a medicinal plant (Diagne, unpubl. obs.).

SYLVICULTURE

Seed Treatment

P. juliflora produces an indehiscent sweet fruit which can contain up to 20 seeds or more. The seeds are protected by cellulosic and rigid tissues that make their extraction difficult. This may explain why *Prosopis* seeds are not attacked by pests.

Laboratory tests were carried out to germinate *Prosopis juliflora* seeds with their endocarps. Seeds were immersed in different concentrations of hydrochloric acid (N to 5N) for 60 minutes. Germination was very poor after four days (<20%). Other lots of seeds were immersed in 20% and 96% of sulfuric acid, respectively, for 10 and 30 minutes (Coulibaly, 1991). None of the treatments destroyed the endocarps entirely and the percentage of germination remained poor (<25%). After shaking for 5 hours in 96% sulfuric acid better results were achieved. The endocarps were destroyed by the acid and the seeds had 80% germination after one day. Although this last result seems encouraging, the chemical method of seed extraction is difficult to popularize. The quantity of concentrated acid to handle is enormous and expensive and its utilization is dangerous. For these reasons mechanical extraction of the seeds is most appropriate for our conditions.

The most traditional mechanical method of seed separation consists of crushing the dried pods into a mortar with a wooden pestle. This method is simple but time consuming and needs a lot of labor. For example 6 to 8 men are required to work for 8 hours to extract 1 kg of seeds (about 28,000 seeds). Electric-powered industrial equipment that includes an electric boiler and disintegrator are capable of extracting 100% of the seeds from the pods in 10 minutes, yielding seeds that have 90% germination in one day. Unfortunately, this equipment, produced by Rayneri, Department Industrie:

Melangeurs Industriels, Z.I., BP 9, 85601 Montagu, Cedex, France, is quite expensive (about US$80,000).

***In vitro* Germination**

Seeds of *Prosopis juliflora* were surface sterilized with different concentrations of sodium hypochlorite (NaOCl) and calcium hypochlorite (CaOCl). The germinated seeds were then incubated in Murashige and Skoog (MS) (1962) medium enriched with 2.5 mg/l of naphthaleneacetic acid (NAA), 0.1 mg/l of 6-benzylaminopurine (BAP) and 20 g/l of sucrose (Seck, 1996).

All the seeds germinated 48 hours after using NaOCl and 72 hours after using CaOCl. These chemicals took effect according to their concentration and made soft the integument of the seeds, lessening the pressure needed for rooting. However, at least 50% of the seeds became infected with the low concentrations of CaOCl (100 to 150 g/l). The best result of disinfection (16% of infection) was obtained with 200 g/l of NaOCl for 15 minutes.

Micropropagation (Seck, 1996)

Microcutting for axillary shoot production

Microcuttings taken from *in vitro* plants were grown in three planting media: Murashige and Skoog (1962), Gamborg *et al*. (1968), and Woody Plant Medium (Lloyd and McCown, 1980). The result showed that the MS medium gave the highest percentage of survival (100% for *P. chilensis* and 87.5% for *P. juliflora*). It appears to be more favorable to the regeneration and elongation of the *Prosopis* buds compared to the other media (Table 1).

The addition of 5 mg/l of BAP allowed 100% survival for the two species and good multiplication. However, this concentration inhibited the extension of the buds. The addition of 1 mg/l of kinetin (6-furfurylaminopurine) to the MS medium did not modify the activity, the percentage of multiplication, or the number of buds of *P. chilensis*. In contrast, 100% survival was found in *P. juliflora* even though the multiplication was less important than the control plants (no Kinetin added).

The combination of 0.1 mg/l of BAP and 1 mg/l of NAA led to 100% of rooting for *P. chilensis* and 0% for *P. juliflora*.

Table 1. Effect of Three Media on the Survival of *P. chilensis* (P. c) and *P. juliflora* (P. j)

Media	N	Survival (%)		Bud Mean Number		Bud Mean Size (mm)		Mean Node Number		Multiplication Rate	
		P. c	P. j	P. c	P. j	P. c	P. j	P. c	P. j	P. c	P. j
MS	24	100	87	1.0a	1.1a	11.7a	6.8a	1.8a	0.9a	1	1.1
WPM	24	88	54	1.1a	0.7ac	2.5b	1.3b	0.4b	0.3b	1.1	0.7
B5	24	67	57	0.9a	0.5bc	2.5b	0.6b	0.4b	0b	0.9	0.6

Means within a column followed by a different letter are significantly different at $p<0.05$ by analysis of variance.
MS: Murashige and Skoog (1962)
WPM: Woody Plant Medium
B5: Gamborg *et al*. (1968)

Shoot production from cotyledons

Cotyledon explants were put in a growth-hormone-free MS medium. Two weeks after, the ratio of multiplication was high: 2 for *P. chilensis* and 2.2 for *P. juliflora*, corresponding to a mean of two active buds per explant. This medium allowed good elongation of buds: 9.56 mm after 30 days for *P. juliflora* and 1.69 mm for *P. chilensis*.

Hardening off of in vitro shoots

During the acclimation stage, about 54% of survival was obtained. After five months, height, number of leaves, and biomass were recorded. They varied according to the species. The length of the tap root reached 89 cm for *P. juliflora* and 68 cm for *P. chilensis*. The height, number of leaves, root length were, respectively, 33, 30, and 48 cm for *P. juliflora* and 52, 47, and 30 cm for *P. chilensis.*

***Prosopis* Introductions**

Several *Prosopis* species were introduced in Bandia to test their adaptability to survive and perform in the Sahel conditions (Diagne, 1992).

***P. alba* introduced in 1982 seems to be well adapted since 90% of the plants survived after six years. Its scrubby trunk, thorny branches and poor forage palatability suggest its most appropriate utilization as a hedge. *P. chilensis* was introduced in Bandia in 1978. Seven years later, 86% of the plants survived the conditions. However, in the following year 22% mortality was observed. *P. chilensis* also appears to be most useful as a hedge because of its scrubby and very thorny branches. *P. cineraria* was introduced in 1977 in Bandia with a 4.5 m spacing between the trees.**

In 1985, alternate rows of these trees were removed (leaving a 9-m spacing) to test their ability to coppice. Fourteen months after harvest all the trees produced coppice shoots. The production of biomass of the coppice can be important: after four months of rain, 1.4 t/ha of dry weight were obtained. Three years after this production reached 3.5 t/ha of fresh weight as against 2 t for the nonthinned trees. The soil structure seems to have an effect on the growth of *P. cineraria*. The best growth was recorded in the depressions (Table 2).

Table 2. Growth of *P. cineraria* (provenance Haryana, India)
According to Soil Characteristics of Bandia

Pedological Characteristics	Topography	Survival (%)	Height (cm)	Basal area per stem (cm^2)	Ground-based surface (m^2/ha)
Very compact clayey layer between 0.5 and 1.0 m	Subhorizontal	96	210	43	2.0
Deep soil and structure less compact	Depression liable to flooding	96	400	181	8.6
Cuirass at 1 m	Subhorizontal	96	270	74	3.6
Compact clayey layer at 1 m	Subhorizontal	100	290	90	4.4

P. juliflora* and *P. cineraria* were tested for use in hedges with the following species: *Parkinsonia aculeata*, *Acacia mellifera* and *A. senegal*. The survival rate was recorded 6, 12, and 18 months after the plantations (Table 3) at Keur Mactar (central Senegal). Table 3 shows that *P. juliflora* and *P. cineraria* survived, in general, at the same rate (>60%) than the other tree species six months after transplantation into the field. After a year, their survival rate decreased rapidly and dropped to less than 40% in pure culture. *P. juliflora* benefited from its association with the *Acacia* species, contrary to *P. cineraria* with *P. aculeata.

Table 3. Survival Rate of Tree Species
At Different Times After Plantation

Tree Species	Survival Percentage After 6 Months	Survival Percentage After 12 Months	Survival Percentage After 18 Months

***P. juliflora* (P. j)**	**85.0**	**20.0**	**19.0**
***P. cineraria* (P. c)**	**65.7**	**50.5**	**38.0**
Parkinsonia aculeata	**100.0**	**99.5**	**34.0**
Acacia mellifera	**90.0**	**84.0**	**81.0**
P. j + *Acacia senegal*	**82.0 + 82.0**	**61.0 + 73.0**	**57.0 + 57.0**
P. j + *Acacia mellifera*	**96.0 + 92.0**	**83.0 + 92.0**	**73.0 + 82.0**
P. c + *P. aculeata*	**99.5 + 79.0**	**28.9 + 17.0**	**14.0 + 9.0**

***P. juliflora* was tested as a windbreak in a sandy soil at Khayes (western Senegal). *P. juliflora* gave better results when grown with *Eucalyptus camaldulensis* than when grown with *Racosperma holocericeum*.**

Provenance Trial

Seven provenances of *Prosopis sp*. from Ecuador and one provenance of *Prosopis juliflora* from Sénégal were grown at the nursery. Inoculated three-year-old seedlings were planted in Bandia in a randomized complete-block design with a space of 4 m between trees. The survival rate, height, and diameter of the plants were measured each month. The superiority of the local *P. juliflora* in terms of height at the nursery, disappeared three months after plantation in the field. No differences between the provenances have been noted for the other parameters. This suggests that the provenances from Ecuador are as well adapted as the Senegalese *P. juliflora* in the Sahel.

Although there was no difference between the provenances in terms of biomass and survival, large variability was noted in the number, size, color, and shape of the thorns; color of the foliage; and the shrubby shape. It would be useful to examine this variability as well as the characters of flowering and fruit formation in more detail.

SOIL AMELIORATION

Water is not the only limiting factor in the semiarid regions. Phosphorus and nitrogen are very important factors that need to be taken into account. The maintenance of the nutrients in the soil is often adversely affected by human actions. Actually, soil nitrogen balance is perpetually modified by farmers during cultivation. According to Jones and Wild (1975), the mean total soil nitrogen level decreases from the Guinean (0.104%) to the Sahelian zones (0.034%). In addition, only 4% of the total nitrogen is mineralized each year in the savanna soils for possible use by the plants (Singh and Balasubramania 1979).

Because of these factors, the degraded and poor soils upon which agrosylviculture is based, require fertilizer. Unfortunately mineral fertilizer is very expensive for the rural populations who obtain their main income from agriculture. Plant residues release mineral nitrogen to the soil, but the fallow is not long enough in the Sahel to substantially increase the soil-nitrogen pool. Due to the possibility of additional nitrogen contributions through nitrogen fixation, the integration of the nitrogen-fixing trees, such as the *Prosopis*, into the agrosylviculture systems could be very beneficial. Prosopis are able to produce nitrogenous substances from the nodules only with associated *Rhizobium*.

The effect of *Rhizobium* inoculation was tested on seven provenances of *Prosopis* sp. and one provenance of *Prosopis juliflora* (Diagne, 1994). The experiment was conducted in a nursery in unsterilized soil. The different responses to inoculation were estimated by comparing the inoculated with the uninoculated plants. After three months growth, plant height from inoculated plants was increased by 31% (provenance 2361) to 147% (provenance 2371), dry weight of shoots was increased by 15% (provenance 2363) to 213% (provenance 2371), and dry weight of roots was increased by

12% (provenance 1516) to 231% (provenance 2371). Although the growth of all the inoculated plants was increased, results indicate that responses to inoculation vary markedly with the provenance. The experiment suggests that given its excellent response to inoculation, provenance 2371 warrants further investigation as a promising semiarid agroforestry species.

Because of the great interest in *Prosopis* species and the need for increasing soil fertility through biological nitrogen fixation, it is important to quantify the amount of nitrogen *Prosopis juliflora* can fix. Despite the great number of research papers involving ^{15}N isotope-dilution estimation of biological N_2 fixation of other species (Chalk, 1985), there is no information on quantitative estimates of N_2 fixation by *Prosopis juliflora*. A few reports have measured nitrogen fixation by other *Prosopis* species using the acetylene-reduction method (Felker and Clark, 1980), micro-Kjeldahl techniques (Rundel *et al*., 1982), or the natural-^{15}N-abundance method (Virginia *et al*., 1984). A study was conducted to assess the nitrogen fixed by *P. juliflora* under seminatural conditions.

A ^{15}N-enrichment experiment was conducted to estimate the proportion of nitrogen derived from nitrogen fixation (pNdfa) for the symbiotic legume tree, *Prosopis juliflora* (Diagne and Baker, 1994). The nitrogen fixation was calculated from the N isotope abundance as described by Fried and Middleboe (1977). Seedlings of *P. juliflora* were inoculated with *Rhizobium* strain Pj-12 and grown in 1 m^3 concrete containers serving as individual microplots. Seedlings of *Eucalyptus camaldulensis* were used as a reference species. All microplots were provided with ^{15}N-enriched ammonium sulfate. Plants were harvested after one year of growth in the microplots. Yields of both *Prosopis* and *Eucalyptus* were good, although *Eucalyptus* had significantly higher total biomass.

In this experiment, the pNdfa for *Prosopis* was relatively low (13.5%) (Table 4). While this could be due to ineffective inoculation, it could also be due to a high level of available N in the soil. The latter explanation is more likely since the data show that *Prosopis* took up more N from the soil than *Eucalyptus*. In any case, the amount of N fixed by *Prosopis juliflora* was very low compared to other leguminous species such as *Leucaena leucocephala* and *Albizia lebbeck* (Högberg and Kvanström, 1982; Sanginga *et al*. 1985; Van Kessel and Nakao, 1986) or two other *Prosopis* species (Rundel *et al.* 1982; Virginia *et al*. 1984).

In a pure stand, *Prosopis juliflora* is usually planted with a 4x4-m spacing, which corresponds to a density of 650 trees/ha. Since the total nitrogen for *Prosopis juliflora* was 278.24 g, the amount of nitrogen fixed was 37.67 g per tree. By extrapolation, fixation would be about 25 kg N/year/ha. However the amount of N_2 fixed can vary according to the environmental conditions of the area where *P. juliflora* is growing. It also depends on the experimental design, and, especially, on the spacing between trees. The choice of a suitable spacing depends on the purpose of the *P. juliflora* plantation (Silva, 1988). For example, in agroforestry systems, *P. juliflora* can be planted with a spacing of 1 m between trees. It would be desirable to estimate the nitrogen fixed directly in the field and to take into account the fact that N_2 fixing activity can decrease with the progressive accumulation of N in the field (Gauthier *et al.*, 1985).

Table 4. Nitrogen Content of the Different Parts of Plants

Parameters	*Prosopis juliflora*		*Eucalyptus camaldulensis*	
	N atom (%)	^{15}N a. e. (%)	N atom (%)	^{15}N a. e. (%)
Leaves	2.49a	0.01c	1.11b	0.08d
Small stems (number <4mm)	0.99a	0.02c	0.33b	0.07d
Large stems (number >4mm)	0.70a	0.03c	0.23b	0.08d

Roots	**1.23a**	**0.02c**	**0.22b**	**0.09d**
Weighted average	**1.35a**	**0.02c**	**0.47b**	**0.08d**

Means within a line followed by a different letter are significantly different at $p<0.05$ by analysis of variance.

CONCLUSIONS

This work has permitted an assessment of the principal properties of the *Prosopis* in the African semiarid zones, especially in the Sahel. The numerous uses of a wide range of *Prosopis* products (wood, forage, fruits, gum, etc.) demonstrate the possibilities to improve the standard of living of the rural populations. Thanks to their symbiosis with the *Rhizobium*, *Prosopis* reforestation can also help in the fight to reclaim the desert and contribute to the amelioration of the soil fertility and soil stability.

Although it is difficult to extract seeds from Prosopis pods, the seeds germinate easily. Among the *Prosopis* introduced in Sénégal, *Prosopis juliflora* is the most promising and the most adopted by the populations. Successful micropropagation of *Prosopis* could be of a great benefit in avoiding some of the deleterious characters that occur as a result of high intra-specific variability in *Prosopis*.

Inoculation with appropriate *Rhizobium* strains can improve the potential of *Prosopis* to grow faster, produce substantial biomass and fix nitrogen. Trees also need mycorrhizae for their growth and functioning to take up nutrients from the soil more easily, especially phosphorus. If the environmental factors are matched closely to the correct provenance of the tree, much improvement in nitrogen fixation can occur. Further inoculation surveys are needed to combine the most appropriate *Rhizobium* strains and arbuscular mycorrhizal fungi to maximize the potential of *Prosopis* species.

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Use of *Prosopis* in Arab/Gulf States Including Possible Cultivation with Saline Water in Deserts

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INTRODUCTION

Mesquite (*Prosopis* spp.) plays a leading role in afforestation of arid lands. Their capability of growing on marginal land under arid conditions has made them especially suitable for this purpose. Being a multipurpose tree, they fit very well into the agroforestry system of arid land, control soil erosion, stabilize sand dunes, improve fertilizer status of the soil, provide fuel energy resources, supply feed and forage for grazing animals, furnish construction timber and furniture wood, supplement food for humans and promote honey production. Mesquite distribution is worldwide, and, although not liked by the growers of fertile land due to the danger of becoming an obnoxious weed, however, it has proved a blessing for the dwellers of degraded wasteland and barren coastal areas. The plant can withstand high temperatures, shortage of water, and saline land; therefore, it grows under haloxeric conditions as well.

Regarding the distribution of *Prosopis* spp. in Asia, one of its species namely *P. cineraria* is native of India (Gujrat, Rajastan and Haryana); Pakistan (Indus plains); Oman (eastern and western boarders of sand sea) and Saudi Arabia (southern boarder of Rub Al-Khali in vicinity of Ghanim), whereas, other species (i.e., *P. juliflora* and *P. glandulosa, P. alba,* etc.) have been introduced probably during last century.

The authors have conduced a survey of naturally growing *Prosopis* plantations of Arab Gulf states during July and August 1994 under the BOSTID Research Programme. The first author has also served as a visiting professor at Sultan Qaboos University, Oman, and visited a local *Prosopis* woodland (September through January 1990).

Prosopis spp. IN ARAB/GULF STATES

Geography of the Area

Apart from the Kingdom of Saudi Arabia, which occupies most of the Arab peninsula, four other states of the Gulf Cooperation Council (GCC), i.e., Kuwait, Bahrain, Qatar, and U.A.E., are situated at the eastern coast of the peninsula on the of Persian Gulf, whereas, the sixth state, Oman occupies the southeastern and southern part of the peninsula, facing the Gulf of Oman and Arabian Sea (Figure 1). Several aquifers are found at the coastal belt where the water table ranges from 90 to 200 m. The minimum temperature in the Gulf region remains about 18°C during winter and may reach 35°C during summer. A belt of sandstone and alluvium up to 150 km wide lies between cuesta ravines and the sea coast. The bedrock is Eocene limestone. The plain is inclined eastward toward the Persian Gulf. Annual precipitation is not more than 130 mm. There is a great dearth of good quality water; water for domestic purposes is obtained through desalinization plants. The Saudi Arabian part of the eastern coast (Al-Hasa Desert) is stony and a considerable area is moving sand. Masses of loose sand alternate with limestone hills (60–80 m high) all along the coast. The mountains of Oman in the southeastern part of the peninsula are folded ranges of Alpine orogenesis with maximum elevation of 3352 m. Some ephemeral streams flow in valleys leading to lowlands in the south of Oman. There is a strip of sandy plain along the Arabian Sea. As a result of over pumping, the groundwater is gradually becoming brackish due to sea water intrusion all along the coastal belt.

Distribution of *Prosopis* spp.

Distribution of *Prosopis* species and their uses in Arab/Gulf states is presented in Table 1. Most fast-growing *Prosopis* spp. (i.e., *P. juliflora*, *P. glandulosa*) were introduced into Indo-Pakistan about 1878 (Parker, 1921), from where they have most probably invaded Arab/Gulf states during late 1950s. Any record of their proper introduction into these states is not available. Species such as *P. alba*, and *P. chilensis*, are being introduced by the horticultural departments of various township of these states as roadside trees and for other ornamental purposes. However, the existence of *P. cineraria* for more than 200 years in Oman, Saudi Arabia, and the Indo-Pak subcontinent has more or less given it native status. The presence of a huge single isolated *P. juliflora* tree (more than 30 m tall) in the central plateau of Bahrain indicates the probability of its early introduction. Although the earliest record of *P. juliflora* introduction to the Indo-Pak subcontinent was in the late 1800s, local people believe this huge specimen is much older. The possibility of its dispersal through the traders of the 1500s, who came around from Africa, cannot be ignored. The soil of the central plateau is a mixture of stony-silty-loam. The climate of this area is arid and precipitation is only 50–100 mm/year, hence, growth of seedlings by dispersion of seeds could not be possible. Furthermore, there are several oil wells with a network of pipelines leading to nearby refineries. It is interesting to note that any plant of more than 15–20 years of age was not seen all over the island, whereas, a single plant more than 500 years old was growing in the central plateau.

The presence of *P. cineraria* in lowlands at the margin of the hot sandy desert Ruba Al-Khali (empty quarters)in Saudi Arabia is another interesting feature. Its native woodland forest in an ephemeral river basin in Oman and along the eastern and western boundaries of Wahiba sea sand (desert) shows the capability of its growth under extremely arid conditions (Brown, 1989).

Cultivation with Saline Water

The capability of mesquite species to grow under stressed conditions have made them most important multipurpose tree of arid and semiarid regions. Their growth and development under arid conditions well documented (Felker et al., 1983a). Comparative studies on their stress tolerance conducted by various workers (Felker et al., 1983b., Ahmad et al., 1994) could help in screening the plant genomes for desired characters.

SAND DUNE STABILIZATION PROGRAMME

The programme started at the coastal belt of Pakistan by the Baluchistan Forest Department in 1970 using underground saline water was mainly aimed toward growing *Prosopis juliflora* at Pasni, Gwadar, and Pishukan, the townships located in sandy coastal belt where good quality water is absent. Ombrothermic diagram for Pasni, based on 30 year's of data (Figure 2) shows the arid climate of the area. Total area of plantation (mostly at sand dunes) was more than 300 ha. divided at three places. Some plantation at compact native sandy strata was also undertaken. Saline water was lifted for irrigation from 1–3 m deep wells dug at a distance of 1–2 km. from shoreline. Electrical conductivity of the water varied from low (1–6 dS m^{-1}) to high (7–20 dS m^{-1}) at various places. Growth performance of plants up to five years old is presented in Figure 3. The plantation is now 15–20 years old. The case history of this plantation is well documented (Khan et al., 1986). Because there was no pruning to make them monostemic, an average of 4–5 basal stems of 15–20 cm in diameter are present in 15-year-old plant. The interplant distance was maintained at 2–2.5 m for sand-dune stabilization and 5 m for fuelwood production. Each plant was irrigated with about 10–12 liters of saline water weekly during summer and fortnightly during winter months. Irrigation was suspended after two years. The plantation has significantly stopped the movement of a huge sand dune that threatened Pasni township. Furthermore, it has provided pods for feeding goats and sheep and provided fuelwood for local inhabitants. In addition, the preparation of charcoal in locally made earthen kilns has provided an other commodity for sale in nearby cities.

Growth With Reference to Interplant Distance

As mentioned earlier, plants at Pasni were placed at an interplant spacing of 2.0S2.5 m for sand dune stabilization. However, due to plant mortalities in some areas, spacing became $\geq$5 m between many plants. The growth patterns of these plants were different from those grown with closer spacing. All the growth parameters of 10-year-old plants with an interplant spacing of 2.0S2.5 m were significantly lower than those of the same age left at $\geq$5 m (Table 2). It indicates that close spacing in *Prosopis* species may be desirable only for sand stabilization purposes. However, a spacing of $\geq$5 m appears more suitable to obtain wood for fuel and furniture.

Wood Quality

Wood quality of *P. juliflora* varies with the age of plants. Figure 4 shows the specific gravity (SG) of wood samples collected from plants of various ages. Specific gravity increased steadily up to approximately five years of age, but, thereafter, became more or less asymptotic. The specific gravity of 4-, 5-, and 9-year-old plants at Pasni growing in nonsaline soil did not significantly differ from those growing at sites irrigated with saline water. Being related with age, it showed the following relationship:

$$\text{SG (wood)} = 0.577 + 0.0823\ \text{Age (years)} - 0.0046\ \text{Age (years)}^2$$

$F = 28.965$	$(t = 5.495)$	$(t = -3.895)$
$r = 0.9038$	$(P < 0.001)$	$(P < 0.002)$

The mature *P. juliflora* has considerably higher specific gravity values compared to 0.61 in *Alibizzia lucida,* 0.61 in *A. lebbak,* 0.68 in *Azadirachta indica* (Manjunath, 1948), and 0.58S0.68 in *Pinus roxburghii* (Krishnamurti, 1969) and is somewhat comparable to 0.80 in *Acacia nilotica,* 0.97 in *A. modesta* (Manjunath, 1948), 0.82 in *Dilbergia sisso* (Sastri, 1952), and 0.91 in *Quercus dilata* (Krishnamurti, 1969).

The calorific value of mesquite wood is also higher, ranging from 3974 to 4636 kcal/kg in dry wood (4215.70 ±28.16 kcal/kg). It was lowest in 1-year plants and maximim for 13-year-old plants (Figure 4).

The wood of *P. juliflora* is heavy and hard, hence, appears to be an excellent fire-generating material. Although growth of the plant is subsequently reduced under highly saline conditions, the quality of the wood is not affected significantly.

Useful conclusions could be drawn from the experiment conducted to study comparative growth of different *Prosopis* species/accessions using saline water irrigation. Six-month-old seedlings of 20 different species/accessions (8 exotic and 12 indigenous) were pre-conditioned to salinity by irrigating them with water of increasing salinities prior to transplantation in pits where they were irrigated with underground saline water (EC: 14-16 dS m^{-1}). Growth performance of the six best species/accessions at the age of 2 years is shown in Figure 3. It is quite evident that local species of *P. juliflora* and *P. glandulosa* would be most suitable for stabilizing sand dunes because of their short stature and multistemic spreading characteristics, thus helping in stopping sand drift. Whereas, exotic species of *P. juliflora* and *P. alba* introduced from Brazil and Texas (U.S.A.), respectively, would be suitable as roadside trees and for timber for furniture/house building. Local *Prosopis* species, if pruned regularly, are also capable of becoming monostemic trees, but their rate of growth is slower as compared to the exotic species.

It has been proven that *Prosopis* spp. are capable of providing shade, fodder, fuelwood, timber, etc., from the wasteland where no other plant of commercial importance could grow due to prevailing arid and haloxeric conditions (Felker et al., 1983a; Khan et al., 1986; Riveros, 1989; Charan and Chouhan,

1993). They also play a leading role in stabilization of sand dunes and stopping shifting sand in hot sandy deserts. Hence, due emphasis should be given to using this plant for the benefit of mankind.

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Table 1. Distribution of *Prosopis* Species and Their Uses in Arab/Gulf States

States	Species	Habitat	Uses
Kuwait	***P. juliflora***	**Introduced during 1950s, now quite wild, grows luxuriantly in patches along coastal sandy belt. Vernacular Name: Ghaf.**	**Fodder, fuel, charcoal, shade, stopping drifting sand, stabilizing sand dunes, roadside tree.**
	P. glandulosa	**Introduced during 1950s, now quite wild, grows luxuriantly in patches along coastal sandy belt. (relatively less vigorous than *P. juliflora*)**	**Fodder, fuelwood, shade, roadside tree.**
	P. alba	**Introduced lately.**	**Ornamental.**
	P. chilensis	**Introduced lately.**	**Ornamental.**
Saudi Arabia	***P. farcta***	**Native, scanty growth around agricultural area and depressions. Found in Wadi Sirhan, At-Qatif, Al-Hasa. Vernacular Name: Yanbut, Awsay.**	**Folk medicine.**
	P. juliflora	**Introduced during 1950s, scattered patches in low land and dry seasonal river beds/wadis in central coastal lowland, Dhahran, Farsan island, Al-Khubar and Al-Dammam. Vernacular Name: Ghaf.**	**Shade, stopping drifting sand, roadside tree.**
	P. cineraria	**Native, few localised patches at shallow sand at southern margin of Rab' al-Khali (empty quarters). Vernacular Name: Ghaf, Shibhan, Hadib**	**Fodder, shade, pole for fencing and hutment.**
	P. koelziana	**Native (confused with *P. cineraria*) found at coastal and central lowland, near ruin sites or villages, northern Al-Hasa Oasis, al Muhtaragah, Sabkhah-south of Thaj, Qarn Abu Wail, Yabrin depressions.**	**Fodder, fuelwood, shade.**
	P. alba	**Introduced lately.**	**Ornamental.**

Table 1. Distribution of *Prosopis* Species and Their Uses in Arab/Gulf States (continued)

States	Species	Habitat	Uses
Bahrain	***P. juliflora***	**Scattered patches of young plants on coastal lowland of the island. A huge single tree (said to be more than 500 years old) is found growing on a mound in central plateau of the island where several oil wells are also present. It is called "Tree of Life" by the locals and its photograph appears on postcards. Vernacular Name: Ghaf.**	**Roadside tree, often planted in close spacing at an area of few hectares on sandy desert. Lower branches are cut regularly to avoid bushy habit. The close canopy provides shade against blazing sun. This place is used for picnics by local people.**
	P. glandulosa	**Introduced during 1950s, scattered patches of young plants are found at coastal lowland. (less vigorous than *P. juliflora*)**	**Ornamental.**
Qattar	***P. juliflora***	**Introduced during 1950s, grows around farmland, isolated, plants are present in depressions. Vernacular Name: Ghaf**	**Hedge plant around orchards, roadside tree, ornamental.**
	P. glandulosa	**Introduced during 1950s, grows around farmland, isolated, plants are present in depressions. (less aggressive than *P. juliflora*)**	**Hedge plant around orchards, roadside tree, ornamental.**
U.A.E.	***P. juliflora***	**Introduced during 1950s, scattered patches at coastal lowland, aggregates in Rasul-Khaima. Vernacular Name: Ghaf**	**Fodder, fuelwood, roadside tree, hedge plant stopping shifting sand, timber for second-class furniture.**
	P. glandulosa	**Introduced during 1950s, scattered patches at coastal lowland, aggregates in Rasul-Khaima. (less vigorous than *P. juliflora*)**	**Fodder, fuelwood, roadside tree, hedge plant stopping shifting sand, timber for second-class furniture.**
Oman	***P. cineraria***	**Native, woodland around depressions in shifting sand and dry river bed. Eastern and western boundaries of Wahiba sea sand. Found in seasonal dry river beds and wadis.**	**Fodder, fuelwood, shade, poles for hutments.**

Table 2. Effect of Interplant Distance on Some of the Growth Attributes of 10-Year-Old *P. juliflora* Plantation

Growth Attributes	Interplant Distance	
	2.0 to 2.5 m	≥5 m
Average height (m)	6.45 ±0.61	9.80 ±0.69
Average number of stems per plant	4.12 ±0.96	7.75 ±2.87
Average diameter of stem (cm)	18.74 ±1.84	26.12 ±4.26
Average canopy cover per plant (m^2)	56.66 ±8.36	88.66 ±14.30
Average basal area per plant (dm^2)	10.61 ±1.03	32.92 ±7.66

ARAB GULF STATES

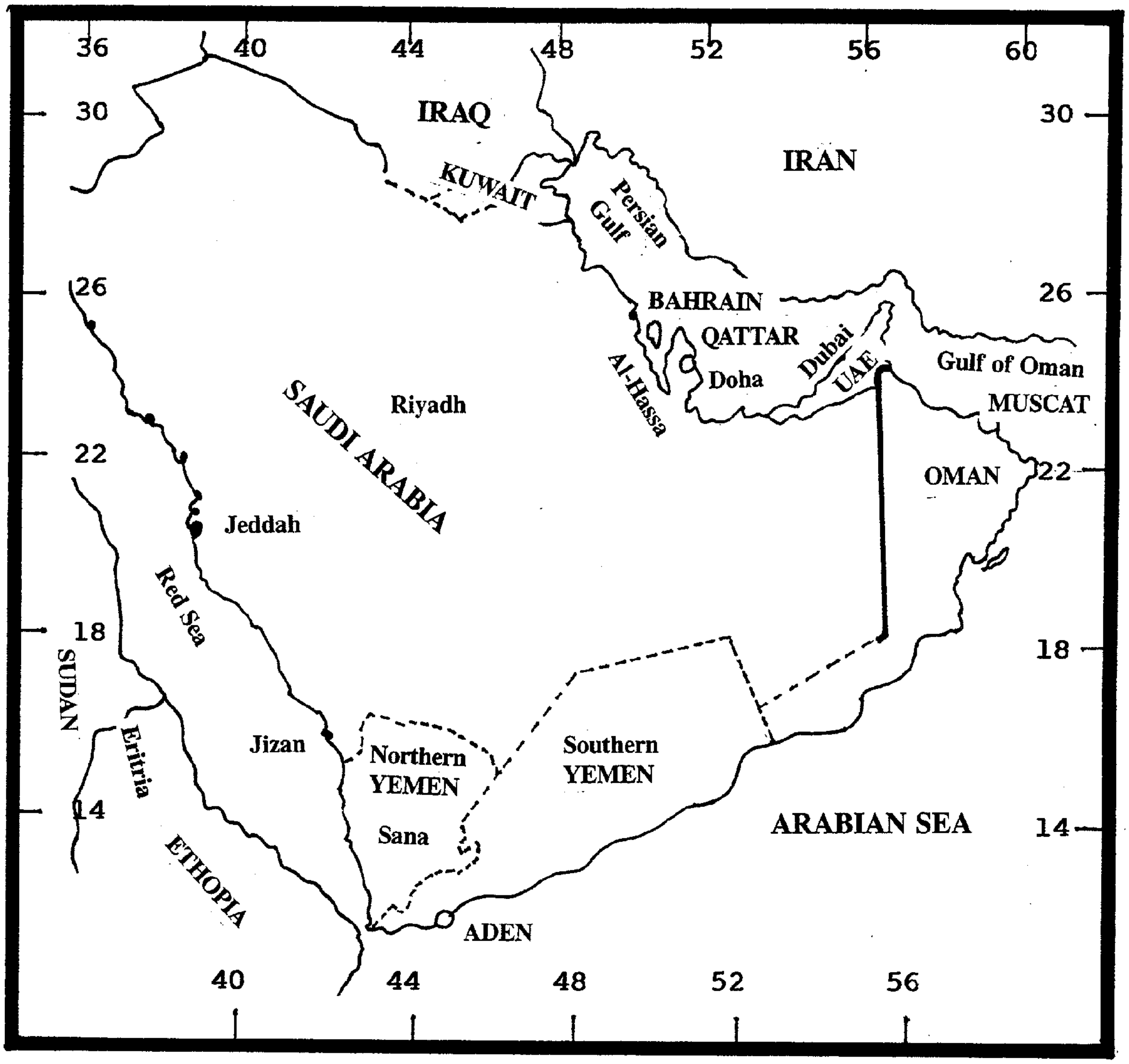

Figure 1. Map of Arab Gulf States Showing Different Places Where *Prosopis* Species Are Found

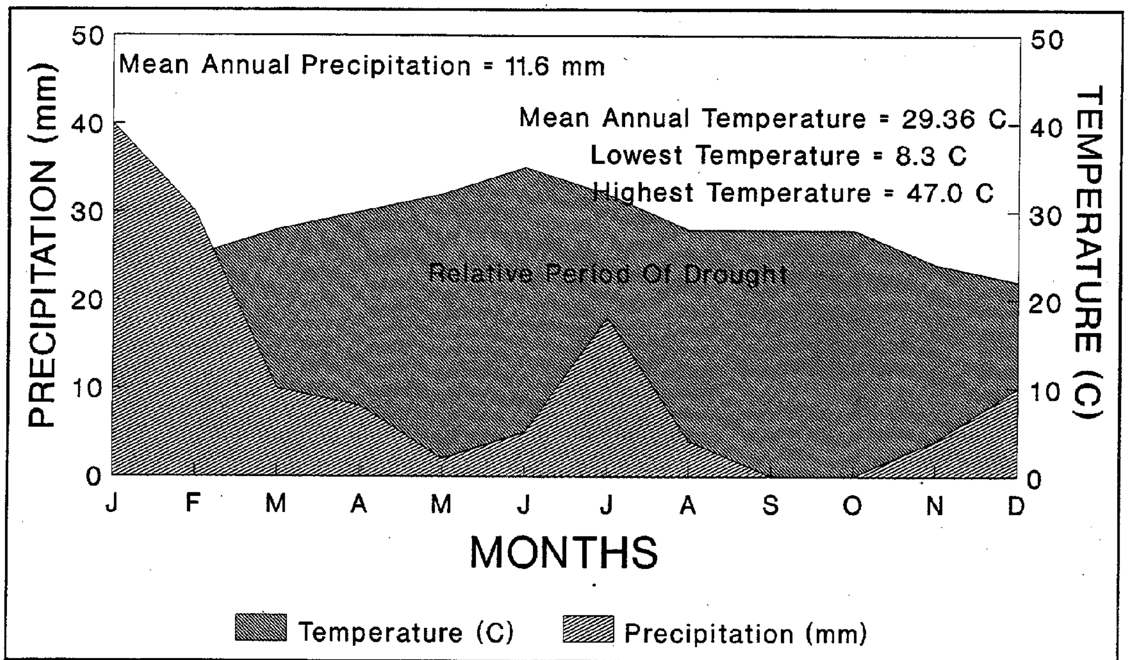

Figure 2. Ombrothermic Diagram of Pasni (on 30-year basis) Where Sand-Dune-Stabilization Programme Was Started in 1970

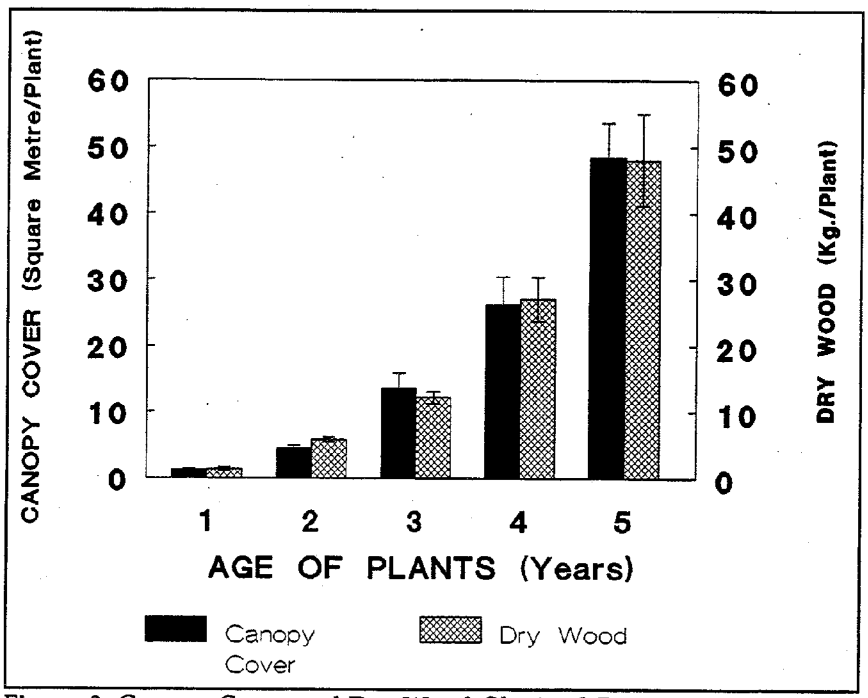

Figure 3. Canopy Cover and Dry Wood Obtained From 1- to 5-Year-Old Plantations of *P. juliflora* Irrigated With Highly Saline Water (EC: 7.0 to 9.2 dS/m) at Coastal Sandy Belt of Pasni (Pakistan)

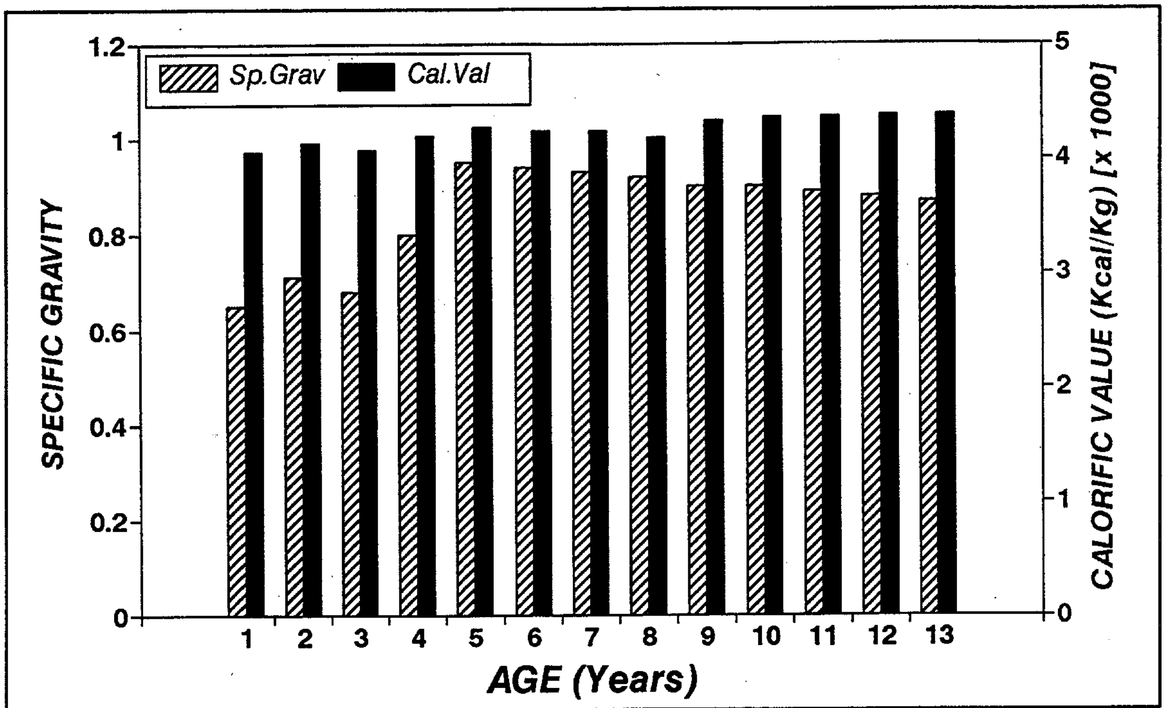

Figure 4. Wood Quality of *P. juliflora* Plants Irrigated With Highly Saline Water (EC: 7.0 to 9.2 dS/m) at Coastal Sandy Belt of Pasni

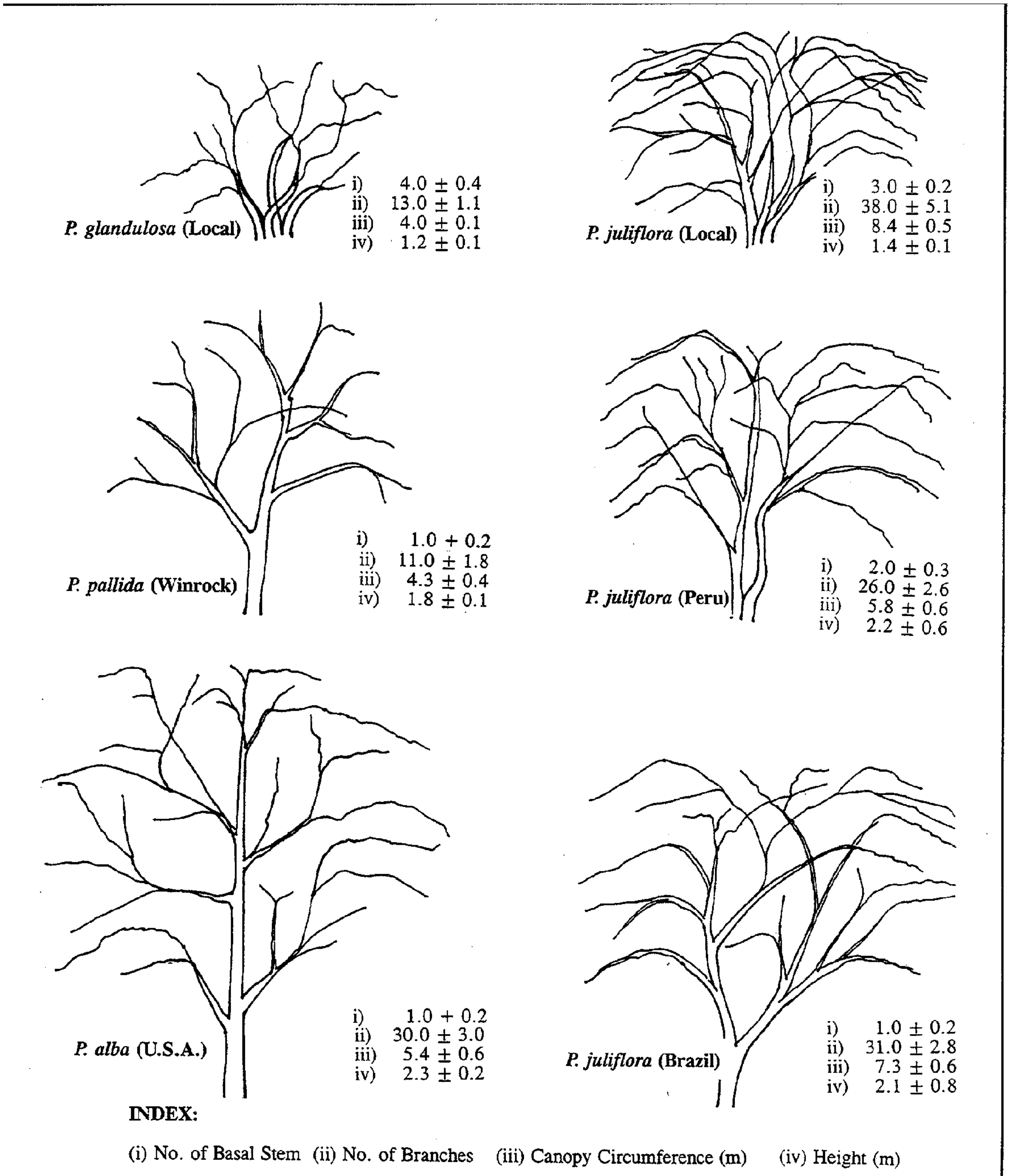

Figure 5. Growth Performance of 2.5-Year-Old *Prosopis* spp. Accessions Irrigated With Saline Water (EC: 14 to 16 dS/m)

Role of Women in the Context of the Implementation of the United Nations Convention to Combat Desertification

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A. Introduction

The 1992 United Nations Conference on Environment and Development (UNCED) recognized the negative impact that rapid environmental degradation has, particularly on women in developing countries linked to their general vulnerable situation. The final document of the Conference, Agenda 21, calls for a Global Action toward sustainable and gender equitable development (Chapter 24) and urges Governments throughout the world to develop strategies of changes necessary to eliminate constitutional, legal, and extralegal barriers that hinder women from participating as equal partners in the sustainable development process. A number of support measures are recommended for the various fields related to development and environment, such as agriculture, fresh water resources, biodiversity, fragile ecosystems, and hazardous waste, to mention a few. The support measures include facilities that specifically address women's need for credit, extension, research, training and education, awareness raising and information, and organizational strengthening.

Empowerment of women is a central concept in the recommendations of Agenda 21. Governments are requested to develop an enabling environment to ensure the active participation of women in natural resource management, including participation in the conceptualization and implementation of programmes.

While Agenda 21 constitutes a very solid document calling for urgent activities to be undertaken, the nature of the document is limited to recommendations to be implemented at each country's discretion and/or potential. But Agenda 21 certainly also constitutes a very ambitious document and its implementation so far has not seen the results that many enthusiastic participants at the UNCED expected. Over the last year, several disappointed voices have been heard, especially from the NGO community.

In the context of the preparation and accomplishment of UNCED, a number of conventions addressing specific fields of the development/environment complex have been prepared and adopted by the international community. Once these Conventions enter into force, they will become legally binding documents obliging the Parties, i.e., governments of developed and developing countries, to undertake a number of measures aiming at sustainable human development.

The Conventions on Biodiversity and Climate Change have already entered into force, while the Convention on Desertification is expected to come into force in 1997. It should be noted that the Convention on Desertification was only prepared after the UNCED and the national ratification process have been launched in many countries.

The following will give a brief overview of some of the main principles of the U.N. Convention to Combat Desertification in countries experiencing serious drought and/or desertification, particularly in Africa (CCD) and analyze its potential impact for promoting the role of women in the drylands. Specific references will be made to gender aspects of fuelwood and dryland management.

B. UN Convention on Desertification

More than 900 million people on the Earth live in areas prone to drought and desertification. The livelihood of women in those areas is often a matter of survival strategies, and environmental concerns are meaningful only when placed in the context of poverty eradication.

The UN Convention to Combat Desertification (CCD) is based on recommendations from the UN Conference on Environment and Development (UNCED) and calls for active involvement of dryland populations in the conceptualization and implementation of national programmes to mitigate the impact from drought and desertification. The CCD emphasizes the strong relationship between sustainable livelihoods and sustainable environment and, in fact, the CCD calls for poverty eradication as imperative to sustainable natural resource management in the fragile ecosystems of the drylands. Special attention should be given to the integration of traditionally marginalized groups like women in the decision-making processes. The CCD was adopted in June 1994 by governments and open for signatures in October 1994. So far the CCD has been signed by more than 115 countries and ratified by 25. The CCD will enter into force on the 90th day after the date of deposit of the 50th instrument of ratification, acceptance, approval, or accession.

Through the CCD, countries affected by drought and desertification commit themselves to "promote awareness and facilitate the participation of local populations, particularly women and youth, with the support of non-governmental organizations, in policy planning, decision-making, and implementation and review of national action programmes [to combat desertification and mitigate the effects of drought]" (Art. 5.d, highlight by author).

The CCD addresses all drylands of the world, including arid, semiarid and dry subhumid areas. Although the mandate is global, the partners are requested to give particular attention to affected countries in Africa, in view of the urgency the desertification-poverty complex plays in some countries in Africa. Presently, activities for the implementation of the CCD have been launched in most affected countries in Asia, Africa, Latin America, and the Caribbean.

The Parties to the CCD are governments from developed as well as developing countries and affected as well as nonaffected countries. All Parties to the CCD commit themselves to promote its implementation and developed countries vow to support financially and technically the activities for the implementation of the Convention.

During the preparation of the CCD, the Parties confirmed the need for a new approach to dryland development and innovative approaches were agreed upon. The Parties agreed to place considerable efforts to ensure the active participation of all dryland populations in the implementation of the CCD. National Action Programmes (NAPs) will be the main operational mechanism of the CCD and emphasis is given to the role of dryland populations in the conceptualization and realization of NAPs. The CCD stresses the need for an on-going planning process, rather than a one-time plan, in order to create a sustainable response to the problems of desertification and drought. The methodology of the NAP process, therefore, calls for the creation of permanent institutional structures to ensure continuous participation of all interested actors.

A broad spectrum of dryland development activities are suggested for the implementation of the CCD according to the national contexts. These activities include development and efficient use of various energy sources, institutional and legal frameworks, and promotion of alternative livelihoods (Art. 10). Of special importance for the gender element regarding the Conventions is that, like the Convention on Biodiversity, it "recognizes the vital role that women play in natural resource management, conservation, and sustainable use of biological diversity and affirms the need for their full participation at all levels of policy-making and implementation."

In the CCD, we have once signed, a legally binding instrument obliging Governments to integrate various stakeholders like NGOs and GROs, research and development institutions, and international cooperation agencies as active partners in the national planning and execution of activities for natural resource management in the drylands. The success of the CCD will depend on the roles accorded to each partner. It is crucial that each partner clarifies their specific roles and prepares themselves for the partnership activities.

C. Women's Participation in the Implementation of the UN Convention to Combat Desertification

Over the last decades, there has been growing recognition of the centrality of the role of women in agriculture and household-food security. In many countries in sub-Saharan Africa, for example, women typically are responsible for the production of at least 80% of the household food production. In addition, women are often responsible for collecting fuelwood and water and are conditioned by land degradation in the form of deforestation and declining agricultural productivity. Yet these same females are rarely systematically targeted for training, extension, research, technology, or improved inputs, let alone involved in policy formulation.

Women's responsibilties in the households are furthermore stressed by the increasing number of households headed by them. The UNDP 1995 Human Development Report shows that in the group of countries with low Human Development Index, to which most sub-Saharan countries belong, 17.5% of households were headed by women in 1990 compared to 13.8% in 1980.

Although there have been many attempts to address gender issues in development, substantial activity, development planning efforts still largely fail to fully recognize women's actual and potential contribution to the development process or the effect of the development process on them. Women are key actors in the economic system, yet their often neglect in development plans has left unused a potentially large economic contribution. Women represent the majority of the population, but they are paradoxically concentrated at the bottom rungs in terms of employment, education, income, and status.

While these gender relations are found throughout the world, they tend to be reinforced by austere and impoverished environments, as experienced in developing countries conditioned by large areas of drylands.

In a presentation of ideas for action and research for engendered sustainable development activities, J. Davidson states that "a major conclusion of recent thinking (developed, for example, in the OECD DAC Women-in-Development Group) is that not only must women's crucial role in protecting and restoring the environment be more widely recognized, but they must be enabled to *benefit* **directly from that role" (J. Davidson, 1991).**

The Parties to the CCD recognize the important role women play, and might play, as natural resource managers and stress the "importance of ensuring the full participation of both men and women [highlight by author] at all levels in programmes to combat desertification and mitigate the effects of drought." Furthermore, the CCD outlines directly specific activities for women that shall be undertaken in its implementation especially at national and local level:

- **Awareness raising (art. 5)**
- **Participation (art. 5 and 10)**
- **Training and capacity building (art. 19)**
- **Education (art. 19)**

But the CCD also contains a number of other provisions for which gender-sensitive activities will be important, e.g.:

- **Poverty eradication**
- **Partnership building**
- **Establishment of national desertification funds**
- **Research and development**
- **Alternative livelihoods**
- **Environmental protection and restoration**

In order to respond to the principle of engendering dryland development activities, it will be necessary to develop and apply gender approaches for the implementation of the CCD at all levels, be it overall policy formulation or implementation of small scale field-level projects.

The gender approaches should include considerations regarding:

- **Power structures within and among social groups like families, communities, and local, regional and national authorities**
- **Differences between women's and men's interests**
- **The dynamic of gender roles**
- **Recognition of local knowledge - including that of women**

Women's voices should, therefore, not only be heard but also be decisive, i.e., women should participate actively in the operationalization and implementation of the CCD.

In a recent meeting for the Inter-Governmental Negotiation Committee on Desertification for the Parties to the CCD (Geneva, Feb. 1996), some NGO representatives expressed their concern regarding the composition of the Government delegations to the Conference, as well as to previous Conferences. The concern was mainly based on the observation that many country delegations only consist of men and that the overall representativeness of women in the meeting might be as low as 10%. It has furthermore, been observed that this picture is repeated at national meetings in the context of the implementation of the CCD. It should be noted that a gender approach does not need necessarily to be developed by women. However, from the political arena, it has been observed that a "critical mass" (about 30%) of female participation in parliaments seems to be decisive for the consideration of women's concerns.

As mentioned in the general presentation of the CCD, the principle of participation is fundamental for the CCD and emphasis is given to the importance of mobilizing the population directly concerned with desertification, i.e., the dryland populations of which more than 50% are women.

To ensure active participation and negotiation on equal terms by all partners, including traditionally marginalized groups like women, a sequence of preparatory activities should take place.

Initially, all potential dryland stakeholders should be identified. A grouping of the populations according to factors, such as their perceived problems and needs, resources, interest in the use of dryland resources, and capacity. This grouping should certainly identify groups that can constitute a rational framework for the promotion of the female dryland populations. The grouping will facilitate the design of targeted and, thereby, more efficient awareness-raising campaigns and capacity building. The capacity-building activities should include negotiation skills and organizational management.

Logistical aspects in relation to participation in the NAP process should also be considered in the preparatory activities. Given their multifaceted roles, women's time is precious and participation in planning activities might be impossible if no incentives are offered. These incentives do not necessarily have to be in the form of financial contributions, but could also be in the form of planning meetings according to women's schedules. Another obvious incentive will consist of awareness raising on concrete activities that the CCD may offer and that are relevant for improving the livelihoods of the intended participants according to their own perceptions.

D. The Fuelwood-Women Complex in the Drylands

In most developing countries, women bear the responsibility for fuel provision and use. Fuelwood still constitutes the primary energy source for most households in the Africa, Asia, Latin America, and the Caribbean.[1] The depletion of the fuelwood resources as a result of the land degradation processes does, therefore, have a special impact on the livelihood of women. Women often constitute a specific target group for projects that have been developed and implemented in most countries facing severe deforestation problems in order to address what has been called the "fuelwood" crisis.

The measures that have been developed to reduce the use of wood for fuel include improved cooking stoves, alternative energies, and fuelwood plantations. The rate of success of all these efforts has been disappointing, but important lessons have been learned, especially regarding the complexity of the problem and the need for holistic and local and participatory approaches (G. Leach and R. Mearns, 1988).

In the context of the complexity of the problem, it should also be mentioned that the gap model[2] used for demonstrating the world's increasing and inherent fuelwood crisis has been questioned more and more over the last years. As such, the model does not consider the local characteristics of deforestation and fuelwood consumption, e.g., studies from Mali show that in certain areas, the fuelwood used consisted only of collected dead branches and twigs (see, e.g., T. Benjaminsen, 1995).

Another point that has been criticized in the approach to reduce the fuelwood consumption is the focus on household use and limit the gender aspect of the complex firewood and land degradation to labour issues within households, while women's role in the overall land management has not received particular attention. "Projects aimed specifically *at* **women have often been unsuccessful, as they tend to ignore the broader social reasons why women are second to men in these concerns." (G. Leach and R. Mearns, 1988). Furthermore, an emphasis of projects aiming at fuelwood reduction is often given to rural contexts. But the over-consumption does not stem from the satisfaction of rural fuel use but rather from urban needs, and the problem should be seen in relation to the channels of provision of fuelwood for the urban areas and the commercialization aspect is, therefore, a key problematic element (G. Shepherd, 1991).**

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[1] As examples, it can be mentioned that in 1992 it was estimated that more than 90% of African households depend primarily on fuelwood as an energy resource (UNEP, 1992). Similar percentages have been found in Bolivia (Lieberman et al., 1995)

[2] The gap model is based on the assumption that the fuelwood consumption is directly linked to tree cutting and that the regeneration rate of the world's forests is lower than the estimated future consumption of wood for energy consumption.

But these commercial aspects of the "fuelwood crisis" do also have an important gender component as rural women in many countries are the primary providers to contractors who commercialize fuelwood in the urban areas. Furthermore, there seems to be an increasing number of women and children marketing fuelwood directly at the markets; often reinforced by the general impoverishment of the rural drylands.

Whether for income-generating interests or for household consumption, a typical "outsider" analysis would show that many dryland women must have an interest in improved accessibility to fuelwood. In an analysis of three social forestry projects in West Bengali, India, C. Nesmith (1991) shows that while the economic benefits from the marketing of the tree products remain with the men, the women villagers recognize some benefits of the plantations as a result of easier access to leaves and dead twigs. As such, it was estimated that the average time for fuelwood collection per household went down from around 29 hours to 14 hours per week. However, C. Nesmith distinguish between these perceived practical and immediate gender needs compared to women's strategic gender needs; in this case, to be expressed in terms of economic independence and stress that the decision of the tree species to be planted in these projects—eucalyptus, which is grown for commercial interests alone—was a direct result of the almost exclusive male-to-male contact between the extension agents and the villagers.

While it might seem obvious that the implementation of the CCD should lead to specific project activities for ensuring efficient fuelwood consumption, actual activities will have to be identified by the stakeholders from the drylands. The development of fuelwood projects will, therefore, depend on the interests from dryland women as well as men and the economic potential for implementing these activities. Further research and development will certainly be necessary, also to prove the cost-benefit relation of various activities integrating the fuelwood problem.

The biodiversity element of fuelwood supply also calls for gender considerations and further development. As such, the role of women in protecting *in situ* **agro-biodiversity is specially important. Not only do they depend on it for their subsistence, but by selecting and planting, they also protect and develop new varieties. Women have an inherent knowledge on biodiversity, but as stressed by J. Aloisi de Larderel (1992) "women's knowledge of biodiversity is eroding as rapidly as the forest resources are being depleted."**

In the design of gender-specific activities for natural resource management in the context of the CCD, the partners, be it dryland populations or outside facilitators, should build on the important lessons that have been learned in the recent reflections over gender and environmental projects.

As an example, it can be mentioned that the results from an analysis of 218 projects worldwide selected for their relative effectiveness with regard to promoting the role of women in environment projects (UNEP, 1992) shows the following characteristics:

- **Participatory approach for environmental problem identification**
- **Low budget with maximum level of local contribution of inputs in form of labour, money, and material**
- **Economic advancement of women to enable them to pursue environmentally beneficial activities**
- **Women participating actively in the conceptualization and implementation of the projects**
- **Education and training on a long-term sustainable basis**

For energy projects, the analysis shows that successful fuelwood projects follow an integrated approach combining the promotion of improved cooking stoves with the development of fuelwood supply, e.g., from through tree nurseries and community woodlots in integrated agro-forestry projects (Madu Sarin, 1992).

E. Conclusions

The CCD is a strong instrument for the advancement of women in natural-resource management and, as such, also for sustainable human development.

The Convention is the result of substantial work, where all signatories or parties have cooperated to the fullest extent in order to develop innovative actions to the benefit of people as well as the environment.

However, the successful implementation of the Convention will require additional substantial efforts from all Governments, including NGOs, and community-based organizations, UN Agencies and Governments from both affected and nonaffected areas to fulfill what they have already committed themselves to do.

With the CCD the promotion of women's participation is no longer limited to small aspects of overall development programmes. Rather, according to the CCD, women should be empowered to participate actively at all levels of dryland management.

Based on its principles of integrated and long-term strategies within a coherent partnership with stakeholders from developed as well as developing countries and affected as well as non affected countries, the CCD might constitute an excellent framework for an integrated approach to *Prosopis* **development. This might cover development of new products, commercialization and development of new markets, efficient energy use, biodiversity, and promotion of agro-sylvo-pastoral systems.**

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Annex 1

The following paper was presented as a background note at a UNDP/UNEP sponsored panel discussion on gender, environment and sustainable human development organized at the International Conference on Women, Beijing, September, 1996. The paper was prepared by UNSO/UNDP and describes major issues related to women's access to land—an issue that is closely linked to land degradation and dryland development.

The note could offer some further insight to the theme of Session 2 of the International Workshop on Prosopis*: Role of* Prosopis *in the Gender/Fuelwood/Land Tenure Complex*.

Women's access to land

Introduction

Various case studies on countries in Africa, Asia and Latin America suggest that without proper solutions for existing land access and tenure problems, participation in natural resource management programmes will not be likely. The key issue is that people do not want to invest time, resources and long-term focused activities in order to preserve a resource if they themselves do not benefit from such an investment through secure rights to a given area (UNSO, 1995).

While secure access to land is a common problem for many agricultural producers in Africa, Asia and Latin America and the Caribbean, the problem is even more critical for the female producers facing discriminatory laws and practices combined with adverse cultural attitudes. The result is that the rural women often lack either ownership or effective control of land, water and other resources, despite their crucial contribution to agricultural production. The negative environmental impact from the lack of motivation in long term natural resource management which is generated from the land tenure situation has in itself a negative impact on the conditions for the rural women.

Secure access to land access for rural women is a decisive issue for sustainable human development. While few national legislations directly discriminate against women's access to land, few legal measures have been implemented that can be considered as directly promoting such access or rights. Enforcement of non-discriminatory legislation that will nullify existing norms mandating all land automatically be titled to men (whether ownership or user rights) would constitute a major step towards sustainable development. In a number of countries it will be necessary to develop and implement special legal measures to promote women's right to land. Such measures would undoubtedly be extremely cost-effective; they would not require important financial resources, but rather substantial institutional capacity building efforts. The result would be increased sustainable livelihoods for rural women, sustainable agricultural production and thereby sustainable development for the concerned societies.

This paper reviews the overall situation of land tenure systems in a number of countries throughout the world in order to show the gender biased situation.

Land Tenure Systems

Land tenure system is an often used concept with a number of definitions, but generally used to describe the social relations that are formed around natural resources (soil, water, flora and fauna) and which determine who can use what resources and how they should be used. Barraclough (S. Barraclough, 1973) suggests that land tenure is the differential distribution of ownership and usufruct rights to land and water among persons or groups. It should be noted, that access to resources does not necessarily include full benefits of the resource, rather it implies that one is under the control of the owner who ultimately benefits from your input (S. Lastarria-Cornhiel, 1995).

Land tenure systems, including allocation of land, are clearly connected to other societal structures which are interlinked with the social relations (e.g. marriage and inheritance systems, economic systems, and power structures). In some rural areas of the Congo, where ethnic grouping is strongly based on "clans", a member of a clan can use land belonging to his clan anywhere in the country. Although the chief of the clan is generally a man, this privilege applies to women and men alike. Similar clan systems exist in Zaire and Angola.

Gender is one of the most important determinants of social relations and rights within rural households and communities. In association with class, gender establishes a person's opportunities, aspirations, standard of living, access to resources, status in community, and perception of self; all factors linked to the existing land tenure systems and all factors linked to sustainable livelihoods for rural women.

Legal Setting and Traditional Institutions

While most constitutions do not discriminate against women, civil codes in several countries still consider the male as the head of household. But even in societies with unbiased civil laws the traditional institutions still function according to patrilineal social structures, which automatically denies women equal access to property and inheritance rights. These traditional institutions or societal structures define the woman or wife as a "transitory" person; a "stranger" to the husbands family. Her transitory status in the male lineage implies that her rights to the land are also only transitory. Thus in cases of divorce or the death of a husband she loses all right to use the land. In many patrilineal societies, due to women's lack of access to land, they thus are rendered dependent on their men or on casual labour (which offers very low incomes). Sometimes women can be found farming fragmented plots of non-arable land, since all the arable land is automatically given to the men. In a recent study on rural women's legal status in Latin America, FAO concludes that "discriminatory customs tend to replace unbiased and sound laws if these are unaccompanied by appropriate enforcement regulations. [Furthermore], in many countries the authorities responsible for allocating land under the agrarian laws refuse to recognize women as heads of household even when law does." (FAO, 1994). Similar situations can be found in Muslim areas in Africa and Asia where both men and women have legal rights to own and inherit land. Though the spouses tend to keep their properties separate, in the end the amount that is inherited by the women amounts to far less than that of the men.

Special problems arise in de facto unions (cohabitation of a man and a woman without marriage). While it is a widespread practice in a number of rural areas throughout the world, there is still a number of countries that do not offer a legal recognition of de facto unions, leaving the women especially vulnerable in situations of separation or at the death of the partner.

There are only a few unique societies in the world which do not abide by the patrilineal structure and instead follow a matrilineal social structure. One example of such a society is to be found among the ethnic group *Minang Kabau* in West Sumatra, where all inheritance rights go to the women. When a woman marries a man, he moves into the woman's family and obtains usufruct rights to the land, but he may never inherit it. It has been observed that men tend to migrate away from home in search of other forms of labour. Similar matrilineal social structures can be found in Bhutan.

Over the last decades, land reforms have been implemented in a number of countries. It is now widely recognized that effective land reforms are not merely a reform of the civil codes and simple redistribution of the land. Rather, land reforms call for an integrated approach requiring a number of support mechanisms like credit and extension facilities in addition to institutional building activities aiming i.a. to change the traditional customs. Effective support mechanisms have failed in most countries that have experienced land reforms and the gender biased customs for land distribution have not been addressed.

Africa

In almost all African countries more women than men live in the rural areas. Men are migrating to other areas in search of other income sources and subsequently women are left at home and the number of female headed households is on a steady increase in rural areas. But their position in society, due to their gender, denies them to further resources (e.g. training, credits, information, capital) and participation in local management institutions.

Riddell remarks that a remarkably diverse set of land tenure arrangements is to be found in Africa (J. Ridell, 1985), reflecting the extremely diverse cultural setting and to a certain extent also the geographical and climactic variations. Customary land tenure, i.e. tenure patterns that have continued to evolve from institutions established before the colonial period, figures predominantly.

In a recent study Mini (1994) reviews some major categories of African land tenure systems:

- In **freehold tenure systems**, land transactions are basically carried out on a traditional basis, that is, even though tenure in these villages is officially described as freehold, the daily land use and land transactions revert back to traditional practices. Unmarried women have no right to arable land. Married women have secured and protected rights to arable land as long as they remain married (upon death of husband, their land rights are passed on to eldest son).

- In the **trust and quitrent tenure systems**, issues of inheritance (in cases of separation or death) are left to the traditional law. This usually means that women inherit little or nothing.

- In **communal land tenure systems**, access to land is based on traditional institutions and the authority remains with the men. The head of the village (a man) of the chieftain has the ultimate authority and control over the communal lands. He is the one who makes all the decisions regarding who has the right to cultivate and use what land (S.E. Mini, 1994).

Those systems imply that women have no direct access to arable land by their own right; they attain such access only by virtue of marriage.

A Workshop on Land Tenure Systems in West Africa held in 1994 (funded by OECD) showed that women's land rights are uncertain, insecure and most importantly, unequal. Women slightly outnumber the men and their agricultural and rural economic contribution is often disproportionately high, yet they form the marginalized majority. Even though women play such an active role in the productive work and have a decisive role in the education and reproduction of the culture, they are continually confronted with inequalities in their access to natural resources (in comparison to men).

The most common way for women to obtain access to land is through the allocation of a plot of land which belongs to their husband's family. Those allocated fields are usually smaller and of lower quality. They only have usufruct rights over this plot of land. Should the husband die, the land is given back to his family, and the woman is left with nothing. In the case of divorce, the land automatically stays with the husband (G. Hesseling, 1994).

Asia

It has not been possible for present paper to identify studies giving a general overview of gender related issues to land tenure systems in Asia. The following will review the subject in the two biggest nations on the Asian Continent.

China has a long tradition of male control over resources and decision making although substantive improvements have been noted since 1949, when one of the major goals of China's social and economic policies was to achieve equal rights for both sexes.

In the 1970's the People's Republic of China began a reform process, bringing the system of rural communes to a halt. The communes were divided up, and management of and income from land were given to the farm households in a smaller production system under what is called the *Household Responsibility System*.

While women certainly have gained improved livelihoods with the general positive trends in the rural economy it should be noted that inheritance of the farm households still goes from father to sons or other male relations. Occasionally widows hold land on behalf of their infant son, though often to entrust it to a male relative.

In **India** one needs to realize that although the caste system has legally been abolished, it still remains ingrained in the minds of the people, especially in rural areas. The caste system is not only class discriminatory but also highly gender biased. Furthermore, the legal system is still reflecting the prevalent religions.

The first step the British administration took was in land reform, which allowed individuals (read individual men) to transfer their interests in land and subsequently diminish the power of landholders and ensure the security of private property. The British did not destroy the traditional structure of Indian society; instead the old mentality of hierarchy just remodelled itself to fit the British administration. Over all the British system had the effect of concentrating land into the hands of few upper castes.

Under the land reform of the 1970s, land was redistributed to landless and small farmers in the name of the heads of the households, namely the men.

With Independence, Indian women got constitutional rights and privileges of ordinary citizens. Some civil laws have targeted the rights of women as the Hindu Succession Act from 1956 which gave female children equal rights to inherit the paternal property.

Latin America and the Caribbean

In spite of a number of agrarian reforms implemented in the Latin American and Caribbean region over the last decades, the majority of the land is still concentrated in the hands of very few owners of the so called latifundios (large estates). This also means that the majority of rural households (more that 2/3 of the total number of rural households) do only dispose of limited land, or minifundios (small farms).

Most of the agricultural laws establish land allocation based on a points or priority system, giving the priority to the men of families. Throughout Latin America, with the exception of Cuba and Nicaragua, agrarian reforms do not recognize women's interests as their direct objectives. Furthermore, agrarian reform takes no account of the fact that women can become heads of households when the men migrate. Rural households headed by women are rapidly increasing mainly as a result of male economic migration. According to Galan between 40% & 50% of the households in the Caribbean are headed by women, in Central American between 15% & 33%, and in South America between 16% & 25% (B. Galan, 1995).

Civil Codes of several Latin American countries still consider the man as the head of household, and even when civil codes recognize women as heads of households the prevalent application of traditional customs and negligence of civil codes prevent rural women to equal land access (FAO, 1994).

FAO has done extensive research on legal status of rural women in Latin America and concludes: "The most usual way for the rural women in almost all Latin-American countries to gain access to land is through succession or through the allocations made under some countries' Agrarian Reform Laws. Although statistical evidence as to the magnitude of this problem for landless rural women is unavailable, some recent studies maintain that there are sufficient grounds to show that rural women are systematically denied access to land and direct control over other means of production" (FAO, 1994).

Conclusion

Evidence from Africa, Asia and Latin America and the Caribbean, shows that securing women's access to land as well as support measures like credit and extension services is crucial, if one aims to promote their sustainable livelihood. The study of women's access to land needs to be looked at with greater urgency, since little has been published about it. A lot of information is to be found on land tenure systems (per se), but the mention of gender in relation to land tenure has still to be pursued. Most studies of land tenure systems mostly neglect to mention how it affects the livelihood of women, although some institutions lately have focused specifically on this very issue (e.g. FAO and the Land Tenure Center at the University of Wisconsin in USA). In studying the various land tenure systems and attempting to comprehend them, it is necessary to refer to the traditional customs and kinship structures, since they have been and still tend to be the barriers to women's equal access to resources.

To promote the possibilities of rural women to become efficient natural resource managers, it will be necessary to institutionalize a number of support mechanisms that deliberately provide women with facilities like credit, information, marketing, extension and appropriate technology. It will also be necessary to promote the representation of women in local management institutions.

It might be interesting to recall paragraph 62 of the *Nairobi Forward Looking Strategies, from the Women Conference in 1985:* "Agrarian reform measures have not always ensured women's rights, even in countries where women predominate in the agricultural labour force. Reforms should guarantee women's constitutional and legal rights, in terms of access to land and other means of production, and should ensure that women will control the products of their labour and income; as well as benefits from agricultural inputs, research, training, credits, and other infrastructure facilities". **We still need those reforms.**

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Annex 2

Specific provisions in the CCD regarding women (highlights by author)

Introduction

The Parties to this Convention,

Stressing the important role played by **WOMEN** in regions affected by desertification and/or drought, particularly in rural areas of developing countries, and the importance of ensuring the full participation of both men and **WOMEN** at all levels in programmes to combat desertification and mitigate the effects of drought,

Article 5

Obligations of affected country Parties

In addition to their obligations pursuant to article 4, affected country Parties undertake to:

(d) promote awareness and facilitate the participation of local populations, particularly **WOMEN** and youth, with the support of non- governmental organizations, in efforts to combat desertification and mitigate the effects of drought; and

Article 10

National action programmes

2. National action programmes shall specify the respective roles of government, local communities and land users and the resources available and needed. They shall, inter alia:

   (f) provide for effective participation at the local, national and regional levels of non-governmental organizations and local populations, both **WOMEN** and men, particularly resource users, including farmers and pastoralists and their representative organizations, in policy planning, decision-making, and implementation and review of national action programmes; and

Section 3: Supporting measures

Article 19

Capacity building, education and public awareness

1. The Parties recognize the significance of capacity building -- that is to say, institution building, training and development of relevant local and national capacities -- in efforts to combat desertification and mitigate the effects of drought. They shall promote, as appropriate, capacity-building:

   (a) through the full participation at all levels of local people, particularly at the local level, especially **WOMEN** and youth, with the cooperation of non-governmental and local organizations;

3. The Parties shall cooperate with each other and through competent intergovernmental organizations, as well as with non-governmental organizations, in undertaking and supporting public awareness and educational programmes in both affected and, where relevant, unaffected country Parties to promote understanding of the causes and effects of desertification and drought and of the importance of meeting the objective of this Convention. To that end, they shall:

   (e) assess educational needs in affected areas, elaborate appropriate school curricula and expand, as needed, educational and adult literacy programmes and opportunities for all, in particular for girls and **WOMEN**, on the identification, conservation and sustainable use and management of the natural resources of affected areas; and

ANNEX I

REGIONAL IMPLEMENTATION ANNEX FOR AFRICA

Article 8

Content of national action programmes

2. National action programmes shall, as appropriate, include the following general features:

(c) the increase in participation of local populations and communities, including **WOMEN**, farmers and pastoralists, and delegation to them of more responsibility for management.

ANNEX II

REGIONAL IMPLEMENTATION ANNEX FOR ASIA

no specific mention

ANNEX III

REGIONAL IMPLEMENTATION ANNEX FOR LATIN AMERICA AND THE CARIBBEAN

no specific mention

ANNEX IV

REGIONAL IMPLEMENTATION ANNEX FOR THE NORTHERN MEDITERRANEAN

no specific mention

Prosopis in Sahelian Forestry Projects: A Case Study from Niger

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ABSTRACT

A review of 20 years of agriculture and natural resource (ANR) projects implemented by CARE International in Niger provides background data for a discussion of the role of *Prosopis* in forestry development projects in the Sahel. All of CARE's ANR activities in the Sahel were intended to address concerns of food self-sufficiency and land degradation. The salient programmatic feature was an emphasis on environmental protection. Within this broad focus project activities evolved from: 1) windbreak establishment and dune fixation, to; 2) tree planting and agroforestry interventions, to; 3) watershed management and soil- and water-conservation activities.

Almost every ANR project over the last 20 years has used *Prosopis juliflora* in one or more of its activities. The most common use is for stream bank stabilization, followed by planting for living fences. It has been tried, unsuccessfully, for both windbreaks and dune stabilization. On a more limited scale it has been used to reforest degraded grazing lands behind stone terraces or in microcatchments.

Advantages of the species include ease of germination and nursery handling, high survival rates, vigorous growth, and nutritious seed pods.

However, the disadvantages are strong enough to deter most farmers from planting the species on their own land. The nasty thorns, aggressive growth, and wide spreading crown of *Prosopis juliflora* make it an undesirable candidate for field planting, and difficult to manage for woodlots and living fences. It is the species of last choice for firewood collectors. The planting of *P. juliflora* has been carried out by development projects on public domain land using food-for-work or paid labor.

Improvements need to be made for greater utilization of the species or alternative species, such as *Prosopis africana*, promoted to maximize benefits to farmers.

INTRODUCTION

A review of 20 years of agriculture and natural resource (ANR) projects implemented by CARE International in Niger provides background data for a discussion of the role of *Prosopis* in forestry development projects in the Sahel (Butterfield and Kauck 1996). The programmatic approaches, technical interventions, and species used in these projects are representative of ANR projects across the Sahel and among various development organizations. Thus, CARE Niger's case history and lessons learned are relevant for other implementing agencies in the region.

Following the disastrous drought of 1968-73, the attention of Sahelian governments, donors, and humanitarian organizations focused upon chronic problems of food insecurity and the degradation of arid and semiarid lands on which rural households ultimately depend for their livelihood. These two problems were understood to be linked and to be deteriorating. In response, the development priorities established by governments and donor agencies focused on increasing food self-sufficiency and implementing antidesertification measures. Food self-sufficiency projects strove to:

- Increase the area devoted to dry season gardening using shallow wells for hand irrigation
- Intensify the use of seasonal and permanent ponds for gardening
- develop small-scale irrigation areas
- diversify production systems through the introduction of fruits and vegetables in gardens

Antidesertification measures focused on reclaiming degraded land and increasing vegetative cover.

Over the last 20 years, all of CARE's ANR activities in the Sahel were intended, in one way or another, to address these concerns. The salient programmatic feature was an emphasis on environmental protection. Project goals and objectives were oriented to "protecting the environment" or "increasing agriculture productivity through environmental protection". Within this broad focus, project activities evolved from: windbreak establishment and dune fixation, to tree planting and agroforestry interventions, to watershed management and soil- and water-conservation activities.

TECHNICAL INTERVENTIONS AND TREE SPECIES USED

Windbreaks and Dune Stabilization

CARE's first agroforestry project, the Majjia Valley, was a response to complaints by local residents about wind damage to crops. Wind-blown sand funneled down the valley, sand-blasting young millet plants. Farmers sometimes had to replant their crop several times, significantly increasing the risk of crop failure. The valley had fertile soil and a high water table, creating an unusually productive site.

The first windbreaks copied existing experimental windbreaks in the valley: double rows of neem trees (*Azadirachta indica*) spaced 4 x 4 m with 100 m between windbreaks (Figure 1). As the trees grew, however, the gap under the crown allowed wind through, diminishing the breaking effect. The project switched to one row of neem trees and, on the windward side, a row of the shorter, wider crowned, slower growing *Acacia nilotica*. *Prosopis juliflora* was also tried as a complementary species to neem but farmers did not want either *P. juliflora* or *A. nilotica* planted in their fields because of the thorns that got underfoot.

On productive sites with high water tables, neem proved to be a good windbreak species due to its fast growth. However, where soil fertility was low and the water table deep, neem did not perform well. A switch to native *Acacia* sp. also proved unsatisfactory due to slow growth and heavy grazing pressures which reduced survival.

In 1976, CARE and the GON (Government of Niger) responded to requests from local residents who were concerned about the encroachment of large shifting dunes on a narrow valley where farmers depended on irrigated gardens for their livelihood. Dune-stabilization techniques consisted of: 1) protecting the area from grazing and farming with fences or guards for two years; 2) constructing 1 to 1.5 km of millet stalk fences per ha (these serve as windbreaks for three years and then fall over and add organic matter to the soil); 3) planting of fast-growing tree species (*Eucalyptus camaldulensis*) as windbreaks followed by native species (*Acacia senegal*); and 4) allowing natural grass and vegetation to reestablish. *Prosopis juliflora* was planted in the early years of dune stabilization but its use was discontinued in favor of *Eucalyptus* and *A. senegal* which had higher survival rates (N'Tirgny 1983).

Despite the technical success of dune-stabilization activities, it is expensive to implement and requires the cooperation of local residents to enforce grazing restrictions. This cooperation is more likely where valuable resources are at stake, such as dune encroachment on intensive farming systems.

Tree Planting and Agroforestry Interventions

Agroforestry interventions that have been widely disseminated by CARE across the Sahel include: 1) live fencing; 2) tree planting in fields, orchards, or along property boundaries; 3) protection of natural regeneration; and 4) wood lots. All of these are innovative ways to encourage tree planting to increase vegetative cover.

Live fencing

Animals are an integral part of the agricultural system in the Sahel. They graze in forests, open pasture land, and on field stubble after grain harvests. During the rainy season, animals are well tended by herders or taken far from villages in order to protect field crops from grazing and trampling. During the dry season, animals graze near villages. Hungry, wandering animals are a problem for dry-season gardening. Traditionally, people build a barricade of thorny branches or millet stalk fences around their gardens, which need to be renewed annually.

The GON viewed traditional fencing as a constraint to expand the area in dry season gardening and a negative practice contributing to deforestation. Therefore, CARE experimented with alternative fencing options, from 5-strand barb wire to cyclone fencing. The idea of live fences was settled on as a low-cost means for farmers to not only protect their gardens but to enjoy additional benefits, such as reducing the amount of branches cut for traditional fences, reducing wind erosion and sand buildup in gardens, creating a favorable microclimate in gardens, and producing forage and firewood. Many different species and combinations were tried until *Prosopis juliflora* became the standard species for live-fence planting.

However, planting trees around a garden does not make a fence. Trees need to be pruned, their branches woven together, gaps replanted—in short, they need to be managed in order to become an effective barrier against animals. Most live fences that were established were never managed (Figure 2) so they were either ineffective or were reinforced using traditional dead branches. The *P. juliflora* thorns discourage pruning and management, while those same thorns make the dead branches effective animal barriers.

Field enrichment planting

The failure of several projects to successfully establish windbreaks on marginal sites with low water tables led to the idea of planting individual trees in farmers' fields, which would have similar effects in reducing wind erosion and increasing water infiltration while replenishing soil organic matter and providing dry-season fodder for animals. Nitrogen-fixing trees were targeted for their potential beneficial effects on soil fertility. *Faidherbia albida* is uniquely adapted for this as it is the only Sahelian species that is leafless during the rainy season and does not shade the cereal crop. During the dry season, it produces nutritious seed pods which are an important food source for animals. CARE estimates that 40 to 60 mature trees per hectare are ideal for environmental protection of agricultural fields.

However, the general belief in the fertilizer effect of *F. albida* may be overly optimistic given modern grazing pressures on the trees. Farmers indicated that the leaves of the tree serve to enrich the soil. Due to the strong demand on the species for fodder, this effect has likely been restricted to the accumulated manure of animals that congregate under the tree for shade, leaves, and fruit. The reduced soil and air temperatures under the tree's crown early in the planting season (before it sheds its leaves) invigorates early plant growth as well. However, in areas with heavy pruning for fodder, the crown of the tree is significantly shrunken, reducing leaf fall and shade effects. Furthermore, if the fodder and seeds are removed from the site to feed animals elsewhere, the main fertilizer effect is also lost.

Several projects promoted the planting of fruit trees, (exotic: mango, papaya, citrus, guava; and native: *Balanites aegyptiaca*, *Ziziphus mauritiana*) and native species whose leaves are used to make sauces (*Adansonia digitata*, *Moringa oleifera*). These species were popular with farmers but were not always planted on the appropriate sites for adequate growth. When planted in "community lots" trees tended to be neglected and survival low. In contrast, farmers cared for trees planted within their compounds or private fields.

Protection of Natural Regeneration

The idea for promoting the protection of natural regeneration in CARE projects started in the Majjia Valley. Grazing restrictions already in force to protect young windbreaks provided an opportunity to protect the natural regeneration of slow-growing but longer-lived native species in farmer fields. These trees might later serve many environmental functions and eventually replace senescent windbreaks (Figure 1).

A Sahelian-wide study of natural regeneration noted that the most common species to be protected by farmers were: *Faidherbia albida*, *Balanites aegyptiaca*, and *Hyphaene thebaica* (Cissé 1991). It also noted that the most important agroforestry species were found on fields closest to the village where farmers spend more time and can thus better monitor seedling development.

Probably the most important physical factor limiting natural regeneration is seed source. Field visits revealed heavy pruning of *Faidherbia albida*, resulting in little or no seed production. Seed that is produced is quickly gathered and either fed to animals tethered in the village or sold. In the former case, the return of animal manure containing the defecated seeds to the fields would promote good seed germination. This is also the likely means for the widespread colonization of *Prosopis juliflora* beyond the original sites where it has been planted.

Woodlots - Public and Private

The rational behind the promotion of woodlots was to produce needed construction wood and poles, thus reducing demand on natural resources and native tree cover. CARE's evolution in their approach to promoting this activity mirrors the overall evolution in the entire ANR portfolio, i.e., a gradual shift from community-based activities toward individual actions by private farmers.

The establishment of village woodlots was a standard component in CARE agroforestry projects for 10 years despite limited success. Villages were requested to identify land for the planting of 2 to 10 ha of eucalyptus or neem trees for wood production. Given the land scarcity in many areas, villagers often assigned the most marginal site to the woodlot in an effort to conserve prime farm or pasture land.

Later agroforestry projects changed their approach to encourage the planting of private woodlots. This has been moderately successful for those farmers with excess land to commit to permanent tree crops, i.e., village chiefs or wealthier peasants. Woodlots are managed through coppicing for the production of poles. The most common species used are *Eucalyptus camaldulensis* and neem. Several farmers have harvested wood more than 2 or 3 times and enjoy a modest income from the activity.

Watershed Management and Water and Soil Conservation

After more than a decade of focusing on reforestation and agroforestry activities, the CARE-Niger ANR portfolio expanded to include broader environmental issues at a watershed level. During the 1970s and 1980s, one of the GON's strategies for addressing food security needs was to develop the irrigation potential of Niger's watersheds. A number of small catchment dams and irrigation systems were built during this period. Within the Majjia Valley concern was expressed about evapotranspiration from the windbreaks and possible consequences on the water table. Grazing and woodcutting restrictions in the valley bottom had intensified those activities on fragile valley slopes and uplands. This contributed to reduced vegetation cover, more water runoff, decreased water infiltration, and a perceived decline in the valley water table. The latter negatively affects dry season gardening, irrigated from shallow wells, in the valley.

These factors lead CARE to a more holistic approach in the treatment of environmental problems that involved large-scale public works for soil and water conservation. Public works activities were intended to mitigate the physical deterioration of the watershed(s). They required labor mobilization through incentives and communal work. Principal project activities included:

- **Construction of parallel rows of dry rock walls** along contour lines of the watershed's steep upper slopes. These were intended to slow rainfall runoff, discourage erosion and, to the extent that erosion continued to occur on the treated slopes, to trap sediment behind rock walls. It was also hoped that increasing soil humidity and sediment capture on upper slopes would encourage the regeneration of vegetation and, subsequently, the creation of new top soil.

- **Tree planting.** Trees planted parallel to and between newly constructed rock walls were also intended to slow runoff, hold soil, and assist the regeneration of vegetation and soil on the upper slopes. Tree planting along stream banks was promoted to slow bank erosion.

- **Construction of check dams** was intended to lower water velocity, thus reducing gully erosion and capture sediment before it reached the bed of the reservoir. This intervention is not discussed in this paper.

- **Microcatchments** were used to increase water infiltration on degraded or lateritic soils for reforestation or marginal agricultural production.

These techniques were standard "antidesertification" practices being promoted throughout the Sahel. Many of them were incorporated into public works projects which used food-for-work to mobilize labor while other technical interventions focused on individual farmers and used no outside incentives.

Rock contour walls

The simplest and most widely adopted type of rock contour wall is a single line of rocks along the field contours (*cordon de pierres*). Rock contour lines are traditional soil conservation techniques already in use by farmers. Project staff teach farmers easy methods for determining the contour (a clear hose with water, or wooden poles). The rocks slow water runoff thus protecting downstream crops while increasing water infiltration. Soil also builds up behind the rocks, conserving an important farm asset. Narrow earth berms are also used for the same purpose.

Stone walls, 40 to 70 cm high, are used on the upper slopes of watersheds to reduce water runoff and soil erosion (*murets*). Trees are planted behind the walls to take advantage of better water infiltration and to reforest denuded hillsides. Hardy species are used which are drought resistant such as *Prosopis juliflora*, *Combretum* sp., and native *Acacia* sp. (*A. senegal, A. seyal, A. nilotica*). On slopes with some soil,

these walls do help to increase vegetative cover and accumulate sediment that would otherwise flow downstream (Figure 3). They are especially effective where slopes meet sandy plains and erosion is acute. However, many *murets* are built on lateritic slopes and show no soil accumulation behind the walls. They may slow water runoff but appear to be unnecessary for soil conservation and ineffective for revegetation.

Stream-Bank Tree Planting

This activity was incorporated into many of CARE's agroforestry projects. It involved planting densely spaced rows of *Prosopis juliflora* along stream banks to reduce bank erosion. Seedlings were provided by the projects, from central, village, or private nurseries, and local farmers were mobilized to plant them. This "biological" control was the only intervention used to reduce bank erosion, no physical barriers were constructed to control water flow (Figure 4).

Where trees were planted far enough away from stream beds to avoid immediate erosion, they thrived and, as larger trees, they seem to be slowing bank erosion. The vigorous growth of this species along stream beds should provide an abundant source of fodder and firewood for local farmers. However, most trees show little sign of harvesting, indicating that they either quickly regenerate or that they are not fully utilized due to the thorns and bushy growth which makes wood harvesting difficult and discourages animal grazing.

Microcatchments

Microcatchments, crescent or V-shaped excavations (*demi-lunes*), were used to reclaim degraded hard-packed soil that has low water infiltration capacity. Grasses, annual crops, and/or trees are planted in the microcatchment where they are able to utilize captured water. Deeply dug trenches around a central shelf, are also used to plant trees and catch runoff (*tranchées*). Despite the recognized success of these methods to establish vegetation or grow a few crops, the high costs and minimal returns are unappealing to farmers. The trenches are unlikely to be tried outside of a project with resources to spend on reforestation. The microcatchments can easily be dug by individual farmers but are only adopted where land is scarce and labor abundant. Other development agencies have planted *P. juliflora* in these demi-lunes as part of public-works projects.

A simpler, cheaper variation of the *demi-lune* are micropockets (*zais* or *tassas*) for sowing seeds. This is a traditional practice which has been "improved" by recommending the addition of animal manure in the pocket and by offsetting each line of pockets in order to capture more water runoff. Where farmers lack decent land for agricultural expansion, the micropockets have been used successfully to grow modest crops (not trees) on previously abandoned land. The technique has been quickly passed from farmer to farmer.

The Role of *Prosopis juliflora*

Figure 5 summarizes the uses of *P. juliflora* within CARE's ANR projects in Niger. Almost every ANR project over the last 20 years has used the species in one or more of its activities. The most common use is for stream-bank stabilization, followed by planting for living fences. It has been tried, unsuccessfully, for both windbreaks and dune stabilization. On a more limited scale it has been used to reforest degraded grazing lands behind stone terraces or in microcatchments.

Advantages of the species include ease of germination and nursery handling; high survival rates; vigorous growth; and nutritious seed pods. Nursery workers who are paid for each surviving tree are keen on *P. juliflora* as they often obtain 100% germination and survival from seedlings. If protected from grazing when very young, the species survives and grows well (especially along stream banks and near gardens). The fruit pods are gathered and eaten by young children who find them a delicious snack. Pods are also gathered and feed to livestock, whose defecations are effective in spreading the species. The Lake Chad basin within Niger is reported to be entirely covered by *Prosopis* sp. (possibly

P. juliflora or *P. chilensis*; W. Mullié, pers. com.), while numerous village roads have been encroached upon by exuberant growth.

The disadvantages, however, are strong enough to deter most farmers from planting the species on their own land. The planting of *P. juliflora* has, for the most part, been carried out by development projects on public-domain land using food-for-work or paid labor (stream-bank protection, along terraced slopes, within microcatchments on abandoned land). The one exception is living fences, but many of these were planted by farmers as a prerequisite to gain access to other project resources such as wells, tools, and/or seeds.

Farmers are reported to have a love-hate feeling toward the species, with the majority of people reporting a strong dislike. Translations of common names given to the tree explain why: "viper", “bastard thorn,” and “dangerous thorn” (Z. Tchoundjeu pers. com.; *shejain kawa*, *mugun kawa* in Hausa: E. Lindenberg pers. com.). Thorn pricks are painful, causing hands and limbs to swell. One unfortunate farmer who stepped on a thorn, developed gangrene and died (E. Lindenberg, pers. com.). In a rural environment with little access to health care and poor hygiene, these concerns are serious.

The nasty thorns, aggressive growth, and wide-spreading crown of *Prosopis juliflora* make it an undesirable candidate for field planting. They also make it difficult to manage for woodlots, or to prune or weave as needed to make an effective living fence. The firewood is appreciated by cooks but it is the species of last choice for wood collecting, again, due to the thorns. Claims of fodder production are unfulfilled as evidenced by the abundant, low-lying, green branches—animals do not eat the leaves. The pods are reportedly underutilized; the nutritive value could be increased by grinding pods for animal feed (Poulsen 1987).

Although the species has proven to be successful in reforestation programs from a silviculture perspective, it's common use around gardens and streams and invasive habit are worrisome. The species does not provide as many benefits as alternative, less thorny, more palatable species might, while it occupies and colonizes sites with higher than average water resources. Improvements need to be made for greater utilization of the species or alternative species promoted to maximize benefits to farmers.

LESSONS LEARNED

The ANR portfolio review identified numerous lessons learned to improve ANR programming and project impact. Two important issues are discussed below: the relevance of tree planting and environmental protection to the needs of farmers and the role of property rights in determining project success and sustainability.

Relevance of Project Interventions

The population of the Sahel has doubled since CARE started its first agroforestry project in the region. Despite the noble intentions of the GON to target food self-sufficiency goals for the country, these goals appear to be unrealistic given the marginal and variable nature of Sahelian agriculture and rapid population growth. Where agriculturalists have expanded into pastoral areas with poor soils and low rainfall, the best development strategy is to minimize risks from agricultural failures and diversify income sources to reduce dependence on harvests (Sumberg 1991). On relatively fertile, higher rainfall sites, interventions need to go beyond environmental protection to include activities for the intensification of integrated farming systems, with a focus on improving soil fertility (Speirs and Olsen 1992).

A central theme of CARE ANR programming in the Sahel has been agroforestry: ostensibly the planting of trees to augment agricultural production. CARE designed or used "agroforestry" systems that were based on simplistic assumptions that trees reduce soil erosion, increase soil humidity, and add organic matter (Sumberg and Burke 1991). With the single exception of windbreaks in the Majjia valley these assumptions were never tested. Tree-crop interactions can be complex and are not necessarily beneficial, especially when roots compete for water and nutrients. While agroforestry is based on sound agronomic principles, in practice, the actual impact of tree cover on agricultural production is often marginal and is extremely difficult to evaluate. Moreover, in most cases, the economic benefits of increasing tree cover are likely to be realized over the long-term, whereas farmers' willingness to invest typically does not extend much beyond the next harvest.

The real implicit goal of CARE's agroforestry activities was reforestation; the reestablishment of vegetative cover to fight desertification. This goal complied with the priorities of the GON and donors. Tree-planting activities were justified in terms of their beneficial long-term impact on the environment, and thus by association, benefiting agriculture (Sumberg and Burke 1991). The underlying assumptions to these rationalizations are that deforestation has lead to climatic change, which, in turn, causes droughts and threatens agricultural land as the desert advances southward. These assumptions, unsupported by scientific data, were in vogue in the 1970s and 1980s (Denève 1995). The long-term and marginal relationship between reforestation and improved agricultural production casts doubt on the ability of anti-desertification measures to adequately address the real and immediate needs of the rural population (Sumberg 1991). Governments and donors need to reformulate development priorities to reflect realistic assessments of environmental limits and socio-economic constraints to development activities.

Property Rights

Development projects have consistently ignored issues of property rights when trying to implement changes in land-use practices. This arises from two causes: 1) channeling of project resources through government agencies who are often "at odds" with traditional resource management and property rights systems; and 2) the divergence of farmer's interest between public goods and private benefits (Bromley and Cernea 1989; Thomson 1987).

The key constraint to greater tree planting and protection of natural regeneration is linked to economic incentives, specifically, property rights. Forestry laws in Francophone Sahel give the national government regulatory authority over ALL native trees and thus do not create positive incentives for tree planting and protection (Thomson 1987). Although, technically, farmers have rights over the trees found in their fields, the special protection given certain species, such as *Faidherbia albida*, and the arbitrary and excessive levying of fines by government agents for offenses leads to a situation where farmers sneak out at night to "steal" branches from their own trees. Farmers are even liable for trees located on their fields, e.g., if someone else cuts the tree, the forester can fine the farmer. Instead of providing benefits, trees become liabilities. Thus, farmers appreciate fast-growing exotic species such as neem, *Eucalyptus*, and *Prosopis juliflora* since they produce results quickly and are not protected by forestry laws.

The dual role of the GON forest service as repressor and promoter sends mixed messages to villagers. The GON has a system of paid informants within villages to assist with their repression activities. This breeds community conflict and provides strong disincentives for tree planting. Not surprisingly, tree planting activities promoted by the forest service are met with skepticism from farmers who suspect that the government is trying to usurp their land by extending their control of forestry resources. Large-scale planting schemes and communal wood lots met with indifference, neglect, and sabotage. Later projects have attracted greater farmer participation by shifting away from village or communal activities towards interventions implemented by individuals on their own land. The key is to ensure that farmers are able to fully capture the benefits from planting and protecting a tree.

Projects involving large-scale public works such as windbreaks and watershed management face problems of long-term sustainability. The scale and expense of project activities are beyond the means of communities to implement themselves while the open-access nature of the benefits diminishes individual incentives for action. Soil and water conservation interventions can produce both public (reduced downstream flooding, less gully erosion, recharging of the water table) and private benefits (water retention and increased yields). When there is a gap between public and private benefits, incentives are needed to stimulate investment, which means that activities stop when the project ends (Kaimowitz 1993). In such cases, it may be unrealistic to expect project activities to be sustainable beyond the life of the project as long as the long-term benefits continue to flow. Where interventions require little input and farmers can capture all the benefits (rock contour lines, *zais*), they are readily adopted and can spread beyond the project zone.

THE FUTURE OF PROSOPIS IN THE SAHEL

Experience would suggest that *Prosopis juliflora* will continue to be planted by development agencies for public works interventions but where farmers have a choice of species, they will avoid planting it on their own land. The species is invasive and will continue to colonize sites with better than average water availability. There is an opportunity, through development agencies, to introduce thornless or more palatable varieties of the species which will meet farmer approval and have a greater chance for farmer-to-farmer dissemination.

Similarly, the successful domestication of species such as *Prosopis africana*, would meet a receptive audience. This native species was once abundant throughout southern Niger and has become increasingly rare. Villagers use it extensively for medicinal purposes (leaves, bark, and roots) and its wood is prized for mortars, tool handles, and charcoal. The pods are used in a variety of ways for animal and human consumption, with an added advantage of no thorns and highly palatable leaves for livestock (von Maydell 1992).

However, *P. africana* trees and seeds are increasingly difficult to find. Germination rates are low, seedling mortality high, and initial growth rates slow. Researchers at ICRAF (International Council for Research in Agroforestry) have completed a Sahel-wide collection of seed and are working on vegetative propagation techniques (Tchoundjeu pers. com.). The species is likely to be more site selective than *P. juliflora*, requiring high soil moisture, but its uses are more varied and it is already widely appreciated by farmers. The planting of *P. juliflora* should be restricted to the most marginal sites requiring hardy species while more culturally acceptable species, such a *P. africana*, should be promoted on fertile sites.

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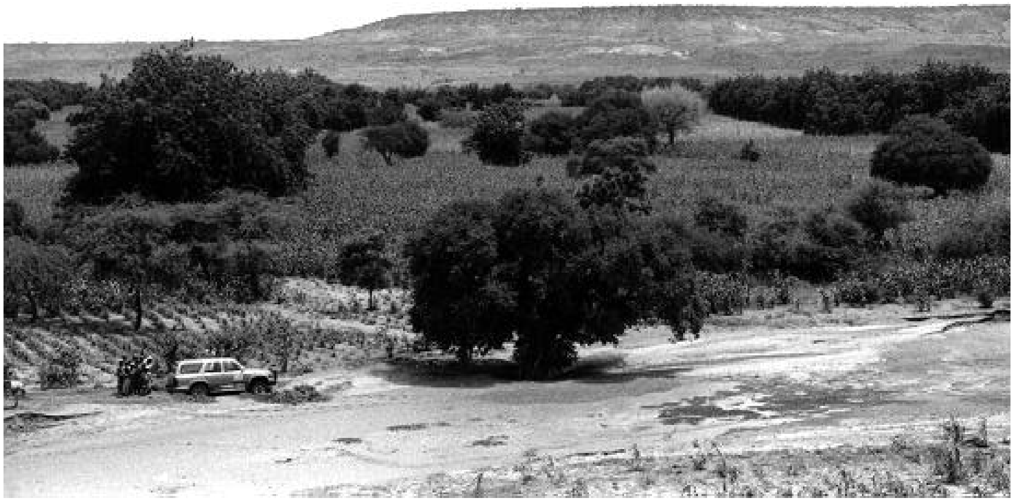

Figure 1. Maggia Valley Windbreaks, 1995 (note regeneration of trees between windbreaks)

Figure 2. Living Fence of *Prosopis juliflora* (note that trees are not pruned)

Figure 3. Rock Contour Lines with Planted Tree [note grass on uphill (left) side]

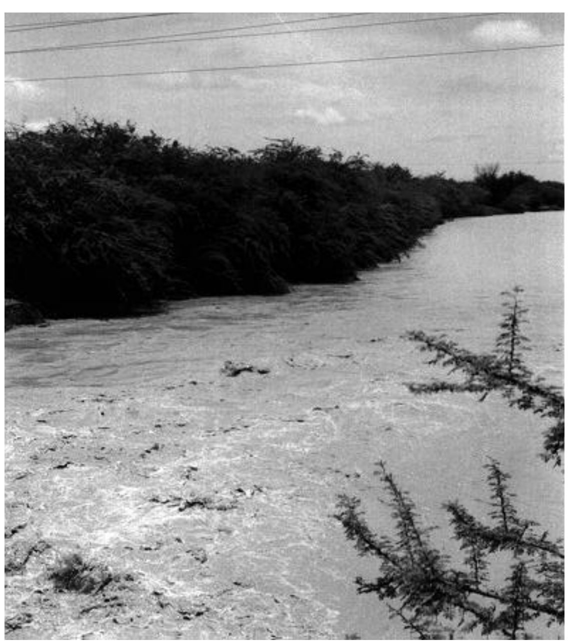

Figure 4. *Prosopis juliflora* Planted for Stream-bank Protection

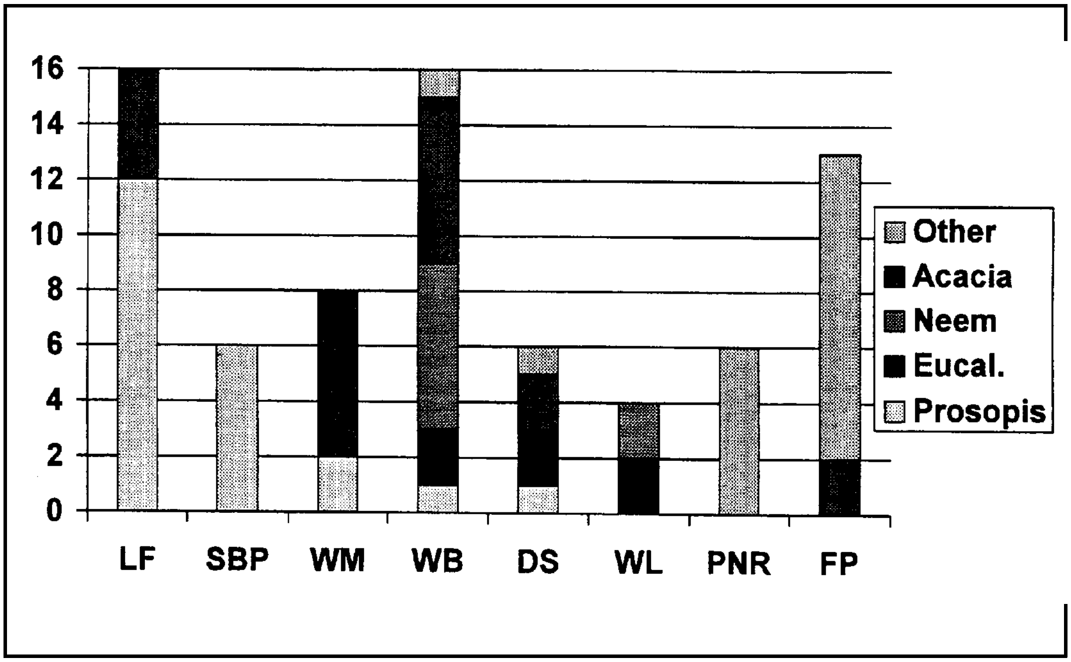

Figure 5. Frequency of Species Use by Activity, Summary of 19 Projects

A Review of Literature on Charcoal in Haiti

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Introduction

Prosopis juliflora **plays a very important role in the charcoal industry in Haiti. This role could be expanded in ways that would contribute to ecological stabilization of the nation's rapidly degrading natural environment. However, it is possible that well-intentioned prejudice against charcoal production in any form is stifling the conservation or "wise-use" and development of the nation's** *Prosopis juliflora* **resources. One senses this attitude at its highest strength and influence among the community of international development specialists working to assist Haiti. One step in bringing about a more productive policy environment relating to this important species is to point out, especially at an international conference such as this, that charcoal production and use in Haiti is not an unadulterated evil that should be unequivocally condemned. This is the objective of this article. Hopefully, this article and the discussion it generates will lead to the development of a sound national and international policy on charcoal that includes a major role for** *Prosopis juliflora***.**

A literature review should take note of, and quickly summarize, past work in a given area to serve as the basis of current decisions and future work. Because literature reviews are not subject to quantitative filters, they are more susceptible to conscious or unconscious editorializing or position promoting than more quantitatively rigorous works that may share the same publishing platform. Thus warned, the reader of this review is invited to read on with an openness of mind that recognizes that this subject tends to be an emotionally charged one in which the biases of writers past and present and those of the reader can have a larger than scientifically justifiable influence on decisions based on the reading.

As a review of mostly consultant's reports, this review is probably more suspect than others since consultants are often paid, a fact admitted openly or not, to support a given point of view. It is common knowledge that experts tend to find problems and solutions within their realm of competence. Perhaps, most importantly, consultants tend to find the problems and solutions indicated, openly or tacitly by their employers. The literature on charcoal production and use in Haiti may be affected by this human tendency more so than other bodies of literature. In reading this literature, it is clear that those who paid the piper called the tune of problems, causes, and solutions. Those who viewed Haiti's problems as deforestation prescribed reforestation. Those who saw the problem as charcoal production prescribed alternative energy sources, centralized charcoal production enterprises, or constraints on charcoal production and marketing.

Having seen the tendency in others, I wish to alert readers to my own bias that the fundamental problem of ecological disaster in Haiti must be that set of causes which keeps most of the Haitian people in a state of poverty, dependent as farmers on a shrinking agricultural base. Thus, this review has an overlay of biases, those of the authors whose works are being reviewed, those of the author, and those of the reader. Hopefully, this review will encourage the advisors of decision makers to convince their bosses to look beyond the easily seen, barren hillsides and easily formulated responses that address only the symptoms and not the causes of the devastation. Hopefully, this will result in more effective programs and policies that begin to reverse what has been, at least, a hundred year old trend of ecological decline.

Deforestation and Charcoal Production

Charcoal production and use in Haiti is generally viewed with alarm as one of the principal factors in the deforestation (UNDP, p. ii) and general ecological degradation of the country. There is another view. In fact, the UNDP qualifies its characterization of the role of charcoal and fuelwood use in the ecological degradation of Haiti. They write, in 1991, that the charcoal industry is only one of the causes and probably not the principal cause of the deforestation of Haiti (UNDP, p. 23). Among the other causes of environmental degradation in Haiti they list:

- **Population growth and its attendant parcelization of agricultural holdings and the farming of land inappropriate for agriculture**

- **The insecurity of land tenure which encourages the over-exploitation of the land**

- **The risky and erosive agricultural practices of the peasant farmers, which has reduced their capital base and exposes them to broad fluctuations in income, has more and more frequently left them only charcoal production as a revenue source in times of need (UNDP, p. 23).**

All policy actions aimed at reversing the ecological degradation of Haiti should be based on an understanding of the role of charcoal production in that decline. The production of charcoal has played a relatively minor role in the destruction of Haiti. According to figures quoted by the UNDP, charcoal contributes a minor part of wood-based energy used in Haiti. The figures show that charcoal provides 90,000 energy units out of a total of 1,061,000 units derived from wood sources. Even taking into account that 60 percent of the energy contained in the wood used to produce the charcoal was lost during production (Foley, p. 79), the wood energy used or consumed associated with charcoal is only about 21 percent of the total. If one adds in other uses of wood for which trees are cut (such as for construction of rural homes), the proportion of national wood resources used in charcoal production drops further and charcoal production's role in the degradation of Haiti is put into perspective, indicating that Haiti's ecological problem will not be resolved by eliminating charcoal production.

An Overview of the Charcoal Economy in Haiti

There are positive aspects of the industry that should be kept in mind. First, the use of charcoal and fuel wood helps put Haiti in the relatively enviable position of being able to provide about 85 percent of energy needs from domestic resources (Smucker, p. 2; UNDP, p. 2). Fuelwood, used mostly in rural areas, contributes 70 percent of the nation’s energy, while charcoal, used mostly in urban areas, contributes only about 6 percent (UNDP, p. 2).

Earl, writing in 1979, estimated the total annual value of charcoal at US$2,883,000, which he estimated provided foreign exchange saving equal to US$64,000,000. The industry provides a redistribution of wealth effect since it is a decentralized industry (Voltaire, p. 10; Smucker, p. 6) peopled by the poorest of the poor (Earl, p. 16-17) and practiced throughout Haiti. The flow of charcoal is from peasant producers to urban consumers (Smucker, p. 2). The industry is quite well adapted to the economic conditions of rural Haiti: the technology is low cost (The earthen kilns are made using simple earth-moving tools, such as spades and picks.), the inputs (trees and labor) are virtually free, the final product stores and ships well. Marketing is often only a matter of getting the bagged charcoal to a roadway where passing merchants will purchase the product. Earl estimated the number of persons employed full time in the production of charcoal at about 4,370 with an equal number involved in the marketing phase. He warned that “Any planned changes in the future energy supplies for Haiti must take closely into account the large number of people who depend entirely upon the charcoal industry for survival” (p. 15). The UNDP estimated, in 1991, the total value of the industry on the order of 50 million dollars (UNDP, p. 26). In 1991, some 150,000 persons were involved in the industry, with 65,000 of those being producers (UNDP, p. 26).

A significant change in the basic economy of charcoal is in the process of occurring, namely, the industry is increasingly based on wood that is purchased rather than obtained gratuitously. Voltaire, writing in 1979, felt that trees used in charcoal production were essentially free goods and felt that this hindered the expected economic rationing process that typically attends increasing scarcity. Writing in 1991, the UNDP noted that the era of free trees is over, citing that nearly 60 percent of charcoal producers purchase their raw material from tree owners.

Usage Rates and Other Data

Charcoal users are predominately urban (Smucker, p. 2 and 20). Given the fact that Port-au-Prince is the largest urban area in the country, it is no surprise that charcoal consumption in this capital city is estimated to account for two-thirds of national charcoal consumption (UNDP, p. 3). In a recent study, the UNDP found that 62 percent of the capital city's residents use charcoal as their "only" household energy (UNDP, p. 5). The same study estimated per capita consumption in Port-au-Prince between 0.36 and 0.42 kg per day. This implied the city consumed nearly 160,000 metric tons of charcoal in 1990 (UNDP, p. 5).

Evolution of Charcoal Price and Deforestation

According to the UNDP, the price of charcoal, in constant Gourdes (the Gourde is the monetary unit of Haiti) doubled between the late 1960s and 1990 (UNDP, p. 31). The rise in price is due primarily to cost increases in the marketing channel. The price at the producer's level remained essentially unchanged, in real terms, between 1979 and 1990. This would imply that, although the industry is increasingly based on purchased wood, the real price of wood does not appear to reflect the otherwise widely perceived scarcity of trees. Perhaps, the expected increase in the value of wood is hidden in the producer's price which includes the purchase price of the wood and the cost of transforming the wood into charcoal. This would be compatible with rising numbers of poorly employed rural residents, i.e., competition among themselves drives the price of wood up and the value of their labor down.

Recent History of Charcoal Production in Haiti

This information is based on separate reports by Smucker and Voltaire who made extensive visits within Haiti in the context of consultancies for USAID in 1979 and 1980. Citing individuals he met during his visits, Smucker places the beginning of large scale charcoal production in Haiti in late 1940's and early 1950's (Smucker, p. 15). For example, he writes that people he spoke with on Ile de la Gonave (the large island located in the bay of Port-au-Prince) "remember charcoal first being produced during the Estime administration (1946-1950)" (Smucker, p. 15). He reports that charcoal was first made in Baie de Henne (a charcoal shipping point on the northern peninsula) by outsiders from Port-au-Prince and Port-de-Paix following Hurricane Hazel in 1954 (Smucker, p. 12).

Market-Oriented Determinants of Charcoal Production

Certainly, without a relatively stable market for charcoal, there would be little charcoal production. Smucker (p. 2 and 20) states that rural farm families generally do not use charcoal themselves. Given the established market for charcoal in major cities and towns, a primary factor in making charcoal production profitable in regions outside of the consumption areas is transportation. Haiti's small (20 to 50 foot) sail-powered vessels have been and continue to be an important means of transportation, especially from the isolated northwest peninsula to the Port-au-Prince market. Smucker sites new roads and the attendant truck transportation as the basis for charcoal industries in several locations of Haiti where charcoal production did not exist as a major occupation prior to the construction of the roads (Smucker, p. 9).

Resource-Based Determinants of Charcoal Production

In reading the literature on charcoal production in Haiti a clear picture emerges of two distinct extreme ends of a continuum of resources (both human and physical) devoted to charcoal production, going from utilization of most resources for charcoal production to the utilization of most resources for agricultural production and almost none devoted to charcoal production. At one extreme, charcoal production occurs with resources that are probably not worth using in other activities. At the other extreme, it occurs as a by-product of agricultural production. It is significant to note that the erosion which so concerns most observers is more a result of activities at the agricultural production extreme of the charcoal production continuum, and, therefore, more the result of agricultural activities of which charcoal production is a by-product, than the result of activities whose chief purpose is the production of charcoal. "Available evidence would suggest that erosion is much more the consequence of heavy cultivation on land that is unsuitable for it." (Voltaire, p. 5).

The importance of charcoal production as a source of income across Haiti varies with the available agricultural resources. As available soil and water resources become more favorable to agricultural activity, charcoal production increasingly becomes a part-time activity. Part-time charcoal production tends to be associated with zones having agricultural resources (soil and water) that permit fuller utilization of available labor. Zones in which charcoal production is an important source of income for the inhabitants are generally characterized by a lack of adequate rainfall or irrigation schemes to support agricultural enterprises and the lack of other employment opportunities (Voltaire, p. 7). In general, the continuum from low agricultural productivity and high full-time charcoal production to high agricultural productivity and part-time charcoal production corresponds roughly with altitude, with the low-lying (often coastal) areas being characterized as arid forests and higher altitude areas being characterized as humid. "Where there is intensive agriculture and a short slack season, there is usually less wood available for cropping, less labor available for the heavy labor requirements of charcoal production, and generally less charcoal made" (Smucker, p. 20).

The relation between available agricultural resources and charcoal production across regions may be mirrored in the continuum of resource control across rural households, i.e., the more agricultural resources a household controls the less time it devotes to charcoal production. In the better-off agricultural zones, "only the poorest peasants are producers" (Voltaire, p. 10). Smucker notes that in the well watered highlands of Haiti, charcoal production is a seasonal complement to peasant agriculture (Smucker, p. 12-15). However, what is more common is for land-poor peasants to produce charcoal on a seasonal basis "...because they are cut off from an adequate living in peasant agriculture and have few other alternatives" (p. 20).

It seems logical to conclude from both Smucker and Voltaire that Haitians produce charcoal when more remunerative activities are unavailable. Thus, as agriculture becomes more profitable and less seasonal, across regions and across individual farms within regions, charcoal production becomes less important as a source of income to Haitians. Note, this implies that even in agriculturally productive regions, there may be a tendency for charcoal production to increase if access to productive agricultural resources is reduced as the rural population increases.

Primary Charcoal Production Areas in Haiti

Voltaire provides a map of the major charcoal production areas in Haiti (Figure 1). At the time (1979), the northwest peninsula produced an estimated 50 percent of Haitian charcoal production, followed in shares of total production (30 percent) by the Côtes de Fer region, located in the southern peninsula between Jacmel and Les Cayes. He estimated that Ile de la Gonave produced 10 percent of the total. The arid areas around Port-au-Prince and between Port-au-Prince and Saint Marc were estimated to produce an additional 10 percent. The UNDP study presented a figure showing the estimated areas of charcoal production in 1980 and in 1990 (UNDP, p. 157). This figure is reproduced here as Figure 1. There is growing evidence that the generally moist Grande Anse (the western portion of the southern peninsula) is becoming more important as a charcoal-supply region for the Port-au-Prince area (Smucker, p. 16 and CARE). Perhaps, this is occurring in response to reduced availability of charcoal from the Northwest.

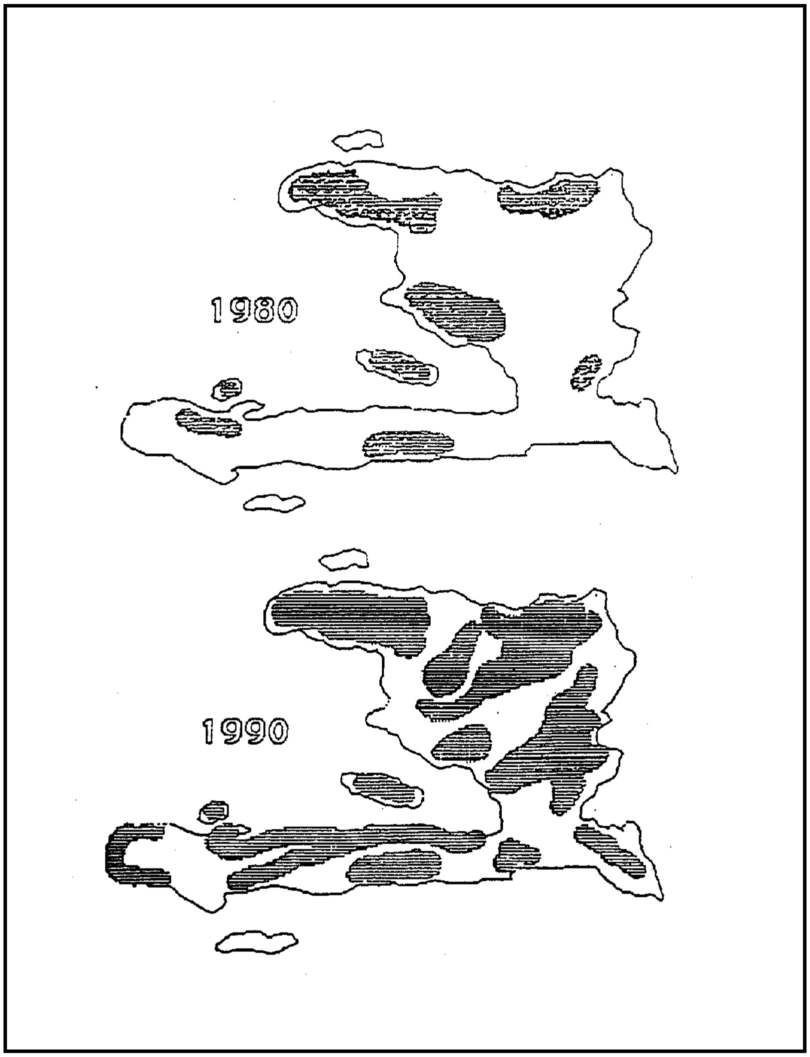

Figure 1. Charcoal Production Areas in Haiti, 1980 and 1990 (UNDP)

Charcoal Production From Arid Forests

As pointed out in the work of Voltaire and Smucker there are sound economic reasons why the arid regions of Haiti are used for charcoal production. These can be summarized in the assertion that such land is not appropriate for other uses. Charcoal production appears to be the most productive use of such land under the regulatory and economic conditions of Haiti. This evaluation is strengthened by the fact that such land is often populated by hardy, drought-resistant trees, such as *Prosopis juliflora*, which coppice readily and, therefore, can provide a succession of harvests with little management input, as long as the stumps and roots of the harvested trees are allowed to remain in place. Coincidentally, such a harvest practice has a minimal impact on soil erosion. Earl recommended that coppicing Prosopis forests, given adequate control, probably can be the best and cheapest source of fuel for Haiti (Earl, p. 25).

Charcoal Industry Cycle in Arid Zones. Smucker (p. 16-19) gives an interesting discussion of what he terms "the charcoal cycle." It is the cycle of events in the expansion and collapse of charcoal production in a given zone or locality. The cycle begins when some outside force triggers the commencement of charcoal production.

Smucker asserts that natural disasters, such as hurricanes or prolonged drought, have been the impetus to charcoal production in some important producing areas in the past (Smucker, p. 16). Economic disasters, specifically, the recent international embargo of Haiti, can also trigger charcoal production and harvesting of trees in moist, agriculturally productive zones where the trees have served as a store of wealth in anticipation of such economically difficult times (Smucker and Timyan, p. 59). Clearly, hurricanes can cause economic damage which can force farmers to turn to charcoal production; however, as the UNDP points out, hurricanes also throw down trees which can lead to higher rates of charcoal production. They use this reasoning to partially explain charcoal price decreases during 1950S1967 (UNDP, p. 30). There was a significant drop in charcoal prices during 1967, the year of Hurricane Cléo.

Commercialization, often aided by newly established penetration roads and driven by nonresident entrepreneurs has been another impetus (Smucker, p. 9 and 16). Charcoal production often begins as an occupation for the poorest local residents. However, if there is excess labor among the better-off residents (which often occurs in localities poorly endowed with productive agricultural resources), these better-off people also enter the business. If forest resources permit, nearly every one in the community becomes involved either as producers, buyers, and wholesalers. The highest quality wood (*Guaiacum officinale*) is used first, then lower quality woods (such as *Prosopis juliflora*), then softwoods and cactus, finally, the stumps of trees harvested earlier are dug up and fired. The local charcoal industry collapses. In some cases, especially when *Prosopis juliflora* is involved, privately controlled land is protected before stump removal occurs and the forest regenerates to be re-harvested at a later time. No doubt this regeneration occurs on some public lands that are protected via market forces, i.e., stump removal is not worth the effort.

Charcoal Production From Farmland

Farmlands are devoted to agricultural crops and not tree crops. Thus, there are a relatively small number of trees available for cutting; perforce, charcoal production from farmland is a sideline activity (Smucker, p. 14). There are occasional quantities of trees available for charcoal making when land that has been in long term fallow is re-cleared for agricultural purposes. Trees in these regions may be more closely guarded and cared for since they represent a form of savings or increasing wealth. Conway, who made a study of farmers' tree planting decisions associated with the USAID Agroforestry Outreach Project, indicated that most farmers viewed their trees as a cash reserve, although most farmers also had autoconsumption in mind for at least some of their trees (Conway, p. iii).

A consensus is building that trees grown in association with such small farms represent a viable (and perhaps the only viable) approach to wood production in Haiti (UNDP, p. 17). Grosenick studied the financial results of farmers participating in the USAID Agroforestry Outreach Project. Participating farmers planted trees on broad spacing in their crop fields. For example, the average participant planted about 235 trees. Grosenick found that about 85 percent of participating farmers obtained financial profits (net present values above zero) from the trees they planted. Street, Hunter, and Bellerive studied the financial returns of selected hillside farmers participating in the same project and found the farms made positive financial returns when the trees were processed either into charcoal or a combination of construction poles and charcoal. Their results also indicated a wide variation in wood production across sites and species and recommended that site-specific production recommendations, based on detailed site descriptions and tree growth studies, are needed for advising farmers on species and cultural practices.

Charcoal Production on Large-Scale Tree Farms

There have been several calls, over the years, for the re-establishment of forests and the establishment of large-scale tree farms for lumber, fuelwood, and charcoal (Burns, 1954; Benge, 1978; Voltaire, 1979). Barkley, Benge, Earl, and Voltaire have discussed the financial feasibility of large-scale charcoal farms using analyses taking place prior to the establishment of the farm. Earl felt that it was "... not financially viable to grow trees for making into charcoal..."(Earl, p. 23). Benge and Barkley felt such farms would be financially successful. History has proven them wrong. The UNDP (p. 17) indicates that a USAID project to develop large peri-urban charcoal plantations was terminated in 1987 due to lack of interest by landowners. Another attempt to develop energy plantations, the National Forestry Project, also failed due to the lack of counterpart funding, negative actions by the local rural population, and other factors, such as weather and animals (UNDP, p. 17).

Economics of Charcoal Production at Farm Level

Charcoal Production Labor Costs

D. E. Earl, a consultant with the FAO, observed the charcoal production process at three locations in Haiti and, using the then current official wage rate of US$1.30 per day, established the per-sack cost of producing charcoal using traditional technology. To convert these data to labor requirements, I have divided Earl's figures by the wage rate. These data are presented in Table 1.

Type of kiln used. Earl conducted a study of the traditional Haitian charcoal making process in 1976 and concluded that charcoal yields (charcoal per quantity of wood) from the traditional Haitian earth kilns was "very good indeed and is tribute to the high standard of skill in Haiti" (Earl, p. 10). Voltaire, p. 9, describes the Haitian charcoal making process: the cut wood is arranged in a grid and covered with straw and green leaves and then various layers of earth. Conspicuously missing is reference to the digging of a pit.

Table 1. Traditional Charcoal-Processing Labor Requirements per 30-kg Sack*

Place	Species	Woodcutting Labor per Stacked m^3 (man-days)	Kiln Operation (man-days)	Total Labor (man-days)
Ganthier	*Prosopis juliflora*	0.57	0.22	0.78
St. Marc	*Rhizophora* spp.	0.33	0.21	0.54
St. Marc	*Rhizophora* spp.	0.25	0.15	0.41
St. Marc	*Rhizophora* spp.	0.50	0.25	0.75
Forêt des Pins	*Pinus occidentalis*	0.57	0.18	0.75
Forêt des Pins	*Pinus occidentalis*	0.50	0.15	0.65

*Adapted from Earl, p. 12.

Labor Costs and Yields from Traditional Haitian Kilns

Earl compared the traditional earth kiln with a pit kiln and a portable steel kiln and provided tables of results, indicating labor requirements and charcoal yield for each type. I have presented some of the data relative to the traditional kilns in Table 2. Earl noted that the workers did not like having to dig a pit and concluded the pit kiln would only be suitable for use at fixed production sites such as sawmills (Earl, p. 10). He did not mention the capital cost of the steel kiln nor the cost of transporting it to new sites as a negative factors in it use. In comparing the traditional kiln and portable steel kilns, Earl, p. 12, found that the labor required to process charcoal in the steel kiln was about 40 percent less than the traditional kiln (19 versus 11 man-days). However, he concluded that the labor savings did not justify "...recommending a change in carbonization techniques in Haiti..." and there was no need to attempt to have Haitian charcoal producers alter their techniques.

Table 2. Labor Costs and Yields from Traditional Haitian Kilns*

Location	Species	Quantity of Wood (stacked m^3)	Labor (man-days)	Time (days)	Charcoal (kg)	Charcoal Yield per stacked m^3 (kg)
Ganthier	*Prosopis juliflora*	3.0	5	4	204	68
St. Marc	*Rhizophora* spp.	2.5	2	3	172	98
St. Marc	*Rhizophora* spp.	2.5	2	3	245	69
St. Marc	*Rhizophora* spp.	2.0	2	3	125	62
Forêt des Pins	*Pinus occidentalis*	2.5	4	4	220	88
Forêt des Pins	*Pinus occidentalis*	2.5	4	4	225	90

*Adapted from Earl, p. 9.

Charcoal Market Channels

Smucker provides an excellent description of the Haitian charcoal market, including the types of marketing agents involved, discussion of modes of conduct between agents, marketing units and example prices. The UNDP provides a diagram of various market channels connecting producers through intermediaries to consumers (UNDP, p. 11). Earl, Voltaire, and Street provide a breakdown of the cost of marketing charcoal. The UNDP provides similar discussion. Voltaire noted evidence of credit being used in the charcoal marketing process: small merchants advance money to producers and middlemen (Voltaire, p.11).

Policy Prescriptions

Consultants have been signaling the decline and eventual depletion of forestry resources in Haiti for more than a century. Most policy prescriptions have relied on the establishment and enforcement of laws and regulations governing the use of public resources, property rights, and the marketing of wood products. All require an effectively operating government ruled by law. Voltaire, writing in 1976, notes: "If one considers various proposals that have been made (since the 1949 U. N. Mission) to counter erosion, we are struck by the fact that almost nothing has been done. Yet the GOH repeatedly reassures everyone that erosion is indeed the main problem [of] Haiti and that it is ready to tackle it up front." (Voltaire, p. 23).

Solutions based on a desired but nonexistent regulatory environment will likely fail. A more realistic approach is to recognize the existing environment and attitudes and develop programs appropriate to the situation. The situation is one approaching a completely open and competitive market. Only programs based on raw market forces can be expected to succeed in such an environment. Reducing the area of the country impacted by charcoal production, then, is a matter of overwhelming the profitability of charcoal production in areas inappropriate for charcoal production through increases in supplies, ideally, from areas appropriate for charcoal production and through increases in supplies (and reduction of prices) of alternative energy types. Increasing the supply of alternative energy supplies is the approach taken by the UNDP.

A complementary approach that addresses the supply of charcoal from targeted production zones would be to encourage increased production of charcoal from existing *Prosopis* **forests. Felker (personal communication) feels that many native stands of** *Prosopis* **in Haiti are too dense (have too many trees per square meter) for maximum wood production and sees a role for pruning and thinning of these stands as a means of increasing production. Additionally, there appears to be significant scope for increasing production through the introduction and use of faster growing species or varieties of** *Prosopis* **via transplanted seedlings or grafts (Felker and Patch, 1996). These suggestions will have to be tested through publicly-funded projects and demonstrated to be economically superior to other alternative uses of the resources before they will attract any attention from Haitian landowners.**

Yet, as long as educated and influential Haitians and their international colleagues maintain their policy of obstructing charcoal production, the necessary projects will not be funded. This virtually condemns the nation to a scenario of further over exploitation of existing forest resources until reduced supplies have driven the price of charcoal out of reach of the Haitian poor. Until imported supplies of energy become affordable for the Haitian poor, the current approach of condemning charcoal production can exacerbate the environmental problem. When charcoal production is made illegal, local private sector, national, and international efforts to protect the environment through managed charcoal forests are also stopped. This reduces the supply, tends to drive the price of charcoal upward and encourages over exploitation. I submit it is time for those individuals with influence over forestry, agricultural, and environmental policy in Haiti to stop condemning charcoal production and begin encouraging ecologically sound charcoal production.

This will include the wise management of existing stands and may well include the planting of new stands of *Prosopis*. **A visionary charcoal policy will foresee the day when increased supplies of charcoal and alternative fuels drive charcoal prices below the level at which forests devoted purely to charcoal are economically viable. Such a policy will have an alternative use in mind for the trees. As we have learned from this conference, there is an economically attractive alternative for** *Prosopis* **as a high-value wood for fine furniture and flooring. Additionally, as described by Henri Vallez of Haiti and Jose Inacio da Silva of Bazil in their presentations at this conference, there is a market for** *Prosopis* **seed pods for the production of human and animal foods. Thus, it may be possible, with wise**

management, to convert today's and tomorrow's charcoal plantations into future suppliers of food for Haitians and their animals and fine wood for Haiti's artisans and craftsmen.

In the interim, charcoal production and use will remain an important component of the Haitian economy and the major use for *Prosopis***. My reading of the available literature indicates that:**

- **Charcoal is a significant foreign exchange earner (saver) for Haiti**
- **It is efficiently produced**
- **It has not been the major cause of ecological decline in Haiti**
- **Some areas of Haiti are well-suited to charcoal production (and perhaps, little else)**
- **It is one of the few available sources of revenue for the poorest Haitians (They turn to charcoal production when they have no other productive use for their labor)**
- **There is indication that trees are being purchased for charcoal production, indicating that under certain conditions charcoal plantations may be economically viable**
- **Better management of existing stands and future plantations of** *Prosopis* **can play a role in establishing an ecologically sound charcoal industry in Haiti.**

Hopefully, these observations will contribute to the development of an ecologically sound national and international policy toward charcoal production and use in Haiti.

Abbreviations

FAO	**Food and Agricultural Organization of the United Nations**
UNDP	**United Nations Development Program**
USAID	**United States Agency for International Development**

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Prosopis juliflora for Irrigated Shelterbelts in Arid Conditions in Northern Sudan

Stephen Bristow
SOS Sahel

1.0 Introduction

The need for shelterbelts to protect homes and farmland in the arid areas of Northern Sudan is now established without doubt. The destruction of natural vegetation, coupled with the increase in population and the decrease in rainfall, has ensured that the effects of desertification have been felt over vast areas of the country. Although the monitoring of the broad spectrum of natural resources is only in its infancy in Sudan, it is possible to say that in many areas the livelihood of much of the population is threatened by the effects of desertification.

What are these effects? To those who live in the arid and semiarid zones the effects are clear and inescapable—decreasing productivity of the land, reducing cover of natural vegetation, less availability of timber and nontimber forest products, increasing aridity and desiccation, lower water tables. The list is a long one. The effects on the population are serious and long term—more poverty; poorer health through lack of nutritious food; and less resources for education, infrastructure, and improvements to agriculture and local industries. Migration, the traditional response to famine, war, and social upheaval, has become an accepted part of rural life. It involves not only the young but, increasingly, the older men and women, as less and less food is available first for export to other areas and, finally, for home consumption.

How important is the role of the environment in all of this? The answer is complex, but the dependency of both rural and urban populations on rural products is high. Food and fuel are perhaps the two most important individual items on every household budget, and although Sudan has many imported items of food and manufactured goods, the basic commodities are home grown and will always remain so. The production of these vital resources is crucially dependent on the state of the environment.

Food production is concentrated in a number of regions of Sudan. One of the most important is the Nile Valley north of Khartoum where irrigated crops of cotton, sorghum, Egyptian beans, wheat, onions, and other vegetables are produced for export to other parts of the country. The fields in which these crops are grown have been protected from the effects of desertification by centuries of growth of natural riverine forest. These forests have all but gone as the relentless pressure of increasing human and livestock populations has taken its toll. The result is sand everwhere—houses and hospitals buried and abandoned, fields inundated and rendered infertile, fruit trees and date palms blasted by sandstorms. And it is getting worse. Everywhere the dunes are gathering. Sand is whipped up by the wind and is carried for miles until it meets an obstacle that slows the wind. The sand is then deposited on or near to that obstacle, which it will eventually bury. Unless, of course, that obstacle is a tree.

But only certain sorts of trees can survive. Some species of tree have an extraordinary capacity to cope with extreme environmental conditions. The most important of these in northern Sudan is *Prosopis juliflora*, known also as mesquite.

This paper explores the utilisation of mesquite in northern Sudan.

2.0 People and Trees

People have always depended on trees and forests for housing, fuel, food, fodder, medicines, clothing and many other needs. In the distant past these needs were easily met, but since populations have grown, life expectancy has lengthened, pressure on land has increased, urban populations have increased faster than those in rural areas and, therefore, make larger fuelwood demands. Forests have not been able to cope with the pressures put upon them and are consequently being degraded—in a few cases they have virtually disappeared while in others there is hope that if action is taken soon, the forests can be brought under sustainable management.

Traditional forms of management are no longer appropriate for the nonreserved forests and, indeed, for many of the reserved forests as well.

The need is to recognise that people have always used forest resources and always will, and that foresters have to learn to work with the people, rather than seeing them as a threat that has to be controlled.

In the "old" days, rural communities utilised the forests in the vicinity of their villages—sheikhs allocated land and resources to individuals and families who were expected to manage them responsibly.

That sense of responsibility has now all but gone, leaving the forests open to anyone and everyone to exploit (the "if I don't take it, someone else will" syndrome). It is now essential to bring user groups into the process of forest management, however difficult this might appear.

This need has been recognised in the Forests Act 1989 which specifically provides for the establishment of community forests. These can be set up by individuals, village or other user groups, institutions and private companies, and, once a contract has been drawn up between the various parties and the Forests National Corporation (FNC), the users have the right to utilise that forest according to an agreed management plan. This legislation has tremendous potential to put responsibility back into the hands of the people and should result in improved environmental management.

Who are these user groups? The most important group is the sedentary farmers, of whom there are large numbers in the Nile Valley. Many have an interest in trees. Work carried out by SOS Sahel in collaboration with FNC since 1985 has enabled many communities and individuals to raise and plant trees for shelterbelts, windbreaks, shade and fodder. Many villages and much farmland are now protected from drifting sand, giving the people much greater security than they had before. Men, women, and children have been trained in all aspects of tree production and maintenance at the Village Extension Scheme (VES) in Shendi and at the Community Forestry Project (CFP) in Ed Debba. Both of these projects are situated in the Nile Valley north of Khartoum (Figure 1).

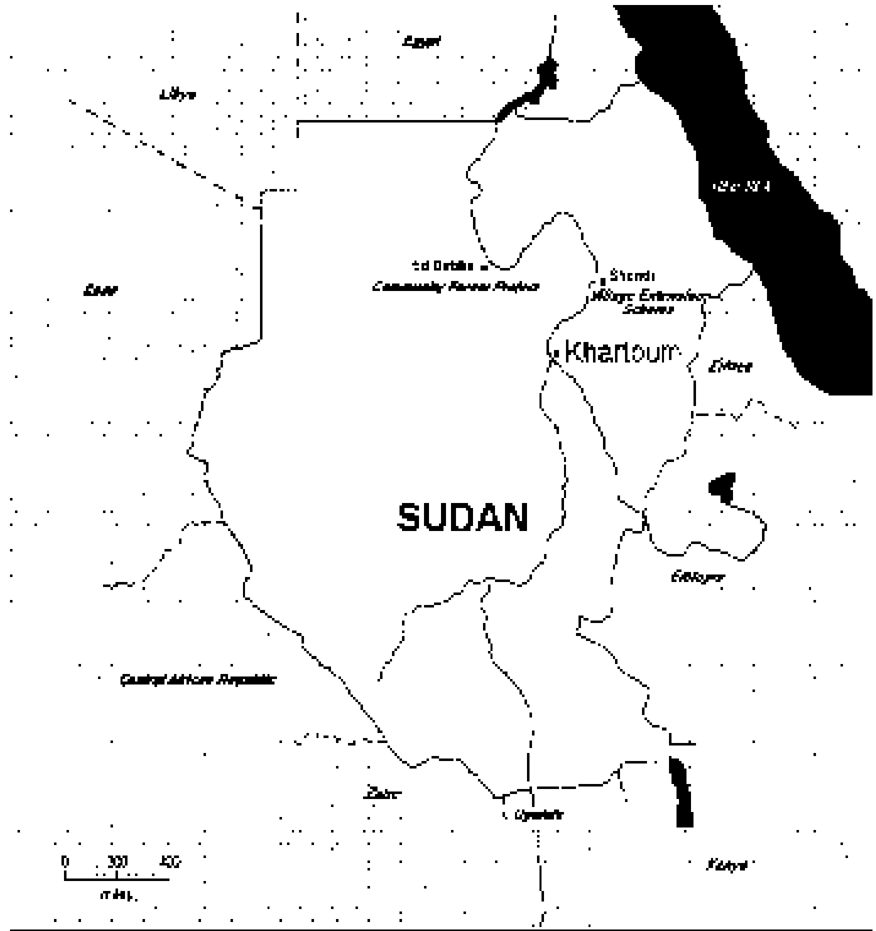

Figure 1. Two SOS Sahel Project Sites

2.1 Identifying a Need

The dependency of rural people on trees is well known. Less well known is how their forest resource has changed over the last few decades and how people have adapted to that change.

The most well known products from trees are, of course, timber for building and wood for fuel. They will only be replaced when other materials for building and fuel become available as acceptable substitutes. This is unlikely to happen in the near future. However, the resource is beginning to run out and alternatives are not easy to find.

A crucial role of trees is to protect soil and to reduce desertification. In the north, blown sand has become a major problem since the much of the natural forest has been destroyed. The results are well known—desert encroachment onto farmland, houses, schools and roads, leading to immense economic and social loss. Trees also improve the microclimate of an area, helping to increase crop yields and lowering air temperatures.

These uses of trees are not all found in one place at any one time, yet, throughout the northern state, trees play a vital role in the local economy and way of life.

But what are the main priorities when it comes to forestry? It is vital that the needs of local people are identified before any forestry activities start. Full involvement of the farming communities in planning and designing these programmes is essential if success is to be achieved.

3.0 Wind, Sand, and Trees

Air movement can be streamlined or turbulent. When wind flows over a flat smooth landscape, the air flow is more or less streamlined. If the air flow meets an obstacle, turbulence is set up and this effect may last for a relatively long distance downwind.

Sand is quite heavy, so light winds are not able to move it. But when wind speeds reach a certain critical level, the sand starts to move. First the grains start rolling along the surface and, as wind speed picks up, lighter grains start to lift. More and more grains take off until the air a few centimetres above the ground becomes saturated with sand. Grains tend to fly short distances, then land again (known as saltation), before being picked up and moved on again. The higher the wind speed, the higher the grains rise. In most sandstorms the majority of the sand can be found within 5 metres of the surface, but, in severe storms, sand can be lifted to great heights.

Sand is found in two main forms: sheets and dunes.

Sheet sand is the most common, and can be found over large areas of the Northern State. Sheets can be anything from 1 cm to 100 cm, or more, deep.

Dunes are more spectacular and are also more dangerous, as they can reach enormous sizes — up to 25 m high in the areas we are discussing. The one advantage of size for us is that the bigger they are, the slower they move, and dunes over 20 m high are very slow movers indeed. Smaller barchan (crescent shaped) dunes 2 m to 3 m high can, however, move 20 m to 30 m a year, burying everything in their path, except certain sorts of trees, such as *P. juliflora*.

4.0 Shelterbelts - When, Where, and How

SOS Sahel started its first Mesquite shelterbelt planting in 1986, and regular monitoring since then has provided a clear picture of what can and cannot be achieved using irrigation. There were some earlier plantings by a number of individual farmers who had the vision to appreciate that only trees could provide a solution to the problem of moving sand. However, little recording of these efforts has been made and we can only learn from what is visible today. The FNC carried out a number of plantings of shelterbelts in the North, including an extensive trial in the desert near Dongola. These unfortunately were abandoned and no useful data is available.

However, we have learned that some trees, especially mesquite, have the extraordinary ability not only to survive sandstorms, desiccation, and temperature extremes but to flourish sufficiently to keep pace with sand deposition. They can create a semipermeable barrier that can actually trap sand and cause it to build up into artificial dunes that remain more or less static, while the trees grow up faster than the sand can accumulate.

How can this be achieved?

Trees are permeable, and they get bigger as time goes on. This makes them far better at stopping sand than solid obstacles. This is because when wind hits a solid obstacle it is forced to change direction. This creates turbulence and airborne sand is dropped all in one place. A large heap can build up in a relatively short time. Trees filter the wind and do not create turbulence in the same way. Thus wind

is slowed but still passes through in the same direction. Airborne sand, instead of being deposited in one heap, is spread over a larger area, with the heavier grains dropping out first, usually in front of the trees, and lighter grains passing through the first rows to be deposited either inside the belt or on the leeward side. This has the effect of reducing the speed of sand buildup, which gives the trees a better chance to grow.

As sand piles up around the trees, they usually manage to grow to keep pace with the sand. In Ed Debba there are trees 9 m tall with sand built up to within 1m of their tops on the windward side.

5.0 Irrigation and Management of Mesquite Shelterbelts

5.1 Evaporation and Water Loss

The climate of arid and semiarid Sudan is far from ideal for plant growth. Most plants thrive best at a temperature of 22°C to 28°C, and a relative humidity (RH) of 75% to 90%. Such conditions are rarely found in Northern Sudan and it is more usual to find high temperatures and low RH. Shade temperatures in excess of 45°C are common in summer, and temperatures in the sun can reach 60°C to 70°C. Relative humidities go as low as 10%. In such conditions water is sucked out of plant material at an extraordinary rate and only plants with specialised water conservation systems can cope.

It is all the more strange that Mesquite can grow so well in these conditions as it has no obvious xeromorphic adaptions. Its leaves are thin and have a high surface area to volume ratio, there is little cuticle to prevent excessive transpiration, and the tree has no obvious water conservation strategy. Despite these apparent drawbacks Mesquite is the species of choice for shelterbelt work as it has a phenomenal ability not only to survive but also to flourish in the conditions found in the region, provided water is available in sufficient quantity and the young trees are protected from livestock.

Potential evapotranspiration (PET) can be more than 2500 mm per year and rainfall is often zero. This water deficit must be made up by irrigation and ground water. Young trees often require irrigation once a week to begin with, reducing to once a fortnight and then monthly. The time taken before the next reduction in watering depends on local factors such as soil type, topography, depth of ground water, time of year, windspeed, etc. Water loss from plants can be high where climatic factors are unfavourable and where the plant has no special xeromorphic characteristics. This limitation must be addressed if tree establishment is to occur as quickly as possible.

5.2 Plant Water Requirements

Irrigated Mesquite can reach a height of 4 m in nine months and can produce a crop of nutritious pods in the same period. Although it can survive with extremely small amounts of water, it needs considerable supplies in its early months if it is to grow at its full potential rate. This is particularly true if it is planted in summer. There is no critical planting season as the daytime temperature is nearly always sufficient for growth. Only in January and February in the north do day temperatures drop so low as to prevent growth occurring.

Water is traditionally applied through open furrows. This irrigation method, although requiring no special technology, does demand high volumes of water. For the first irrigation of a new shelterbelt near Shendi it was found that approximately 260 litres of water were being pumped for each tree in the belt. Such quantities are clearly unnecessary from the trees' point of view, but are inevitable with the open furrow system. Experiments with pipes show that trees can be successfully grown using as little as 9 litres at each watering. However, such a regime is unlikely to allow the tree roots to penetrate deeply into the soil, and they are, therefore, unlikely to reach ground water unless the latter is particularly near the surface. The aim must be not just to provide sufficient water to allow the tree to grow, but to encourage it to grow roots down into the soil towards the water table. This requires sufficient water to drain down to ground water level and to maintain a "damp cylinder" of soil below

the plant. It is very difficult to predict how much water this will take, and it will in any case vary with site conditions, soil type and topography.

Where conditions permit it is far more economical to use smaller quantities of water carefully directed to the individual trees than to use large quantities in open furrows of which the greater part is wasted. The former strategy however requires more equipment and materials and these may not always be available. Pipes of some sort, either semirigid alkathene, lay-flat woven nylon or reinforced polyethylene, are necessary and can be used in a variety of ways.

5.3 Irrigation Methods

5.3.1 Furrow

Furrows have already been mentioned. Although there are many different methods of irrigation, the use of furrows is well known and understood. It is a modification of the method that is most widely used for irrigating larger areas. In the Nile Valley there are thousands of wells that use diesel-powered pumps to irrigate farmland. The well discharges into a main canal which leads via smaller canals or furrows to basins in which a variety of crops is grown. In furrow irrigation the crops (trees in this case) are grown in furrows rather than in basins.

Advantages:
The system is well known and uses locally available technology. It depends on imported engines, pumps, and fuel, but these, and spare parts, are usually always in stock in the main towns. Ground water is independent of rainfall and river flow, and is reliable provided the installation is carried out correctly. Relatively large volumes of water can be pumped and made to flow considerable distances—up to 1000 m.

Disadvantages:
Topography:
Ground topography must be fairly level. If there are changes in level between the well and the trees then it can be very difficult to build a main canal that will carry water to the desired place. Large quantities of water can be lost—shelterbelts are often planted on freely draining sites and a great deal of water is lost through seepage. If the well is near the trees, it can be argued that seepage water contributes to the general field water content which will eventually be used by the trees. However, where the main canal is long (more than 25 m to the trees), seepage can be considered as a loss to the system. This can be compensated for by planting trees or other crops on the canal bank to utilise the water. However, land tenure and traditional user rights in the area will affect what can be done in this respect.

Fuel/spare parts:
Even though the technology is well known and relatively sustainable, any event that prevents fuel or spares reaching the area can cause serious problems. These can be severe enough to cause total failure of the programme.

Responsibility:
Ownership and responsibility for the equipment can also be a problem and needs sorting out at the beginning of the project. Ideally, the people benefiting from the shelterbelt should provide the equipment as there will then be no problem about who is responsible for its maintenance. However, not all communities will have the necessary resources and it may be necessary to provide some items of equipment on a credit basis through an arrangement with the local bank or directly with the project. In this case there should be a clear and unequivocal contract between the project or government department and the community. Failure to ensure this will result in endless problems.

Blown sand:
A major problem with the furrow system is that of blown sand. Shelterbelts are often planted for the main purpose of stopping blown sand, but this very sand can be a main cause of failure. Sand collects at any rough point or object on the surface, and furrows ploughed into a smooth surface are an ideal trap for moving sand. Depending on the site factors, the time of year and the depth of the water table, the furrows may need cleaning of sand prior to each watering. This is a very time consuming and laborious job, but is essential if proper irrigation is to be achieved. It is sometimes possible to plough some extra furrows to windward of the shelterbelt to trap the lowest levels of airborne sand, but large quantities are still carried on to the irrigation furrows and cleaning will almost certainly be necessary.

Where sand movement is severe, mechanical fences of any locally available material can be set up about 15 m to windward of, and parallel to, the belt. These fences, of date palm stems, brushwood or other material, will trap sand and create an artificial dune, helping to protect the furrows and young trees during their establishment phase.

The best solution is to try to get the trees' roots down into the ground water as quickly as possible—this will remove the need for irrigation and, hence, furrow cleaning. The time needed for this to occur depends mainly on the depth of the water table. In some cases it may be so deep that tree roots may never reach it, in which case irrigation, and hence furrow cleaning, will be needed permanently. However, once the most windward rows of trees are a reasonable height (1.5 m to 2 m), they will stop sand from reaching the next rows. Even if these most exposed trees die, they will, if left in place, continue to stop sand and, thereby, remove the need for furrow cleaning further to leeward. This sacrifice of possibly 2 or 3 rows of trees could be planned into the shelterbelt management programme as an effective method of reducing labour demand for furrow cleaning.

Salinity:
One last problem that needs mentioning is the possibility of finding saline water. When used for furrow irrigation the dissolved salts crystallise on the surface of the furrows and can build up to phytotoxic levels. Mesquite, fortunately, is salt tolerant, but there is a limit and too high a salinity level can eventually prevent successful establishment.

5.3.2 Pipe

The use of small-diameter pipes for irrigating trees is relatively new, depending as it does on the existence of a regular supply of low-pressure water. Such a supply is usually only available from the water storage tank of a village domestic supply, many of which have been installed only in the last few years.

Advantages:

The water source is usually reliable and of good quality, and no extra machinery is required for irrigation. The management of such a scheme is, therefore, very simple, involving only moving the pipe from one tree to the next and delivering the correct quantity of water at the correct period.

Disadvantages:

The length of pipe available, and the water pressure, will determine the length of shelterbelt and the distance of the farthest tree from the water source. Also, the amount of water that it is acceptable to take for each irrigation (assuming that the primary function of the supply is for domestic purposes) will be set by the community and will limit the size of the belt that can be irrigated at one time. Suitable pipe is not usually available locally and has to be imported, and the 2-inch lay-flat material that has been used successfully at several sites is prone to damage by thorns and stones.

5.3.3 Tanker

This is a well understood method for delivering water that has been used in forestry projects such as SOS Sahel's Community Forestry Project in Ed Debba where tanker-irrigated shelterbelts have been very successful. Water is delivered to individual trees according to a predetermined management program until their roots reach the water table. In another project in the same area a system of water transport with a tractor and trailer was used. This, however, was not as successful as the tanker.

Advantages:

Highly mobile tanker irrigation enables trees in any situation accessible to a vehicle to be irrigated regularly. Tankers can operate in all sorts of terrain and can carry water long distances, if necessary. Water sources can be a river, a matara well, a hand-dug well or a seasonal water course. Water can be delivered quickly and in considerable quantities. If Bedford TJ1090 trucks are used, the maintenance problems are greatly reduced as spares and know-how are locally available. It has been found that where shelterbelt establishment is attempted on dunes, the sand must not be deeper than about 4 m, otherwise, the trees do not survive even if they have sufficient water. This seems to be because there is insufficient fertility in the sand to enable the trees to grow down to the soil.

Disadvantages:

Any form of vehicle is likely to cause problems and these can sometimes be serious or even catastrophic. Fuel and oil supplies are often sporadic and a long interruption of supply could be fatal to young trees. Tankers cannot go everywhere — if the land is too steep or too sandy, the vehicle will be unable to reach the proposed planting area. Skilled staff are needed to operate and maintain the tanker.

5.4 Constraints and Problems

- First, the main constraint is a general lack of experience in implementing community forestry activities. This can cause problems as initiatives involving the voluntary participation of people require flexibility, compromise, and not a little psychology — skills which only come with experience. Too rigid an approach, or an unwillingness to meet the community on the same level, can result in no progress being made. On the other hand, too easygoing an approach or too great a willingness to compromise can lead to exploitation of the project by a village, resulting in too great a burden being placed on project resources.

On the technical side, problems of water management are considerable:

- **Too much water wastes valuable resources.**
- **Too little water causes stress and eventual death of the trees.**
- **Pumping equipment always needs regular maintenance and repair. Sand storms can bury pumpsets in a matter of an hour or two.**
- **Fuel supplies are often unpredictable.**
- **Water availability can vary and can diminish over time.**
- **Getting water to the trees can be difficult, whatever system is chosen.**
- **Water losses through seepage and evaporation can be very large.**
- **Water delivery systems invariably create problems which can sometimes prevent successful completion of the project.**

6.0 Species Selection

6.1 Mesquite and Other Exotics

Mesquite (*P. juliflora*) was introduced into Sudan from South America some time around 1940. It is in the legume family and fixes atmospheric nitrogen to assist in its growth. It does not look particularly drought resistant. In fact, there are many other tree species that will survive longer without water, but its major advantages for shelterbelt work are its rapid growth and its extraordinary ability to cope with heat, sandstorms, and sand buildup.

It is thorny (although there are thornless varieties available) but that does not stop its being eaten by livestock, especially goats, when there is no better forage around. It needs good water supplies if it is to perform well, but with sufficient water, good stock control, and no visits from locusts, it is possible to grow a substantial shelterbelt on a good site in two years.

Once mesquite trees have reached about 3 m height, goats are no longer a problem. The pods provide excellent fodder for goats, although the species can become a major weed problem if goats spread the seeds in their dung in areas of higher rainfall or irrigated farmland.

Its thorniness makes it difficult to manage, especially if irrigation furrows need to be cleaned regularly. On good sites it can be coppiced, but this should never be done if there is any chance that this will effect its value as a shelterbelt. General management of mesquite is relatively easy once it has grown through its first few months. It is pest and disease free on the whole, and can cope with extreme conditions, but is susceptible to drought. In difficult areas guards will be needed to keep livestock away.

To raise trees in the nursery, collect seed when it is ripe, and store in sacks. When needed, decorticate the seed and pretreat with sulphuric acid for 20 to 30 minutes before sowing.

The only places in northern Sudan where mesquite is unsuitable are irrigated farmland. As a boundary to farmland, mesquite is fine as long as the farmers look out for seedlings in their fields. However, there are plenty of farmers who do not clean their fields regularly and once mesquite gets a hold on irrigated land it is difficult to eradicate. In some areas of Sudan, such as the Tokar Delta and parts of

the Red Sea coast, mesquite has become a noxious weed. It should never have been introduced there. Careful site identification should prevent its introduction into areas where there is any danger that it might become a weed.

Other exotics, such as *Eucalyptus camaldulensis*, *E. microtheca*, *Parkinsonia aculeata* and *Pithecellobium dulce*, have all been tried in shelterbelts. However, none of these to date has been demonstrated to establish and grow better than Mesquite, nor do they have Mesquite's sand-stopping abilities.

6.2 Indigenous Species and Farmer Preference

Can indigenous species be used for shelterbelts? Several have been tried including *Leptadenia pyrotechnica*, *Acacia tortilis*, *A. nilotica*, and *Balanites aegyptiaca*. However, although these species can be grown with irrigation, they do not do particularly well, and cannot compete with Mesquite. In one trial, irrigation was stopped after some months, and the indigenous species survived a shorter time than Mesquite. This is probably because they developed shallow root systems under irrigation rather than the deep roots of naturally occurring trees. However, few species respond really well to irrigation, and it is not surprising that the indigenous species do not flourish in these conditions.

The advantages of indigenous species are that they have evolved within the ecosystem and should, therefore, be able to cope with the conditions better than introduced exotics. However, this advantage would only become apparent once the trees were mature and established, and it is doubtful whether this would ever be possible under irrigation.

Farmers have no doubt which species they prefer: mesquite for shelterbelts and *Eucalyptus camaldulensis* and *Pithecellobium dulce* for on-farm windbreaks. The latter two species are fast growing, produce strong poles, and *P. dulce* also produces edible fruit. Farmers also like *Azadirachta indica* for village planting (it is pest and disease resistant, very drought tolerant, can be pollarded, and is easy to grow). *Leucaena leucocephala* (very fast growing and nitrogen fixing) has been tried both on farms and in villages. Farmers do not want to plant indigenous trees, although they are happy to have big *Acacia tortilis*, *A. nilotica*, *A. seyal* and *Faidherbia albida* (syn. *A. albida*) around the villages.

7.0 VILLAGE EXTENSION SCHEME 1985–1996

7.1 Background

The Village Extension Scheme (VES) was set up in 1985 to help Nile-side villagers near the town of Shendi, 100 miles north of Khartoum, to combat desertification. Village tree nurseries and woodlots were established and protective mesquite shelterbelts and windbreaks planted. By the end of Phase One (October 1985 to September 1989), the project had set up 7 operational nurseries, 4 woodlots, and 10 village shelterbelts. During Phase Two (ended September 1993), seven new shelterbelts and three woodlots were established, by which time all the sites were under the management of village-elected committees. A third phase involving mesquite shelterbelts and an extended women's program ends in December 1996.

7.2 Mesquite Shelterbelts

The shelterbelt programme proved to be one of the most successful of the project's activities. So far, 19 village shelterbelts have been established, some of which are over 2 km in length.

A huge amount of sand has been trapped by the trees that would otherwise have reached the houses. At Goresh, it is estimated that approximately 50,000 tonnes of sand have been prevented from encroaching on the village and, at Taragma, at least 15,000 tonnes. Such an effect has profoundly impressed the villagers — new-house building is now taking place in the lee of the shelterbelts on land that was previously considered useless. Such long-term investment is happening at several shelterbelt sites including Goresh, Taragma, Rahamab, and Abdutab.

At many sites the shelterbelts are so valuable for their protection value that the villagers are unwilling to attempt to harvest them for firewood (Mesquite shelterbelts do not produce good straight poles, although strong forked poles can be found). Nevertheless, at sites where the shelterbelts can be relatively easily irrigated, to allow for rapid regrowth, they can also provide a valuable source of timber. To date, only one private shelterbelt has been coppiced to provide income. This is a desert farm about 2 km south east of Goresh where a single row of Mesquite was planted in 1987 and was cut and sold for £S 60,000 ($200). It was expected to regrow within two years. Such a return will become quickly known to other farmers in the area and more of this activity may well be seen in the future.

7.3 Women's Programme

Through the women's programme, over 6,800 women have been involved in forestry activities in 39 villages by growing trees in woodlots and in their home compounds. Women are now growing a wide variety of tree seedlings: Mesquite, lemon, guava, mango, henna, and arak as well as forestry species in their home nurseries. The working area has been expanded to incorporate new villages where women expressed interest in joining the programme. The women's programme has also started another training programme to show women how to build and use improved fuel-efficient stoves.

Subsequent to the success of the Women's Programme, a wider, low-input women's forestry project in the Northern State was proposed. Ten villages were studied, with the aim of establishing the most suitable areas for intervention. By the end of August 1993, 40 groups had already been set up, involving 460 women. The women began by growing forestry species, such as *P. juliflora*. The new extensionists then started to train women to grow fruit and ornamental trees and to build improved mud stoves.

7.4 Village Participation

Levels of enthusiasm and involvement in project activities varied considerably from village to village, and depended on a variety of factors, including the nature of the committee, the cohesiveness of the village, and the perceived benefits of the activity. Participation in implementation and in planning and decision making are discussed separately below.

7.4.1 Participation in Implementation

In each village, the committee would arrange for kafirs (community work days organized by local political structures) to carry out the physical work required, at which "everyone participated in the work." In some villages, women were allowed to work, in others they provided food and drink for the men working. Schoolchildren often helped in nursery work, for example filling polybags or planting out seedlings in the shelterbelts, particularly if their teachers were committee members.

Inevitably, those who benefited most from the project's activities, those whose houses were threatened by sand inundation in the case of the shelterbelts or those who benefited from the income in the case of the woodlots and nurseries, were most likely to be willing to contribute either their labour or their money.

In a village like Wad Killian, which is poor, small, and fairly homogeneous, the majority of the village felt affected by the sand movement. They regularly worked in nafirs to plant and tend their shelterbelt and still contribute financially to the running costs of the pump, each family according to its ability.

In El Hosh, which is a much larger settlement, the shelterbelt was managed from the start by the Popular Committee, most of whom lived in areas less directly affected by sand inundation, and were, therefore, not particularly motivated to make the belt a success. Those worst affected were the nomad communities that had settled recently on the outskirts of the village, but they were not an integral part of the village community, and were not involved in the project.

After handover, in many villages, the committee experimented with using hired labour instead of voluntary village labour. This seemed a sensible option for two main reasons. First, most of the village men are farmers; they complained that they were too busy working on their farms to have time to spare to devote to the project's activities. Second, much of the day-to-day work now required could be easily carried out by one or two people, and some of the tending tasks would be better performed by someone with some forestry experience.

7.4.2 Planning and Decision Making

After the initial meeting in which the committee was elected, the rest of the village tended not to be very involved in decisions taken regarding project activities. The committee and project forester often worked closely together and, in general, other villagers were not involved in their discussions or training sessions.

There was occasionally a strong feeling that the committee was operating on its own, without consulting the village as a whole about their decisions. It is not known whether this may be due to a lack of interest on the part of the village or because the committee did not invite their comments.

In some villages, such as Wad Killian, the whole community participated in the implementation of the shelterbelt, by offering their labour and financial contributions, and are more involved in decisions regarding it. However, even with full village participation on these levels, there was an additional responsibility, previously borne by the project staff, to be borne by someone or a small group of people (the committee): management and supervision of the activities on a daily basis. This responsibility remained regardless of whether the work itself was carried out by paid labourers or voluntarily.

7.5 Achievements

7.5.1 Shelterbelts

Most shelterbelts perform a useful protective role against the incoming desert sands. The main reason cited by the village representatives for joining the project was to stop sand inundation. According to the villagers, the benefits of the shelterbelts were that they kept the sand away; provided shade, fodder and some fuelwood and improved the view. Women were very clear about the benefits, saying, "Sand used to get everywhere before, in our food and our clothes and it gave people allergies and other health problems. It is much better now with the belt." There were also indications that some migration had been stemmed as a result of the belts, and there was evidence of new building in the lee of the belts. The peace of mind provided by the belt was also mentioned. "Before the belt, I knew if I didn't get the sand this year, I'd get it later on. It's different now," said one man from Taragma.

However, the belts can have some negative aspects: they can attract birds and children, a problem in areas where belts were located near to farmers' fields. Complaints about the evils of the invasive mesquite (the species with which all the belts are planted) often aroused heated debates. One man in Taragma summed up the situation by saying, "we accepted the mesquite in the shelterbelt as a lesser evil than the sand."

The two belts that were in poor condition, El Hosh and Goresh, had suffered different types of problems. At El Hosh, the problems seem to have resulted mainly from poor management and lack of motivation of the Committee who were in charge. Most of the Committee were not from the part of the village that was under threat. At Goresh, the village was extremely motivated — the belt had been planted out four times. The problems encountered were the result partly of bad luck and partly of insufficient technical experience.

7.5.2 Women's Programme

The women's programme consisted of three components: home seedling production and tree planting, improved stoves, and vegetable production. The improved stove component started late in Phase Two. Many women claimed that they used less firewood and produced less ash and mess. However, the coverage of the programme was fairly small.

Women extensionists also taught women how to grow seedlings to plant in their home compounds or to sell or give away. The scheme was popular in most villages. The benefits of the trees planted in home compounds were shade, fodder (from mesquite), toothbrushes (from Arak) and fruit (from lemons and guavas). Some women grew vegetables in their compounds or in the village woodlots or next to shelterbelts, but in almost all cases this stopped, in the woodlots and shelterbelts because irrigation was not frequent enough (now that the trees were better established) and in the case of home planting "because we are lazy."

Despite considerable efforts to explore marketing options for excess seedlings produced, these remained elusive. Selling seedlings was always difficult, especially so in villages where the home nursery programme was most successful. In Abdotab at one time there were 70 operational nurseries. With the restrictions imposed on women's movements in this traditional Moslem society, women could not easily travel beyond their village to market their seedlings. A small village such as Abdotab could not absorb the production of 70 nurseries. Therefore, it is not surprising that home nursery production ceased once women had grown sufficient seedlings for themselves and their friends and families.

The emphasis placed by the programme on self-sufficiency meant that women could usually obtain all the inputs they needed to raise their seedlings (including polybag alternatives), and knew how to collect and prepare seed. They were also often aware of the prices for which they could sell their seedlings and which species were most popular.

An important spin-off benefit of the women's programme was that the project had helped to raise women's status in some villages. When the women extensionists were first employed by the project and started working with women, other villagers were very dubious of their activities, and they suffered taunts and even accusations of being "loose women." However, when many of the village women succeeded in growing seedlings, and making some (small) income from them, the taunts stopped and people began to realise that they were serious. The extensionists are no longer working for the project, yet women still stop them in the street to ask their advice about their seedlings. The women's programme is perhaps in some way helping to change attitudes in these small conservative villages.

7.6 Evaluating Success

"Success" in a particular village was determined only partly by factors within the project staff's control, as so much depended on the villagers themselves. It also is very much determined by the time scale used for the assessment. It is worth noting that perhaps what could in some ways be judged to be the most and least successful villages, Wad Killian and El Hosh, were managed by the same forester. It is possible that the project should have been more willing to withdraw from unmotivated villages and invest the project's equipment and foresters' time at other sites.

7.7 Harvesting Belts

When a Mesquite shelterbelt is to be harvested to provide fuelwood, it should be cut in rows, in rotation, leaving approximately 1.5 years between cuts of the same row. In a belt of six rows, two rows could probably be harvested at one time. Cutting alternate rows means that the whole belt still offers some protection even after the cut. The prevailing wind direction at the time of the cut should be identified and the cut arranged so that the cut rows are those most protected from the wind. The cutting should be timed just before any possible rains, as this will help regeneration of the cut trees.

However, it should be noted that on each occasion when shelterbelt harvesting was discussed by the project with the villagers, they had categorically stated that they did not want to cut the belts in case it affected their efficiency as sand barriers.

7.8 Future Need

There is an increasing backlog of demand from villages for technical and financial assistance with shelterbelts which could not be met under the existing programme. A "Shelterbelt Office" based in Shendi would provide low-input support and technical advice for the establishment of shelterbelts in the area.

8.0 COMMUNITY FORESTRY PROJECT - 1988–1996

8.1 Background

Since 1988, SOS Sahel's Community Forestry Project has been working with agricultural communities in the Nile Valley around the town of Ed Debba, about 150 miles northwest of Shendi. Several of the highly fertile areas along the river are being gradually buried by encroaching desert sand. Mobile dunes creep foreward onto cultivated land, and windblown sand damages crops and machinery, fills wells and canals, and buries houses.

Although the desert has been nearby for a very long time, the stories of older local farmers suggest that until the late 1950s the Nile Valley was covered by a fairly dense vegetation of trees and shrubs for several kilometres on both sides of the river. In some places, large herds grazed the pastures and moving sand dunes were not present. Overgrazing and tree cutting are likely to have contributed to the devegetation of the valley.

Before 1945, no rainfall figures are available. But the rainfall figures for the Dongola station (about 100 km north of Ed Debba) show a drop from a yearly average of about 30 mm in the 1950s to 10.2 mm in the 1980s. Farmers say that before 1945 annual rains were substantially more important than in the last 40 years, and that until about 50 years ago some wadis used to flow into the Nile during the rainy season (for example near Abkor).

A possible drop in the ground-water table linked to the decrease in rainfall and decrease in the frequency of flooding of the Nile might have hampered tree regeneration. Major Nile floods in the project area have only occurred in 1946, 1954, 1975, and 1988, while, before 1945, floodings apparently occurred every two to three years.

Whatever the causes, at present the tiny fertile flood plains along the Nile are threatened by moving sands and dunes coming from the desert. Some small villages have already been buried. Moreover, the decreasing frequency and magnitude of the Nile floods badly affects the soil fertility of the agricultural flood basins. In comparison with the limited resources available, population density in the Nile valley has been relatively high for a long time.

The fertilising Nile floods were a safeguard against soil exhaustion and successive technological innovations ensured progressive intensification of agricultural production allowing increasing population densities.

However, the steady pressure of population growth has been squeezed between a chronic land shortage and the techno-economic endeavours to increase productivity on the limited natural resource base, resulting in successive waves of out-migration. The introduction some years ago of diesel-powered pumps for irrigation and more recently the use of these pumps to open up new land behind the flood basins are good examples of local efforts. Nevertheless, out-migration could not be stopped, and at present more than half of the population originally from the area now live elsewhere.

At present, farming systems have reached a relatively high level of sophistication, and it is estimated that two-thirds of the total income from crop production is used to cover production costs, for irrigation by diesel-powered pumps, fertilisers, mechanical land preparation etc., indicating that the bulk of the economy has been monetarised.

However, in recent years, agricultural profitability has decreased sharply. Costs of inputs (pumps, spare parts, fuel, fertilisers, mechanical land preparation) have increased more rapidly than the farm-gate value of production. For example, between 1985 and 1992, the price of fertiliser increased tenfold, while the selling price of beans went up only fourfold.

The aims of the first phase of the project were: to enable people to grow Mesquite shelterbelts and windbreaks and to stabilise mobile sand dunes in order to protect farmland and homes, to demonstrate to comunities that they can help themselves to protect their environment, and to research the most appropriate techniques for the establishement of trees on difficult desert sites.

During phase one, villagers from outside the orignal project area approached staff for assistance with seedling production and technical advice for shelterbelt establishment. Many of these villagers were already buying seedlings from the project, but lacked the technical expertise and inputs, such as seed and irrigation equipment, to produce a sufficient quantity and quality of seedlings to plant themselves. As a result a second phase of the project was planned, which began in January 1992, to extend activities to cover these new villages. This phase ends in December 1996.

8.2 Project Achievements

During the period 1988 to 1993 a total of 54.5 km of external shelterbelts, sand dune fixation, internal shelterbelts, and windbreaks were programmed (Table 1). The achieved total was 61.1 km.

Table 1. Targets and Achievements 1988–1993

Type of Activity	Targets		Project Output
	1988S1993 (km)	1988S1995 (km)	1988S1993 (km)
External Shelterbelts (ESB)	5.7	8.5	6.3
Sand-dune Fixation (SDF)	21.0	27.0	15.9
Internal Shelterbelts (ISB)	10.3	11.5	16.4
Private Shelterbelts (PS)	12.2	19.0	12.7
Windbreaks (W)	5.3	6.7	3.0
TOTAL	54.5	72.7	54.3

The total number of seedlings produced in the period 1988 to 1993 was 157,400. Approximately 56,750 seedlings were used for the activities coordinated by the project (including replacement of dead trees at 15%). The remaining 100,650 seedlings were sold, given to community members, or used outside the project area. The project produces seedlings from central nurseries run by project staff but also directly from private nurseries run independently by community members. These nurseries will have been established with the help of the project. Project-run nurseries produced 96,000 seedlings, which constitutes 61% of total production. Men from the community have

contributed a total of 430 working days and women contibuted 200 days toward the production of these seedlings. The remaining production was divided as follows:

- **Women's private nurseries, 45,900 (29% of total production and 3,094 working days)**
- **Men's nurseries 15,500 (10% of total production and 1370 working days).**

Assuming an annual prodiction at each private nursery of about 300 seedlings, the annual mean number of private nurseries over the last five years is about 30 for women and 10 for men.

By the end of 1994, the project had planted 93.3 km of shelterbelts. Severe floods in August and September 1994 destroyed some of the more recent shelterbelt plantings. Three kilometres of shelterbelts were lost as their trees were fully submerged by floodwaters for over two months. However, the project was also able to make good use of the flood waters collected in dune hollows and about 4 kms of shelterbelts were planted at sites which were previously categorised as inaccessible.

8.2.1 Seedling Production

Total seedling production during 1994 was 59,700, of which 23,800 were produced at the main project nurseries of Argi and Affad. The rest were produced by individuals in extension nurseries. Seedling production at extension nurseries in the Phase I sites of Affad and Argi decreased substantially as the demand for seedlings is dwindling.

Affad nursery was severely damaged by the Nile floods in September. Most of the young seedlings were lost, as well as the nursery buildings and the well. Production began again in March 1995 after the water table had subsided and the nursery rebuilding and repairs had been completed. Seedling production at Argi nursery and in the private extension nurseries has been increased to compensate for the loss of production from Affad.

8.2.2 Planting

During 1994, 10.612 km of shelterbelts were planted in the project area. Nearly all planting has taken place at Phase II sites. Irrigation at the external shelterbelt sites is proving to be difficult at all Phase I and Phase II sites due to sand burial and low community participation.

8.3 Extension and Women's Programmes

The male extension team have used puppet theatre as an extra tool for extension messages. This idea was pioneered at Shendi (Village Extension Scheme) and proved very effective there. Four shows were put on during the year which were well attended and were reported to be very popular.

The women's programme team began showing women how to construct improved fuel-efficient wood burning stoves, using techinques they had learnt during their visit to an FAO project in the Eastern State. Thirty women were trained in mud stove production.

8.4 Handover

The timetable for handing over the management of the project sites to the villagers has not yet been fully implemented, mainly due to the low participation at external shelterbelt sites, which are not yet fully established.

8.5 Effectiveness of the Mesquite Shelterbelts

Technically the shelterbelts are in excellent shape. The survival rate of planted seedlings is very high and the mere 15% of seedlings which do not survive have been replanted successfully.

Nearly all of the labour inputs needed for planting and watering of the shelterbelts have been provided by the local communities (almost exclusively by men) without any payments from the project. The project provides technical assistance, seedlings (or pays for them if locally produced), pumps for shallow wells or a water-tanker service for irrigation until the trees' roots reach soil moisture.

Physically, the shelterbelts are highly effective. They hold the sand back and will protect land and houses for some time. Some dunes that have built up behind the Mesquite shelterbelts are now 12 m high.

Due to the necessity of prolonged irrigation over more than a year, shelterbelt production is expensive. However, no alternative planting technique is available. Major project benefits are the protection of agricultural land against sand encroachment and the protection of houses.

Immediate (short-term) beneficiaries are a minority (about a quarter) whose land and houses are adjacent to the incoming moving sand and dunes. Medium-term beneficiaries can be estimated at more than half the total population. Longer term and indirect benefits affect the total population of the project area.

Monetary estimation of the benefits is very difficult, as the choice for those threatened with sand encroachment is between staying or leaving and loosing it all.

Internal and individual shelterbelts protect agricultural land, have an impact in the short-term and are "individually" planted by the adjacent farmers. They elicit the highest levels of participation and need a lower level of project "subsidies." External shelterbelts have more impact on homes (in the short-term) than on land (longer term) and have to be undertaken communally. Moreover, they are further off. As a result, the external shelterbelts, in the eyes of the villagers, have a lower priority and a lower cost/benefit ratio. They presented participation problems and required a higher level of project inputs. Participation in sand dune fixation work is somewhere between these two extremes.

The bulk of the seedling production for the project as well as women's and men's nurseries is *P. juliflora* with some *E. camaldulensis*.

Examples of the use of *Prosopis* are shown in Figure 2: Overview from the top of a sand dune fixed with *Prosopis (upper left)*, Camel by a shelterbelt with date palms in the background *(upper right)*, Villager beside irrigation canal for an external shelterbelt *(lower right)*, and Measuring the growth of mesquite *(lower left)*.

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Figure 2. Examples of the Use of Prosopis

A Mesquite Pod Industry in Central Mexico: An Economic Development Alternative

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Abstract

In central Mexico's semiarid highlands, mesquite pods are utilized for food and livestock feed. In 1975, a union of 53 rural communities opened a storage and processing facility for mesquite pods. This paper presents information from a 1986 study of the cooperative, including interviews with subsistence farmers, feed dealers and large-scale ranchers in 26 communities, data collection from the cooperative and supporting institutions, and an economic analysis of current operations and potential improvements. The study concludes that the mesquite cooperative has increased the cash incomes of rural farmers and provided a local source of nutritious livestock feed. The net returns of the enterprise could be increased through pest control in mesquite storage areas, production of mixed feeds, and better marketing of mesquite pod products. Similar operations could succeed in areas with dense mesquite woodlands, a history of pod collection and use, and a need for supplemental income sources.

Introduction

In the semiarid portion of San Luis Potosí, Mexico (S.L.P.), 97% of the land is unfit for agriculture (INEGI 1986a). In an effort to improve the livelihood of the rural populace, 53 communities organized an economic development cooperative in 1975. Their first effort was the establishment of a storage and processing facility to produce livestock feed from the pods of native mesquite trees (*Prosopis* **spp.) called the** *Unión de Ejidos Productores de la Vaina del Mezquite 'Emiliano Zapata' (Unión)***. A study of the** *Unión* **in 1986, presented in this paper, has attempted to:**

- **Identify the social, economic, and environmental factors affecting the harvest of mesquite pods in the** *altiplano* **(central Mexican highlands)**
- **Evaluate the systems used by mesquite dealers to transport, store, and mill the pods**
- **Analyze the market for mesquite as a livestock feed**
- **Estimate the costs and benefits of making structural and technical improvements to the cooperative mesquite operation.**

Methods

The first phase of the field research consisted of interviews with 35 mesquite harvesters in 26 *ejidos***, 8 large-scale private ranchers, and 12 private mesquite-pod dealers. Interviews were conducted in Spanish in the informant's home, ranch, or store following one of three questionnaire formats. The second phase of research involved data collection from the** *Unión***, the** *Secretaría de Reforma Agraria* **and** *Bancorural* **in Matehuala. Phase three focused on mesquite research in Mexico, including meetings with researchers from universities and institutions in three states and an extensive literature review. The last phase of the field work involved collection of climatological data from mesquite-producing areas of San Luis Potosí and southern Nuevo Leon.**

The Study Area

The cooperative's storage and milling facilities are located in Matehuala, San Luis Potosí, in east central Mexico at an altitude of 1570 meters, and a few kilometers north of the Tropic of Cancer. The surrounding *altiplano* encompasses 21,510 km^2 and varies from 1500 m to 2000 m in altitude. The region's erratic and poorly distributed rainfall is concentrated in the summer months, and mean annual precipitation averages 200S500 mm (Gomez 1985). Matehuala's mean annual temperature is 19ºC, with maximum temperatures reaching 38ºC in August and minimum temperatures as low as S3.5ºC in January. Freezes occur 15 to 20 days per year, from November through March (Dir. de Fomento Económico e Industrial 1986).

Mesquite trees in the *altiplano* can be found on 3,349,442 hectares (Villanueva n.d.), with densities ranging from 10 to 250 trees/ha. Overall, mesquite density averages about 100 trees/ha. The region's most common mesquite species is *P. laevigata*, a species found also in other areas of Mexico and in Peru (Galindo 1983, Ffolliott and Thames 1983). A second important species is *P. glandulosa* var. *torreyana*. Hybrids of these species have been noted locally (Galindo 1983).

The vast majority of rural communities in the *altiplano* were established through federal agrarian reform laws on government-owned land. All range and forest land in these communities, or *ejidos*, is shared communally; hence, mesquite found on communal land can be harvested by any *ejido* member. In 1986, 54% of the *ejidos* had no electricity, 42% lacked potable water, and 98% had no sewage systems (INEGI 1986a). Illiteracy rates were about 16%. Only 1% of the *ejido* fields were irrigated (SARH 1987).

Uses of Mesquite

In many areas of semiarid Mexico and the southwestern United States, mesquite pods constituted a major portion of the diet of indigenous peoples. The Chichimecas, a hunter-gatherer group that inhabited the highlands of San Luis Potosí, counted mesquite pods and mesquite honey as two of their principal diet components (Galindo 1983). Today, the mesquite pod is consumed fresh, boiled in its own syrup, or prepared as a sweet flour (*pinole*), a dried candy (*queso* or *piloncillo*), a beverage boiled in water or milk with corn meal (*atole*), and occasionally as an alcoholic drink (Galindo 1983). In Matehuala, an estimated 21,000 *piloncillos* of molded mesquite flour are sold in August-October. In 1988, each sold for 250 pesos or about 16 U.S. cents.

A 1965 survey of nine Mexican states recorded a collection of 43,000 tons of mesquite pods, with a total value of 14 million pesos or more than US$1,000,000 (Gomez et al., 1970). In San Luis Potosí, total commercial value of pods surpassed that of mesquite wood products by 70 times. Commercial pod values far exceeded wood values in every state except Sonora (Table 2). These figures indicate that pods were, and may still be, more important economically than wood in at least seven of the states (Table 1).

Aside from its uses for pods and wood, mesquite rates as a valuable honey plant (Martin 1985). Its gum is being investigated as a substitute for gum arabic (Anderson and Farquhar 1982, Espejel 1981) and several tons have been bought in the *altiplano* for research purposes (Yrizar 1987). Various parts of the tree have been used for medicinal purposes (Galindo 1983). Mesquite plays an important role in providing food and cover to a wide variety of birds, rodents, large mammals, and insects (Schuster 1969). In addition, it is used for landscaping, erosion control, and reforestation.

Commercialization of Mesquite Pods

The first known commercial effort to market mesquite as a feed in Matehuala began in the 1940s, with an average of 300 tons of pods sold per year. In the 1950s, a second mesquite dealer began purchasing an average of 500 tons annually, with as many as 900 tons in his best year. Both businesses sold pods whole, milled, or milled and mixed with other feeds. Other entrepreneurs bought pods in

the *ejidos* to sell to the feed stores, and ranchers also bought mesquite pods directly from *ejido* residents.

Formation of the *Unión*

Government-sponsored workshops on small business management and leadership training in the 1970s sparked the idea to establish a farmers' cooperative to buy, mill, and sell mesquite pods and to develop other rural industries based on indigenous natural resources. With government funding and organizing assistance, the cooperative initiated operations in July 1975 (Union de Ejidos 1986). A goal of the *Unión* has been to eliminate intermediaries in mesquite sales and to allow *ejido* farmers to gain control over prices.

The *Unión's* warehouses and mill are located a few miles northeast of Matehuala on Highway 57, the major highway between S.L.P. and the northern cities of Saltillo and Monterrey (Appendix A). The four 70 x 12 x 5 m warehouses are constructed of cement block with corrugated tin roofs. Together, they hold 2,800 tons of pods at capacity. The milling room stands behind the warehouses and contains two Wetmore hammer mills with 30-horsepower electric motors. As mesquite pods are milled, the fine flour is blown into two 15 x 12 x 5 m cement-block storerooms with sliding metal doors for easy access and loading. For weighing incoming and outgoing mesquite, the *Unión* has a truck scale adjacent to a 5 x 6 m office in front of the warehouse. They also have an auxiliary electric substation and transformer, but power is turned on only during the milling season. In 1987, the cooperative owned an 11.5-ton Dodge truck, 1976 model, for transporting mesquite from the *ejidos* to the warehouse. The *Unión* had no telephone and all files and records were kept either at the Bancorural or at homes of *Unión* officers. Total capital invested in the structures and equipment upon establishment was US$48,997 (Bancorural 1975).

Production and Sales of the *Unión*

The *Unión's* mesquite harvest seems to depend largely on fluctuating mesquite yields. The 1982 harvest of 2,843 tons shows the highest recorded level of production since formation of the cooperative. In 1990, the *Unión* produced 2,000 tons. In 1980 and 1981, the Unión showed no harvest (Figure 1), and data has not been accurately kept from 1988 to 1995, with the exception of 1990. The majority of the harvest came from the neighboring state of Nuevo Leon (53.6% of pods in the seven years where records on pod origin were kept), although all *ejidos* belonging to the *Unión* are in the state of S.L.P.

In its first few years, the *Unión* sold almost all mesquite as milled flour and individual ranchers made up the majority of *Unión* customers. However, by 1985, the *Unión* sold 83.5% of the mesquite as unprocessed, whole pods and one buyer bought 55.9% of the harvest. By 1987, he was purchasing 65.8% of the *Unión's* production, all as unmilled pods. Discussions with this buyer revealed that he mills the pods for resale, mixed with other livestock feeds, and ships most of it to large-scale ranchers in S.L.P. and other states. A second buyer bought more than 15% of the total in 1985 and 1987 (the only years with complete sales data). This buyer ships the mesquite to dairy farmers and some cattle ranchers in the neighboring states of Jalisco and Guanajuato, at least 400 km south of Matehuala. A third buyer from Matehuala purchased almost 10% of the production as whole pods, later selling it as a milled feed to local ranchers.

Interview Data

Of the 35 respondents interviewed in the *ejidos*, 82% earned a living through a combination of agriculture, indigenous plant collection, and livestock and 13% through wage-earning jobs. In the last 10 years, 59% had immediate family members who had migrated to the United States for work and 31% had family members who had worked in other parts of Mexico. Only 10% of the families had never worked outside the region. Ninety-four percent harvested mesquite pods for sale, livestock feed, or family food. Almost half had collected mesquite throughout their entire lives. Another 36% began

harvesting after they heard about the formation of the *Unión*. The vast majority (93%) of all respondents said their parents or grandparents used mesquite, but only 38% of them had sold the pods.

According to respondents, it takes an average of 27 minutes for an individual to harvest 10 kg of mesquite. If one selects only high quality, sweet pods, it could take as long as three hours for the same amount. The whole family participates in the harvest: men often gather pods as they walk to the fields and children collect pods after school, sometimes to earn spending money from ranchers on private land.

Harvesters stated that mesquite and *tuna*, the fruit of the prickly pear cactus, bring in the first bit of cash income before crops ripen. They praised mesquite as a type of insurance crop, repeating as if a chant, *"Cuando no hay maiz, hay mezquite Y cuando no hay mezquite, hay maiz."* ("When there's no corn, we have mesquite. And when there's no mesquite, we have corn.") They believed that good mesquite harvests alternate with good corn harvests. However, all agreed that 1986 and 1987 had been poor years for both crops.

In the two years before the study, pod harvests had been exceedingly low, with 75% to 85% of the respondents stating they sold no mesquite. The largest harvest of any family in either of those years was 3 metric tons. The largest harvest in any year recalled by a single family was 14 tons. Every person stated that fluctuations in pod yields were extreme. Respondents frequently blamed poor production on freezes or cold weather during flowering (46% of all causes mentioned). Other causes given included (in order of most frequent mention): eclipses, insects, hail, ballmoss, rain at harvest time, dry years, and wind.

While the majority did not tend mesquite trees, 20% said they pruned lower branches and weeded underneath the trees to facilitate the harvest or to strengthen the tree and increase growth and pod production. One man also removed ballmoss from the branches of high-yielding trees. A woman mentioned that she had worked with an small *ejido* nursery that had attempted to grow mesquite from other regions that might prove resistant to ballmoss. The nursery abandoned the project when all seedlings died, apparently from damp-off. Another respondent frequently removed mesquite seed or seedlings from stock manure to plant around her yard and field.

Fifty-two percent of the respondents harvested from specific trees known to be especially productive or to yield sweet pods. Many identified the qualities of specific trees, such as color, texture, size, and flavor of pods. All believed pod quality and production differed greatly between individual trees

All respondents who owned livestock used mesquite pods for feed, and 38% bought additional pods for this purpose. Twenty-one percent had fed mesquite as flour, and another 38% would prefer using flour to pods if it were affordable and readily obtained.

Of the *ejido* members interviewed, all used fuelwood for cooking, although 65% also had gas stoves. Mesquite was the most common, and often the only, wood used. All informants claimed not to fell trees for fuelwood, but instead lopped off branches of live trees or gathered deadwood from areas cleared for agriculture. Mesquite, some noted, was too valuable for its pods to be cut for fuel. When asked if there were more mesquite trees now or 15 years ago, 44% said there were less now because of the felling of trees for charcoal industries and mines and the clearing of land for agriculture. Two informants in Nuevo Leon mentioned that government agricultural development projects had cleared mesquite stands to plant prickly pear or peaches. Another 37% felt mesquite was more prevalent now than 15 years ago because charcoal and fuelwood use had declined. Some also noted that mesquite had proliferated in agricultural fields abandoned due to urban migration. "Mesquite is very prolific,"

one woman explained. “Wherever a seed falls, a tree is born. In the old fields, they come up faster because the soil is fertile and soft.”

Factors Affecting Pod Harvest

Comparisons of harvests of mesquite beans with those of corn and field beans indicate an inverse relationship for the years for which data is available (1981S1985). Nonirrigated crops generally yield more with higher precipitation; however, heavy rains could decrease mesquite pod yields, especially if they occur while trees are in flower. Social and economic factors affecting the harvest must also be considered. Farm families expecting high corn and bean yields might feel less of a need to harvest mesquite beans, although the mesquite harvest occurs primarily in July and August, while corn harvests do not occur until October and November. During a dry year, range forage and cultivated feeds are in short supply, so a farmer might feed mesquite to his/her livestock instead of selling pods. Migration may also increase in dry years, playing a role in total harvest.

Mesquite Pod Processing

Techniques for milling mesquite range from the crude mortar and pestle carved from mesquite wood that is used in the *ejidos* to an advanced process that separates the pod into cotyledon, seedcoat, endocarp hull, and exo-mesocarp flour for use in the food industry (Saunders et al. 1986). The *Unión's* milling process consists of air drying and grinding the entire pod, including the seed, in a hammer mill. Six workers are needed, and in years of large harvests, two work shifts have been used. Although the mills have a theoretical capacity of 2 tons/hour each, the total output reaches only about 12 tons/day because of the time-consuming task of cleaning stones from the mesquite batches. Clogging of the mills is also a problem. Other mesquite buyers in the *altiplano* mill mesquite with dried corn cobs, alfalfa, or sorghum to reduce clogging. This mixture allows a throughput of 800S900 kg/hour while mesquite alone allows only 500S600 kg/hour.

Markets for Mesquite Pods

Mesquite use as a livestock feed has been reported throughout the world (D'Antoni and Solbrig 1977, Habit 1981, National Academy of Sciences 1979, Douglas 1973, Mahadevan 1954, Abdelgabbar 1981, Kargaard and Van der Merwe 1976, Smith 1950, Gomez et al. 1970), making the livestock industry an obvious market for mesquite pods. The market for mesquite in processed human food products is largely unexplored. In Chihuahua, Mexico, a manufacturing plant has successfully marketed a candy of 10% mesquite flour with peanuts, sugar, and salt and has distributed mesquite flour to natural food stores in Chihuahua with positive responses (Saunders and Becker 1987). Recipes using mesquite have been developed (Niethammer 1987), and several nonprofit institutions in Arizona have sold flour for food products. Studies on the health benefits of mesquite and other desert products have been conducted (Snow et al. 1987). These factors point to a potential market for human consumption of mesquite flour, both in the U.S. and in Mexico.

Nutritional Value of Mesquite Pods

Proximate analyses (Table 1) show mesquite pods to be high in fiber (17.0% to 30.8%) and low in fat (1% to 4%), with the seed similar in protein to soybeans and the outer pod similar to rice or barley. Sugar content varies from 13% to 41% (Zolfaghari and Harden 1982, Del Valle et al. 1983, Becker 1982). Total digestible nutrients (TDN), a measure of gross energy of a food minus the energy lost in the feces, is a good general indicator of feed value. In mesquite pods, TDN is high, ranging from 70.5% to 84.1% in whole pods (Mahadevan 1954, Castano 1966, Barbosa and Campos 1981, Morrison 1965, Talpada et al. 1979), falling between values reported for oats and corn, but slightly higher than barley (Lane 1988). Crude protein levels are adequate for maintenance and milk production. Studies on mesquite consumption by cattle, sheep, goats, pigs, and rabbits have shown it to be an economical feed, with varied production results, depending on the rations (Del Valle and Marco 1985, Castano 1966, Garza and Narvaez 1963, Talpada et al. 1982, Buzo et al. 1972, Kargaard

and Van der Merwe 1976, Debler 1974, Portilla 1967, Rojas 1963, Castillo 1979, Awad-alkreem and El Sammani 1985, Zelada 1986). Problems related to mesquite consumption seem to be due to diets based solely on mesquite, especially whole pods. (Alder 1949, Dollahite and Anthony 1957, Garcia 1976).

Livestock Feeding in the *Altiplano*

In S.L.P., mesquite is used to feed beef and dairy cattle, sheep, goats, horses, burros, mules, and pigs. Ranchers feed goats whole pods, but most prefer mesquite flour for other livestock. Those interviewed stated that they use mesquite because, in order of frequency of mention, it leads to good weight gains, gives good overall results, is palatable, can be fed on the day of the sale to make cattle look fat and healthy, has a high protein percentage, is recommended by the veterinarian, and is better than any other feed. Seventy percent of livestock owners using mesquite had never had problems with it, but some mentioned its laxative effect and the hazards of intestinal obstruction from feeding too much whole mesquite. Deaths of five horses and one cow were reported by two informants.

Informants provided a number of mesquite feeding rations. The largest rancher in the *altiplano* uses the following milled ration for finishing beef cattle in a feed lot: 20% mesquite flour (can substitute molasses), 40% sorghum, 20% sun-cured corn stalks, and 20% poultry manure, combined with 10 kg of salt per ton. Alfalfa is substituted for chicken manure for sheep. Other milled rations for sheep and cattle combine 10% mesquite with 30% corn stalks, 25% corn kernels, 25% alfalfa, and 10% chicken manure, or 15% mesquite flour, 60% chicken manure, and 25% bran. According to one dairy farmer and to feed dealers, mesquite is particularly beneficial for increasing milk yields. Dairy cows have been successfully fed 75% mesquite flour with 15% bran and 10% corn. For good growth and production in high yielding dairy cows, such as Holsteins, mesquite's crude fiber must be balanced with a feed high in crude protein such as cottonseed meal or soy paste.

Price Comparisons

Mesquite, which is highly palatable, is often used as a substitute for molasses or sorghum to increase consumption. Interviews show the great desire for mesquite among livestock owners in central Mexico, particularly dairy farmers. Cost and availability, however, form the major barriers to increasing mesquite's share of the livestock feed market.

In all but one of the interviews, livestock owners stated that mesquite prices have steadily increased in relation to other feeds. The federal government sets minimum and maximum prices for most agricultural products, but no price limits have been established for mesquite. Several ranchers stated they buy whole mesquite if its price is less than that of whole sorghum, but are willing to pay the same price for mesquite flour as for milled sorghum due to the high milling costs of mesquite.

In the fall of 1987, the price of whole mesquite at the *Unión*, reached 200 pesos/kg or 12.7 cents US/kg, surpassing that of sorghum at 175 pesos/kg or 11.1 cents US/kg (Table 9). Mesquite can often be purchased for lower prices from other sources, such as feed dealers and *ejidos*. In 1987, ranchers bought mesquite from non-*Unión* sources for 30S150 pesos/kg (1.8 to 9.5 cents US/kg).

Potential of the Mesquite Pod Industry

The extreme variability of pod yields is probably the greatest barrier to the success of a mesquite industry, particularly when harvesting from natural mesquite. Great fluctuations in the *Unión*'s harvest from 1977S1987 (Figure 1) suggest that there may be an alternate bearing cycle in mesquite. From 1987 to the present, records were kept only in 1990, when the Unión purchased 2,000 tons.

Mesquite pod production has been measured at 33S20,000 kg/ha (Glendening and Paulsen 1955, Felker and Bandurski 1979, Smith 1950, Douglas 1973). Annual pod production in the *altiplano* has

been shown to vary from 4S50 kg/tree and from 200S2,200 kg/ha, with stand densities of 25S445 trees/ha (Villanueva n.d., Morales 1967, Galindo 1983, Bancorural 1975).

In an effort to explore variations in annual yield, separate regressions were run comparing annual precipitation, date of last spring freeze and number of spring freezes to the *Unión*'s total harvest. No significant correlations ($p \leq 0.05$) were found. Next, pod harvests in years with late freezes were compared to harvests in years without late freezes. In four of five *municipios* or townships, harvests were greater in years in which there was no freeze after March 14 (Table 3), but one *municipio* showed average harvest to be 55% higher in years with late freezes.

Insect damage is a second barrier to the mesquite industry. Under natural conditions, seed beetles (Bruchidae) can destroy from 8% to 75% of the seed crop in a given year (Johnson 1983). In Chile, insects have been noted to reduce seed crops up to 90% in a given year (Habit 1981). The *Unión* estimates losses due to insects at 10% to 25% of the harvest during storage.

The bromeliad called ballmoss, or *Tillandsia recurvata*, has also been considered a threat to pod production in the *altiplano*. Dense colonies of the epiphyte may inhibit photosynthesis through shading effects when growing on mesquite trees.

A fourth and quite serious threat to the industry stems from the widespread destruction of natural mesquite woodlands. This may be due to cutting for fuelwood or charcoal, or to clearing areas for agriculture. Without irrigation or water harvesting, however, cleared fields are often abandoned in two to three years (Medellin and Gomez 1979). Mesquite woodlands in southern Nuevo Leon have been cleared to plant range grasses, primarily *Pennisetum ciliare*, but these plantings have often failed due to freezes, poor drainage, or inadequate moisture. Thirteen thousand hectares of prickly pear were planted in the same area, after clearing mesquite trees, but did not withstand the area's cool temperatures. On another site, a joint Canadian/Mexican project cleared mesquite in 1986 to "reforest" an area with cypress (*Cupressus* spp.), carob (*Ceratonia siliqua*) and casuarina (*Casuarina equisetifolia*). Of the species chosen, none offered the fuelwood quality of mesquite, and only one (carob) had good forage value (de la Cruz 1987). The species were poorly adapted to the site, and only a few saplings remained 18 months after planting.

Because mesquite woodlands are often viewed as favorable sites for agriculture, the value of protecting a mesquite grove was compared to the clearing of the area to create croplands. Costs and returns per hectare of corn and bean production (SARH 1987) were compared to those of mesquite production in Table 2. Harvest was the only cost incurred for mesquite production, and cost was based on a conservative average of 1,400 kg/ha pod production and an estimated rate of harvest of 20 kg/pods/hour harvest cost. The harvest of mesquite, which requires gathering, but no cutting or picking, requires less effort per hectare than the harvest of corn or beans. This conservative estimate shows mesquite production to generate over twice as much return to farmers per hectare as nonirrigated beans and much more than nonirrigated corn, which had a negative value for the five-year average. Mesquite produced only 32% as much in earnings as irrigated corn and 15% as much as irrigated beans. Mesquite also provides benefits not counted in this comparison, such as fuelwood, forage, honey, shade, and windbreaks.

Operating Expenses of the *Unión*

The *Unión* has paid off an initial loan of $877,500 pesos made in 1976 at an interest rate of 13%, and has obtained and paid several other loans. Detailed financial information was difficult to obtain. Annual expenses from the available years, 1978-1983, are shown in Table 3. During these years, with the exception of 1981, in which the Union closed for lack of harvest for two consecutive seasons, the average percentage spent in the various categories was: 49.8% for raw material (mesquite pods), 16.5% for personnel, 21.7% for interest payments, 4.8% for electricity, 1.7% for gas, service, and

repairs on the truck, 1.5% for maintenance of mills, building, and other equipment, and 4.1% for miscellaneous expenses.

A baseline estimate of annual expenses for a mesquite storage and milling facility has been prepared (Table 4) for pod harvest levels of 1,000 and 2,000 tons. Estimated expenses are shown for 5%, 10%, and 15% interest rates. The estimated total annual expenses are US$152,995 to US$165,655 for a 2,000-ton harvest and US$79,766 to US$86,096 for a 1,000-ton harvest. Annual net return for a 2,000 ton harvest, based on this estimate, equals US$46,372 at 5% interest, US$40,042 at 10% and US$33,712 at 15%. For a 1,000 ton harvest, the return is US$19,968 at 5%, US$16,803 at 10%, and US$13,638 at 15%.

Improvements Needed at the *Unión*

Fumigation or drying of pods before storage could reduce the current 10% to 25% loss of the harvest due to insects. If insect losses could be reduced from 25% to 2%, benefits to the industry would be in the order of US$65,506/year for a 2,000-ton harvest, or US$32,703 for 1,000 tons (Silbert 1988). In order to fumigate, structural changes may need to be made to the warehouses to close off broken windows and openings in the roof. Pesticides could be used, but possibilities also exist for use of carbon dioxide or other materials in an airtight environment.

The major problem in mesquite drying, as in other legumes, is the high resistance of seeds to air-flow. A simple method, similar to coffee and cocoa drying systems throughout the world, could be to spread pods on corrugated tin painted black, raking each day to allow for air circulation. A second method would be to install clear corrugated fiberglass roofing and a black attic floor in one warehouse, pulling hot air though the pods through use of a fan and an attic duct. An electrically powered heat pump could be installed to provide constant drying at night and during low insolation periods. The most costly option would be to use a drying oven, such as that described by Meyer (1984) for mesquite pods. Cost of this system is estimated at US$61,000 plus operation and capacity would be 2.7 tons. The oven would require electrical heating coils and exhaust fans, and pods would move through on a conveyor belt.

Drying would not only aid in pest control, but it would also allow the Union to more quickly mill pods into flour. This would enable earlier sales and a faster turn-around time on loans, ultimately saving interest charges. Methods would have to be tested on a small scale to determine if temperatures could be raised high enough to kill bruchid beetles and dry the pod to moisture levels low enough for milling (8% to 13%).

Through improved marketing, a mesquite pod operation such as the *Unión* **could develop promotional pamphlets explaining the qualities and uses of mesquite as a livestock feed, place advertisements in livestock journals and with livestock associations, survey ranchers to determine needs for related feed products, and look at other methods for boosting sales. Sales of milled mesquite would also need to be increased to recover the highest value of the product.**

Improved marketing would require a production and marketing manager to analyze sales potential, product development, and promotion, a business office with a phone, an efficient and dependable vehicle, and improved organization of the operation. Estimated additional costs of this option are US$10,147 per year. Additional net returns would be US$12,004 to US$34,157 for a 2000-ton harvest and US$929 to US$12,004 for a 1000-ton harvest (Silbert 1988).

Production of balanced livestock feeds would increase sales and could be especially important in years of poor mesquite harvests, when mixtures with little or no mesquite could be prepared. A location, such as that of the *Unión* **facility on a major Mexican highway, is visible, accessible, and convenient for ranchers traveling through on their way to livestock markets. A well-organized, reliable feed outlet**

would mesh well with the marketing option because the manager could also make decisions on feed rations and direction of sales efforts. The additional annual cost of preparing 3,500 tons of a cattle ration is estimated at US$147,472, utilizing half the supply of mesquite in a 2,000-ton harvest or all of the mesquite in a 1,000-ton harvest. Assuming all is sold, additional net return would equal US$162,655 to US$664,557 (Silbert 1988).

A clear strategy for establishing buying and selling prices for mesquite is needed. At the *Unión*, there has been no correlation between the current year's buying or selling price and the quantity harvested. To increase mesquite sales, prices should be based on prices of competitive feeds (especially sorghum), availability of mesquite, and demand for mesquite. Whole mesquite pods should be kept below the price of whole sorghum in abundant harvest years and milled mesquite at or below the cost of milled sorghum in poor harvest years.

The problem of inconsistent availability of mesquite pods remains a major stumbling block to the mesquite-pod industry. Expansion of harvest areas could reduce impacts of localized weather patterns on production. Storing pods in high harvest years and producing mixed feeds would allow for greater industry control. Finally, as more is learned about factors affecting mesquite pod production, options may be developed to improve mesquite woodland management or establish mesquite plantations.

Conclusion

The *Unión*'s mesquite facility in Matehuala has proven to be beneficial in providing an income option in rural *ejido* communities and in providing a source of locally-produced feed to livestock owners. Several improvements, which must necessarily be coupled with better management and a more stable pod supply, would increase the profitability of the mesquite cooperative, thereby increasing the return to rural residents.

Mesquite shows great potential as a multiple-use resource in dryland areas, but further study is needed in the areas of pod production, nutritional qualities, management and values of native stands, plantation establishment, agroforestry and silvo-pastoral systems, and economic comparisons of mesquite with other dryland production options. In the area of pod production, the possible alternate bearing pattern in mesquite needs further investigation, including study of the impact of spring freezes and precipitation levels. Cultural methods for improving yields, especially low-capital, labor-intensive techniques should be considered for management of native stands. Pruning methods in particular may be viable since they can be combined with the harvest of fuelwood. The effect of the epiphyte ballmoss on pod yields should be studied.

The Mexican *altiplano* is an ideal location for research and development of mesquite plantations because of the knowledge and interest in mesquite, the ecology and climate, the availability of land and labor, and the potential for mesquite to be further utilized in economic development efforts. Improved pod and/or wood yielding varieties suitable for this and other regions need to be identified, along with management techniques as mentioned above.

Mesquite pods represent an important natural resource for poor, rural families in dryland Mexico, as well as a desirable livestock feed product for ranchers. The *Unión de Ejidos,* although not without its flaws, can serve as a model for other community development projects in mesquite-producing regions. Such an innovative approach to produce income through natural resource utilization is worthy of attention from natural resource managers, government agencies, rural communities, and others involved in development work.

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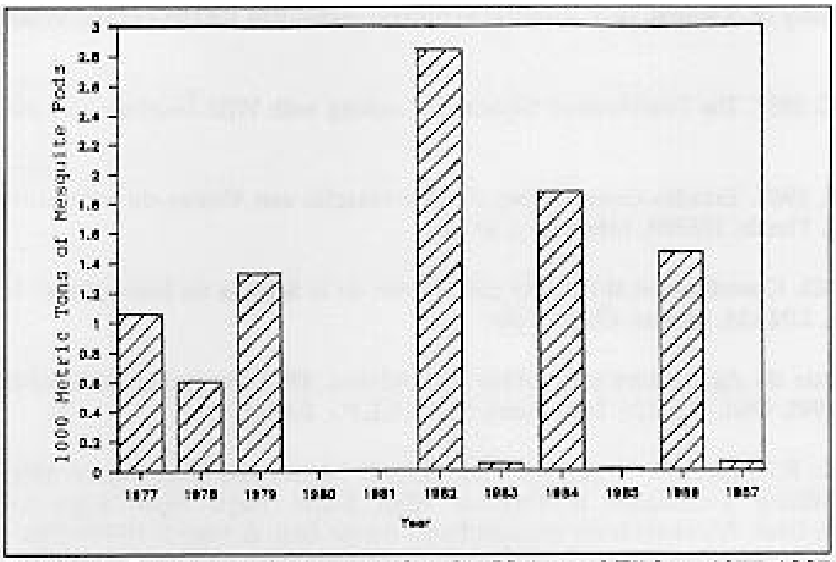

Figure 1. Purchase of Mesquite by the Union of Ejidos, 1977-1987

Table 1. Proximate Analyses of *Prosopis* Pods of Various Species

Species	Origin	Moisture (%)	C.P. (%)	Fat (%)	Ash (%)	Fiber (%)	Source
laevigata	S.L.P.	4.73	10.12	1.62	3.16	26.07	Villanueva n.d.
species	Mexico	15.09	20.30	1.68	5.24	26.18	Castano 1966
glandulosa	Texas	7.55	9.38	2.66	3.27	21.68	Becker & Grosjean 1980
glandulosa	Chihuahua	0.79	11.33	1.63	3.00	28.30	Del Valle et al. 1987
glandulosa	California	2.20	14.00	--	3.40	20.00	Becker 1982
velutina	Arizona	7.27	11.81	2.36	4.83	22.61	Becker & Grosjean 1980
velutina	California	2.83	13.00	--	4.03	25.00	Becker 1982
juliflora	Chihuahua	9.00	14.70	3.20	5.50	21.30	Del Valle et al. 1983

Note: Figures from Becker (1982) are averaged for each species.
C.P. = Crude Protein

Table 2. Comparison of Costs and Returns/Hectare of Mesquite, Corn, and Beans (1986 pesos)

Type of expense	Mesquite, wild	Corn, dry.	Corn, irrig.	Beans, dry.	Beans, irrig.
	COST OF PRODUCTION				
Land preparation					
Plowing		7000	7000	7000	7000
Disking			7200		3600
Irrigation (gravity)			4550		4800
Seeding					
Seed		2850	3960	12950	11750
Fertilizer			11075		5270
Labor		5000	4200	4200	4200
Cultivation					
Fertilization			5400		
Weed control		4000	6400	3200	6400
Insect control		4900	5400		5075
Irrigation			27440		30630
Harvest	11725	1098	9150	4000	4950
Indirect costs					21777
Insurance		5055	13873	5055	
Interest		8642	38015		
Total pesos	11725	38545	143663	36405	105452
	PRODUCTION AND VALUE				
Tons produced/ha	1.4(a)	0.3(b)	2.5(b)	0.2(b)	1.5(c)
Gross return/ha (d)	61600	36000	300000	60000	440789
Net return/ha	49875	-2545	156337	23595	335337
Net return/ha(U.S.)	$74.92	($3.82)	$234.85	$35.44	$503.74

a. Average of three mesquite production estimates in the Altiplano: 2.2 ton/ha, 1.8 ton/ha, and .2 ton/ha.
b. Five year average.
c. 1986 figure available only. May reflect higher return than five year averages of other crops.
d. 1986 prices. Fall 1986 dollar = 665.69 pesos.

Source of production data: SARH (1987).

Table 3. Annual Expenses of the Union de Ejidos, 1978-1983 (US$)

Year	Mesquite harvest (tons)	Raw material	Person-nel	Electr. energy	Trans-port	Main-tenance	Misc.	Interest	Total	Adjusted for inflation
1978	602	37097	8332	1933	2478	710	60	--	50611	73843
(%)		73.3	16.5	3.8	4.9	1.4	0.1	--		
1979	1337	87927	9723	2018	856	81	1803	19866	122274	151494
(%)		71.9	8.0	1.7	0.7	0.1	1.5	16.2		
1980	0	0	6984	3232	276	1098	74	4134	17798	17798
(%)		--	50.5	18.2	1.6	6.2	0.4	23.2		
1982	2843	91345	4125	--	1055	--	1322	--	97847	199660
(%)		93.4	4.2	--	1.1	--	1.4	--		
1983	51	2835	920	14	--	--	4517	18402	26668	40266
(%)		10.6	3.4	0.1	--	--	16.9	69.0		
Avg.%		49.8	16.5	4.8	1.7	1.5	4.1	21.7		

Note: In 1981, there was no production or sale.
Source: Records of the Union de Ejidos Productores de la Vaina del Mesquite, Matehuala, S.L.P.

Table 4. Baseline Estimate of Annual Expenses of a Mesquite Storage and Milling Facility at Two Levels of Production and Three Interest Rates (US$)

Category	At 5%	% of total	At 10%	% of total	At 15%	% of total
HARVEST OF 2000 TONS OF MESQUITE						
Raw material	126,600	83	126,600	79	126,600	76
Personnel	9,285	6	9,285	6	9,285	6
Energy	330	<1	330	<1	330	<1
Transport	5,250	3	5,250	3	5,250	3
Maintenance	3,200	2	3,200	2	3,200	2
Miscellaneous	2,000	1	2,000	1	2,000	1
Interest on loan	6,330	4	12,660	8	18,990	11
Total expenses	152,995		159,325		165,655	
HARVEST OF 1000 TONS OF MESQUITE						
Raw material	63,300	79	63,300	76	63,300	74
Personnel	7,860	10	7,860	9	7,860	9
Energy	165	<1	165	<1	165	<1
Transport	2,625	3	2,625	3	2,625	3
Maintenance	1,626	2	1,626	2	1,626	2
Miscellaneous	1,025	1	1,025	1	1,025	1
Interest on loan	3,165	4	6,330	8	9,495	11
Total expenses	79,766		82,931		86,096	

Raw material = $63.30/ton x total tonnage of pods.
Personnel = 1 administrator @ $5/day, 1 truckdriver @ $4/day, warehouse workers @ $3.50/day, all 312 days/yr. For 2000 tons, 4 mill operators $3.50/day for 96 days. For 1000 tons, 2 mill operators.
Energy = 50% of harvest x 11 kwhr/ton x $.03/kwhr
Transport = 75% of harvest x 1 trip/10 tons x $35/trip.
Maintenance = 2% of avg. total expenses
Miscellaneous = office expenses, unexpected costs, etc.

Prosopis juliflora as an Alternative Source of Food in the World's Semiarid Areas

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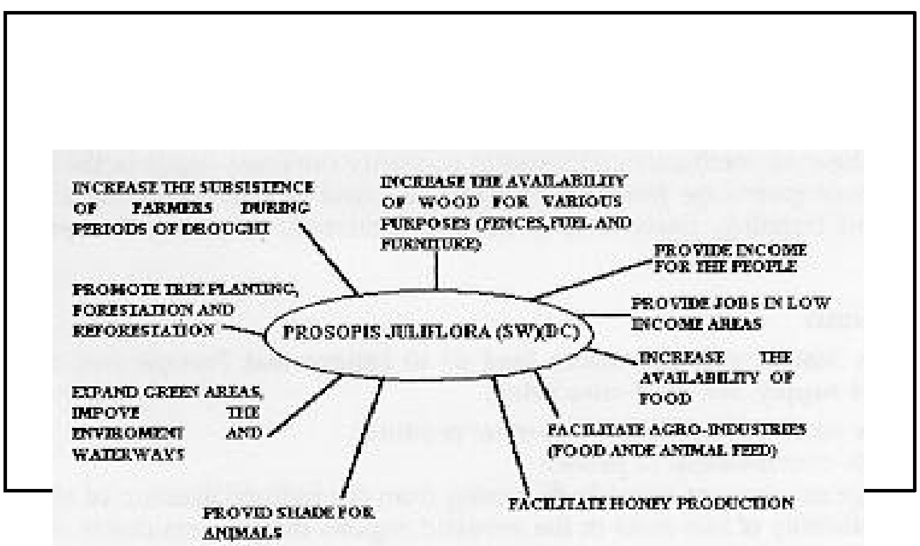
We are gathered here to treat of a subject of utmost importance to all humanity and especially to people who live in the world's semiarid areas. In speaking of *Prosopis juliflora* we are, at the same time, addressing the problem of how to develop the semiarid impoverished areas in dire need of improving the living standards of their people.

Many people see algaroba (*Prosopis juliflora*) as an alternative foodstuff for animals. However, it is the perspective of this presentation that it can also be widely used for human food, being especially useful in providing more protein for human consumption. To sustain and increase the provision of food for people is of the utmost importance, assuming that the world population will double within the next 40 years.

The world's forests are now decreasing at a rate of almost 1% per annum, bringing serious problems to millions of people. This is where algaroba has a significant contribution to make because it helps augment the amount of green matter available, thus improves the environment in critical areas.

In arid northeastern Brazil, where drought conjoined with poverty afflicts the population and the environment, *Prosopis juliflora* (algaroba) can contribute to the development of a region of over 1,000,000 square kilometers with rainfall varying between 300 and 600 mm per annum, with a population of more than 16 million, 60% of whom live below the poverty line (Figure 1).



As a politician, one devoted to public affairs, and a rural businessman, I have struggled and striven to have *Prosopis* exploited fully and sensibly. I cannot say I have witnessed great advances: *Prosopis* still remains classified with weeds and useless vegetation. The challenge of the present time is to discover and implement means to make the rural areas viable with the aid of plants and vegetable growth to support industry and protect the environment.

The semiarid world is aware of the potentialities, virtues, and drawbacks of *Prosopis*. These drawbacks will continue unless we are determined to modernize its cultivation and production. We are gathered here to find solutions, which will not be found unless we control and plan the cultivation of algaroba as a basis for industrial agriculture. If industrial agriculture does not develop, there is little advantage in talking about algaroba. In fact, we may even be promoting unplanned and disorderly invasion of land by algaroba seeds and seedlings.

Special attention must be given to spacing with due regard for the fertility of the areas in question and the purpose of cultivation, whether for foodstuffs, timber, or reafforestation. No matter what spacing is adopted, seeds and fruits will be produced, making harvesting imperative to avoid disorderly growth and undesirable propagation. Where undesirable crops invade areas, recourse must be had to weeding and thinning to improve productivity.

Therefore, it is critical that the stands be managed. On our *Prosopis* plantation of about 4,000 ha, we intensively manage the trees. The trees are staked and pruned to allow a single stem to 1.8 m height that will produce good lumber. The trees are also pruned to enlarge the foliage crown to stimulate increased fruit production. The trees are initially planted at 10 m by 10 m spacing. With regular cultivation between the trees, no invasion of young trees occurs. When the trees become larger, they are thinned to a 20 m by 20 m spacing by harvesting alternate rows. The harvested trees are used for timber, stakes, and fuel. With this spacing and periodic pruning, the growth of the plants at the 20 m by 20 m spacing will improve and produce up to 300 kg of pods per tree.

By crowding small trees together on a close spacing (i.e., 4 m by 4 m) and pruning all side branches, it is possible to obtain single stems 7 m long that would be very useful for timber.

Without careful management, *Prosopis* can invade open areas, resulting in very high densities of small trees. As both horses and cattle have great fondness for the high-sugar-content pods, and as their chewing mechanism only serves to scarify the many seeds in the pods, hundreds of seedings may germinate from a single pile of horse or cow dung. As a result, without cultivation and thinning, pastures may develop thousands of young *Prosopis* seedlings per hectare.

Animal Foodstuff

As previously stated, various reasons lead us to believe that *Prosopis* can contribute to an increased food supply, the chief ones being:

- Low cost in comparison with other products
- High concentration of protein
- Large numbers of byproducts arising from the industrialization of algaroba
- Availability of idle areas in the semiarid regions that are unsuitable for cultivation of products of a short growth cycle but are suitable for the cultivation of *Prosopis*
- The ease with which the plant adapts to semiarid conditions, making increased herds possible in these areas

Prosopis can be a useful source of animal feed, substituting or reducing, at much lower costs, the use of maize, soybeans, and wheat, all of which can be produced on only a very limited scale in the semiarid areas. A comparison of the protein content of mesquite leaves and mesquite pods with other common feeds from the arid regions of Brazil is in Table 1, which illustrates the fact that mesquite has higher protein content than all common feeds from arid regions (alfalfa has to be irrigated).

Table 1. Comparison of Protein Content of Mesquite Products
in Comparison to Other Products Common in Brazil

Description	Protein
Mesquite pods (*Prosopis juliflora*)	12.9
Mesquite leaves (*Prosopis juliflora*)	13.6
Manioc (*Manihot esculenta*)	1.6
Maize (*Zea mays*)	6.0
Alfalfa (*Medicago sativa*)	14.1
Guinea grass (*Panicum maximum*)	2.6
Spineless cactus (*Opuntia ficus-indica*)	0.4

Source: ITAL -1987

In Brazil, 1 kg of food made from algaroba sells for $US0.18, wheat bran (of much less nutritive quality) sells for $US0.20, and maize (of equal nutritive quality) sells for $US0.24. In the case of large and medium-sized animals, the addition of 1 kg of algaroba bran per animal to the roughage feeding (grass, hay, and chicken feces) acts as a complement to the feeding and stimulates roughage consumption.

Thirty percent of concentrated feeds can be replaced by algaroba bran without lessening productivity and at considerably reduced costs. Research by the Federal University of Pernambuco recently has shown that the introduction of up to 10% of bran from algaroba pods can substitute other normal food without affecting productivity of chickens and other birds raised for meat. The research has also shown that up 30% of the food of cattle, horses, goats, sheep, and pigs can be furnished by algaroba bran.

These statistics show the existence of a huge store of algaroba foodstuffs, calculated at between 300,000 and 400,000 tons annually, in northeastern Brazil alone.

In considering the value of *Prosopis* pods for feed, we must realize that the pods have three main components: the seeds in the very interior which contain about 43% protein (Table 2), a high-sugar-content pulp near the outside of the pods, and a leathery capsule that separates the high sugar pulp from the seeds. The pulp which is about 55% of the weight of the pods, is the only part that can be digested by animals without processing. Due to the hard seed coat the animals are unable to digest the seeds unless the pods are ground. Thus, if the pods are not ground, there will be a loss of 45% by weight of potential feed that includes the 43%-protein-content seeds. In addition, if cattle are fed unground pods, when they return to the fields these animals will spread the seeds through their dung.

It is also necessary to process algaroba pods because their unprocessed consumption has proved harmful to the organs of animals. Consumption of unprocessed pods has lead to diseases such as "Lingua de Pau" (Timber Tongue) "Cara de Torta" (Crooked Face) and also the puncturing of stomach and cud. Death has occurred in some cases, especially with cattle and horses.

On our ranch we pay workers to collect pods by the weight of pods they collect. It is important to verify the daily production of each worker by measuring the weights of the pods they collect.

Table 2. Proximate Analyses of Dried, Ground Mesquite Seeds
and Refined Flour from Mesquite Pods

Characteristic	Dried Ground Mesquite Seeds (%)	Refined Mesquite Flour from Pods (%)
Moisture content	N.D.	2.3
Ash	N.D.	3.8
Fiber	9.6	8.0
Protein	43.5	8.3
Lipids	9.0	8.7
Total carbohydrates	N.D.	73.8

The analyses were performed by the Nutrition Department, Federal University of Pernambuco, Recife, Brazil. Mesquite seed analyses were conducted by Maria Olivia Cutrim Tavares and pod flour by Vera Lucia Viera.

The high sugar content of the pods has a very great affinity for water in the atmosphere. If this water is not removed by a drying process before grinding, the partially ground flour will adhere to itself and all machinery components, resulting in clogged machinery. Before grinding, but before drying, the pods are chopped into segments several centimeters long. The chopped pods are dried in rotary driers adopted from the coffee-drying process. The driers are heated with with wood-fired furnaces. We have used industrial hammermills for grinding the pods after they have been dried. The output of the grinders feeds directly into bags, which are then sewn shut and transported to the warehouse. This product can be refined further for human use.

In view of all this, I would like to stress how vital it is for the production and cultivation of *Prosopis* that all those concerned should be fully aware of the need for processing the algaroba pods.

Food for People

While algaroba is useful mainly for animal feed, I should like to point out and stress its possibilities for use as human food. Historical studies show that algaroba was used in various Latin American countries as human food by the indigenous people, not the least in northeastern Brazil where significant traces of its use as human food can be found. The composition of the mesquite-pod flour in Table 2 shows that while it is moderate in protein (about 8.3%), it has a very high level of carbohydrates (73%). The amino-acid profile of the mesquite pods presented in Table 3 shows that it is above the FAO requirements for children for every essential amino acid. This is rather unusual since most legume-seed proteins are deficient in the sulfur amino acids and in tryptophan.

Algaroba pods can be processed to produce honey, flour, coffee, alcoholic drinks, ice cream, gums of the galactomannan type (similar to the widely used carob gums in the food industry). Some of these products, especially ice cream and biscuits, have had a very good reception because of the delicious taste and agreeable texture that is gratifying to the palate.

In 1984, as a special secretary for Northeastern Brazil to the Minister of Agriculture, I took part in the first International Conference on *Prosopis*, in Arica in the Atacama Desert of Chile. On that occasion, the International Prosopis Association (IPA) was established, and I was chosen President, a distinction I proudly continue to hold to this day. During that meeting, I vigorously proposed the need to process *Prosopis* pods, giving some suggestions and indications of how processing might be done. In 1986, as Pernambuco state Secretary of Agriculture and President of IPA, I presided over the Second International Meeting of the Prosopis Association held in that state. At that stage, the factory showed clear signs of improvement and evolution. I am proud to say that I surmounted many barriers and obstacles so that now a well-setup industry exists, culminating in production of 20 tons/day of human and animal foodstuff derived from *Prosopis.*

Table 3. Average Amino-Acid Content of *Prosopis juliflora* Pods
in Comparison with Nutritional Requirements
for Children and Adults as Indicated by FAO

Component	Mesquite Pods (g/16 g N)	FAO Food Values (1973)	
		Children (g/16 g N)	Adults (g/16 g N)
Isoleucine	3.56	4.0	2.0
Leucine	7.86	7.0	2.8
Lysine	5.04	5.5	2.4
Total sulphur amino acids	4.73	3.5	2.6
Total aromatic amino acids	7.21	6.0	2.8
Threonine	3.03	4.0	1.4
Tryptophan	2.23	1.0	2.0
Valine	5.85	5.0	2.0

Source: ITAL/SÃO PAULO (1987)

Needless to say, I am fully convinced of the importance of algaroba in contributing to the food supply of the world, chiefly in the arid and semiarid areas, and also of its role in developing a sustainable growth rate in these areas.

In this gathering, we bear a serious responsibility. Let us share experiences and develop projects and plans with suggestions for the ruling authorities in the semiarid areas to reflect upon, especially the possibility of improving cultivation and the fullest possible exploitation of algaroba. Postponing decisions will mean missed opportunities for investments capable of producing important economic returns with social benefits for people in the lowest income brackets (Figure 2).

Relying on my life-long experience devoted to the study of algaroba and its products and being fully aware of the difficulties presented by rural areas for industry, I appeal to all present, researchers, technicians, rural producers, government representatives, and business people, to ensure that this meeting produces a document assuming responsibility for the exploitation and processing of algaroba.

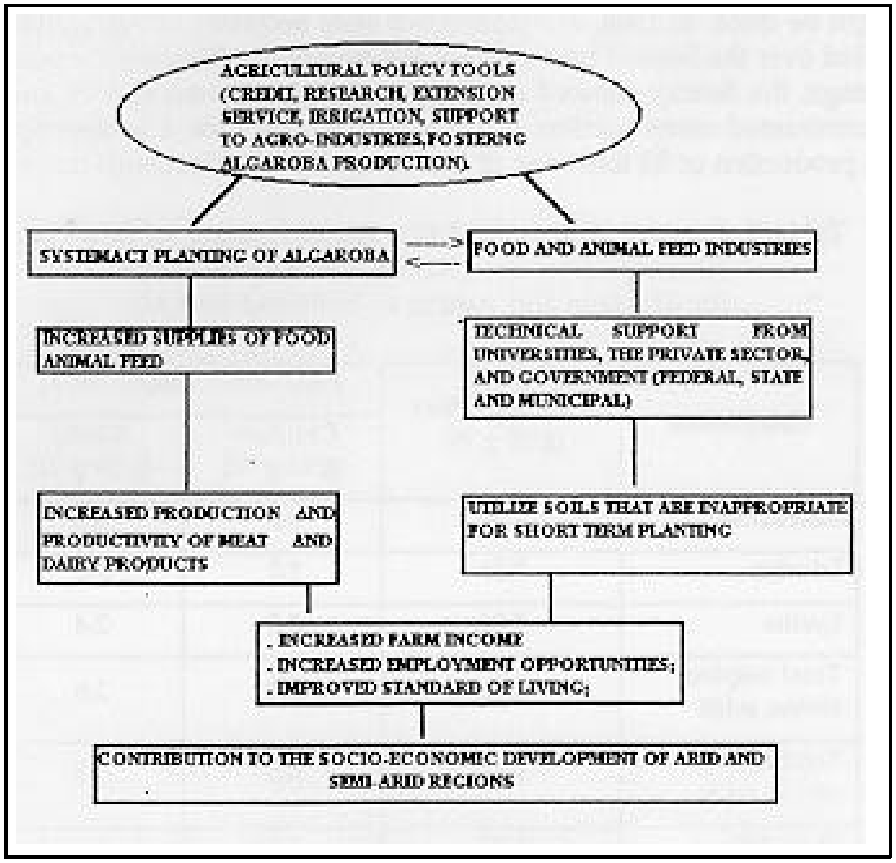


Figure 2. Development Strategy for the Semiarid Region Making Use of *Prosopis*

New Approaches to Industrialization of Algarrobo (*Prosopis pallida*) Pods in Peru

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ABSTRACT

Peruvian "algarrobo" (*Prosopis pallida* and *Prosopis juliflora*) and its fruits are described and some new ways for its industrialization are suggested on the basis of the research done at the University of Piura since 1984.

The processing alternatives of *Prosopis* pods developed at the University of Piura are focused especially on the different uses for each part of the fruit [exocarp, mesocarp (pulp), endocarp], and the episperm, endosperm and cotyledon from the seed. Each of these components has specific industrial applications.

Several specific components have been determined. Sucrose is the main sugar (46% in weight) in the pulp. In the endosperm the polysaccharide is a galactomannan, with a 1:1.36 galactose/mannose ratio. Among the important amino acids in the seed cotyledon are: glutamic acid, arginine, aspartic acid, leucine, proline and serine. In the pulp, vitamin C, nicotinic acid, and calcium pantothenate have also been found. In the seed the content of vitamin C and E are significant. The dietary fiber of the pulp and endocarp hulls is basically insoluble dietary fiber.

The results of the research show the feasibility of industrialization of *Prosopis* in Peru. The basic equipment for a pilot plant is being installed at the University of Piura to demonstrate this fact.

Introduction

Piura is on the northwestern coast of Peru (Figure 1), an arid zone where the annual rainfall is below 100 mm. The average annual temperature is 24°C and the relative humidity is 74%.

Algarrobo (*Prosopis pallida* and *Prosopis juliflora*) [1] is one of the few arboreal species that occur naturally in these desertic areas (Figure 2). It has, therefore, an enormous importance in the protection of this fragile environment. Some trees can be 15 meters tall. *Prosopis* forests cover about 85 000 ha of land in northern Peru [2].

Algarrobo is the name the Spaniards gave the tree when they arrived in Peru in the 16th century, due to the similarity of its fruits to those of the mediterranean carob. The Peruvian native names for *Prosopis* were Thacco or Guarango, which are not often used today [3].

Thanks to its wood and fruits, *Prosopis* plays an important role in the daily life of impoverished local farmers in northern Peru. They use *Prosopis* wood in constructing their rustic houses and cattle fences, and as fuel for cooking; fallen *Prosopis* leaves, as an organic fertilizer (called puño); and their fruits, with a high sugar content, are used as forage and food (mainly as algarrobina syrup). Since *Prosopis* is one of the few trees growing in this area, the people and the animals can also enjoy the shade of the tree, which is a very important benefit.

Figure 1. Location of Piura in Peru

Figure 2. Tree of *Prosopis pallida* in Piura, Peru

Figure 3. Desertification Areas

Nevertheless, fuelwood is not only used for cooking but is also commercialized as fuel for brick baking furnaces, bakery ovens, and making charcoal for grills in chicken restaurants. The excessive extraction of *Prosopis* fuelwood has caused a reduction of the availability of this resource (Figure 3). It is estimated that from the 1950s to the 1980s, 200 000 ha were deforested [4]. In 1983, as a result of the *El Niño* phenomenon, rainfall reached 2 411 mm [5], resulting in new areas of land being recovered by *Prosopis* trees.

The University of Piura has been developing a project for conservation and propagation of *Prosopis* since 1984. The success of this project is based on showing that *Prosopis* has many other rational uses. One part of this project includes the characterization of the fruit and the studies of new products and processes; another part includes agroeconomical aspects for forestation of these arid areas. There are 80 ha of *Prosopis* at the campus of the University for these studies (Figure 4).

Prosopis Pods Production And Storage

Since *Prosopis* trees are not cultivated but grow wild in desertic areas, the fruits are not harvested but collected by those who need them.

***Prosopis pallida* and *Prosopis juliflora* are varieties with especially large and sweet fruits (Figure 5). The fruits are yellow pods of up to 30 cm long, with an average weight of 12 g. The sugar content of its pulp is 46% [6, 7].**

The tree produces twice every year: the main pod production is between December and March. The second, minor production season, is between June and July. The productivity depends mainly on the age of the tree and on the soil quality. Some trees produce up to 300 kg of fruits per year.

Figure 4. Experimental Plantation at the Campus of the University of Piura

Figure 5. Pods of *Prosopis pallida*

The pods fall to the ground when they are ripe, and remain there for a long time until they are collected or eaten by animals, such as goats, sheep, or donkeys.

During the production period, the fruit has a very low price because of its abundance. A metric ton of pods costs US$27. The collecting is done by very poor children and women as an activity parallel to their agricultural tasks (Figure 6). One person can collect about 150 kg of pods in a day, which is equivalent to less than US$5.

The quantities of comercialized *Prosopis* pods are not officially recorded. An estimation based on measurements done on representative parcels of land [2] would give an approximate production of 300 000 metric tons per year in the northern region of Peru. However, not all of it is used. More than 50% is lost because it is not collected, 15% is used as animal food and the remaining 35% is bought by dealers who sell it in feed stores in other cities (Figure 7).

In fact, the main use of *Prosopis* pods in Peru is still the feeding of animals, which eat the pods without any previous processing. Some factories produce feed mixtures for livestock. It is interesting to point out that *Prosopis* is prefered by ranchers because they believe it has some special properties in addition to its recognized nutritional value, that make it irreplaceable. It is enough to say that a large part of the production is fed to racehorses.

***Prosopis* pods are attacked by insects which eat the pulp and the seeds. The most numerous are insects of family *Bruchidae*, but *Tribolium castaneum (*fam. *Tenebrionidae), Laspeyresia leguminis* and *Cryptophebia sp.* (fam. *Olethreutidae)* and *Plodia interpunctella* (fam. *Pyralidae)* are also known to eat the seeds [8]. Rain also damages the fruits. When the fruits lying on the ground get wet, they become rotten (Figure 8).**

To reduce the damage, the pods are usually stored in rustic storage rooms, on the ground, or underground. Once a room is full it is sealed with clay. A typical storage room made from adobe is showed in Figure 9. Chemicals are not often used to control insects during storage, but natural-repellent plants are used. Phostoxin™ has proved to be efficient in avoiding proliferation of insects in the storage rooms, but a considerable number of pods are damaged in the tree or on the ground and no control methods for the damage is known.

Because of the seasonal production of *Prosopis*, storage is necessary to supply seeds throughout the year. Between August and October, the price rises up to 5 times.

Traditional Human Food Products From *Prosopis* Pods

For many years, inhabitants of northern Peru have prepared and consumed algarrobina, a concentrated sugary extract of the pods. The concentrated syrup has a brilliant, dark brown color and is thicker than honey.

Algarrobina is used in different ways: it is taken by spoon as a medicine or is added to juices and milk as both sweetener and a natural flavoring. We must say that a delicious drink is algarrobina cocktail, a mixture of a small quantity of algarrobina, pisco brandy, and milk. Algarrobina is produced now in very simple plants and is sold in reusable glass bottles (Figure 10).

Ancient people talk about another product, yupisin, a beverage obtained in the same way as algarrobina, but is not concentrated. It is consumed directly or used to prepare desserts with sweet-potato flour or corn flour. Yupisin is consumed in rural areas only; it is not bottled.

Figure 6. Children Collecting *Prosopis* Pods

Figure 7. Loading a Truck With *Prosopis* Pods

Figure 8. Typical Damage in *Prosopis* Pods

Figure 9. An Algarrobera (Rustic Storage Room for *Prosopis* Pods)

Figure 10. Bottles of Algarrobina from Local Producers

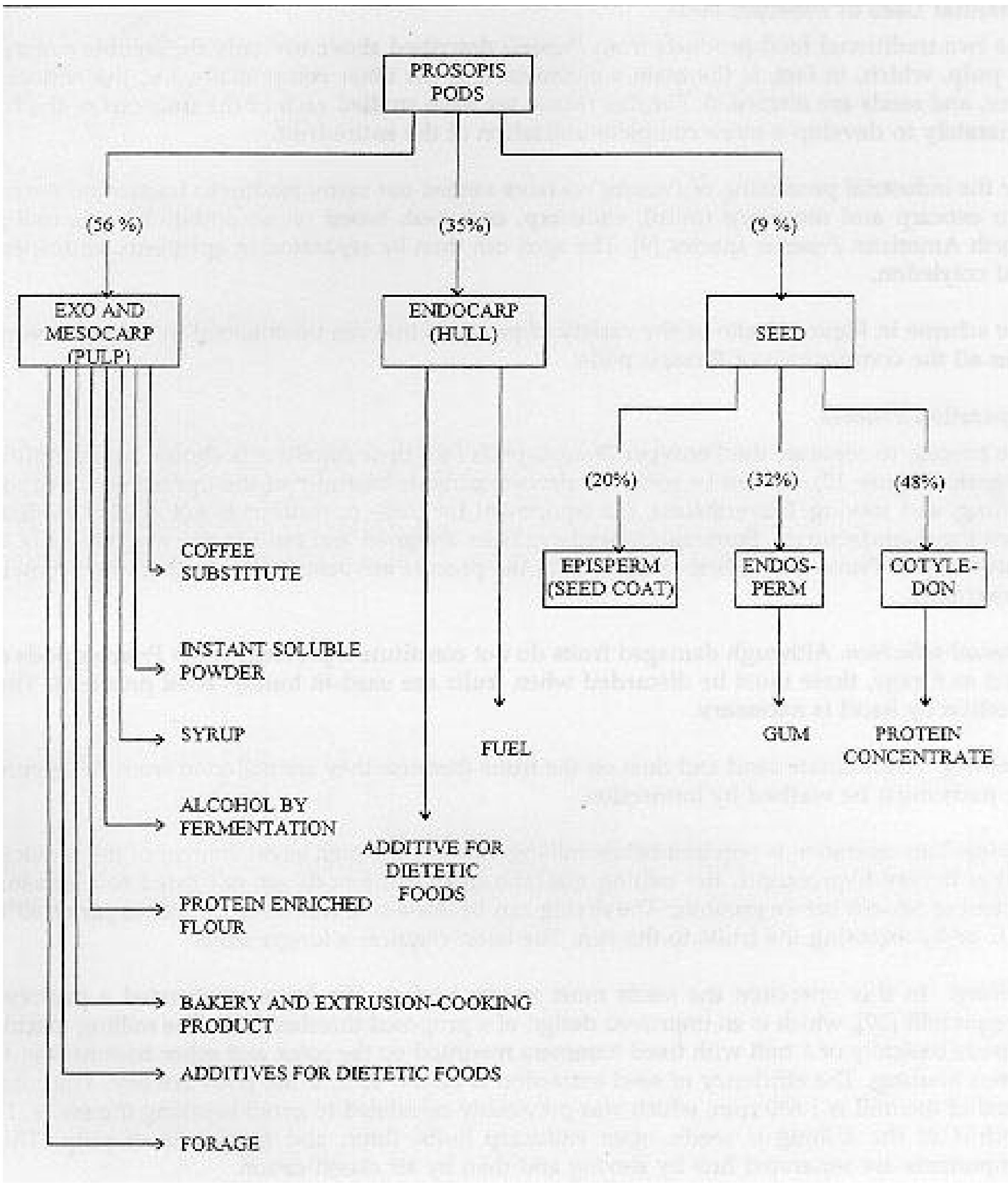

Figure 11. Potential Uses of *Prosopis* Pods

Potential Uses of *Prosopis* Pods

The two traditional food products from *Prosopis* described above use only the soluble sugars in its pulp, which, in fact, is the main constituent and the other components, i.e., the endocarp, fiber, and seeds are discarded. For this reason we have studied each of the fractions of the fruit separately to develop a more complete utilization of the entire fruit.

For the industrial processing of *Prosopis* we have carried out many studies to fractionate the fruit into exocarp and mesocarp (pulp), endocarp, and seed, based on an ambitious proposal for North American *Prosopis* species [9]. The seed can then be separated in episperm, endosperm, and cotyledon.

The scheme in Figure 11 shows the variety of products that can be obtained in a process which uses all the components of *Prosopis* pods.

Separation Process

The process to separate the Peruvian *Prosopis* pods into their fractions is shown in a simplified diagram (Figure 12). As can be seen, the process consists basically of the operations of drying, milling, and sieving. Nevertheless, the equipment for these operations is not readily available from the manufacturers. Some machines have been designed and built in the workshops of the University of Piura. Individual operations in the process are described briefly in the following paragraphs.

Manual selection: Although damaged fruits do not constitute a problem when *Prosopis* pods are used as forage, these must be discarded when fruits are used in human food products. Thus, selection by hand is necessary.

Washing: To eliminate sand and dust on the fruits (because they are collected from the ground) the pods must be washed by immersion.

Drying: This operation is required before milling. Because the high sugar content of the mesocarp makes it very hygroscopic, the milling machine clogs if the pods are not dried to a moisture content of 5%S6% before grinding. The drying can be done in a forced-air tunnel dryer at 60°CS 70°C or by exposing the fruits to the sun. The latter requires a longer time.

Milling: In this operation the seeds must not be broken. We have constructed a prototype *Prosopis* mill [10], which is an improved design of a proposed thresher [11]. The milling machine consists basically of a mill with fixed hammers mounted on the rotor and other hammers in the screen housing. The efficiency of seed extraction is about 45%, if the pods are dry. The rotary speed of the mill is 1 690 rpm, which was previously calculated to avoid breaking the seeds. The product of the milling is seeds, open endocarp hulls, flour, and fragments of pulp. These components are separated first by sieving and then by air classification.

Sieving: The fractions that can be obtained depend on the mesh of the sieves. We obtained four fractions using 6-, 10-, and 60-mesh sieves. The nature of each fraction is described in Figure 12.

Air classification: Fraction 1 has the greatest quantity of seeds. In a wind tunnel with collection pockets, the seeds can be obtained free of endocarp fragments.

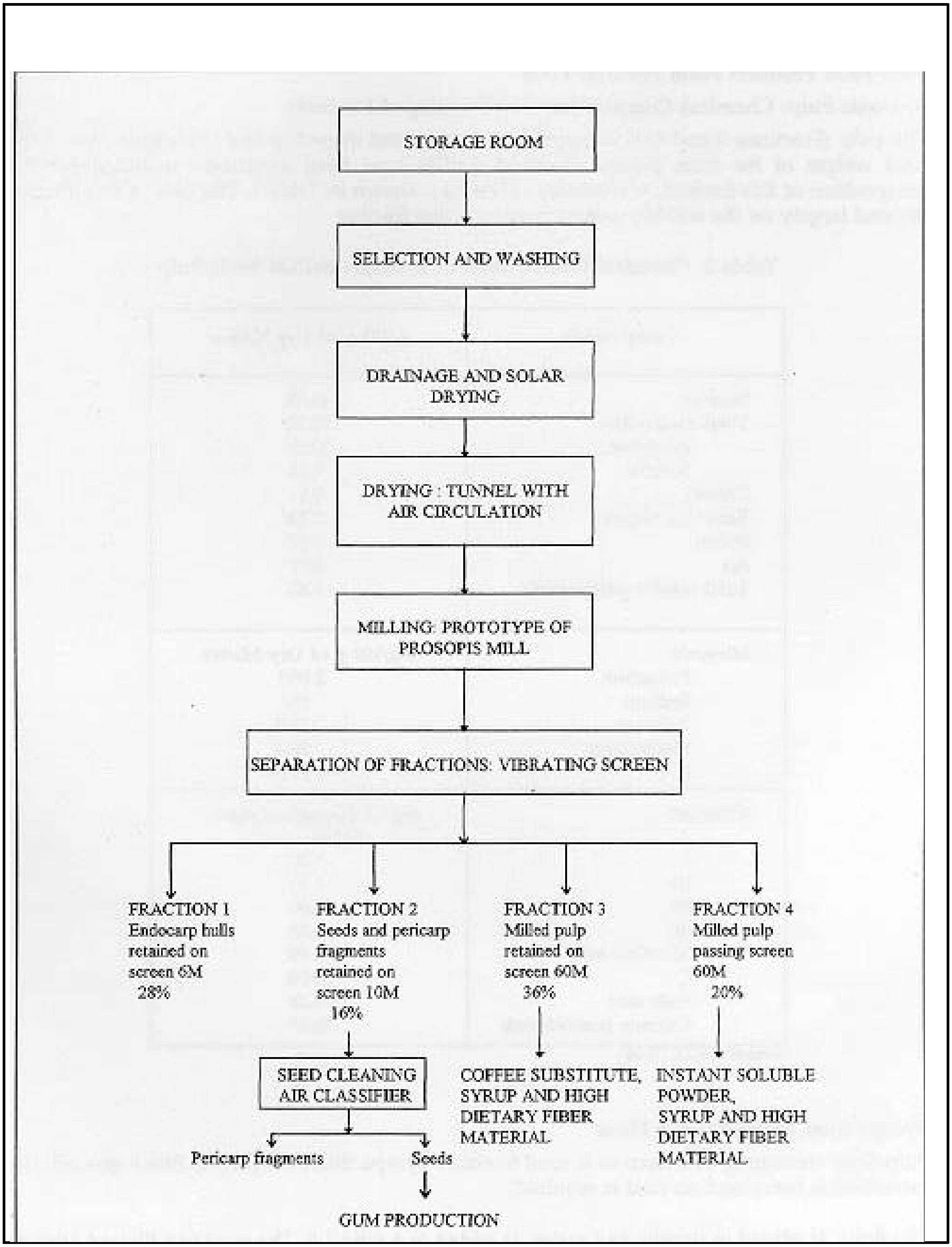

Figure 12. Processing of *Prosopis* Pods for New Products

New Food Products From *Prosopis* Pods

Prosopis Pulp: Chemical Composition And Developed Products

The pulp (Fractions 3 and 4) is composed of exocarp and mesocarp and represents 56% of the total weight of the fruit. Several chemical studies have been conducted to determine the composition of this fraction. A summary of results is shown in Table 1. The uses of this fraction depend largely on the soluble sucrose portion of the fraction.

Table 1. Chemical Composition of *Prosopis pallida* Fruit Pulp

Components	g/100 g of Dry Matter
Sucrose	46.35
Total dietary fiber	32.22
Insoluble	30.60
Soluble	1.62
Protein	8.11
Reducing sugars	2.14
Pectin	0.80
Fat	0.77
Total soluble polyphenols	0.82
Minerals:	mg/100 g of Dry Matter
Potassium	2 650
Sodium	113
Calcium	75.9
Magnesium	90.4
Iron	33.0
Vitamins:	mg/kg of original matter
A	not detected
E	5.00
B1	1.90
B2	0.60
B6	2.35
Nicotinic acid	31.00
C	60.00
Folic acid	0.18
Calcium pantothenate	10.50

Source: [6,12,13,14]

Syrups from *Prosopis* Pulp Flour

Pulp flour containing 46% sucrose is used to obtain syrups. Since the pulp is finely ground, the extraction is faster and no heat is required.

The flour is placed in vessels and water is added in a ratio 1:5. The resulting filtered juice of 11°Brix is transfered to a second extraction stage where it is enriched to 23°Brix. This juice is then concentrated in an open evaporator at boiling temperature until the juice rises to 70°Brix.

The filter cake resulting from the extraction can then be washed and dried. It can be used in fiber-rich dietary products. Currently, studies are being conducted in order to determine the physiological properties and positive effects of the *Prosopis* fiber on the prevention of colon cancer and in the reduction of cholesterol levels.

Chemical studies of fiber and associated components of *Prosopis* pulp show that it contains 30.6% insoluble fiber and 1.6% soluble fiber. Proteins (2.2%) and condensed tannins (0.33%) are associated with the insoluble fiber, while soluble tannins (0.08%) are associated with the soluble fiber [6].

Prosopis Flours In Bread And Biscuits

The rheological behavior of *Prosopis*-wheat composite flours has been studied [15]. *Prosopis* flour causes the dough resistance to decrease and the dough elasticity to increase, which, from a practical point of view, results in softer but smaller pieces of leavened bread. Sweet bread with 5% *Prosopis* flour is good in texture and taste.

In biscuit manufacturing, *Prosopis* flour replaced wheat flour up to 25%. Its high sucrose content makes possible to decrease sugar requirements in traditional biscuit recipes. A slightly bitter aftertaste has been reported in the biscuits, which some people seem to favor.

Instant Soluble Powder

In the form of flour, *Prosopis* pulp can be used in a variety of products such as cakes and ice creams. Current studies are being carried out to produce an instantaneous soluble powder for use similar to commercial cocoa and breakfast-cereal mixes.

One of the local small factories manufacturing *Prosopis* products has developed a powder tradenamed "garrofina" (Figure 13) made by fine grinding of the whole fruit (particle size <100 mesh).

In our studies [16], a soluble powder is obtained from Fraction 4 by fine milling and sieving through a 100-mesh screen. This product is more soluble than garrofina since this fraction has the highest sucrose content. Addition of sugar and lecithin, as well as agglomeration processes are being studied to improve the powder dispersability in milk, yoghurt and juices. Mixes with Andean cereals (*kiwicha*) have been tried also.

Coffee substitute

Manufacture of a coffee substitute from *Prosopis* was studied at the University of Piura in 1988 based on information from Brazil. Roasting of the whole pods was the first process to be considered [17]. Since then, we have found that a better quality is obtained by roasting the single Fraction 3 at 120°C until it is dark brown. Finally, the roasted flour is reground. The finished product can be used in the same manner as coffee, in either filtration or expresso coffee machines.

***Prosopis* coffee substitute has advantages over real coffee. First, it is not a stimulant nor dangerous to health because it does not contain caffeine. Second, it has a lower price. In addition, due to the natural sugars remaining in the roasted *Prosopis* pulp flour, it has some nutritional value that coffee does not have.**

Several small industries in Peru have adopted this technology to produce their own trade names of the *Prosopis* coffee substitute or "café de algarroba". The product is successfully commercialized in the Peruvian market packed in 250-g plastic bags. The cost of one pack is US$1.50 (Figure 13).

Figure 13. *Prosopis* Products of Local Small Factories

Other aspects of *Prosopis* pods, for example, production of alcohol and protein-enriched flour, as well as chemical analyses of endocarp, have been studied, but they are not detailed in this paper [18, 19, 20]

Prosopis Seed: Chemical Composition And Potential Uses

An efficient method to separate the three components of *Prosopis* seed (episperm or seed coat, endosperm, and cotyledon) has not yet been well defined. The main difficulties come from the very small size of Peruvian *Prosopis* seeds and strong adhesion of the seed coat to endosperm. However specific studies of endosperm and cotyledon have been conducted to determine the major components of the seed and some functional and nutritional properties, in expectation of an industrial use of these components [6, 12, 21, 22].

Endosperm or Gum

Chemical analyses of *Prosopis* endosperm show that it is a galactomannan polysaccharide [6,12, 21]. Galactomannans are macromolecules capable of absorbing a great quantity of water that increases its volume several times to form a highly viscous solution. Food additives called gums possess this behavior. Gums from leguminous seeds, such as carob, guar, and tara, have a large market in the food industry because they are used as thickeners, stabilizers, or gelifiers in products like icecream, sauces, cheese, yoghurt, sausages, and bakery products.

The individual constituents of *Prosopis* seed polysaccharide is shown in Table 2.

The main components, galactose and mannose, are present in a 1:1.36 ratio. This ratio is near that of guar gum (1:1.2) but is smaller than the ratio in carob gum (1:1.9).

Table 2. Composition of *Prosopis pallida* Endosperm Polysaccharide

Component	g/100 g of dry matter
Rhamnose	0.00
Fucose	0.25
Arabinose	1.56
Xylose	0.19
Mannose	46.28
Galactose	33.97
Glucose	0.93

Source: [6]

Other studies at the University of Piura [21, 22] focused on the rheological behavior of *Prosopis* gum solutions, depending on different gum extraction methods. Viscosity of *Prosopis* gum solutions are comparable to that of carob, guar, and tara gums. Viscosity values up to 3000 mPa in 1% gum solutions have been found that are stable over a wide range of pH.

With regard to the gum extraction, we have tested wet extractions and also mechanical and mechanical-chemical methods. Until now, only wet (aqueous) extraction is feasible.

Cotyledon

Chemical studies of *Prosopis* cotyledon [12, 23] show that 65% protein and 7% oil are present.

Fatty acids in this cotyledon oil have been quantified: palmitic 12.56%; stearic 9.6%; oleic 28.99%; linoleic 39.30%. This oil is of high quality, needs no bleaching treatment, and has a low acidity (1.7%) and an iodine value of 103.

Amino acids of the cotyledon proteins were determined as shown in Table 3.

From the amino acid composition of protein we can confirm that the main part of nitrogen is of amino-acidic nature, with an important content of essential amino acids. Thus, *Prosopis* cotyledons can be considered a source of proteins for other foods. For example, the improvement of amino-acid profile of starch flours by mixing with *Prosopis* cotyledon flour could be a useful research topic.

In addition, the contents of vitamins in *Prosopis* seed are shown in Table 4 (the three components of the seed are included).

Table 3. Amino Acid Composition of *Prosopis pallida* Cotyledon

Amino Acid	g/100 g of original matter
Aspartic acid	4.980
Threonine	1.626
Serine	3.103
Glutamic acid	11.842
Proline	3.297
Glycine	2.594
Alanine	2.465
Cysteine	1.686
Valine	2.317
Methionine	0.404
Isoleucine	1.742
Leucine	4.632
Tyrosine	0.945
Phenylalanine	2.390
Lysine	2.314
Histidine	1.633
Arginine	9.842
Total	57.812

Source: [12]

Table 4. Vitamin Contents in *Prosopis pallida* Seeds

Vitamin	mg/kg of original matter
A	not detected
E	47.00
B1	7.30
B2	0.60
B6	0.64
Nicotinic acid	15.00
C	210.00
Folic acid	0.69
Calcium pantothenate	17.10

Source: [14]

Algarrobo: Facts and Promises in Peru

As evidenced by this paper, the industrialization of algarrobo or *Prosopis* in Peru is promising. Doubtless, one of the most important needs is to conduct pilot-plant-scale studies to improve or refine the process and to study its economics. The results of the pilo-scale study will stimulate the interest of the people in this valuable resource.

As a first step, we were pleased to join an European Union research project for developing and studying new foods from *Prosopis* pods. However, much more work is needed to solve other very

complex problems, such as the separation of the seed components, insect control, or harvesting methods, for which technological and financial help from developed countries are welcome.

Working side by side with rural people has an enormous importance for the success of our long-term purpose, that is, the prevention of desertification by adding value to the *Prosopis* forests in the arid northern coast of Peru.

The University of Piura is interested in dessiminating the results of the research done on the processing of *Prosopis* pods. Clearly, the main objective is to reach the poor people who live in the desert rural areas for whom the algarrobo is the support of their economies.

For this purpose, for example, we have developed a pilot project for the improvement of the storage and the marketing of *Prosopis* pods to help poor farmers of the Asociación de Campesinos Nuevo San Vicente. This association has 50 families who own 5 460 ha of *Prosopis* forest in arid land, without easy water availability. Five simple storage rooms of 20 metric tons each were built with financial support of the nongovernmental organization CODESPA from Spain.

Also, a brochure containing the basic information about new food products from *Prosopis* was edited and distributed to many farmers and rural women. Many times we have trained housewives in rural areas surrounding Piura through cooperative workshops with local organizations. In this brochure, there are easy-to-understand processing diagrams and useful and practical advice that can help people to make effective use of the *Prosopis* resource.

There are also several Peruvian producers of *Prosopis* coffee substitute, algarrobina syrup, and so1uble powder, who are very interested in introducing their products into overseas markets and even have potential customers. Our efforts to help them export have not been successful, primarily due to the very restrictive food regulations of other countries to new products from the Third World.

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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.

Acknowledgement

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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 ($\div^2$, $p=0.01$). (+) 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				

Performance of *Prosopis* Species in Arid Regions of India

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Introduction

In dry tropical regions of India, woody species have key roles in environmental protection vis-a-vis rural economy. From time immemorial they have been a main energy source in addition to providing food and medicine (Hoking 1993). Despite all developmental efforts, the dependence on woody vegetation is not likely to shift for many years to come, especially for fuelwood and fodder.

To satisfy the need for fuel, fodder, and timber, the local vegetational resources have been exploited ruthlessly in the last four decades. This is primarily because of the tremendous increase in human and livestock populations during this period. Inhospitable climatic conditions do not support much required natural regeneration and subsequent growth of the vegetation. Consequently, vegetation in the area has become sparse and consists of scattered trees, shrubs and grasses (Tewari et al., 1993). The prominent tree species of the region are *Prosopis cineraria, Tecomella undulata, Capparis decidua, Calligonum polygonoides, Acacia jaquemontii, A . senegal,* etc. (Satyanarayan, 1963)

In view of the availability of limited number of very slow growing woody species and the high requirement of fuel, fodder, and timber, especially in arid tracts of India, we decided to introduce fast-growing exotics from other isoclimatic regions of the world. *Prosopis juliflora* is one of the species which was introduced in India in 1877 (Muthana and Arora, 1983). Owing to its tremendous capacity of seed production and excellent coppicing ability, this species has spread to almost all parts of arid and semiarid tracts of India and, in fact, it has now become naturalised. This species often provides as much as 80% to 90% of the fuel needs of population of arid and semiarid parts of the country (Saxena and Ventakeshwarlu, 1991). *Prosopis* pods have also been processed for use as cattle feed and the gum of the plant has been used in industry (Sharma, 1995). In recent years, due to recurrent droughts in vast stretches of arid and semiarid region, *Prosopis* is gradually becoming an important alternative to annual crops in marginal areas.

Status of *P. juliflora* in Arid Tracts

P. juliflora was introduced in Indian arid tracts about 1877 owing to its fast-growth features and drought hardiness (Muthana and Arora, 1983). Mass-scale aerial seeding of this species was done by the ruler of the erstwhile Marwar state during the 1930s. In 1940, the species was declared a "Royal Tree" and instruction was given to all the officials to plant and protect this tree species (Muthana and Arora, 1983). Due to its rapid colonizing and fast growth, the species has spread over large areas of arid and semiarid tracts.

The ecological amplitude this species is very high. It has been grown in highly saline areas, such as Rann of Kutch in Gujarat State, as well as the sand dunes of the Thar Desert (Saxena and Venkateshwarlu, 1991). In Rann of Kutch, it is the only tree species which has grown naturally and that has been exploited for gum, fuelwood, and fodder (pods). It has been estimated that in the Kutch district more than 200,000 ha are covered with *P. juliflora* (Varshney, 1993). At the moment, *P. juliflora*

is the main source of fuelwood in larger parts of arid and semiarid regions of the country (Saxena and Venkateswarlu, 1991).

The Present Study

In view of the wide ecological amplitude and multiple uses of *P. juliflora* , recently, a number of other *Prosopis* species have been introduced into the arid tract of India.

The objective of the introduction was to study the production potential of *Prosopis* , especially in terms of pods and biomass. In 1991, more than 200 accessions of five *Prosopis* species, mainly of Latin American origin were introduced at Central Arid Zone Research Institute at Jodhpur. These *Prosopis* accessions were examined for their adaptability and growth potential in the environmental conditions of the Indian arid tract.

Setting of Trial Region

The Indian arid region, lying between 24° and 29° N latitude and 70° and 76° E longitude, covers an area of 317,909 sq. km and is spread over seven states viz., Rajasthan, Gujarat, Punjab, Haryana, Maharashtra, Karnataka, and Andhra Pradesh. Of these seven states, Rajasthan alone accounts for 61% of the Indian arid tract. The arid tract of western Rajasthan is better known as the Thar Desert, and is located between the Aravalli ranges on east and the Sulaiman Kirthar range on the west (Rode, 1964).

The climate of the regions is characterized by extremes of temperatures ranging from below freezing in winter (mid-December to February) to as high as 48°C in summer (April to June). Rainfall is precarious and erratic, ranging from 150 mm in extreme west (Jaisalmer area) to 375 mm in eastern part (Jodhpur and parts of Pali district). The mean monthly wind speed ranges from 7.3 km/hr (December) to 20 km/hr (May). However, in the summer, the wind often suddenly increases to 100 km/hr, resulting in severe dust storms (Pramanik and Harisharn, 1952).

The soils in the region are generally sandy to sandy loam in texture. The consistency and depth vary according to topographic features of the area. In general, they are poor in organic matter (0.04-0.02%) and low to medium in phosphorus content (0.05 to 0.10%). The nitrogen content is mostly low, ranging between 0.02% and 0.07%. The infiltration rate is very high (7 to 15 cm/hr) (Kaul, 1965; Gupta, 1968).

Materials and Methods

The experimental site was located in silvatum of CAZRI, Jodhpur. The seeds of more than 200 single tree selections of five *Prosopis* species, mainly of Latin American origin, were procured from Texas A&M University-Kingsville, USA. The *Prosopis alba, P. chilensis, P. flexuosa,* and *P. nigra* accessions were collected by E. Marmillion of Cordoba, Argentina. The Peruvian *Prosopis* were collected by A. Sagastegui of the Universidad Nacional de Trujillo, Peru. They were selected on the basis of earlier performance. The seeds were sown in 10" x 4" polyethylene bags perforated at the base in February 1991. Of these, more than 200 accessions seedlings of only 106 accessions were obtained in numbers to conduct a replicated field trial. These 106 accessions of five *Prosopis* species were out-planted in the field during July 1991. These included: *P. nigra* (12), *P. flexuosa* (23), *P. alba* (30), *P. chilensis* (19) and *Prosopis* spp.-Peruvian (22). One accession of local *P. juliflora* was taken as a control.

To establish the experiment on the field, a block design with four replicates was employed. Each replicate consisted of a row of five trees with a spacing of 4.0 x 2.5 m. Seedlings were planted in pits of 45 x 45 x 45 cm size. After planting, each seedling was irrigated with 10 liters of water at monthly intervals during first year of establishment. Percentage survival, height increment, and collar diameter was recorded at the beginning of winter season, i.e., at the end of growing season each year up to 1994 (in the month of December). The diameter at 30 cm above the ground of the single largest stem

was taken to be the collar diameter. For computation of biomass from multistemmed trees, all stems originating below 30 cm in height were measured. The biomass of individual stems was estimated from basal diameter measurements using the regression equation described below. The biomass of all these stems were summed to obtain biomass per tree.. The biomass was estimated in the third year using the prediction equation (Felker et al.,1989):

log 10 Dry Weight (kg) =2.1905 [log 10 stem diameter (cm)] –0.9811

after verifying it by selective destructive sampling. Biomass data were also subjected to Duncan's multiple-range analysis following the procedure as given in Gomez and Gomez (1983). Pod production during the study period was also measured. The pods were subjected to nutritive-value analysis (carbohydrate determinations where conducted according to Yemn and Willis (1954) and protein content was measured by the Kjeldahl technique). Vegetative propagation studies on some of these introduced species were also conducted.

Results and Discussion

Field out-planting and survival

Nursery-raised seedlings of 106 accessions of procured exotic *Prosopis* species and one accession of local *P . juliflora* (total 107) were out-planted in the field after the first effective monsoon rain, i.e., in July 1991. Species survival after five months was maximum (95%) in case of *P. nigra*, followed by *P. juliflora* (91%). The species varied from 87% to 88% survival.

The percentage survival was again recorded in March 1992 (8 months after initial out-planting).The survival among the species ranged from 74% to 90%, maximum being for *P. nigra* and minimum for *P. flexuosa*.

Within the species, great variation in survival percentage was noticed for different accessions. Accessions 158, 161, and 219 of *P. nigra*, and accession 144 of *P. alba* had 100% survival. The greatest survival in the other species were 94% for accessions 51 and 195 of *P. flexuosa*, and 94% for accession 30 of *P. chilensis*. Accession 421 of the Peruvian species had maximum survival for this group. Early results indicated that although all the introduced species/accessions were fairly adaptable to environmental conditions of the Indian arid tract, *P. nigra* had better survival than the other species.

General growth performance of different Prosopis species

A wide range of variability for plant height and collar diameter was found among species and in different accessions of same species. Only few accessions within species have shown consistently better performance across all four years.

Among species, the best performance for plant was noticed for *Prosopis* spp.-Peruvian(276 cm/plant) followed by *P . alba* (251 cm/plant) and *P. chilensis* (238 cm/plant) (Table.1). In contrast, for growth in collar diameter, *P. alba* (4.13 cm/plant) was found best, followed by *Prosopis* spp.-Peruvian (3.80 cm/plant) and *P. chilensis* (3.55 cm/plant).The mean annual increment (MAI) for collar diameter was maximum in *P . alba* (1.09 cm/tree) followed *Prosopis* spp. - Peruvian and *P. chilensis*. *P. nigra* had the lowest MAI among all the species.

In general, the coefficient of variation for collar diameter was greater than for plant height in all the *Prosopis* species under study. It was also observed that within accessions of same species, there was a great deal of variation in height and collar diameter. The variability for any character is determined to a great extent by the natural and human selection sieves through which population had passed during its phylogenetic history (Swaminathan, 1969).

The *P. nigra* , accessions were not significantly different from each other for plant height for all four years. In contrast, they were significantly different for collar diameter in first two years. Different accessions showed variable growth pattern and accession 219 from San Javier, north of Cordoba, exhibited comparatively better performance(over means i.e., means of all the accessions)across all the four years for both plant height and collar diameter (Table 2). The maximum plant height was recorded in accession 222 from Guemes in Salta Province, accession 119 from Villa Angela in Chaco Province 179 and 219 (each having 218 cm/plant), while maximum collar diameter was found in accession 179 (3.63 cm/plant). While accession 219 had a smaller collar diameter than 179, it had nearly twice the biomass of 179.

The collar diameter was measured from the single largest stem at 30 cm height while the biomass was computed by summing all the stems below 30 cm in height. Because accession 179 had more and larger stems, it had the greatest biomass. The parent trees for these accessions were located at the points of a triangle, each more than 500 km distant from the other. Thus, there was no apparent good geographical source for *P. nigra*.

The *P. flexuosa,* accessions were significantly different for plant height in the second and third year. Collar diameter was not significantly different among the accessions for any of the years. Accessions 51 (La Puntilla, Catamarca), 64 (Anilaco, Catamarca), 181 (Catamarca)and 197 (from Valle Calcha in Salta Province) have shown consistently better performance across all four years (Table 3). Plant height and collar diameter maximum in accession 64 (plant height 329 cm/plant; collar diameter 4.87 cm/plant) followed by accession 52 (plant height 322 cm/plant; collar diameter 4.80 cm/plant).

The *P. chilensis* , accessions were significantly different for plant height in years 1, 3, and 4 (Table 4). For collar diameter, they were significantly different only in the fourth year. *P. chilensis* accessions 30, 85, 100, 105, 108 and 118 had consistently better performance for all four years (Table 4). The maximum plant height (305 cm/plant) was recorded in accession 108, followed by accession 105 (297 cm/plant). The maximum collar diameter was in accession 30 (5.03 cm/plant),followed by accession 105 (4.86 cm/plant). Accessions 108, 105, and 30 were from Catamarca Province.

In *P. alba* , the accessions were significantly different for plant height in all four years (Table 5). However, for diameter they did not show any significant differences. Accessions 28, 65, 78, 120, 147, and 151 performed consistently better for all four years (Table 5). Plant height was maximum in accession 67 (386 cm/plant), followed by accession 73 (339 cm/plant), both from La Rioja Province, while collar diameter was maximum in accession 78 (5.55 cm/plant), a special tree whose seed was supplied by Ula Karlin, closely followed by accession 73 (5.31 cm/plant).

In *Prosopis* spp. - Peruvian, the accessions were significantly different in the first two years for both plant height and collar diameter. Accessions 418, 420, and 424 had consistently good growth rates across all four years (Table 6). Plant height was maximum in accession 442 (387 cm/plant), followed by accession 424 (373 cm/plant). The collar diameter was maximum in accession 424 (6.05 cm/plant), followed by accession 442 (5.35 cm/plant). Accessions 418 and 420 were collected in the Procedencia El Nino and Procedencia Porota of Departmento La Libertad of the province of Trujillo. Accession 424 was collected in Procedencia Algorrobal (Distro San Benito) Departmento Cajamarca of Province Contumaza. Accession 442 was collected in Procedencia Huancaco (Viru). Departmento La Libertad in Province of Trujillo.

It is significant that the Argentine trees with the greatest height and collar diameter originated from the most arid (western) provinces of La Rioja, Catamarca, and Salta.

Provenance trials conducted on native *P. cineraria* by Kackar (1988) in Indian arid tracts found similar trends in growth behaviour of provenances collected from different locations. Jindal et al. (1991) also

reported similar genetic variation in a progeny trial of Tecomella undulata , an important arid-zone timber species of India.

Fuelwood production

The fuel production from all 107 accessions of all the *Prosopis* spp. under study was estimated approximately at four year's age.

It is important to recognize that substantial differences in ranking of biomass and collar diameter are attributable to the fact that the collar diameter is the diameter of the single largest stem at 30 cm height, while the biomass is the sum of all the branches. Thus multistemmed trees had greater biomass than single-stemmed trees of the same collar diameter. The mean biomass production for the species (across the accessions) was greatest in *P. alba* (4.34 kg/individual) (Table 5) followed closely by *P. chilensis* (4.11 kg/individual) (Table 6). Minimum biomass occurred (1.90 kg/individual) in *P. nigra* . In the case of local *P. juliflora* (control species) the biomass accumulation during the study period was 1.47 kg/plant. Although *Prosopis* spp.-Peruvian, attained the maximum height during this period, its mean biomass production as a group ranked third, primarily due to straight-bole characteristic of the species. Only very few branches originated from the base or from the lower part of tree trunk of the Peruvian species accessions. The straight-bole characteristic of the Peruvian species may be of greater economic significance than use as fuel because it can be used in high-value timber applications.

The production of fuelwood within the different accession of same species was also assessed. The early results revealed considerable variation in fuelwood production among different accessions of the same species.

In *P. nigra*, accession 219 of this species gave maximum (3.01 kg/individual) average dry fuelwood per plant (Table 2). The minimum (0.99 kg/individual) fuelwood production was recorded in accession 42. The multiple-range analysis of fuelwood production data showed that accessions 168, 165, and 159 belonged to the same group, while accessions 158, 43, and 167 belonged in another distinctive group. In the rest of the accessions, no clear trends were observed, rather, they exhibited overlapping.

There was significant variation in dry fuelwood production among different accessions of *P. flexuosa*. The average wood production was maximum im accession 197 (3.67 kg/individual) and minimum in accession 183 (0.73 kg/individual) (Table 3). The multiple-range analysis of fuelwood production data of different accessions exhibited presence of three distinctive groups. Accessions 198, 183, 119, 194, 103, 133, 195, 111, 180, 196, 52, and 51 belonged to the same group. Similarly, accessions 186, 192, 112, and 117 belonged to another group. Further, accessions 106, 107, and 110 belonged to a third group showing similarity in fuelwood production. In the remaining accessions, viz., 181, 64, and 197, no clear trend was discernible.

Of the 19 accessions of *P. chilensis*, accession 257 gave average maximum (7.81 kg/individual) fuelwood production, followed closely by accession 30 (7.63 kg/individual) (Table 4). The minimum average fuelwood (1.34 kg/individual)was recorded in the accession 226. The fuelwood production in different accessions varied significantly. The multiple-range analysis of the data revealed the presence of two distinctive groups as far as fuelwood production is concerned. Accessions 100, 228, 108, 29, and 118 belonged to one group, while accessions 95, 99, and 241 belonged to another group. In the remaining accessions, the patterns were not as distinct.

Of the 30 total accessions of *P. alba* introduced, the maximum fuelwood production (7.84 kg/individual) was recorded in accession 146 and minimum (1.84 kg/individual) in accession 74 (Table 5). Statistically, the variation in values was quite significant. On the basis of multiple-range

analysis, three distinct groups were identified. Accessions 74, 153, and 152 belonged to the first group, showing similar range biomass production in terms of fuelwood yield. Similarly, accessions 149, 233, 67, 135, 120, and 144 belonged to the second group. In accessions 128, 66, 28, 147, 126, 71, 151, 65, and 72, the values exhibited more or less similar trends, but these accessions also exhibited overlapping of values and, thus, it roughly forms a fourth distinctive homogeneous group. In the remaining accessions, trends were not clear.

In the different accessions of *Prosopis* spp.-Peruvian, the fuelwood yield ranged between 8.77 kg/individual (accession 424) to 1.17 kg/individual (accession 432) (Table 6). On the basis of multiple-range analysis, three groups can be identified. While accessions 420, 431, 440, and 439 belonged to the first homogeneous group, accessions 442, 435, and 438 formed the second homogeneous group. Accessions 430, 446, 428, 434, 441, and 443 also form more or less one homogeneous group, but the trend was not as distinctive as in the case of earlier two groups.

Pod production and their nutritive value

Pod production of the introduced species/accessions was initiated in the fourth year after initial field transplantation. In *Prosopis* spp.-Peruvian, 6 of 22 accessions exhibited flowering and produced pods. Only one accession of each *P. chilensis* (105), *P. flexuosa* (69), *P. alba* (70), and *P. nigra* (158) produced pods. The maximum quantity of pods occurred in accession 423 of *Prosopis* spp.-Peruvian (2.059 kg/plant). The minimum was produced by *P. chilensis* (7.8 g/plant).

The maximum carbohydrate content (40%) was found in the pulp of *P. nigra*, followed by *P. alba* (38%), and *P. chilensis* (37.5%). While the average carbohydrate content of *Prosopis* spp.-Peruvian was 30%, its variability between accessions was very high, ranging from 18% to 37%. The crude protein content in *Prosopis* spp.-Peruvian was also quite variable, ranging from 5.11% to 11.55%, with an overall average of 8.44%. The protein content of *P. alba*, *P. chilensis*, and *P. nigra* pods was 8.8%, 4.48%, and 5.99%, respectively. Further investigations in this regard are in progress.

Vegetative propagation

Raising seed orchards through seeds leads to heterogeneity in the population due to out crossing in the species. In order to propagate good germ plasm both for thornlessness and high nutritive value, the cleft grafting technique was followed (Wojtusik et al., 1993).

Nonthorny grafts from superior *Prosopis* spp.-Peruvian were grafted on the local thorny *P. juliflora*, both on one-year-old field-transplanted saplings and five-month-old nursery seedings. About 70% success was obtained on both field-outplanted saplings, as well as in nursery seedlings. The nursery-raised grafted seedlings were supplied to different institutions in India to evaluate their performance in different agroecological zones. Moreover, *P. chilensis, P. alba*, and *P. nigra* have also been grafted successfully on local *P. juliflora*. The success rate with these species of these species was about 50%. In addition to grafting, all five exotic *Prosopis* species have also been propagated using stem cuttings in the mist chamber.

Conclusions

The species of genus *Prosopis* have the capacity for thriving on poor fertility soils and in hot dry climates (Vasquez et al., 1985). Currently, between 36% and 43% of the earth's area is rated as desertic. According to modern historians, the origin of civilization in the Nile, Indus, and Tigris-Euphrates valleys could be linked to the increasing aridity of the surrounding areas, which forced the population of steppes and savannas to move to these valleys where they had to irrigate and cultivate the land (Habit, 1985). Now, vast areas of the world are threatened by desertification. According to conservative estimates, arid zones and their advance affect approximately 384 million people directly or indirectly. This population accounts for 12% of the world's total population, most of which belongs to the Third World (Duhart, 1985).

In India, more than 0.3 million square kilometers are categorised as hot arid and the western part of Rajasthan state, commonly known as the Thar Desert, accounts for 61% of the total arid zone of the country. Beside the native *Prosopis* species, *P. cineraria*, vast stretches of tropical arid and semiarid parts of the country have been covered by *P. juliflora*.

The present study has shown that all the introduced *Prosopis* species are highly adaptable to environmental conditions of the Indian arid tract. The study of Sharma (1995) further substantiated this fact that, although all the newly introduced *Prosopis* species in 1991 have performed well, but among them, *Prosopis* spp.-Peruvian has performed much better. Lee et al., (1992) also reported the excellent performance of this species from Haiti. Harris et al. (This volume) have also found the Peruvian *Prosopis* to have superior biomass and survival. Thus, the Peruvian genetic stock is near the top in evaluations in three distinctly different environments: Haiti, Cape Verde, and the interior deserts of India.

Early results of the present study indicated that the introduced species of multipurpose utility of genus *Prosopis* (mainly of Latin American origin) has tremendous capacity for biomass and pod production in inhospitable soil and climatic conditions of the Indian arid tract. All these features make them highly suitable candidates for plantation and agroforestry activities in arid and semiarid tracts of the country.

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Table 1. Average Performance of *Prosopis* Species in Different Years

Species	Plant Height (cm)				Collar Diameter (cm)			
	1991	1992	1993	1994	1991	1992	1993	1994
P. nigra	39	79	134	188	0.60	1.17	1.79	2.45
P. chilensis	53	100	183	238	0.92	1.79	2.86	3.55
P. flexuosa	58	100	169	229	0.69	1.23	2.22	3.20
P. alba	47	90	189	251	0.92	1.78	3.14	4.13
Prosopis spp.-Peruvian	89	159	210	276	0.88	2.16	3.02	3.80
P. juliflora (check)	40	50	167	204	0.40	0.88	2.82	3.34

Table 2. Mean Values of Plant Height and Collar Diameter of 12 Accessions of *P. nigra* at Four Growth Stages

US No.	Accession No.	Plant Height (cm)				Collar Diameter (cm)				Biomass (kg)
		1-year	2-year	3-year	4-year	1-year	2-year	3-year	4-year	
42	EC 308027	32	60	99	142	0.61	0.94	1.62	2.14	0.99
43	EC 308028	45	90	121	182	0.71	1.27	1.26	1.58	1.85
44	EC 308029	39	73	147	196	0.56	0.84	1.51	2.34	1.03
158	EC 308034	38	76	114	173	0.47	0.92	1.45	2.25	1.65
159	EC 308035	48	86	126	175	0.71	1.64	1.56	2.19	1.19
161	EC 308037	32	86	152	187	0.63	1.17	2.26	2.67	2.47
165	EC 308041	45	79	98	153	0.53	0.86	0.96	1.66	1.30
167	EC 308043	34	79	140	213	0.58	1.20	2.02	2.39	1.91
168	EC 308044	32	75	109	176	0.53	0.91	1.54	1.99	1.67
179	EC 308045	39	73	171	218	0.60	1.21	2.66	3.63	1.98
219	EC 308046	43	90	164	218	0.67	1.95	2.33	3.08	3.01
222	EC 308047	38	83	166	218	0.55	1.14	2.33	3.45	2.55
	Mean	39	79	134	188	0.60	1.17	1.79	2.45	1.90
	±SE	6.88	9.41	25.94	34.21	0.11	0.22	0.45	0.67	0.63
	Range	32-48	60-90	98-171	142-228	0.47-0.71	0.91-1.95	0.96-2.66	1.58-3.63	0.99-4.16
	CV %	25.1	16.8	27.4	25.7	26.2	26.9	35.2	3.86	46.88
	CD 5%	-	-	-	-	0.45	0.92	-	-	1.28
	CD 1%	-	-	-	-	0.61	-	-	-	1.73

Table 3. Mean values of plant height and collar diameter of 23 accessions of *P. flexuosa* at Four Growth Stages

US No.	Accession No.	Plant Height (cm)				Collar Diameter (cm)				Biomass (kg)
		1-year	2-year	3-year	4-year	1-year	2-year	3-year	4-year	
51	EC 308063	60	108	224	309	0.73	1.28	3.01	3.93	2.99
52	EC 308064	53	85	259	322	0.66	1.21	3.28	4.80	1.27
53	EC 308065	66	94	148	183	0.71	1.27	1.24	1.84	1.58
64	EC 308066	69	131	244	329	0.77	1.81	3.74	4.87	3.03
103	EC 308067	58	93	177	223	0.67	1.45	1.98	2.38	1.68
106	EC 308068	59	95	186	243	0.60	1.05	2.21	3.28	1.28
107	EC 308069	53	99	172	214	0.70	1.37	2.76	2.98	1.16
110	EC 308070	58	98	151	212	0.63	1.21	2.23	3.66	1.11
111	EC 308071	60	100	128	182	0.66	1.18	1.34	2.03	1.55
112	EC 308072	62	113	145	214	0.70	1.35	2.48	3.69	1.25
113	EC 308073	57	103	184	220	0.62	1.12	2.62	3.14	1.25
117	EC 308075	62	90	167	230	0.64	1.12	2.31	3.23	1.46
119	EC 308076	56	93	114	193	0.58	1.36	2.07	3.35	1.19
180	EC 308081	68	114	183	224	0.61	1.46	2.30	3.11	1.62
181	EC 308082	56	103	194	273	0.81	1.40	2.55	3.98	2.50
183	EC 308084	56	94	153	229	0.52	0.85	1.71	3.23	0.73
186	EC 308087	56	96	172	217	0.66	0.97	1.68	2.69	1.22
192	EC 308093	61	98	137	202	0.78	0.90	1.86	2.92	1.27
194	EC 308095	65	119	181	211	0.59	1.46	1.88	2.27	1.79
195	EC 308096	58	91	146	217	0.77	1.29	1.90	2.50	1.86
196	EC 308097	44	76	136	185	0.88	1.37	1.81	3.01	1.60
197	EC 308098	58	117	170	229	0.85	1.73	2.51	3.57	3.67
198	EC 308099	49	93	120	205	0.67	1.27	1.49	2.91	1.21
	Mean	58	100	169	229	0.69	1.23	2.22	3.2	1.66
	±SE	6.6	11.5	38.3	47.4	0.11	0.30	0.76	1.09	0.68
	Range	44-69	76-131	114-259	182-329	0.52-0.88	0.85-1.81	1.24-3.74	1.84-4.87	0.73-3.67
	CV %	16.0	16.3	32.0	29.3	23.1	32.5	48.32	48.30	58.16
	CD 5%	-	23.0	76.20	-	-	-	-	-	1.35

Table 4. Mean Values of Plant Height and Collar Diameter of 19 Accessions of *P. chilensis* at Four Growth Stages

US No.	Accession No.	Plant Height (cm)				Collar diameter (cm)				Biomass (kg)
		1-year	2-year	3-year	4-year	1-year	2-year	3-year	4-year	
29	EC 308160	53	92	161	184	0.86	1.87	2.63	2.36	3.84
30	EC 308161	43	110	214	269	1.01	2.32	3.76	5.03	7.63
85	EC 308170	49	102	240	282	0.96	1.89	3.66	4.25	6.35
86	EC 308171	46	99	210	216	0.75	1.84	3.22	3.83	4.70
91	EC 308174	49	81	158	201	0.90	1.25	1.94	2.15	2.48
95	EC 308177	59	93	215	294	0.81	1.43	3.39	3.87	3.58
99	EC 308180	42	94	168	220	0.91	1.65	2.81	3.12	3.08
100	EC 308181	53	102	202	271	1.03	2.14	3.38	4.85	3.28
105	EC 308184	61	129	243	297	0.89	1.86	3.63	4.86	6.62
108	EC 308185	54	106	220	305	0.96	1.92	3.30	4.09	3.75
118	EC 308187	64	112	183	245	1.02	2.05	2.85	3.64	3.59
139	EC 308188	53	89	163	206	0.82	1.38	1.81	2.74	2.61
140	EC 308189	53	96	127	204	1.08	1.78	2.22	3.33	2.88
226	EC 308196	42	67	96	179	0.95	1.50	1.85	2.22	1.34
228	EC 308197	44	90	196	207	0.87	1.67	2.91	2.85	3.13
235	EC 308199	50	90	198	275	0.78	1.71	3.30	4.07	5.48
237	EC 308200	51	77	136	203	0.81	1.40	1.80	2.70	2.03
241	EC 308204	51	95	185	217	0.96	1.80	3.12	2.79	3.98
257	EC 308206	89	166	172	254	1.10	2.63	2.80	3.72	7.81
	Mean	53	100	183	238	0.92	1.79	2.86	3.55	4.11
	±SE	8.73	22.64	32.36	36.52	0.14	0.45	0.78	1.00	1.34
	Range	42-89	67-166	96-243	179-305	0.75-1.10	1.25-2.63	1.80-3.76	2.15-5.03	1.34-7.81
	CV %	23.4	32.2	24.9	21.7	20.9	35.6	38.4	40.0	46.12
	CD 5%	17.5	-	64.7	73.0	-	-	-	2.0	2.68
	CD 1%	23.2	-	86.1	97.2	-	-	-	-	3.56

Table 5. Means of Plant Height and Collar Diameter of 30 Accessions of *P. alba* at Four Growth Stages

US No.	Accession No.	Plant Height (cm)				Collar Diameter (cm)				Biomass (kg)
		1-year	2-year	3-year	4-year	1-year	2-year	3-year	4-year	
28	EC 308109	42	104	215	305	0.95	2.11	3.94	4.99	5.76
57	EC 308112	43	88	186	253	0.88	2.02	3.80	4.30	5.59
65	EC 308119	60	102	225	291	1.06	1.76	4.19	5.09	7.05
66	EC 308120	52	98	192	220	1.06	1.81	2.33	3.04	4.21
67	EC 308121	47	87	259	386	0.79	1.31	3.78	5.22	2.39
68	EC 308122	56	78	169	239	0.88	1.41	3.32	3.84	4.62
70	EC 308123	49	93	185	243	1.01	1.90	2.90	3.81	4.04
71	EC 308124	59	92	181	227	0.95	1.78	2.87	4.02	5.23
72	EC 308125	50	98	173	237	0.90	2.48	3.41	3.76	6.75
73	EC 308126	43	88	249	337	0.63	1.39	3.76	5.31	3.80
74	EC 308127	49	72	126	178	1.13	1.90	1.99	2.99	1.84
75	EC 308128	61	112	186	239	0.92	1.57	2.97	3.82	2.67
78	EC 308129	36	100	224	289	0.97	2.31	4.36	5.55	4.59
120	EC 308130	44	103	261	239	0.93	1.81	3.92	4.84	4.15
122	EC 308132	54	88	167	187	0.95	1.66	2.31	2.54	2.69
126	EC 308133	58	123	231	246	0.94	2.11	3.48	4.02	6.04
128	EC 308135	53	96	184	246	0.82	1.78	2.95	4.39	5.09
135	EC 308141	50	91	168	225	0.87	1.39	2.91	4.07	2.91
144	EC 308142	42	82	198	246	0.98	2.00	2.73	3.72	3.80
145	EC 308143	44	82	179	242	0.97	1.86	3.12	3.76	4.80
146	EC 308144	40	100	154	225	0.81	2.22	2.76	3.84	7.84
147	EC 308145	43	104	220	291	1.09	2.24	4.07	5.24	5.81
148	EC 308146	39	67	141	200	0.79	1.19	2.52	3.38	3.43
149	EC 308147	41	68	151	209	0.89	1.54	2.38	3.79	2.38
150	EC 308148	46	76	202	287	0.94	1.48	3.46	5.87	4.71
151	EC 308149	42	104	208	265	1.01	2.15	3.48	4.82	6.30
152	EC 308150	38	67	160	233	0.87	1.42	2.78	4.36	2.21
153	EC 308151	46	74	153	195	1.14	1.78	2.58	3.86	2.82
230	EC 308154	42	84	179	266	0.84	1.69	2.84	4.05	4.35
233	EC 308156	40	73	133	179	0.66	1.26	2.12	5.31	2.26
	Mean	47	90	189	251	0.92	1.78	3.14	4.13	4.34
	±SE	5.51	12.6	39.16	49.56	0.15	0.39	0.84	1.06	1.59
	Range	36-61	67-123	126-261	178-337	0.63-1.14	1.19-2.48	1.99-4.36	2.54-5.55	1.84-7.84
	CV %	16.62	19.89	29.37	27.95	23.23	31.18	37.74	36.21	52.00
	CD 5%	10.96	25.11	77.93	136.97	-	-	-	-	3.16
	CD 1%	14.49	33.19	-	181.02	-	-	-	-	4.18

Table 6. Mean Values of Plant Height and Collar Diameter of 22 Accessions of *Prosopis* spp.-Peruvian at Four Growth Stages

US No.	Accession No.	Plant height (cm)				Collar diameter (cm)				Biomass (kg)
		1-year	2-year	3-year	4-year	1-year	2-year	3-year	4-year	
417	EC 308207	63	134	209	266	1.01	2.32	3.04	4.53	3.90
418	EC 308208	120	269	280	323	0.94	3.56	3.99	4.65	6.59
420	EC 308210	128	288	222	326	1.22	3.74	3.60	3.85	6.55
421	EC 308211	103	227	216	271	1.13	3.03	3.09	4.38	5.40
423	EC 308213	79	162	213	289	1.03	3.29	4.48	4.46	4.97
424	EC 308214	108	235	264	373	1.08	3.31	5.09	6.05	8.77
428	EC 308218	89	156	245	315	0.81	2.32	3.60	4.57	2.67
429	EC 308219	73	126	161	189	0.67	1.26	1.66	1.99	1.22
430	EC 308220	90	146	144	228	0.90	1.65	1.54	2.81	2.05
431	EC 308221	80	126	181	256	0.77	1.67	3.19	2.52	1.93
432	EC 308222	80	104	178	227	0.77	1.32	1.74	2.58	1.17
433	EC 308223	97	164	230	301	0.85	2.05	3.57	4.10	3.32
434	EC 308224	81	124	187	260	0.81	1.41	2.84	3.31	2.29
435	EC 308225	87	122	230	311	0.88	1.57	3.41	4.62	2.01
437	EC 308227	95	163	204	254	0.88	1.89	2.88	3.56	2.43
438	EC 308228	82	124	166	236	0.75	1.80	2.04	2.80	2.38
439	EC 308229	75	114	191	215	0.78	1.47	2.05	2.90	1.98
440	EC 308230	93	152	191	247	0.68	1.75	2.58	3.34	2.02
441	EC 308231	89	142	187	254	0.91	1.89	2.58	2.89	2.66
442	EC 308232	87	132	292	387	0.75	2.23	3.81	5.35	2.20
443	EC 308233	86	162	234	296	0.96	2.13	2.74	3.78	3.02
446	EC 308236	84	132	196	250	0.70	1.77	2.97	3.54	4.03
	Mean	89	159	210	276	0.88	2.16	3.02	3.8	3.35
	±SE	14.9	28.6	51.4	70.23	0.12	0.38	1.13	1.3	1.47
	Range	63-128	104-288	144-292	-	0.67-1.22	1.26-3.74	1.54-5.09	-	1.17-8.77
	CV %	23.6	25.5	34.6	36.0	19.4	25.2	52.8	47.52	62.04
	CD 5%	29.8	57.30	-	-	0.24	0.76	-	-	2.94

Managing Coppice, Sapling, and Mature *Prosopis* For Firewood, Poles, and Lumber

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INTRODUCTION

In managing native *Prosopis* stands, the two most important considerations are to:

- **Capitalize on the intra specific genetic variation to increase the genetic potential of the stand**
- **Optimize the tree size/tree spacing relationship to obtain maximum economic benefit from fuelwood, lumber, pod production, and soil improvement**

These principles appear to hold true whether one is working with immature dense stands (3-cm to 5-cm diameter trees spaced 1 m apart), stagnated mature stands (15-cm to 30-cm diameter trees spaced 6 m apart), or multiple-stemmed coppiced stands (15 to 20 resprouts/stump with 4-m stump spacing).

Before discussing specific issues related to various categories of *Prosopis*, it is important to illustrate the importance of intra specific genetic variation and tree size/spacing relationships.

INTRA SPECIFIC GENETIC VARIATION

California field trials that measured biomass production, pod production, and pod sugar and protein concentrations found enormous variation among species and among progeny from the same mother tree. In the fifth growing season, pod production per tree ranged from 0 to 7.16 kg for 25 families that were each represented by four trees in a randomized complete block trial (Felker et al., 1984). Three mother trees (each represented with four replicates) from Arizona *P. velutina* had the greatest *mean* pod production of 3.2, 5.9, and 7.1 kg/tree. While the mean production was high, the pod production per tree (from the same parent) ranged from 0 to 11.5 kg/tree, 0 to 12.6 kg/tree and 3.2 to 12.2 kg/tree, respectively. In this replicated trial, 6 of the 110 trees produced 66 kg or 61% of the total pod production at the end of the fifth growing season (Felker et al., 1984).

This enormous variation in pod production has also been observed for pod sugar, pod protein (Oduol et al., 1986), stem form (Lee et al., 1992), and biomass production (Felker et al., 1983). As this variation was exhibited in a replicated field trial of the same age and management conditions, we assume that part of this variation must be attributable to genetics. If this variation for pod production occurred in a plantation, then it could equally well occur in natural stands. Therefore, it is important to measure the characters of interest (form for lumber, pod production, pod sugar, lack of spines) in native *Prosopis* stands, map location of superior trees, and initiate management plans to improve the overall productivity. Since fuelwood, charcoal production, and lumber harvests are a normal part of nearly all *Prosopis* stands, it is useful to direct tree harvests at the *Prosopis* with the least desirable characteristics, i.e., poor form and low productivity.

TREE SIZE/SPACING RELATIONSHIPS

In most tree species there is a relationship between tree size and the number of trees per hectare that can be obtained at that size. In forestry operations, reducing the number of trees per hectare, i.e., thinning, is a common practice that concentrates the growth on fewer trees, resulting in fewer trees of larger size. If a block in the center of a pine forest is harvested, tens of thousands of volunteer pine seedlings/hectare germinate and grow to form stands with 50-cm spacings and heights of only about 2 meters. As some of these trees die, the resultant trees become larger to dominate the site. Until the stand is again harvested, the tree population never increases, it only decreases with larger and larger trees dominating the rest of the stand.

We believe this same kind of self-thinning also occurs with *Prosopis*. To examine the relationship between tree spacing and tree size, the tree diameters and number of trees per hectare was measured in 27 diverse locations in Texas (Felker et al., 1988). Some of the plots were thinned, but no irrigation or groundwater was provided at any of these sites. The plots ranged from 18,000 stems/ha of 1.88 cm mean basal diameter to 6 trees/ha with 51 cm mean basal diameter. When the basal diameter and average tree spacing of these diverse stands were regressed and plotted on a logarithmic scale, a highly significant straight line relationship was observed (Figure 1). This regression expresses the fact that the greater the number of trees/ha the smaller is the stem diameter.

For the rainfall and growing conditions in Texas, the equation predicted that 30 cm and 40 cm diameter trees could be obtained on spacings of 8.3 m and 10.9 m respectively. The reddish/orange wood from *Prosopis* is very dimensionally stable (Weldon, 1986) and while it is usually only available in small pieces (<15 cm wide and <1 m long), it is exceptionally valuable for flooring and small furniture (Felker et al., 1994). Using equations of Rogers (1984) to predict sawn lumber as small as 5.1 cm by 15.2 cm from small logs, and the biomass-prediction equations of El Fadl et al. (1989), we estimated the total sawn-lumber potential in these diverse *Prosopis* stands. Since sawn lumber cannot be obtained from trees less than 15 cm in diameter, the equation predicted that no lumber could be produced from densities greater than 3000 stems/ha. Sawn lumber was maximized (23 cubic meters/ha) at densities of about 111 stems/ha (9.5 m spacings). At retail prices of US $425/cubic meter, the nonselect lumber from a stand of 111 trees/ha would have a value of US $9775/ha.

This significant regression has two important ramifications. First, from the diameters desirable for harvest of 10-cm-diameter poles, or 50-cm-diameter trees, the equation predicts the minimum spacing necessary to achieve those diameters. For recently colonized stands of dense trees, the equation predicts the amount of thinning necessary to achieve the target tree diameter.

Second, the equation implies that if a fully occupied stand of large trees, i.e., >40-cm diameter were established, it would not be possible to have dense stands of small diameter trees beneath their canopies. Thus, intraspecific competition from large trees may provide the mechanism to prevent the establishment of dense stands of small trees that constitute a weed problem.

We have observed numerous dense stands of small-diameter *Prosopis*, but we have never observed such stands under the canopies of large (45-cm diameter) *Prosopis*. In one 500 ha Texas pasture that has been mowed yearly with a tractor, there are many scattered large *Prosopis*. Between the canopies of the large *Prosopis* there are many small, multistemmed *Prosopis*. However, directly beneath the canopies of the large *Prosopis*, there are no young colonizing *Prosopis*. Thus, it appears as if one defense against encroachment of dense stands of small *Prosopis* are large *Prosopis* trees.

MANAGEMENT OF DENSE STANDS OF IMMATURE *Prosopis*

The most problematic of all *Prosopis* stands are the dense (10,000 stems/ha) stands of small trees (<7 cm basal diameter and 2-m to 2.5-m tall). In contrast to larger trees where the soil N and soil C has accumulated (Virginia and Jarrell, 1983; East and Felker, 1993) and where there is luxuriant growth

of grass such as *Panicum maximum* and *Setaria* spp, there is usually virtually no grass or forbs beneath the closed canopies of these *Prosopis*. Additionally, the stem diameters are too small to be useful for anything other than fuelwood.

In the past, Texas ranchers have attempted to kill the entire stand with aerial applications of herbicides or to use heavy equipment, i.e., bulldozers, to sever the roots and, thus, kill the trees (root plowing). The root plowing provides virtually 100% immediate kill of all the *Prosopis* in the stand. However, 10 to 15 years after root plowing, a similar high density stand of *Prosopis* often occurs from seeds in the soil.

Thus, we examined the possibility of thinning young weedy *Prosopis* to wider spacings (Cornejo-Oveido et al., 1991). The initial density was 1740 trees/ha (8700 stems/ha). The objective was to achieve large trees on wide spacings that would provide intra specific competition to prevent the encroachment of small *Prosopis*. A nontreated area and five other thinning treatments were established in the fall of 1986 in southern Texas. To facilitate rapid movement of equipment for possible further treatments, strip thinning of 8-m width was performed in two perpendicular directions. Crop trees were left on 10-m spacings to accelerate their growth. From a self-thinning study (Felker et al., 1988), we determined that 10-m spacings should be capable of supporting trees with a 37-cm basal diameter. We were concerned that thinning trees from 1700 trees/ha to 100 trees/ha was too great an initial thinning. We realized that 3- to 4-cm diameter trees on 10-m spacings would provide little competition to newly encroaching mesquite seedlings and that individual trees on such wide spacings would have a tendency to produce many more lateral branches than desirable for quality lumber production. While an initial thinning to 3S4 m (from 8700 stems/ha to ca. 1000 stems/ha) would have been more desirable, we did not have sufficient manpower to conduct this thinning by hand. To thin the stands, we took advantage of a biomass harvester (Ulich, 1982) that severed, shredded, and captured trees less than 10 cm in diameter for fuel purposes.

Our goals in this study were to:

- **Measure the diameter growth rate of *Prosopis* as a function of various management practices**
- **Determine the number of new seedlings that would colonize previous thinned areas**
- **Identify potential intercropping management practices that would reduce seedling encroachment, increase tree growth, and be of benefit to cattle and wildlife.**

Therefore, various treatments (Cornejo-Oveido et al., 1991) were imposed on the areas between the trees such as:

- **Control (no harvesting and no treatment)**
- **Harvest underlaying spaces with biomass harvester**
- **Harvest spaces with biomass harvester and spray individual resprouts with the herbicide triclopyr**
- **Underlaying areas harvested and resultant trees thinned to single stems**
- **Underlaying areas harvested, trees pruned and underlaying areas moldboard plowed**

- **Underlaying areas harvested, trees pruned, underlaying areas moldboard plowed and winter rye grass planted for winter forage (this treatment was conducted for only the first three years)**

After three year's growth, the basal diameter growth was 0.49 cm/tree/year in the control and 1.25 cm/tree/year in the treatment with harvest + prune + plow + intercrop (Cornejo-Oveido et al., 1991). After three seasons, the number of live coppice locations was 1739/ha in the control, about 600/ha in the plow treatment, and 195/ha in the herbicide-treated plots. (The resprouts include 30-cm tall seedlings which were to be killed the following year.)

After nine growing seasons, very similar results were observed. The growth was 0.54 cm/yr in the control, 1.02 cm/yr in the harvest alone, 1.18 cm/yr in the harvest + herbicide spot treatment, 1.01 cm/yr in the harvest + prune, 1.27 cm/yr in the harvest + prune + plow, and 1.28 cm/yr in the harvest + prune + plow + ryegrass intercrop. However, in the last four years of the experiment, the annual rye grass was not incorporated and in only about half of the years was annual cultivation conducted.

The growth rate of 1.28 cm/year observed over the first nine years compares very favorably to growth of temperate hardwoods, such as 0.89 cm/yr for sweet birch *(Betula lenta*), 1.27 cm/yr for black cherry (*Prunus serotina*), 1.35 cm/yr for yellow poplar (*Lirodendron tulipifera*) (Smith and Lamson, 1983), 0.41 cm/yr for red maple (*Acer rubra*), 0.41 for red oak (*Quercus rubra*), and 0.96 for yellow poplar (*Lirodendron tulpifera*) (Lamson, 1983).

Using the annual growth rate of 1.28 cm/yr over the nine growing seasons obtained by Patch and Felker (1997a), the rotation age to achieve the maximal diameter for 10-m spacings of 37-cm diameter can be calculated to be about 30 years.

We would anticipate that after initial reduction in stand density to about 100 pruned trees/ha, additional prunings would be required 3, 8, and 13 years later. In developing countries, the material from these thinnings would be valuable for fuelwood. Developed countries would just have to absorb the cost of prunings from the sale of lumber at the end of the rotation. Since about 40 trees/hr can be pruned with a chain saw, less than 3 hours labor/ha would be required.

The value of the intercropped plants, the avoidance of perennial land clearing to eliminate young mesquites, and the final lumber sale all point to the advantages of managing immature mesquite growth.

RESPROUT REDUCTION ON PRUNED TREES

In efforts to reduce the number of stems per hectare and to improve the form of the remaining trees, pruning of multiple stems and low-lying limbs is desirable for intercropping. When high-value lumber is a management objective, it is important to obtain long straight trunks. In the latter situation pruning of limbs and prevention of stem resprouts is most important. El Fadl (pers. comm. 1995) found that when *P. juliflora* in the Sudan was pruned it did not resprout along the stems. This is in marked contrast to extensive stem resprouting from *Prosopis* in Texas.

Meyer and Felker (1990) measured resprout growth at 5, 10, and 18 months; after pruning alone; after pruned surfaces were treated with 0.5% NAA,;or after pruned surfaces were treated with 1.0% NAA. While the 1.0% NAA caused about a 50% reduction in weight of resprouts, there was still very substantial resprouting. Meyer and Felker (1990) also reported a significant increase in growth of the main stem for treatments that reduced resprouts.

Patch (unpub. obs.) examined much more comprehensive treatments for reducing resprout formation on *Prosopis*. She compared the best formulation observed by Meyer and Felker (1990), i.e., 1.0% NAA to a control, tree wrap, and 17 combinations of picloram, triclopyr, paclobutrazol and clopyralid in water and diesel mixtures. Trees of about 10-cm diameter and 3-m height were pruned to single stems and the chemicals applied with a paint brush. If a single tree had multiple stems arising from the base, all the stems except for one were removed and the chemical mixture applied to the severed base. Separate measurements were taken for the weight of the resprouts that occurred along the main stem and from those that occurred from the base of severed stems.

The total weight of resprouts for the 19 treatments ranged from 37 g to 3028 g with the control having 1170 g of resprouts. A 20% solution of triclopyr in diesel gave the lowest weight of resprouts both along the main stem, i.e., 30 g and at the base of severed trees, i.e., 7 g. The nonchemical tree wrap had the second lowest weight of resprouts along the main stem but did not control resprouts originating from the tree base.

An example of a pruned tree with multiple resprouts (Figure 2) and a tree treated with 20% triclopyr in diesel fuel is shown in Figure 3. Clearly, the latter treatment appears most promising. Since these same formulations were designed to kill the trees, caution must be exercised in their use so as to not damage the trees. Ongoing experiments are being planned to measure growth-retarding effects of these treatments on the growth of the main stem.

MANAGEMENT OF COPPICE REGROWTH

While we have not worked in management of coppice regrowth, we have observed exciting management techniques for coppice regrowth by farmers in Haiti (Figures 4, 5, and 6). If *Prosopis* is severed at ground level, depending on the stem diameter, dozens of coppice shoots will emerge. Due to an extensive pre-existing root system, these shoots usually grow much faster than seedling growth. In addition, as there are fewer stress events per unit time, i.e., wind, browse, and trampling, the coppice shoots tend to be much straighter than the original seedling shoots. When the number of coppiced shoots is thinned to a single shoot per stump, rapid and straight growth is observed that would be beneficial for poles or lumber. Casual observations of managed coppice shoot production in Haiti suggests that 5 cm to 7 cm diameter poles about 2.5 m in length could be obtained from coppice shoot growth in 2 to 3 years.

Grafting superior scions onto coppice regrowth using the techniques of Wojtusik and Felker (1993) could offer additional exciting developments. That is, after trees were harvested and the coppice regrowth were thinned to a single stem, scions with superior pod production, pod quality, lack of spines, or superior form could be grafted onto the coppice shoots. With the combination of an extensive root system providing rapid growth, and superior genetic materials, much progress in genetically upgrading the stands could be made very quickly.

Prosopis AS A WEED

In many instances, *Prosopis* has been considered to be a weed. The most undesirable *Prosopis* stands often occur 15 years after land clearing, or when the main stem has been repeatedly harvested, either with a tractor-drawn mower or, in developing countries, by fuelwood cutters. In such instances, there may be as many as 20,000 2-cm diameter stems/ha (Felker et al., 1988). Clearly, such dense stands of mesquite offer very little benefit (except perhaps to fuelwood cutters) and are very undesirable for pod production, lumber production, or grass production below their canopies. These stands require a substantial program to improve forage production, lumber production, and just to allow passage of man and his animals. In the past when such stands occurred, landowners would aerially spray the entire area with herbicides or bulldoze, root plow, stack, and burn the areas. Generally, about 15 years after root plowing a similar situation with dense *Prosopis* arises once more.

We believe that the *Prosopis* invasion of recently cleared pastures is heavily favored by depleted soil nitrogen pools which give nitrogen-fixing *Prosopis* (Johnson and Mayeux, 1991) a competitive advantage over non-N fixing grass species. Therefore, simply physically removing the *Prosopis* by bulldozers, still does not address the fundamental issue of depleted soil N reserves.

We believe that once *Prosopis* has occupied an area, the only long term, permanent, and sustainable solution is to thin the dense impenetrable stands to isolated trees that can be encouraged to grow into large trees. These large trees then will provide the intra specific competition to prevent dense encroachment by young *Prosopis*.

In developed countries, the thinning might use bulldozers, or biomass harvesters, such as are under development at Texas A&M University-Kingsville (McLauchlan et al., 1994). In developing countries where fuelwood is an important commodity that is harvested by hand, crop trees at the designated spacing can be marked to be saved and then all other material harvested for fuelwood.

After the trees are thinned, it is necessary to keep the underlaying spaces free of seedlings until the crop trees grow large enough to provide substantial intraspecific competition. Annual cultivation with production of intercrops or individual tree herbicide treatment are options to reduce *Prosopis* seedlings during this phase. It is our experience that a 2% solution of triclopyr in diesel, applied as a gentle stream to wet the 5 cm of bark above ground, provides virtually 100% kill of small mesquite seedlings. However, unless a heavily fertilized grass pasture is established or large *Prosopis* are managed to dominate the site, killing small mesquites with herbicides will only provide temporary absence from arid lands.

MANAGEMENT OF MATURE STANDS OF *Prosopis*

Given the contrasting values for different size classes of *Prosopis*, i.e., about $40/ton for fuelwood (US $2/million BTU), $400/ton for barbecue wood, and $1,200/ton for dimensional lumber (at $850/cubic meter and 700 kg/cubic meter), it is important to maximize the total revenue from stands of *Prosopis*. Additional benefits in terms of enhanced forage production and quality from N fixation and soil improvement also need to be maximized.

From the data on tree-diameter versus plant-spacing relationships, it is possible to predict whether the stand has too many or too few stems. If there are too many stems, the stems of lowest value should be eliminated first.

To determine which factors were most important in controlling the growth of a mature stand of *Prosopis*, we examined the influence of brushy understory removal, phosphorus fertilization, and thinning on a mature stand of *Prosopis* (Cornejo-Oveido et al., 1992). The stand had 193 trees/ha, but because many trees had multiple stems at or near ground level, there were 356 stems/ha. Individual stems had a mean basal diameter of 16.4 cm with a 5.7 cm to 40.7 cm range.

To estimate the growth in weight and volume, 20% of the trees were fitted with permanently mounted verniers at the base of the tree. The verniers were capable of reading to 0.25 mm. From the increase in basal diameter and previous regression equations relating basal area to volume and biomass, we calculated the growth as a function of the treatments (Cornejo-Oveido et al., 1992).

In considering how much to thin the stand, we considered that 100 trees/ha (10 by 10 m spacing) with 37 cm mean basal diameters would maximize lumber volume in this stand (Felker et al., 1988). Given the current density of 193 trees/ha with a total of 356 stems/ha, it appeared prudent to just convert all multiple-stemmed trees to single-stemmed trees, thus eliminating 163 stems/ha. When this was done, the stacked volume of thinned trees and branches greater than 3 cm in diameter was found to be 32.7 ±2.4 cubic meters/ha. In 1989, the value of the thinned material was $22/cubic meter, thus

the retail value of the thinned material was $726/ha. The labor cost for thinning, pruning, and stacking the small logs with chain saws was $320 at $3.35/hr. Thus, not only did we open up the stand for potential growth, but the malformed stems were eliminated and a net revenue of about $400/ha was projected.

After three seasons of growth, there were not many significant differences in the treatments. However, two of the treatments that contained understory removal were significantly different from the control treatment (Cornejo-Oveido et al., 1992). The major influence on the growth appeared to be removal of the brushy understory. Surprisingly, P fertilization which is generally felt to be the most important limiting nutrient for legumes, did not have a marked effect on growth.

At the end of nine growing seasons, these treatments were reevaluated (Patch and Felker, 1997b). Some of the plots had a low number of trees, which lead to considerable variability in absolute growth rates among treatments. Therefore, we corrected the absolute growth rates by comparing absolute growth rate increases to the initial standing biomass of the plots. The result of this analysis are shown in Figure 7.

Optimizing Forage Production Beneath Prosopis Canopies

In addition to maximizing the tree-spacing versus diameter relationships for fuelwood and lumber, it is important to take advantage of the soil-improving properties of *Prosopis* and to maximize the forage production from grass species grown beneath *Prosopis* canopies. We have found certain valuable grass species are found only beneath the canopies of mature *Prosopis*. For example, *Setaria texana* and the highly productive tropical grass *Panicum maximum* are usually only found beneath the canopies of *Prosopis* or other mature trees. For this reason we established two cool-season and two warm-season grasses beneath the canopies of mature *Prosopis* (East and Felker, 1993). We found that *Panicum maximum* had significantly greater dry matter production ($P=0.001$) and crude protein content ($P=0.0004$) under the mesquite than outside the canopy. Karlin (1990 pers. comm.) found that in Argentina, buffel grass had greater forage production under the canopy than outside the canopy. Many range specialists feel that *Panicum maximum* cannot be grown in Texas for forage production. Most of this belief is apparently based on the failure of *P. maximum* to grow in open rangeland or when screened for adaptability in open fields on agricultural research stations.

There is an urgent need to screen highly productive grasses not previously known to be adapted to semiarid lands by planting them under the canopies of *Prosopis* and other tree legumes. The combination of lower air and soil temperatures and greater soil N and soil C may make it possible to grow grass species not before considered possible.

Genetic Upgrading of Natural *Prosopis* Stands

The opportunity to dramatically improve the production of native stands of *Prosopis* is illustrated by the fact that in a plantation of uniformly treated trees, less than 5% of the trees produced 61% of the total pod production at the end of the fifth growing season (Felker et al., 1984). In a California native stand, we found *Prosopis* with bitter pods and with 40% sucrose nonastringent pods within 50 m of each other.

There are two obvious general approaches to improve the genetic composition of the stand. One approach is to eliminate the inferior trees through culling trees for firewood, charcoal, etc. The other general approach is to insert genetically improved material into the stand.

The first approach simply involves ranking all the trees for desirable characters such as pod production, pod quality, erect growth, rate of growth, form, and lack of spines. Then trees that do not meet a composite score of the desirable characters are removed from the stand.

This same ranking should also be used to select the elite materials that are well adapted to the site. The most expedient technique for establishing additional individuals of the elite material is simply to graft budwood from the elite materials onto the coppiced shoots of the trees that have been culled. Wedge-graft techniques have been described (Wojtusik and Felker, 1993) that, during the correct time of the year, have a high percentage of successful graft unions. Due to the rapid growth rate of coppice shoots, the existing root system, and the few new trees required, this is a very economical and reliable technique to genetically upgrade native *Prosopis* stands.

PLANTATION ESTABLISHMENT

High temperatures and lack of rain in semiarid regions create more severe problems for tree establishment than in other ecosystems. It is most useful to take advantage of the long tap root of *Prosopis* by growing seedlings in long containers. To reduce the seedling container weight, these containers can be long and narrow. We routinely use 3.75-cm by 3.75-cm by 37.5-cm cardboard containers with open bottoms to allow air pruning. These containers are placed in plastic milk crates with inside dimensions of 30 cm by 30 cm, thus allowing 64 seedlings to be handled in a single unit.

We initially used polyethylene bags for seedlings. However, as they continually fell over and had to be handled individually, this system was abandoned in favor of the cardboard plant band system. We compared the growth and survival of *Prosopis* grown in these long containers to seedlings grown in 2.5-cm diameter by 20-cm tall plastic dibble tubes that were removed prior to planting (Felker et al., 1987). In a dry year, the cardboard plant bands gave a 25 % survival advantage to both *Leucaena* and *Prosopis* over the plastic dibble tubes (Felker et al., 1987).

When these long cardboard containers were combined with subsoiling and deep plowing that began the rainy season prior to planting, over 98% survival was achieved. This high survival was achieved although no rain occurred six weeks before planting or seven weeks after planting when 41°C temperatures also occurred (Felker et al., 1989).

In Haiti, a no-till, nonmechanized site preparation system was used that employed Roundup™ and Karmex™. When these herbicides were applied beginning the rainy season prior to transplant, 93% survival was obtained without irrigation using these plant bands (Lee et al., 1992).

Growth of the trees following transplant is heavily influenced by weed competition. In a survey of 12 herbicide and cultivation combinations, Felker et al.(1986) found that herbicides plus cultivation increased first year biomass production by 250%. Some of the older herbicides, for which patent protection has expired, i.e. Karmex™ (diuron) and Lorox™ (Linuron) are inexpensive ($9/kg), have nearly year-long control, and, at the dosage required (3 kg/ha), are competitive with hand weeding in developing countries.

After plantation establishment, it is still necessary to cultivate several times per year for weed control. When the trees are less than 1-m tall, a single-row sweep cultivator can easily pass over the trees and a disk harrow can be used in the rows.

When good site preparation is used the season before transplant, deep plowing is done before planting, and good weed control is used during canopy closure, we obtained 98% seedling survival and a high dry-biomass productivity of 20 metric tons/ha without irrigation (Felker et al., 1989).

Multiplication of Superior Trees from Natural Stands or Progeny Trials

Obviously *Prosopis* produces copious amounts of seeds that readily germinate that could be used. However, because *Prosopis* is obligately out crossed, half the genes are from an unknown male parent, while the genes from the female will likely be very heterozygous due to mesquites out-crossed breeding system. Thus, trees from seed will not be true to the parental type. For example seedlings

from thornless trees are both thorny and thornless. If seeds are to be used, a mechanized seed cleaning system for *Prosopis* capable of producing 100 g of cleaned seed/hr (4300 seeds) is available (Pasiecznik and Felker, 1992).

To take advantage of exceptional characteristics from individual trees, some form of clonal propagation is desirable. There is danger in using clonal material for plantations and insertion into existing stands, due to a restricted genetic base that may not have sufficient genetic variability to be resistant to new pests and diseases. There is also the possibility that inbreeding depression may result from seed of a narrowly restricted genetic base. It is difficult to know what is the correct balance between the outstanding gains to be achieved from using the very best individual trees, versus the dangers from exposing narrow genetically based stands to pests and diseases.

It is our opinion that the extreme phenotypic diversity in pod production, pod quality, and growth characters is sufficiently great that commercial stands will have to use either improved seed with less variability in commercial characters or some form of clonal propagules. Some lessening of the phenotypic diversity is critically needed to provide material for commercial plantings.

Of the four types of clonal propagation, i.e., tissue culture, air layering, rooting of cuttings and grafting, the latter two techniques are the most promising. Despite many Ph.D. person-years of research on *Prosopis* tissue culture, no viable system has resulted (Felker 1992). Air layering is successful, but this technique is much slower than either grafting or rooting of cuttings.

While it is virtually impossible to root cuttings of mature field trees, greater than 50% success can often be achieved grafting young branches of mature trees onto seedlings or shoots on other trees. Thus grafting provides a technique to capture the first asexual propagule of mature trees that have passed the juvenility stage and are nearly impossible to root. Resultant grafted seedlings can be grown under drip irrigation in pots in a greenhouse environment, from which young shoots can be harvested monthly which have 40% to 70% rooting success with the proper environment.

Nonmist, high-humidity boxes (Leakey et al., 1990; Sandys-Winsch and Harris, 1991) and solar powered mist systems (Wojtusik et al., 1994) have both been reported to be successful in rooting *Prosopis* cuttings. Routine commercial production of *Prosopis* cuttings has been difficult. A Texas company propagating *Prosopis* for ornamental street trees had excellent success propagating *Prosopis alba* clone B2V50 but much more difficulty propagating another thornless *P. alba* strain and was completely unsuccessful in propagating a thornless *Prosopis glandulosa* var. *glandulosa* (Felker, unpub. obs.).

Because 2,000 two-node cuttings can be produced per month from 80 stock plants in 20-liter pots in a greenhouse under drip irrigation, two people can cut and place these in pots under a mist system in 8 hr, and 50% of these will root under ideal conditions in four weeks, rooting of cuttings is the most efficient way to produce clonal propagules. Grafting will routinely produce much higher percentage success than rooting cuttings, but it is much slower.

Production of seed from improved trees is an alternative to clonal production that has some advantages. At Texas A&M University-Kingsville, we have 100 trees of *P. alba* family 0591, 100 trees of *P. alba* 0685, and 100 trees of *P. chilensis* 0009 that are 15 years old and that are being grown on a 4-m by 5-m spacing for improved seed. The biomass performance of these families has been measured in previous field trials. Thus, these trees represent a known and reliable seed source. Due to the high cost of maintaining the orchards, collecting the pods and cleaning the seeds, the seed cost is high (about $130/kg). *P. alba* 0591 is the most desirable family in that about half the progeny are thornless and produce 30% sugar pods.

There is also the possibility of obtaining seed from clonal seed orchards of thornless trees to produce hybrid thornless seed. Because *Prosopis* is self-incompatible, two clones in the same seed orchard should produce virtually 100% hybrid seed of the two parents. If all parents were thornless, even if thornlessness were recessive or dominant, the seed should produce thornless progeny.

Given the outstanding characteristics of the thornless Peruvian *Prosopis*, it would seem very worthwhile to establish seed orchards using clones of thornless high-sugar-content trees.

THORNLESS, ERECT, FAST-GROWING PERUVIAN *Prosopis*

We feel it important to highlight this very important and unique germplasm source. When 70 half-sib *Prosopis* families of diverse origins in Argentina, Chile, Haiti, Mexico, Peru, and the United States were evaluated in a Haitian coastal environment, the Peruvian *Prosopis* were the tallest, straightest, and some were thornless, after four year's growth (Lee et al., 1992; Wojtusik et al., 1993). Five of the best trees were cloned and brought to the United States to ensure their survival outside of Haiti. In addition, the same half-sib Peruvian *Prosopis* families were the tallest and straightest in an interior-Indian-desert progeny trial with over 200 *Prosopis* families (Harsh, this volume).

A comprehensive genetic evaluation of all major sections of the genus *Prosopis* in Cape Verde also found this *Prosopis* family to be the fastest growing with the best form (Harris et al., this volume).

Since this genetic source of *Prosopis* has been the top biomass producer, with the best form, on three continents with very different climates, it is clear that major programs should be undertaken to evaluate this material in many new locations and to rapidly multiply the genetic material for distribution. Texas A&M University-Kingsville has stock plants of the five best clones that are available to provide scions for the cost of shipping and handling. (It is to be noted that the Peruvian material is strictly tropical and will not tolerate below freezing temperatures without complete mortality to rootstock and above-ground portions)

With the presence of Peruvian collaborators at this meeting, perhaps the original seed source can be recollected. Clonal seed orchards need to be established to provide near thornless seed. In addition, germplasm banks, collected according to half-sib family need to be made in Peru and evaluated in diverse regions of the Caribbean, Africa, and the Indian subcontinent.

CONCLUSIONS

In the past, Prosopis has been regarded as a terrible noxious weed and as a wonderful source of fuelwood, feed for livestock, and feed for animals. Past attempts to eradicate the trees and shrubs without considering the underlying causes for their spread, such as selective advantage over non-N fixers on impoverished sites, have usually led to reestablishment of dense stands.

It appears that management of tree density/size relationships with intercropping or thinning of tree densities by other means, will provide long-term sustainable improvements in soil fertility, herbaceous forage production and valuable wood products in the form of firewood and luxury-quality timber.

Due to the extensive natural *Prosopis* stands in Asia, Africa, North America, and South America, the greatest and most cost-effective returns will probably come from managing native stands rather than plantation establishment. After monitoring productive trees in native stands, i.e., for form, pod production, pod quality, lumber, and spine characters, undesirable trees should be eliminated and sold for firewood and lumber. Scions from the remaining elite trees can then be grafted onto the coppice resprouts of the culled trees without having to produce seedling nurseries or transplant trees to establish new quality trees in the stand.

With Prosopis having exciting new genetic material and being subject to new sustainable genetic improvement techniques, the future for arid lands looks very bright indeed.

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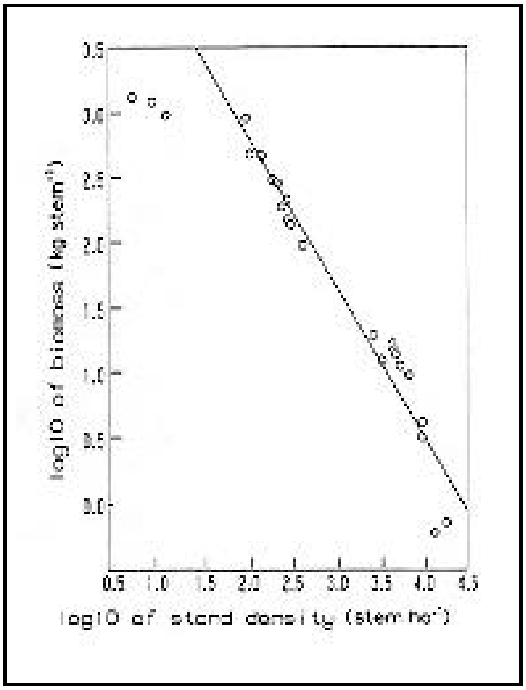

Figure 1. Self-thinning Line for Mesquite (*Prosopis glandulosa* var. *glandulosa*) Stands in Texas

Figure 2. A Pruned *P. glandulosa* in Texas with Multiple Resprouts in Which None of the Pruned Surfaces Were Treated

Figure 3. A Pruned *P. glandulosa* in Texas in Which Pruned Surfaces and Cut Stumps Were Treated With 20% Triclopyr in Diesel (note absence of resprouts)

Figure 4. Coppiced Stumps of *P. juliflora* in Haiti
(note the profuse number of coppiced shoots per stump)

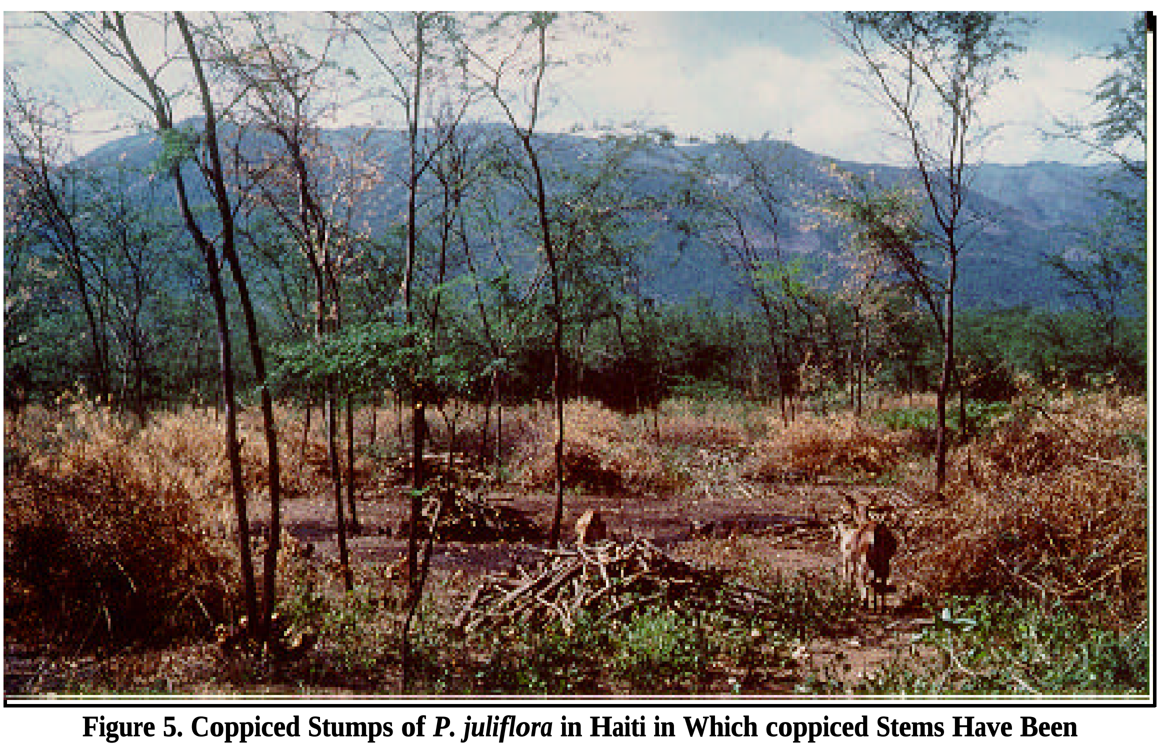

Figure 5. Coppiced Stumps of *P. juliflora* in Haiti in Which coppiced Stems Have Been Pruned to a Single Stem and the Remaining Wood Used for Firewood or Charcoal

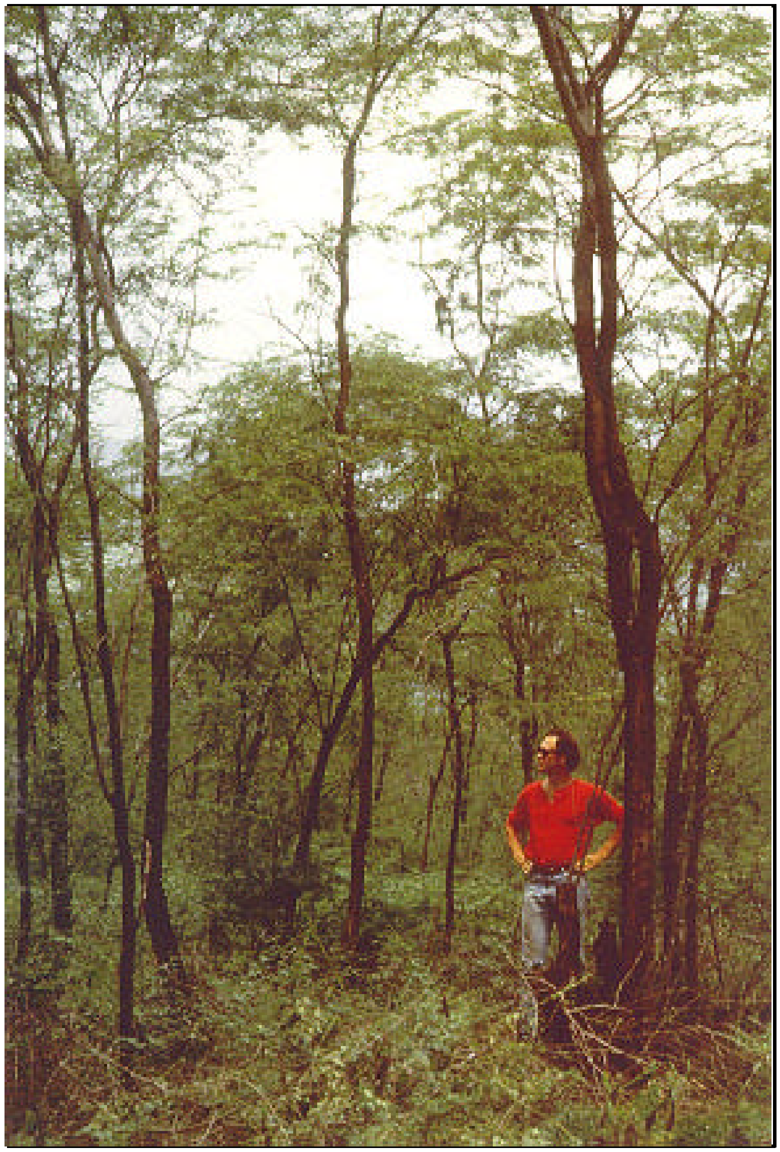

Figure 6. Coppiced Stems of *P. juliflora* in Haiti in Which Coppiced Stems Have Been Pruned to a Single Stem

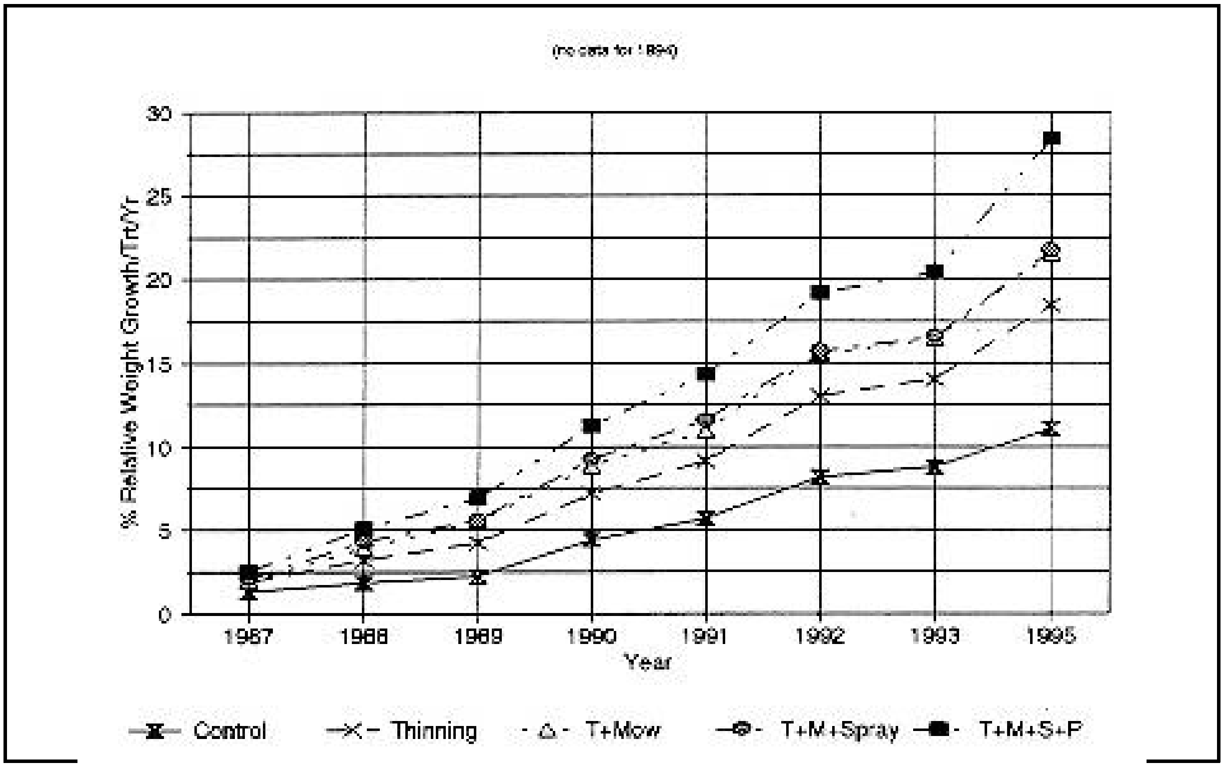

Figure 7. Growth of Mature Stand of *P. glandulosa* in Texas Following: no treeatment (control); thinning multiple-stemmed trees to single-stemmed trees (thinning); thinning multiple-stemmed trees and manually eliminating shrubby understory (T+Mow); thin trees, eliminate understory, and spray shrub resprouts with herbicides (T+M+Spray); thin, eliminate understory, spray resprouts and apply 100 kg/ha P fertilizer (T+M+S+P)

The Importance of Value Added: The Potential Role of *Prosopis* in Rural Development Forestry

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Summary

Small and subsistence farmers in the tropics grow and plant trees for a variety of multipurpose uses. Increasingly, these uses include sale in the market both for regular income and for risk management. The genus *Prosopis* is particularly well suited to meeting both domestic and commercial needs. The development of reliable and equitable markets for small farmers' tree products is essential if the planted trees are to meet their owners' perceived needs. Possible future scenarios for agroforestry in sub-Saharan Africa, Latin America and tropical Asia are briefly reviewed and it is concluded that although *Prosopis* is seen largely as a fuel and fodder crop in poorer areas, there should be potential for increasing the markets and, therefore, the price obtained for its timber, especially as many of the world's most valuable timbers are marketed in small sizes.

Introduction

Rural Development Forestry may be defined as all forms of forestry and agroforestry activity where the primary objective is improving the livelihoods of rural communities, as opposed to activities which have major objectives of industrial production or conservation (Table 1). Although many activities may have a variety of objectives it is well to identify the major ones from the outset, and most aid donors identify poverty reduction and rural development as major aims for their aid.

Table 1. The Context For Rural Development Forestry

Classification	Objective	Methods
Rural development forestry	Private and farm forestry	Rangelands, woodlots, agroforestry
	Communal forestry	Natural woodlands, planting
	Social forestry (often welfare)	Mostly planting
Industrial forestry	Plantations	Plant old forest or ex-agriculture land
	Natural forest management	Enrichment plant or regeneration
Conservation forestry	Reclamation	Planting
	Conservation	Enrichment plant or regeneration
Urban and amenity forestry	Private amenity- Public amenity-	Street trees Park trees Protection

With the major emphasis on the livelihoods of rural people, many of whom are subsistence farmers, it has been traditional to pay attention to basic human needs insofar as these can be provided by trees.

Thus, for most of the 1970s and 1980s, fuelwood has been a major concern and it is significant that in some countries the control of fuelwood programmes has been given to Ministries of Energy rather than to Natural Resources or Agriculture. But concentrating on fuelwood, however much as this may be needed by subsistence farmers, leads to an emphasis on growing for one of the lowest-priced markets. In a number of instances farmers have sought higher priced markets for their trees than the fuelwood market for which a donor-funded project intended to be served.

Table 2. What Do Development Agencies Seek?

Addressable Through Trees	Not Addressable
Poverty alleviation	Illicit drug control
Human development-education	Children by choice
Advancement of women in development	HIV/AIDS
Economic liberalisation	
Development of the private sector	
Improved productive capacity	
Efficient democratic government	
Sustainable agriculture and food security	
Sustainable forest management	
Biodiversity conservation	
Environmental protection	
Urban development	
Research livelihood improvement	
Energy efficiency	

What Do Rural People Want?

The many systems for rural appraisal, variously called Rapid Rural Appraisal, Participatory Rural Appraisal, Diagnosis and Design (Raintree, 1987) have produced some very important findings on what the aspirations of small farmers are. Many of the identified needs related to land use, especially farming systems and yields of agricultural crops. But, often, more important concerns are for family welfare and survival, and for the majority of countries, cash, because most small farmers are increasingly part of the cash economy, albeit at the very lowest levels. In particular, increasing agricultural productivity with improved crop varieties requires fertilizer and pesticide inputs, both of which cost money and both of which are less and less subsidized by national governments. More and more, therefore, farmers are seeking cash incomes, though there is a gender bias towards men, women often prefer subsistence benefits. It should be emphasized that rural appraisal is a continuous process and that the information obtained at any one time is only a guide to current needs. Also, the process is a dialogue; asking people what they want can be revealing, yet what can feasibly be done to enable them to obtain it is necessarily a compromise. The choice of *Prosopis* for planting must necessarily also involve compromise.

Why Do People Plant Trees?

For most developing world farmers, *Prosopis* will be a tree to plant rather than one to harvest from the wild. Its well-known propensity to spread naturally, however, means that in many places, for instance in Rajasthan, India, the genus has become naturalized and it represents virtually a wild resource. If it is necessary to plant, what are the factors in farmers' decisions to do so on small farms? Arnold and Dewees (1995) outline four major reasons which are particularly relevant to the use of *Prosopis*:

a) To maintain supplies of tree products as production from off-farm stocks declines

b) To meet growing demand for tree products as populations grow, new uses for tree outputs emerge, or external markets develop

c) To help to maintain agricultural productivity in the face of declining soil quality or increasing damage from exposure to sun, wind, or water runoff

d) To contribute to risk reduction and risk management in the face of needs to secure rights of tenure and use, to even out peaks and troughs in seasonal flows of produce and income, and in seasonal demands on labour, or to provide a reserve of biomass products and capital available for use as a buffer in times of stress or emergency (Ibid)

In most farming situations, several of these factors will operate, but the importance of value added is apparent mainly in b) and d), that is, marketing and risk management.

There is certainly a trend to suggest that growing trees mainly for sale in the market will become an increasingly important objective of small farmers in the future and the characteristics of *Prosopis* species on different sites gives it the potential to meet this objective particularly well. The genus provides a number of very important species with a wide range of multipurpose uses, both products, such as fodder, fuel, and timber, but also services such as shade and soil amelioration.

If a major concern of governments is development in poor rural areas, it becomes important to find ways of increasing the quality of the wood and marketing it equitably. The multipurpose outputs of *Prosopis* make it valuable both for short-rotation production of wood for income and also for long-term security as mature timber trees retained on farm. These characteristics also enable it to provide domestic benefits for women in farming systems.

Market Potentials for Prosopis

The market price of fuelwood is commonly $1 to $2 per tonne. Most of this represents the value added by the labour of collection and preparation for sale. By contrast, the price of lumber is orders of magnitude greater, even in local markets. By the time that produce reaches international markets, such as that in London, England, the prices per cubic metre or tonne are of the order:

Teak	US$3000
Rosewoods	US$4000
Blackwood	US$6000
Iroko (general-purpose West African hardwood)	US$500

(Note: These prices suggest orders of magnitude only and should not be taken as indicative of any current market prices. The latest prices can be obtained from *Tropical Timbers*, a bi-monthly British journal.)

All the above species can be grown on farms, but only a few woods fetch really high prices. Iroko, for example, is a first-class hardwood with some similarities to teak, that is often grown on farms, yet

the price does not reflect this. The reason may be that it is not sufficiently specialized to have its own market niche. General-purpose softwoods are even cheaper, so we need to ask whether *Prosopis* has qualities that might lift it into the special-purpose market. Whereas the species listed above are readily saleable on both local and international markets, even in small sizes, wood from planted *Prosopis* is still relatively unfamiliar on local markets, especially if the species is an exotic. However it is worth recording that in November 1995 the author noted in the (wood-based) ship-building yards in coastal Gujerat, India, that *Prosopis juliflora* was increasingly being used for frames and planking in place of more traditional and increasingly scarce indigenous woods, notably teak. It is also worth noting that much of the teak in international trade is of small-sized stock.

Future Forestry Scenarios

What potential is there likely to be for Prosopis growing in the next millennium? I will look briefly at the three main tropical regions.

Sub-Saharan Africa

An increasing need for forest clearance for agriculture will result in fewer forest products and a probable rise in prices. At the same time, increasing concerns of the rural and urban poor over food security will arise as more and more marginal areas are farmed. There is likely to be an increase in concern of rural farmers for cash incomes as a way to address food security, resulting in an increased interest in cash crops, including *Prosopis,* which will also supply domestic fuelwood for which there is no foreseeable prospects of any reduction in demand, though there will probably be an increase in its commercialization.

Increased transportation fuel costs for non-oil producers will lead to increased transport costs for all products, more costly agricultural fertiliser and decreased capacity for mechanised agriculture. The main concern for the African continent, therefore, continues to be sustainable agriculture in the face of decreasing per capita wealth and rising populations and oil prices. The multipurpose nature of the *Prosopis* genus should ensure it has an important role in drier areas of Africa, especially if its timber can be marketed successfully.

Latin America

In Latin America there is considerable variation between and within countries. Rising oil prices will certainly be of concern, but food production on a continental basis is less threatened than in Africa. The developing industrial economies have a strong interest in helping rural economies to develop and this includes encouraging value added in the rural forestry sector. Sustainable agriculture for increasing populations is increasingly important. There will be increasing commercialization of wood in all forms and *Prosopis* should have an increasing role to play in this.

Tropical Asia

In Asia the position is more complex. Populations are still rising but so is industrial production, China and India, for example, are expected to be in the world's top three industrial nations in less than 20 years. Urbanization will continue and agricultural production may rise if farms increase in size. Increasing national incomes will ameliorate the position over oil and food imports. The poorest countries, e.g., Nepal, Afghanistan, and some middle-eastern countries may experience similar problems to some of the African countries, however. Increasingly sophisticated industries markets could well provide lucrative markets for *Prosopis* products.

The Way Forward

If there are potentials for *Prosopis* development, how should research on the utilisation and marketing of its products be planned? It is possible to identify the following groups of stakeholders or special interest groups who should be part of the process:

- **Small-farmer producers and direct sellers**
- **Resource owners**
- **Small and medium traders in products**
- **Processors, handlers, entrepreneurs**
- **National and international markets**
- **Officials, donors, financial institutions**

The following matrix suggests some suggested research priority areas:

	Food Security	**Income Need**	**Livestock**
Small Growers and Producers			
Traders			
National Planners			

Conclusions

The identification of constraints on the wider use of *Prosopis* in improving rural incomes would respond to a number of initiatives. Some ideas for these are suggested below, though this is by no means exhaustive.

1. **Set up a Research Working Party in the International Union of Forest Research Organisation.**

2. **Establish demonstrations in key countries and areas of *Prosopis* utilisation showing its key potentials as a fine wood. Any project of this kind could be expected to cover other small saw-log-producing species also.**

3. **Prepare a practical how-to-do-it manual on *Prosopis* use for small farmers, emphasising the risks as well as the benefits**

4. **Improve seed supplies of suitable provenances, especially thornless varieties and improved forms for better food and wood production.**

5. **Improve and disseminate information on the technology and marketing of *Prosopis* as a food product**

6. **Hold a series of training courses in different key countries and languages, such as Argentina, India, Senegal, Sudan, to cover all the technologies in items 2 and 5 above, plus propagation methods.**

7. **Ensure that potential aid donors are aware of the potentials of the genus for meeting development criteria.**

Several questions remain, notably, who should be responsible for any of the above, how the activities should be funded, where, and when. The Proceedings of this workshop will form one of the principal ways of publicising the need.

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The Importance of Mesquite to the 21st Century

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President, Los Amigos del Mesquite

The Importance of Associations in the Mesquite Industry

Let me begin my remarks by encouraging us to make this *Prosopis* **conference a regular event. Those of us who work with mesquite are probably thought of as odd ducks by many of our peers. We need to be reassured occasionally that what we are doing is meaningful and beneficial to mankind, as indeed it is. Thus, I propose that we here begin the process of forming an international association of those who are involved the study, development, and utilization of** *Prosopis***. Here are a few reasons why I believe we should do that.**

Associations, which can be formal or informal, are necessary to promote and encourage the dissemination of information and techniques. Formal associations give a better service and clearer purpose to their constituents. There are elements of special information that some may not want to disclose, believing that the information is exclusive to them. Generally, these individuals do not participate in associations. But, for the majority of people in the mesquite industry, associations are an essential element that allows us to become better informed about new ideas and technology and will help us reach our goals.

Benefits

There are many benefits to having a mesquite association at any level. Five areas of benefit that accrue to an organization dealing with the special interests of mesquite are outlined in the following paragraphs.

The first objective of a mesquite organization is being able to *identify*:

- **Common interests**
- **Problems**
- **Solutions**

Coming together in one location is necessary for that to happen. Thus, some schedule of regular meetings is needed. An organization devoted to the study and utilization of mesquite gives us the opportunity to explore these three areas and can benefit everyone.

The second objective is to *exchange*:

- **Ideas**
- **Goals**
- **Needs**

This will allow us to encourage and enable communication and widen the sphere of information to include others who might be influential in helping us accomplish our goals.

The third objective is to *promote* **our common goals.**

This allows us to build a stronger base and achieve a greater good. The result is that we can publicize our objectives and obtain funds to further the work with mesquite.

The fourth objective is to *share* both triumphs and defeats, our victories and failures.

> **We learn most from our failures, if we don't quit. Others learn from our victories.**

The fifth objective is to *encourage* one another.

> **We need to be able to recognize and reward those who have made significant achievements in our field. There is pride in achievement, both our own and others.**
>
> **An association allows us to have fellowship with others about our common interests. One of life's most rewarding pleasures is be able to give something of ourselves that benefits another. An association can create an important type of family that benefits everyone involved.**

Now, let me share a few thoughts and facts about my involvement in the fledgling mesquite industry in Texas.

Overview of the Mesquite Lumber Industry in Texas

My perspectives of the mesquite lumber industry in Texas have been developed by being president of one of the largest mesquite lumber sawmills in Texas, located in Bastrop, Texas. It has also been my great pleasure to have served for two years as the President of Los Amigos del Mesquite. This organization represents sawyers, wood workers, barbecue-chunk manufacturers, and nurserymen who sell mesquite, as well as scientists interested in applied aspects of mesquite.

Los Amigos del Mesquite hosts an annual convention in Texas to promote all aspects of mesquite. The evening before the convention we have an invitation-only wine-and-cheese reception for architects and furniture designers to provide an opportunity to see the very best furniture, flooring, carvings, and accessories that mesquite has to offer. We have one full day of technical presentations on wide-ranging subjects. In the past, we have had presentations on stand management, furniture finishing, demonstrations of new sawmill techniques, demonstrations of turning and furniture manufacture, marketing of furniture products, and ecological aspects of nitrogen fixation by mesquite. Competition for the best furniture, sculpture, and flooring products—with cash prizes—has also been a regular feature of our mesquite conventions.

Following the technical sessions we have a weekend-long exhibition and sale of mesquite products. In the past few years we have held this in conjunction with a major festival in Corpus Christi, Texas, so that many people become exposed to all the products of mesquite. This is a good opportunity for architects, builders, and homeowners to see mesquite products and consider their value. This past year, a mesquite flooring manufacturer met an interior designer who decided to specify a mesquite floor for the new offices of one of the oldest and largest law firms in Corpus Christi. These annual conventions also offer an excellent opportunity for new and old mesquite sawyers, landowners, and furniture manufacturers to meet each other to develop collaborative business opportunities.

The following remarks, while primarily about Texas mesquite (*Prosopis glandulosa*), are equally applicable to mesquite as it grows anywhere in the world. Some properties of Texas mesquite, such as excellent stability, are similar to other *Prosopis*, for example, *Prosopis alba* in Argentina. We know very little about the wood technological properties of most *Prosopis*. However, most of the facts and principles outlined here can be applied to both developing and developed countries.

There are approximately 55,000,000 acres (about 22,258,000 hectares or 222,740 square kilometers) of mesquite in Texas. At the current estimated rate of usage of approximately 5000 acres (2024 hectares) per year and, assuming no regrowth from trees cut, there is only an 11,000-year supply of mesquite left in Texas! We know, of course, that mesquite proliferates by various means. At present, 97 companies indicate that they have a full-time business that mills or processes mesquite wood. Of the 97 companies, only about 20 are really sawmills. All of these are very small mills. No single mill can produce more than 1000 to 2000 board feet of lumber per day and most of them produce much less. There are also 84 companies that identify themselves as part-time users of mesquite wood and 86 companies and individuals that classify themselves as hobbyists for commercial wood-processing

purposes. These wood processors are producing mostly ungraded lumber, some graded lumber, flooring, furniture and furniture parts, doors, and small items.

At the retail level there are craft items, flooring, furniture, and lumber. The groups that are obviously missing are brokers, distributors, wholesalers, and concentration yards.

The suppliers of mesquite logs are the least identifiable and least unified of all those that work with mesquite. Many of these loggers are part time or seasonal workers.

The cooking-wood and charcoal segment of Texas' mesquite industry is the most efficient, is the most successful, and has had the greatest impact economically.

Outlook for Mesquite Lumber Products

As more pressure is exerted on common woods, mesquite will become more acceptable as an alternative. Mesquite's outstanding stability and hardness are the chief reasons for this acceptance.

Mesquite is a trendy wood at present. Its very scarcity as a lumber and furniture product makes it all the more desirable for upscale use.

There needs to be developed more efficient means of harvesting and processing mesquite to lower the cost of finished products and to allow it to flow through the normal channels of commerce: manufacturers to distributors to brokers to wholesalers to dealers to consumers. The distributors, brokers, wholesalers, and dealers are largely absent in the sales of mesquite lumber products. This is primarily due to the high cost of these products and the inefficient production methods used by the mesquite industry. This creates a "catch 22" scenario of the product being too expensive for the consumer if the middle distribution players are included. On the other hand, manufacturers cannot afford to advertise and market their product effectively because of the low sales volume. The solution, of course, is to generate a much greater volume of sales using the proven channels of marketing. There has to be sufficient room for mark up of the product for the middlemen to get it to the consumer at an affordable and desirable pricing. This calls for much greater efficiency from the producers, and the opportunity for the supply channel to make a profit and still entice consumers to use mesquite products.

Another great problem for the established wood industry in trying to obtain mesquite products is the lack of any inventory of mesquite lumber. This is where concentration yards and distributors will play a major role if there is to be a viable, significant mesquite-wood industry in Texas. Because they cannot obtain mesquite-wood products in a timely manner, most of these middle supply channels have chosen to not offer mesquite because of unreliable delivery times and uncertain quality.

Hopefully, we can address this problem by establishing the first mesquite concentration and distribution yard. My plan is to buy mesquite lumber and flooring, grade it, and create a sufficient inventory to give the wood-using industry confidence in the quality and inventory of mesquite-wood products. The creation of a regular, consistent buyer will enable most of the small producers to purchase or lease better and more efficient equipment, stabilize and standardize their overhead, and become part of the established wood-producing industry in Texas.

As the United States wood-producing industry is enabled to obtain and use mesquite wood products, international sales also become a possibility.

Mesquite's good growth characteristics will enable sustained production of this outstanding wood. Since the early 1950s, the USDA has had a "Mesquite Eradication Program" in place and billions of dollars have been spent trying to destroy and get rid of mesquite. When this program was started there was an estimated 41,000,000 acres of mesquite in Texas. After more than 40 years of effort and billions of dollars spent, we have only 55,000,000 acres left! Obviously, mesquite is not in any danger of becoming an endangered species. *Prosopis glandulosa* is the species of mesquite that grows in Texas.

Studies by Texas A&M University have shown that with very minimal silviculture practices mesquite will grow in diameter at the rate of ½ inch, or more, per year. This rate is comparable to other hardwood lumber species.

Development and Marketing of Mesquite Flooring and Furniture

At the present stage of development of the mesquite industry, we need to optimize how and where mesquite is used. One of the methods of multiplying a limited supply is to use *veneers***. Veneer allows the supply to stretch further. Any mesquite-lumber piece is, at present, more expensive than its common-wood counterpart. The use of veneers can narrow the gap between common woods and an exotic such as mesquite.**

For instance, the wholesale price for select-grade mesquite *lumber* **varies from about $6.00 to $8.00 per board foot. The same grade of oak would be about $1.20 to $1.50 or a ratio of about 5:1. The price difference between mesquite veneers and oak veneers is only about 2:1 to 3:1.**

There are some other limiting factors in producing and using mesquite lumber.

There is a very limited quantity of clear boards. Almost every mesquite log has a radial crack or wind shake crack in it. The tree does not grow straight up and thus produces logs that must be "straightened" by cutting out the bends and crooks. The resulting logs are short, usually less than six feet long. We must develop lumber sized to meeting the need of the flooring and furniture industry based on what the logs can produce. Fortunately, both of these industries use pieces that are less than 4 inches wide and less than 36 inches long for approximately 80% of their parts. Mesquite lumber can accommodate those dimensions.

As indicated, there is a very limited market for mesquite-wood products. This is primarily due to the high cost and very limited availability. In order to overcome this fact we must be very diligent in reaching the number of affluent people who can afford to buy mesquite-wood products or reduce the cost and increase the availability of mesquite-wood products.

The technology and machinery to do this are already available and in constant use in the wood-producing industry. Short-log sawmills can produce 30,000 to 40,000 board feet of lumber a day using as few as seven workers. This is more than twice as much as all the mills in the mesquite industry can produce in a month, at present. This is technology and equipment that is directly transferable to the mesquite industry. Utilizing this equipment alone would probably increase the efficiency of mesquite production and decease the cost by 50% to 70%. The log supply would also have to increase greatly and efficiency measures taken to increase quantity and reduce cost to the mills. Again, the equipment and proven technology are already being used in harvesting other species. Other ways to increase the availability of mesquite is to utilize and perfect finger-jointing techniques that will be acceptable for a high-end product, reeducate consumers to appreciate the natural character of mesquite, and incorporate these normal mesquite characteristics into the finished products. There is an enormous amount of room to increase the efficiency of the processing of mesquite-wood products. The mesquite-wood barbeque industry is far more developed than the mesquite-wood-products industry. The mesquite barbeque industry is using whole logs, many of which could be used for fine lumber and wood products. They do this out of necessity, because there are not nearly enough by-products to meet their needs as there are in the other species in the wood using industry. If the mesquite-wood-products industry were producing even nominal amounts of lumber, the barbeque industry's supply would be met with by-products as it is in other wood species.

As mentioned earlier, the supplier chain needs to be completed in order to increase availability and, as a result, increase availability and decrease the ultimate consumer price.

Technical Facts About *Prosopis glandulosa* (Texas Mesquite)

Mesquite is a most unusual plant. It belongs to the legume family. The legume family has the ability to fix nitrogen in the soil. This ability in mesquite is not readily seen unless the tree is allowed to

mature in semi-open savannahs. This also happens to be the very type of growing condition that allows mesquite to mature into fine-lumber trees. When thinned to 20-foot to 40-foot spacings, mesquite grows quite rapidly. Tests by Texas A&M University-Kingsville have recorded average growth rates of ½ inch in diameter per year and more. This compares very favorably with other fine-hardwood species. The current price for green mesquite *logs* averages nearly $1000 per thousand board feet. This is more than most kiln-dried lumber sells for. It is far more than oak, walnut, cherry, or maple logs sell for. Thus, there is ample incentive for landowners to take care of and cultivate their good mesquite trees. Assuming a mesquite thicket with no log-size trees, the recommended practice needed to produce mesquite trees of lumber size include removing all mesquite leaders except one healthy trunk to a spacing of 20 feet to 40 feet. The resulting wood recovered will pay for the labor of this process and return an immediate profit to the landowner. This wood is sold for firewood at the prevailing prices of $60.00 to $80.00 per cord. This immediately allows this land to be used as an improved pasture with the added bonus of having the nitrogen boost from the mesquite trees in just a few years. Few people would believe it a wise move to cut down healthy young walnut trees to improve a pasture. Yet, that is exactly what has been occurring for decades. Of course, until recently, there was not a market for mesquite lumber. However, there now is a market and we hope to expand that market to the point of sustained equilibrium for mesquite trees.

Texas mesquite, *Prosopis glandulosa*, is the most stable of all natural woods for which we have technical data. The volumetric shrinkage from green to 6% moisture is only about 4%. More importantly the tangential to radial ratio is 1:1. Thus, the wood moves uniformly in all planes. This give mesquite incredible stability and allows its use in products that need the stability that cannot be achieved in any other wood. Texas mesquite is very hard, averaging more than 2340 PSI. Southern red oak, considered to be a very hard wood, is about 1060 PSI. Texas mesquite is highly figured in an unusually high percentage of the surface of its boards. Texas mesquite has a rich, unique auburn color. In all, it is a wonderful resource.

I would like to share a personal story that I believe has an application to our present situation with mesquite. One morning in October 1977, my wife, Suzanne, and I were discussing our financial situation. I was the minister of a church in the central Texas town of Weimar. We did not have a very large salary, and our expenses seemed to be exceeding our income for that month. After discussing several options which did not appear to be the needed solution, we decided we would pray together at the kitchen table. First we each prayed out loud, then began to pray silently, asking God to please show us a way to pay all our bills. As I prayed, I became annoyed by noises that seemed to interrupt my thoughts and made it difficult to concentrate on "hearing from the Lord." Finally, in desperation, I got up and told my wife I was going to go outside and see what all the commotion was about. When I stepped out the back door to see what it was that was falling on my roof and making all the noise, I was amazed to see a virtual rainstorm of pecans. They were falling everywhere from a brisk wind that buffeted the large pecan trees in our back yard. It then struck me that those pecans were the very answer to our prayers! We got some sacks and began to pick up the noisy intruders. In a few hours we gathered several large sacks full that we sold at the local feed store for more than $120. We had money to pay all our bills and about $40 left over! The noteworthy lesson we learned was that we had a resource available to us all along that we had failed to see. God opened our eyes to it, and we had our needs met. I believe the present situation with mesquite is much like that. We need more jobs, economic growth, and trade. We have a bothersome thing that we have spent much effort to rid our land of, thinking of it as only an aggravation. In reality, it is a blessing and a potential source of great benefit to the people of Texas and the world.

Conservationists, environmentalists, consumer advocates, entrepreneurs, capitalists, and government agencies could work together to achieve a truly remarkable result. A result that each of these diverse groups might rightfully claim as a victory, while helping everyone involved.

For just a moment, let's pretend that this is the early 1900s. Someone comes to you and tells you about a black gooey substance that they have discovered under the ground. However, you have the great fortune to know beforehand all the benefits and potential of this substance called oil. You would

be in the position of taking advantage of one of the greatest discoveries in this century. And of course, you would immediately invest all that you could afford, even taking risks to obtain the benefits this wonderful substance would provide.

I believe that mesquite could be the "discovery" of the 21st century. We have a super abundant supply of it; it defies eradication; it has amazing stability that is superior to all other woods; it has unusual figuring, color, and hardness; and it is has an immediate, well developed by-product market. Of course, it has to be developed and refined to be properly utilized. We have the knowledge and technology to turn this "pest wood" into an economic and ecological bonanza. Just think of the chemicals that would *not* **be sprayed, the millions of gallons of fuel that would** *not* **be expended to bulldoze, and the millions of man hours that could go from being an economic negative to producing a big positive for everyone from the farmer and rancher to the hired laborers who could be employed in the many businesses that would all benefit in creating a cleaner environment and utilizing something we already have and turning it into fine and useful products for our society and the world.**

In summary, let me suggest that if we are willing direct our energy and resources in a very positive direction, we can achieve several remarkable things. We can help achieve a cleaner environment, reduce the consumption of endangered/threatened species of other woods, provide jobs for ordinary people, stimulate economic growth, and develop a new source of high protein food by utilizing a plant that defies eradication.

You can do this. We can do this. Will you do your part? Together we can!

While many of my remarks have related to our Texas mesquite, there are many of the same possibilities for other mesquite species around the world. The beneficial attributes of mesquite can provide erosion control, pasturage, food products, cooking products, and lumber products wherever mesquite grows. Several other conference speakers will cover some of these areas. Mesquite is an exciting plant that can provide many of the basic, and not so basic, needs we have in the 21st century.

The Mesquite-Wood Industry in 1996

Jerry M. Lawson
President, W.W. Woods

During the past decade, the mesquite-wood industry has evolved from a fledgling collection of entrepreneurs, craftsmen, artists, ranchers, and haters or lovers of mesquite.

During the early 1980s the mesquite mystique took on a life of its own. Hundreds of entrepreneurs tried vainly to figure out how to use the seemingly unlimited supply of mesquite and turn it into successful commercial products. One of the most significant of these efforts was pursuing the use of mesquite for outdoor cooking. Many people who had lived in, or even passed through, Texas knew of or had experienced food cooked over mesquite. Most of the people who had a first-hand experience with it, whether it was eating food prepared on mesquite or actually preparing it themselves, were convinced of the significant difference this type of cooking provided.

Many people originated in rural areas of the Southwest where the traditional outdoor cooking device was a large open-air grill that allowed broken limbs, branches, and even stumps to be placed in the grill and cooked down to coals. However, as many of those Texas natives began to move to large cities with small back yards, few mesquite trees, and barbeque pits that were built for apartment balconies or small patios, the only real fuel for these grills was the charcoal briquets that were originally developed by Henry Ford and sold in local supermarkets. The tradition of cooking with mesquite at home, while still a part of our conscious memory, was no longer a reality.

During the late 1970s and early 1980s, numerous pioneers attempted to develop a process for mesquite that would allow it to be used in small backyard grills. The original product used aged dry wood that had been cut or cleared and allowed to dry for two or more years. This accomplished two things: dry wood was easy to start and, after two years, most of the bug infestation was gone after the sap had dried out of the wood.

There were dozens of "Rube Goldberg" devices built to attempt to convert mesquite logs into some type of chunks that could be used for outdoor cooking. Sizing of the product was important in that you needed the small pieces to start the fire quickly and large pieces to achieve long burning times.

Most of the early producers envisioned the consumer using their mesquite as a flavor additive for charcoal. Packaging of the product ran the gauntlet, including paper, plastic, burlap, and bundles of logs tied together with string.

As some of the early producers with the typical zeal of a pioneer set out around the country to sell this hottest new craze from Texas, they oversold everything and the retailer bought into the craze without any concept of the problems that lay ahead. The orders began to materialize and producers chipped, chopped, and chunked any mesquite that was available. Unfortunately, no one really knew the importance of moisture content for the wood that would control how easy or difficult it was to light. Also the high moisture content could create the most awful looking and smelling mildew in a bag. Probably the worst consequence was the bug infestation of the green wood that still contained the sweet mesquite sap.

The retailers' first mistake was to assume that if this product was as good as everyone said, that surely it would sell in multiple truck load quantities, just like charcoal. They bought heavy and stood back to start counting their money. What happened for a while was nothing. The typical package did

nothing to tell people what the product was and how it was used. Other than maybe a little flurry of sales when it first arrived, the modern consumer did not have a clue about what to do with this product. The retailers began to become concerned when the product did not sell and then in many cases it began to mildew and grow little green things in the bag. That was when the dreaded powder post beetle began to show up on retail shelves with their tell-tale sign of yellow powder and, in some cases, the sounds of the beetles eating their way through the green wood.

All of these happenings began to take their toll on the early companies as they struggled to put the formula together for how to produce, dry, package, and, most import, sell all-natural mesquite wood. Eventually, the lessons were learned about most of the production problems that had kept productivity at low and unprofitable levels.

As the productivity improved, retail and wholesale prices began to drop from the niche level toward the commodity level. As this took place, the consumer began to take notice and sales began to grow steadily.

Hundreds of thousands of consumers were first introduced to cooking chunks by way of their smokers. These were great appliances that could be purchased for under $30 and needed long-burning aromatic wood for flavor enhancement while using charcoal as fuel.

As the all-natural cooking-wood category developed more, consumers began to learn how to grill with these cooking chunks as their only fuel. Basically, the average outdoor cooking enthusiast learned by word of mouth. There was no significant advertisement to help educate the consumer. It became a long slow learning process as neighbor taught neighbor and families gathered around the barbeque pit and the kids picked up on what was becoming a slow trend toward the use of all-natural cooking-wood products.

Along the way toward this growing market, there were huge obstacles to overcome as the dwindling number of producers learned the lesson of marketing consumer products to a very sophisticated retail trade that, in many cases, had been burned by mesquite products in the 1980s. One of the keys to the retail distribution was to learn and understand the buying pattern of each class of trade. The grocery retailers reviewing process was different in many ways from the mass merchants, home centers, and convenience stores, etc. Each class of trade had to be learned and worked with from the standpoint of local broker representation to pricing and profit goals. Package size and price points had to be understood so that the product could be matched with the demographics of the particular retail customer.

As these various factors began to build the industry volume, the retail prices for the consumer continued to drop and sales began a long-term growth curve for mesquite all-natural cooking-wood products.

Today, many brands of cooking-wood products in both chip and chunks can be found in almost every major chain in the grocery, mass merchandising, and home-center retail trade in the United States (U.S.) Many areas of the country are still in the very early stages of development as to the size of the market, but indications are that there will be continued growth of this category.

There are currently eight producers in the U.S. Most of the producers are in the Southwest, with at least five of these producers in Texas. The Barbecue Industry Association reports that, in the year ending August 1996, 20,478,964 pounds of all-natural cooking-wood products were sold in the U.S.

Texas A&M University-Kingsville has estimated that there are more than 53,000,000 acres of mesquite in Texas. Today, less than 10,000 acres are being harvested into commercial products each

year. There are many acres being pushed and burned with no commercial value or economic benefit being derived for the landowner, processor, or the citizens of Texas.

Today, there are producers that are using everything harvested from the mesquite log, including the sawdust. During the past decade there has been a tremendous growth of successful new products including mesquite flooring, furniture, crafts, and art objects.

Landowners throughout Texas need to continually monitor the progress of the these products to know how their mesquite stands can best be optimized for commercial products.

The Texas Department of Agriculture can best assist the effort to maximize this segment of the Texas Wood Industry by promoting and helping to make the world market aware of this truly Texas product that provides the great sizzle for other outstanding Texas products such as our beef, poultry, pork, and wild game.

Texas mesquite cooking-wood products can now be found in markets throughout the U.S. All major chains such as K-Mart, Wal Mart, Sears, Home Depot, Builders Square, Lowe's, Kroger, Albertsons, and many, many more handle our great, all natural and renewable mesquite products.

A Review of the Social and Economic Opportunities for *Prosopis* (Algarrobo) in Argentina

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INTRODUCTION

It is a great pleasure to share my experiences with one of Argentina's great trees with you. Today in Argentina, *Prosopis* is known as algarrobo, but, in quechua, the language of the indigenous people, its name was "taco", which means "el arbol" or "the tree" (Bravo, 1977). My work in Argentina has been primarily with cactus (*Opuntia*) for fruit production. We have made excellent progress with cactus fruit production with more than 500 ha planted in the last two years. Growing up and working in Argentina, I always had *Prosopis* around me. My interest in algarrobo is from its potential for integrated, sustainable economic development, rather than any particular scientific discipline. I was fortunate enough to have been involved in a major *Prosopis* workshop in Argentina in July 1995 that brought scientists, development people, and algarrobo furniture builders together. Information resulting from this workshop will be used to provide an overview of the social and economic status of algarrobo in Argentina. My colleague, Mariano Cony, a geneticist, will illustrate the genetic diversity of *Prosopis* in Argentina. Because of the vast arid and semiarid land with great ecologic and geographic diversity, there is great genetic variability in this *Prosopis* genus.

Prosopis has a rich history of uses in Argentina. The ancient inhabitants had a special appreciation for *Prosopis* as evidenced by the use of a simple word that was reserved only for the algarrobo tree. When the Spaniards arrived in America, there were extensive algarrobo forests. Historians have noted that the fruits, picked up and stored together with maize, became the daily food that was kept in storage for use during the rest of the year. In their long travels, the men would restore their energy in the Indian villages that they found on their way. As Diego de Rojas (1453-1546) said:

> "en el camino no habia agua, porque era tierra seca de ella, sin haber otros arboles que algarrobos. Caminaron con toda la prisa que permitia el bosque de algarrobos que entorpecia el paso de cabalgaduras y cargueros, y desafiando la creciente falta de luz(In the road there was no water as this was an arid land with no trees other than algarrobos. They hurried as fast as the algarrobo forest allowed, which was a hindrance to the horses feet and the oxcarts in the dim light of the forests" (Prebisch, 1986)

The evolution of the utilization of algarrobo occurred in about six stages:

- In the first and longest stage, the algarrobo was mainly used as food for indigenous people. The impact of this utilization on the ecosystem was very low.

- The second stage occurred with the introduction of European cattle in the later 16th century. The pods of the algarrobo were a very important source of forage and the pods are still an important source of forage today. The introduction of cattle lead to the general degradation of the algarrobo due to fires in the ecosystem that were created by the cattlemen to improve the grass production and quality of the land.

- In the railroad construction stage, that lasted until the First World War, the trees were used for railway ties and for fuel for the locomotives, thus increasing the demand for *Prosopis*.

The main railroad centers were built in Monte Coman in Mendoza, Patquia in Llanos de la Rioja, Chumbicha in Catamarca in the Zone del Rio Dulce of Santiago del Estero, etc. These sites were abandoned when the forests were depleted. An example of the type of devastation that occured from overharvest of algarrobos is shown in Figure 1. Fortunately, as can also be seen in Figure 1, young algarrobos are beginning to occupy the drainage channels, which should begin to slow the erosion.

- With the continuing increase of population came an increase in the use of algarrobo for firewood and charcoal (Roig, 1992). This demand lead to an irrational use of the forest. About 1940, with the increased use of hydrocarbons for fuel (first kerosene then natural gas), the use of algarrobo for fuelwood declined.

- While crude furniture for the ranch has been made from algarrobo for centuries, there has been a recent interest in fine furniture fabrication from algarrobo as described in more detail below. With regard to harvest of *Prosopis alba*, Burkart (1976) remarked "Trees with straight trunks 8 to 10 m tall occur, but these are becoming extremely rare, from being cut in preference to shorter ones. Thus, a negative artificial selection is taking place that should be counteracted by genetic improvement of the best lines in experimental plots".

- And last, a broad-based reawakening of interest in algarrobo has occurred in Argentina. This revived interest in the sustainable use of algarrobo has given rise to new taxonomic, biological, ecological studies as well as development of seed banks, forestry trials, genetic improvement programs and utilization projects.

GEOGRAPHIC SITUATION

The genus *Prosopis* in Argentina is widely distributed. Roig (1993) has classified the *Prosopis* distribution into the following six major climatic regions of the country (Table 1):

- Chaqueño-Mesopotamico, with subtropical trees and without a dry season

- Chaqueño-xerico with dominant trees, and few shrubs, subtropical climate but with dry season

- Pampeano with mild climate and least discernible seasons, with rainfalls around 600 mm

- Preandino in hills and valleys, xeric with a wide variation of temperatures

- Monte, predominantly shrubs in semiarid to arid climate and continental climate

- Patagonico with only shrubs, cold climate and frequent freezing of the soil.

In some very arid (<350 mm/yr) regions of northwestern Argentina, *Prosopis* occurs in areas that receive runoff between mountain chains. One such example is the Salar de Pipianco, located west of the city of Catamarca (Figure 2). Near the center of this salar, where the water table is close to the surface, large algarrobos, principally *P. chilensis* and *P. flexuosa* can be found (Figure 3).

SOCIAL ASPECTS

The gathering of fruits in the fields, was and still is, one of the most important activities in the life of the Indians in some regions of Argentina (Rusconi, 1961). Even today, algarrobos are left in cultivated fields as illustrated by this *Prosopis alba* being grown in a tobbaco field in Salta (Figure 4). Where there were fields of algarrobos near Indian settlements, each village was the owner of one of the algarrobo groves. Occasionally, there were arguments between the owners about the use of the trees. The

disputes between owners of algarrobo groves were resolved with government rules in the Tucuman region as early as 1576 (Rusconi, 1961).

Today, many of the people and Indian cultures in the north of Argentina [los Pilagas, Wichis (matacos)] (Alvarsson, 1988) use the pods. They eat them fresh and store them in a granary for use later in the dry season. The indigenous people also use the wood for carving, toolmaking, and as fuelwood.

ALGARROBA FLOUR

The main use for the fruits of algarrobo has been for flour production to make loaves of algarrobo (patay) (Figure 5) in order to store the value of the pods for a long time. This is necessary because, normally, the pods ripen and fall quickly; the time for use is very short (a month). (Burkart, 1952). Patay is not cooked, but is only a coarsely ground flour from the entire pod. Due to the very high sugar content of the pods (30S40%), this flour is also very high in sugar and thus hardens after the moistened flour is pressed into cakes. The most commonly used species to make patay are *P. alba*, *P. nigra* and *P. flexuosa*, and in less quantity *P. elata*, *P. ruscifolia*, *P. vinalillo* (Arenas, 1981). Burkart (1952) explains the process to make patay and gives details of its food value. Patay prepared in the traditional manner is very coarsely ground and not very attractive to contemporary buyers. However, this author finds the flavor very pleasing and thinks that algarrobo pods could be developed into highly marketable products by contemporary chefs and culinary professionals. Currently, the Mendoza government has approved a research project to supply public hospitals and school dining rooms with a food made out of concentrated grape juice and algarrobo flour. This program would produce one million portions per semester with a cost reduction of 50% compared to the normal supply made from corn or wheat flour, eggs, and cane sugar. The algarrobo product would have the additional advantage of using local byproducts from the wine industry, which is the most important industry in Mendoza Province (Mariano Cony, 1996 pers. comm.).

ALGARROBO PODS IN BEVERAGE PRODUCTION

Another important use of algarrobo pods is beverage production. Chicha or aloja is a drink made from the fermentation of the pods in water. It is flavorful and has a high alcohol content. A great variety of species are used to make the drink. Favorites are *Prosopis alba* and *P. chilensis* (Burkart, 1952), *P. ruscifolia* (Martinez Crovetto, 1964), *P. hassleri* and *P. torquata* (Ragonese y Martinez Crovetto, 1947), *P. elata*, and *P. vinalillo* (Arenas,1981). Añapa is another drink made of ground pods of algarroba in cold water. It is a fresh sweet beverage. The same species used to make Anapa is used to make Chicha.

ALGARROBO COFFEE

Cafe de algarrobo is produced from toasted and ground pods. Local people believe it to have medicinal value (Ochoa unpub. obs.), and it is free of caffeine. Different species of *Prosopis* are used to make cafe de algarrobo.

FORAGE

The semiarid Chaco region of Argentina, Bolivia, and Paraguay has more than 2,000,000 head of cattle, a similar amount of sheep and goats, and around 300,000 horses (Saravia Toledo,1990). Algarrobo is a very important forage supply for these livestock. An example of goats being hand fed *Prosopis alba* pods is shown in Figure 6.

The shift in the use of algarrobo from human food to forage has resulted in the unsustainable use of pastures. The importance of algarrobo as forage lies in its quality, it is high in protein (15S25%) and energy (in pods)(Karlin, 1983). The fruit is very well appreciated, but the leaves, at least of black algarrobo (*P. flexuosa* and *P. nigra*), are not palatable to livestock. In our country there is only general knowledge about individual tree pod production. Karlin and Diaz (1984) estimated pod yield per adult tree to be 5 to 100 kg or 50 to 10,000 kg of pods per hectare. These yields vary depending to the region, species, year, and plant density (Karlin and Diaz, 1984).

Forage yield normally occurs in summer, i.e., from the end of December to February. At this time, the fruits ripen, fall, and are eaten by wild and domestic animals. To improve the use of the pods, it is necessary to harvest and store them so they will be available in the season of shortage of forage supplies. Today, this is done in northwestern Argentina (Karlin, 1979), where the fruit is manually gathered and stored on elevated platforms. These procedures are possible only in low-rainfall areas. In the province of Salta, 30% of the diet of goats is ground pods (Carlos Lewis pers.com.1995). Ground pods are rich in protein and carbohydrates and have been reported to have equivalent digestibility to alfalfa (Felker, 1979). A major drawback to the use of algarrobo pods for forage is the wide variability of fruit production from year to year due to factors such as rainfall, wind, and late frost.

MEDICINAL USE

Many documents state the medical uses of *Prosopis* (Arenas, 1981; Munoz et al., 1981; Pena, 1901). For example, the resin (gum exudate from the bark) of *P. chilensis* in small quantities is used to rinse the mouth and fix the teeth (Munoz et al., 1981). *P. strombulifera* pods are chewed to calm toothache and swollen gums. *P. kuntzei* pods have been used to alleviate pain from toothaches (Arenas, 1981). The leaves of *P. ruscifolia* have been used as popular medicine to heal sight problems, and is still used by the inhabitants of those regions for this purpose. According to Parodi (1981), a noncrystalized, nitrogen alkaloid with a sour, astringent taste is a popular medicine for the eyes (Hieronymus, 1882; Ragonese and Martinez-Crovetto, 1947). The leaves of *P. strombulifera* have been used as a diuretic (Munoz, et al.,1981). Remarkable diuretic effects have also been reported from a fermented infusion of the seeds of *P. chilensis* (Munoz, et al.,1981) The unripe fruits of *P.* sp. (sub *P. dulcis*) are astringent and have been used to treat dysentery (Pena, 1901).

FUEL

Firewood and charcoal have been considered by the government and R&D advisors as renewable resources. Nevertheless, the high rate of extraction has exceeded the regeneration rate, leading to substantial deforestation. Therefore, the designation “renewable” for firewood and charcoal is dubious. In northwestern Argentina, algarrobo is a major source of fuel for marginal poor people who constitute 15% of Argentina's population (Velez, 1992). Here we must add that the energy conversion efficiency from fuelwood to charcoal is very low due to the crude rural techniques that require 5 kg of wood per kg of charcoal produced.

BUILDING

Prosopis has been an important source of building materials, such as beams, frames, pillars, doors, and windows for rural houses and sheds. Keels of ships used in our Parana and Paraguay rivers were also made out of algarrobo wood (Dobrishoffer, 1783). In addition, artisanal looms made of *Prosopis* wood are still used. (Michieli,1984).

In the arid regions of South America, *Prosopis* wood has had multiple uses. For example, *P. alba* and *P. kuntzei* have been used for tobacco pipes and the thorns of *P. ruscifolia* for tattooing (Martinez-Crovetto, 1964). *P. caldenia* was used as pavement in Buenos Aires streets.

One of the problems in marketing *Prosopis* wood is the lack of standardization of its qualities. Today, it is sold by weight; the price depends on the condition of the logs. The price range is US$70-90 per ton, and is used mainly for furniture. Only the best stems are harvested. The lesser quality stems and large branches are left in the fields as waste.

Inexpensive, simply constructed algarrobo furniture has been widely used for durable, utilitarian purposes, such as high-use restaurant settings (Ochoa, unpub. obs.). Algarrobo has also been widely used for parquet floors throughout Argentina. However, it has been only recently that fine algarrobo furniture suitable for use in corporate offices and elegant homes has been made. Figure 7 illustrates the excellent quality furniture made by the Fioramonte furniture company in Santiago del Estero. Another company that produces excellent furniture is Tulio Riva in the cities of Cordoba and Carlos Paz.

The low radial (2.1%) and tangential (2.8%) shrinkages of *Prosopis alba* (Tortorelli, 1956) are lower than the rosewoods, teak, mahogany, walnut, and oak (Chudnoff, 1984) and indicate greater dimensional stability than these other woods. When priced competitively with these other luxury woods at US$450/cubic meter, clearly, *Prosopis* lumber is one of the most valuable products from arid lands. The best return is for the fine wood used in furniture (Felker, 1991). The extraordinary value of the algarrobo lumber is not yet widely known in the furniture industry, a circumstance that must be changed.

Research on parquet flooring from *Prosopis* (Figure 8) found that it can be produced economically from small, short logs using special equipment (Martinez, 1991). This process is also suitable for use in salvaging the wood of *Prosopis nigra* that is devastated by large wood-boring insects (*Criodion augustatum*) (Fiorentino and de Medina, 1987; Fiorentino and Bellomo, 1995).

ROADSIDE FORESTATION

Roadside planting is another possibility for *Prosopis* because this tree requires little care, both in initial establishment and maintenance of established trees. As *Prosopis* naturally grows on the roadsides in the arid Chaco regions, one could think of imitating nature, to establish roadside wood and fruit production entities. Other crops such as alfalfa are already produced in Santiago del Estero in this manner (Ochoa, L.H., 1995 pers. comm.).

DUNE STABILIZATION

There are major shifting dune areas that are approaching villages and economic units that must be stabilized and stopped. Examples include the arid lands such as Fiambala and Salar de Pipanaco in the Province of Catamarca and Cafayate in the Province of Salta. Figure 9 shows an example of *Prosopis* halting sand dune movement toward the vineyards in Cafayate, which are a major economic unit in this region. Many of these dune areas were former algarrobo forests that had been harvested. An important role for the *Prosopis* and *Opuntia* Associations could be to establish plantations as a fence to arrest the progress of the dunes. *Opuntias* provide excellent architectural characteristics and

have a high percentage of rooting (Ochoa, 1992), and *Prosopis*, according Hueck (1950), is the best species for the same purpose.

APICULTURE

Algarrobo is very important in beekeeping because it is widely distributed and flowers when there are almost no other flowers in the fields. Thus, bees can start their work earlier, significantly increasing honey production. An additional advantage is insect pollination, which enhances production of many fruit trees. Records in India state that an adult algarrobo tree can produce 1 kilo of honey (Burkart 1952).

CONCLUSIONS

The natural *Prosopis* forests in our country were exploited, without exception, since the beginning of the century. Exotic forests were studied more intensly, probably due to the economic possibility of an early return on the investment. Besides, it is often the case that people do not take special care of those resources that are naturally given, among which, *Prosopis* is a good example.

On the other hand, the lack of consistent, well-defined national policy and legislation for this genus has had the following consequences: lack of clarity in the objectives, poor coordination in research, and limited exchange of experiences. During the *Prosopis* workshop held last year in Santiago del Estero, the following proposals were suggested: creation of data banks using the Internet; establishment of genetic improvement of the genus *Prosopis* with enough flexibility to adequately address the diverse objectives for its improvement. Facing the insufficient trials in the management of native forests, it is suggested as necessary to concentrate on applied research in plantation forestry and the wood industry. A summary of the major research areas of emphasis in Argentina is provided in Table 2.

An elevated awareness must be spread in the society about the intrinsic value of *Prosopis* in all aspects: economic, social, and ecological. A strong recommendation to the government was the urgency of promoting and obtaining financial support for forest management and reforestation of this species.

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Table 1. Phytogeographic Distribution of *Prosopis* in Argentina

Group I Chaqueño-mesopotamico

Trees:	*Prosopis hassleri, P. hassleri* var. *nigroides, P. fiebrigii, P.alba, P. affinis, P. kuntzei, P. nigra* var. *longispina, P. alba* var. *panta*

Group II Chaqueño-Xerico

Small trees:	*P. nigra, P. ruscifolia, P. chilensis*
Trees:	*P. pugionata, P. vinalillo, P. torquata, P. abbreviata*
Shrubs:	*P. elata, P. sericantha, P. reptans, P. campestris*

Group III Pampeano

Trees:	*P. caldenia, P. flexuosa*
Shrubs:	*P. humilis*

Group IV Preandino

Trees:	*P. laevigata* var. *andicola, P. ferox*
Shrubs:	*P. humilis*

Group V Monte

Trees:	*P. flexuosa, P. chilensis, P. chilensis* var. *catamarcana, P. chilensis* var. *riojana*
Small Trees:	*P. alpataco* var. *lamaro*
Shrubs:	*P. flexuosa* var. *depressa, P. strombulifera, P. strombulifera P. ruiziana, P. alpataco, P. argentina*

Group VI Patagonico

Shrubs:	*P. denudans, P. denudans* var. *patagonica, P. denudans* var. *P. stenocarpa, P. ruiz lealii, P. catellanosii*

**Table 2. *Prosopis* Research and Development Projects
Grouped According to Research Area, Province, and Species**

SUBJECT	PROVINCES	SPECIES
Agrosilvopastoril Systems	E.Rios, Cordoba, Sgo del Estero, Salta	
Geneology	Cordoba, Tucuman, Mendoza, Jujuy	*chilensis, alba, flexuosa*
Ecophysiology	Mendoza, Cordoba, Sgo.del Estero, Jujuy	*alpataco, flexuosa, chilensis, strombulifera*
Wood Technology	Santiago del Estero	all
Wood and Seed Diseases	Sgo. del Estero, Cordoba, Jujuy	all
Wood Anatomy	Sgo. del Estero, Buenos Aires	all
Bioecology	Cordoba, Mendoza, Buenos Aires	*alba* var. *panta,nigra, chilensis, torcuata, elata, flexuosa*
Isoenzyme Studies	Cordoba, Buenos Aires, Jujuy	all
Taxonomy	Buenos Aires, Sgo. del Estero, Mendoza	all
Forestry	Jujuy, Cordoba, Mendoza, Chaco, Sgo. del Estero, Tucuman, Salta, La Rioja	*alba* var. *panta, chilensis, nigra, flexuosa*
Stand management	Santiago del Estero, Salta, Cordoba	
Germplasm banks	Sgo. del Estero, Cordoba, Mendoza	
Forage Quality	Cordoba, Tucuman, Salta, Jujuy	*alba* var. *panta, chilensis, nigra, alba*

Figure 1. An Algarrobo Forest That Was Overexploited for Railroad Ties and Charcoal

Figure 2. View Toward the Center of the Salar de Pipanico

Figure 3. Large *Prosopis flexuosa* Near the Center of Salar de Pipanaco

Figure 4. ***Prosopis alba*** **Intercropped With Tobacco Near Salta**

Figure 5. Patay, the Flour of ***Prosopis*** **Pods Sold for Human Food**

Figure 6. Goats Being Hand Fed *Prosopis alba* Pods, as is Common in Northwestern Argentina

Figure 7. Tables and Chairs Manufactured of Prosopis by Fioramonte of Santiago del Estero

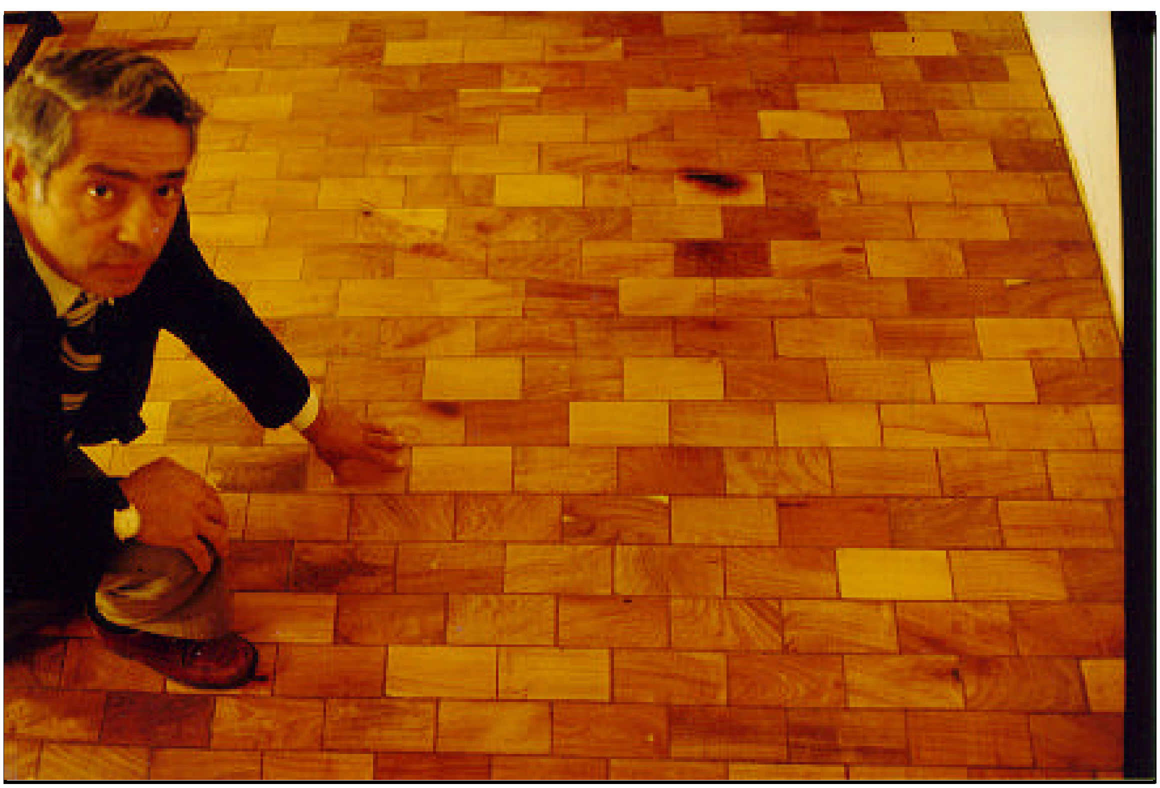

Figure 8. *Prosopis* Parquet Flooring in Cordoba, Argentina

Figure 9. Natural *Prosopis* Forest That Has Halted the Sand Dunes From Advancing on Prime Vinyards Near Cafayate

Genetic Potential of *Prosopis* in Argentina for its Use in Other Countries

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Intragenus Diversity of *Prosopis* in Argentina

The Republic of Argentina (Figure 1), at the southern tip of South America, is 4,025,695 km^2 (2,795,695 km^2 without the Argentina Antarctic) in area, reaching from 21° S latitude to 55° S latitude in the continent and to the Pole, in Antarctica (Cabrera, 1976).

Because of its great latitudinal expanse, which ensures a variety of climates, Argentina has 28 of the 44 species of *Prosopis* known in the world. These are distributed between the 22° S and 48° S, either in the plains or up to 3000 m above sea level, and from zones with 80 mm annual rainfall to zones with 1400 mm of rain per year (Roig, 1993). Even though the genus occurs over most of Argentina, with the exception of Misiones and south of Patagonia, the majority of the species grow in the arid and semiarid zones that are 70% of the country's surface. Sixteen of the species are trees and the others are shrubs, although some arboreal species can occur as a shrub. In the chaqueña zone (mesopotamica and xerica), phytogeographic region of Argentina (Figure 2), the trees of the *Prosopis* genus (*P. alba, P. nigra, P. hassleri, P. ruscifolia, etc.)* prevail over shrubs, which are rare. In contrast, the number of arboreal species diminishes in the Pampeana and Preandina zones. In the Monte zone there is a clear domain of shrubs, and trees disappear in the Patagonica zone (Roig, 1993). The distribution of some of the most important species in the country are shown in Figures 3, 4, 5, 6, and 7.

Intraspecific Diversity

In addition to the great diversity of species naturally growing in Argentina, there exists great intraspecific morphologic variability especially in those species that have wide distribution in the country. Despite the enormous intraspecific genetic variation for *Prosopis*, probably attributable to the great edaphic and climatic varibility in Argentina, there have been few studies to develop these genetic resources. In addition, the fact that several species of the *Algarobia* section (Burkart, 1976), such as *P. chilensis, P. flexuosa* (Simpson, 1977; Masuelli & Balboa, 1987) and *P. nigra* (Palacios & Bravo, 1981) are not self-compatible and, therefore, of obligated outcrossing, would guarantee a high recombination and wide genetic variation in the natural populations (Hunziker et al., 1986).

Saidman and Vilardi (1987) while studying isoenzymes with seven enzymatic systems in populations of seven native species of *Prosopis*, found an average percentage of loci polymorphic (P) of 45%, with maximum values of 50% for *P. flexuosa* and minimum of 38% for *P. ruscifolia*. These authors determined the heterozygosis mean values by locus and by individual (H) of 18%. These results, based on the study of 20 to 23 loci, demonstrated a high genetic variability in several of these species (mainly the arboreal species). In addition, isoenzymatic and chromatography of phenolic compounds studies demonstrated the existence of intraspecific hybrids (Hunziker et al., 1986), that, although present in low percentages, had pods with viable seeds. These previous studies, combined with the high morphologic variation, suggested that a selection program could be successful in spite of the considerable extinction of the "elite" trees undergone by most of the species belonging to this genus (Hunziker et al., 1986).

Morphologic and isoenzymatic studies recently done, more thoroughly, with different populations of *P. chilensis* and *P. flexuosa* in the arid Chaco, confirmed the existence of fertile genetically intermediate forms (hybrids), that could be morphologically identified (Verga, 1995).

Program for Conservation and Improvement of *Prosopis* Native Species in Argentina

Even though laboratory studies proved strong evidence to support the existence of intraspecific genetic variability, there were no field studies to confirm it. In 1990, supported by the IDRC, a program was developed in Argentina for "Conservation and Improvement of the native species of *Prosopis*" (Cony, 1993). Its short-term goal was to assess the existing variability in the growth and development traits within four of the most important arboreal species of this genus: *P. chilensis* and *P. flexuosa* in the phytogeographic province of the Monte (arid zone) and *P. alba* and *P. nigra* in the phytogeographic province of Chaco (semiarid and subhumid zone). The program had the following objectives:

- Identify genetic material areas (GMA) or sampling areas within the natural area of distribution of these species. (We presumed the GMAs would be sufficiently isolated by the orography in the mountainous valleys and by distance in the plains that the gametic exchange between areas would be restricted.)
- Select individuals within each area with the only criterion that they differed between them from a morphological viewpoint
- Obtain a germplasm collection from the GMAs and the individuals

Finally, the program completed the collection of three of these species, with the exception of *P. nigra*, having selected and harvested 84 *P. chilensis* trees in 9 GMAs, 86 *P. flexuosa* in 13 GMAs (Figure 8), and 57 *P. alba* in 8 GMAs (Figure 9). A portion of the collected seeds was conserved in refrigerated chambers, and the other portion was used to establish family-provenances trials. In Mendoza (Monte) work was done with *P. chilensis* and *P. flexuosa*, and in Santiago del Estero (Chaco), with *P. alba*.

Family-Provenance Trial in Mendoza

In 1991 and 1992, 84 families from *P. chilensis* and 86 from *P. flexuosa* trials were set up in the center of the Monte phytogeographic province. A randomized complete block design with five replicates was used. The families were planted in three-tree row plots. Thus, with 5 replications, 15 half-sib families from each family were evaluated. Spacing in the trials was 4 m x 4 m, with a single buffer row surrounding each trial. Because the water table stood at 3-m depth, the trees were watered monthly during the year, giving a total of 500 mm in addition to the rainfall (an average of 200 mm per year), until the roots reached the phreatic level. Afterwards, watering was discontinued.

The assessed traits were: height and basal diameter, branching, straightness, and thorniness, even though for the three last traits the results presented are only for *P. flexuosa.*

Data obtained were submitted to variance analysis and the means separated according to the multiple-comparison Duncan test. Restricted maximum-likelihood variance components were also estimated. In order to estimated the influence of the variation owed to the provenances effect and families within provenances, the proportion of each variation was calculated with respect to their sum.

Heritabilities at individual and family level for all the *P. flexuosa* traits, and height and basal diameter for *P. chilensis* were estimated using the following equations, according to Pires (1984):

$$H_i^2 = \frac{4V_f}{V_f + V_{Rf} + V_e}$$

$$H_F^2 = \frac{V_f}{\frac{V_e}{KR} + \frac{V_{Rf} + V_f}{K}}$$

where:

H_i^2	=	**heritability in narrow sense at individual level**
H_F^2	=	**heritability in narrow sense at family level**
V_f	=	**families variance**
V_{Rf}	=	**family x replication interaction variance**
V_e	=	**variance error**
K	=	**mean number of trees per plot**
R	=	**replication number**

Also, genetic and phenotypical correlations were estimated between all the *P. flexuosa* traits.

The trials after being established for 34 months for *P. flexuosa* and 42 months for *P. chilensis*, showed the existence of high variability for all traits studied, at the provenance level as well as at the family level within provenances.

For example, for the height trait, the *P. flexuosa* and *P. chilensis* trees that came from the northernmost parts, Bolsón de Fiambalá and Bolsón de Pipanaco, had greater growth, while those from the southernmost, Río Colorado-General Conesa and Llanos de Angaco-Lavalle, had the lowest growth (Tables 1 and 2). Similar results occur with basal diameter, although in the case of *P. flexuosa* there were provenances from intermediate latitudes with smaller diameters (Tables 3 and 4).

When analyzing the remaining traits for *P. flexuosa*, Río Colorado-General Conesa the southernmost provenance stands out again, as it has more branching and fewer straight trees. No provenance possessed low thorniness (Figure 10).

The families, in both species, did not always behave similar to the provenances. While the *P. chilensis* provenance from the Bolsón de Pipanaco has the greatest mean height, the 13 *P. chilensis* families within this provenance ranged in family rank for height from 1 to 75 (Table 6). Similarly, while the *P. flexuosa* provenance from the Bolsón de Pipanaco had the greatest mean height, the eight families within this provenance ranged in rank for height from 2 to 30 (Table 5). This dissimilar behavior of the families within the provenances was accounted for by the high proportion of intraprovenance genetic variations (Tables 7 and 8). This same phenomenon has been detected by Cony and Trione (1996a, 1996b) when evaluating the germination capacity of *P. flexuosa* and *P. chilensis* at low temperatures and low water potentials. Lopez, C. (1995, pers. com.) has observed very similar behavior in performance of progeny trials for *P. alba*.

In reafforestation programs of arid lands with multipurpose trees, the rapid production of aerial biomass is an important objective. If we take into account that the height as well as the basal diameter are directly proportional to the aerial biomass (Stewart et al., 1992), the provenances from Bolsón de

Fiambalá, for *P. flexuosa,* and from Bolsón de Pipanaco, for *P. chilensis,* would be recommended since they ranked first both in height or in basal diameter. This great variation found between families for all the assessed traits would diminish the risks of inbreeding, if reafforestation was done with only one provenance.

The heritabilities at family level were high for all the traits in both species, while for *P. flexuosa* the heritability at individual level for basal diameter and branching were low (Tables 9 and 10). The high values of heritability at individual level for height and thorniness in *P. flexuosa,* would permit genetic advances in the short term with use of mass selection programs for the tallest and least thorny plants. For other traits, the selection should be carried on at family level, because their values of family heritability increased in high proportion with respect to the individual level.

Even though there are clues of stability in the growth heritability traits (Solanki et al., 1992; Cony, unpublished data), there is a need for future evaluations before deciding the best improvement strategy to be followed.

For *P. flexuosa* high positive genetic and phenotypic correlations were found for height with basal diameter (Table 11). Thus, given the multistemmed and very thorny nature of this species, it seems reasonable to use only height as a selection criteria for aboveground biomass.

Conclusions and Perspectives

The results presently reached in Argentina about the genetics of different Prosopis species show the existence of high variability at all levels studied (genus, species, provenances, families, and individuals). This, added to the existence of interspecific hybrids that give more variability to the wild genetic pool, increases the probabilities for success to obtain improved germplasm of these species. Outstanding traits, like straightness, fast growth, lack of thorns, high biomass production, abundant pod production and resiliency to different causes of stress are available in the gene pool. When these genetic resources are combined with the best management techniques for rainfall catchment, drought avoidance, establishment methods under hydric deficit, successful vegetative propagation, and the choice of the right sites, reforestation programs with *Prosopis* species in different arid and semiarid zones of the world will have excellent probabilities for success.

Establishment of a national network of family-provenances trials of the most important species of *Prosopis* will permit us, in relatively short time frames, to assess this important native germplasm resource to be used in different arid and semiarid zones of the world.

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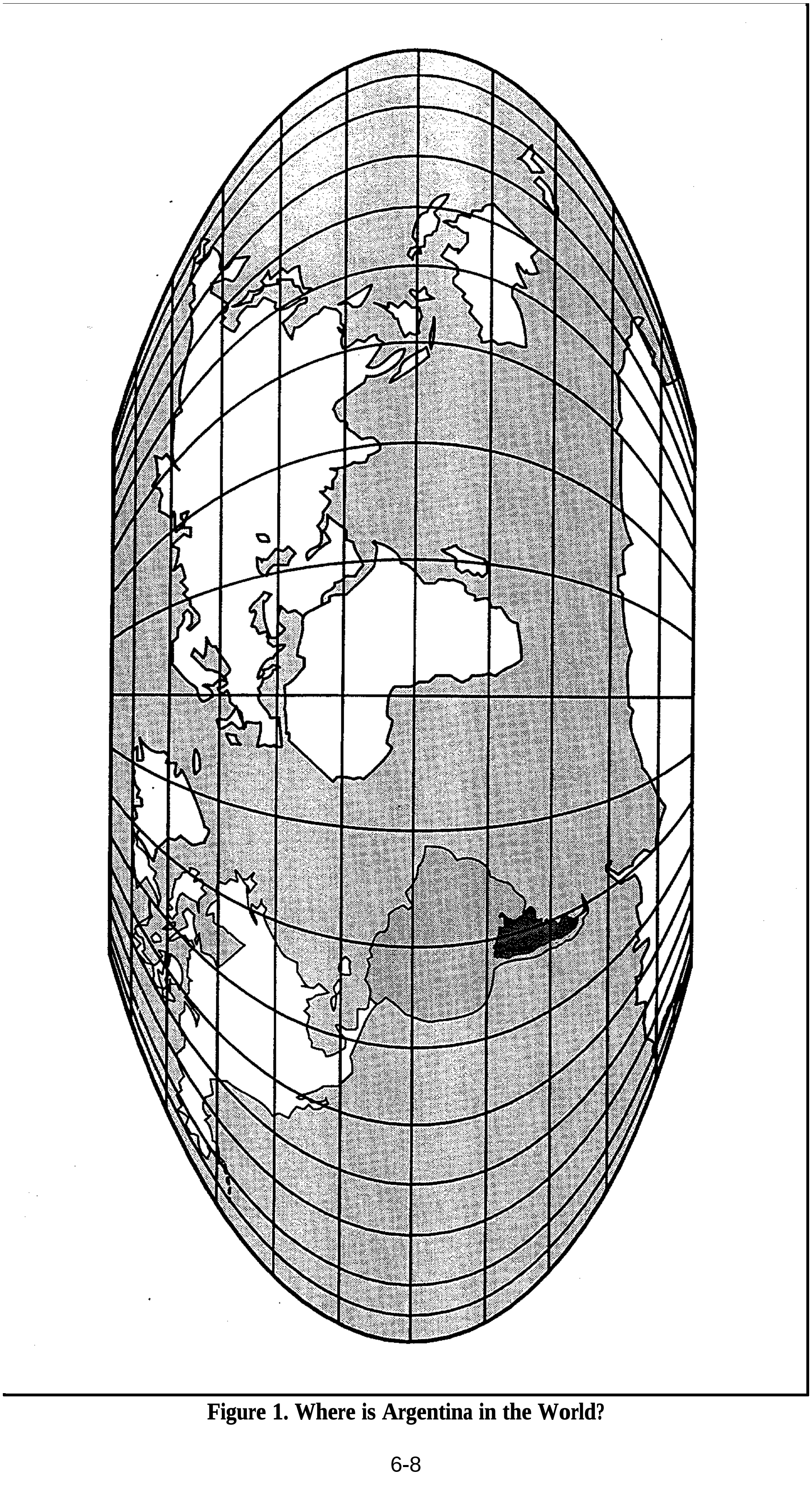

Figure 1. Where is Argentina in the World?

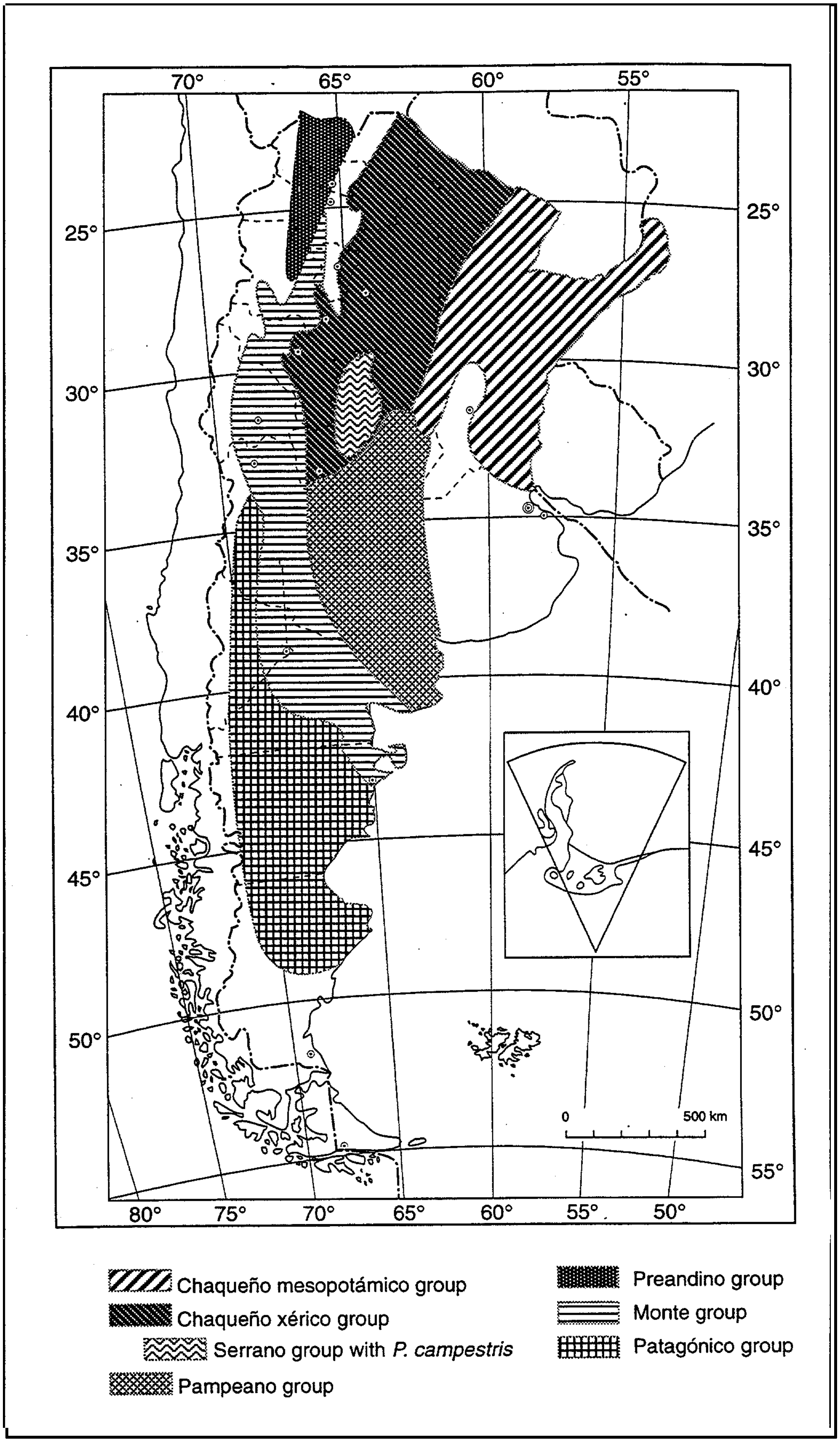

Figure 2. Argentinian *Prosopis* Grouping According to the Landscape

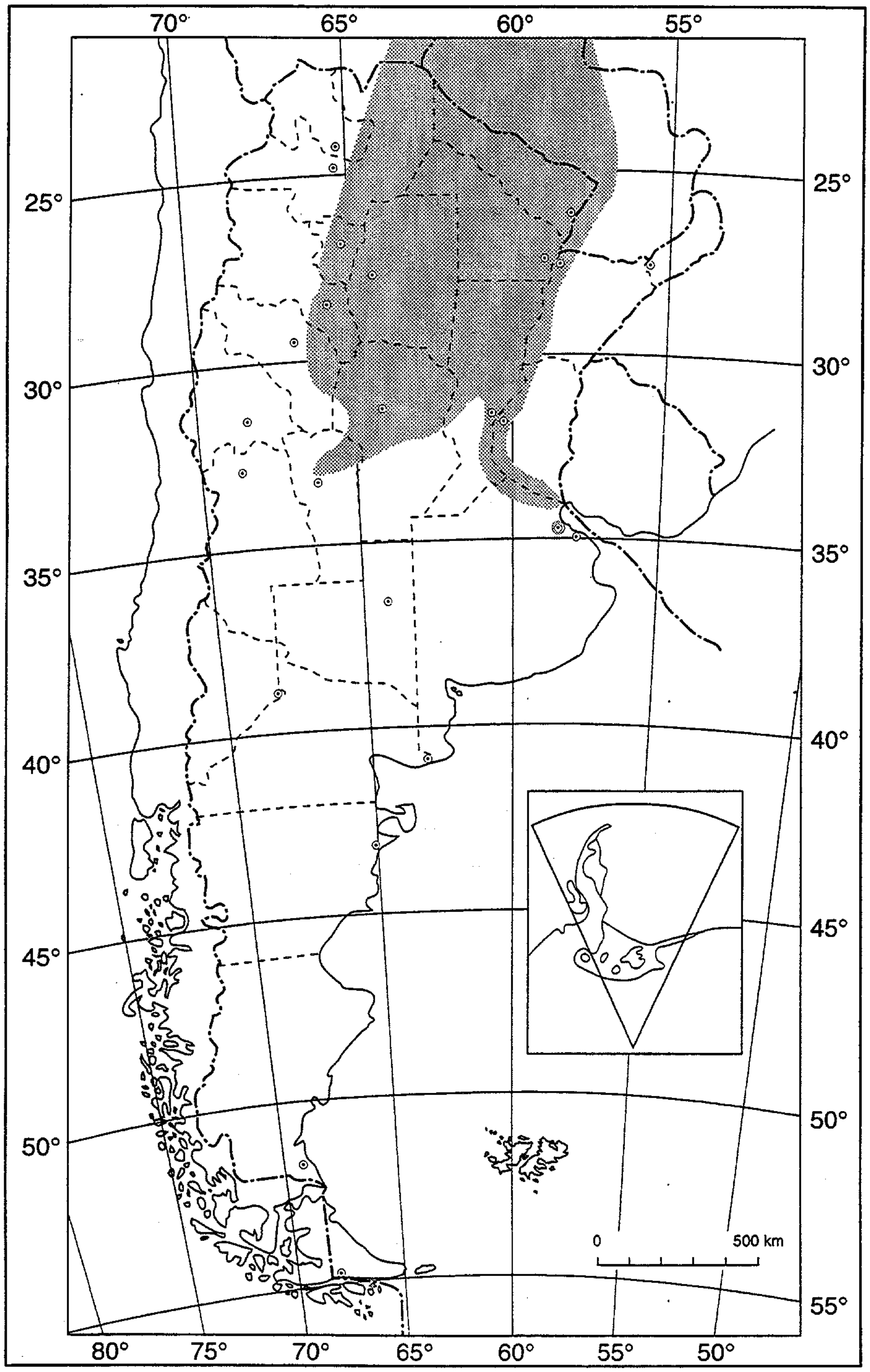

Figure 3. *Prosopis alba* Distribution in Argentina

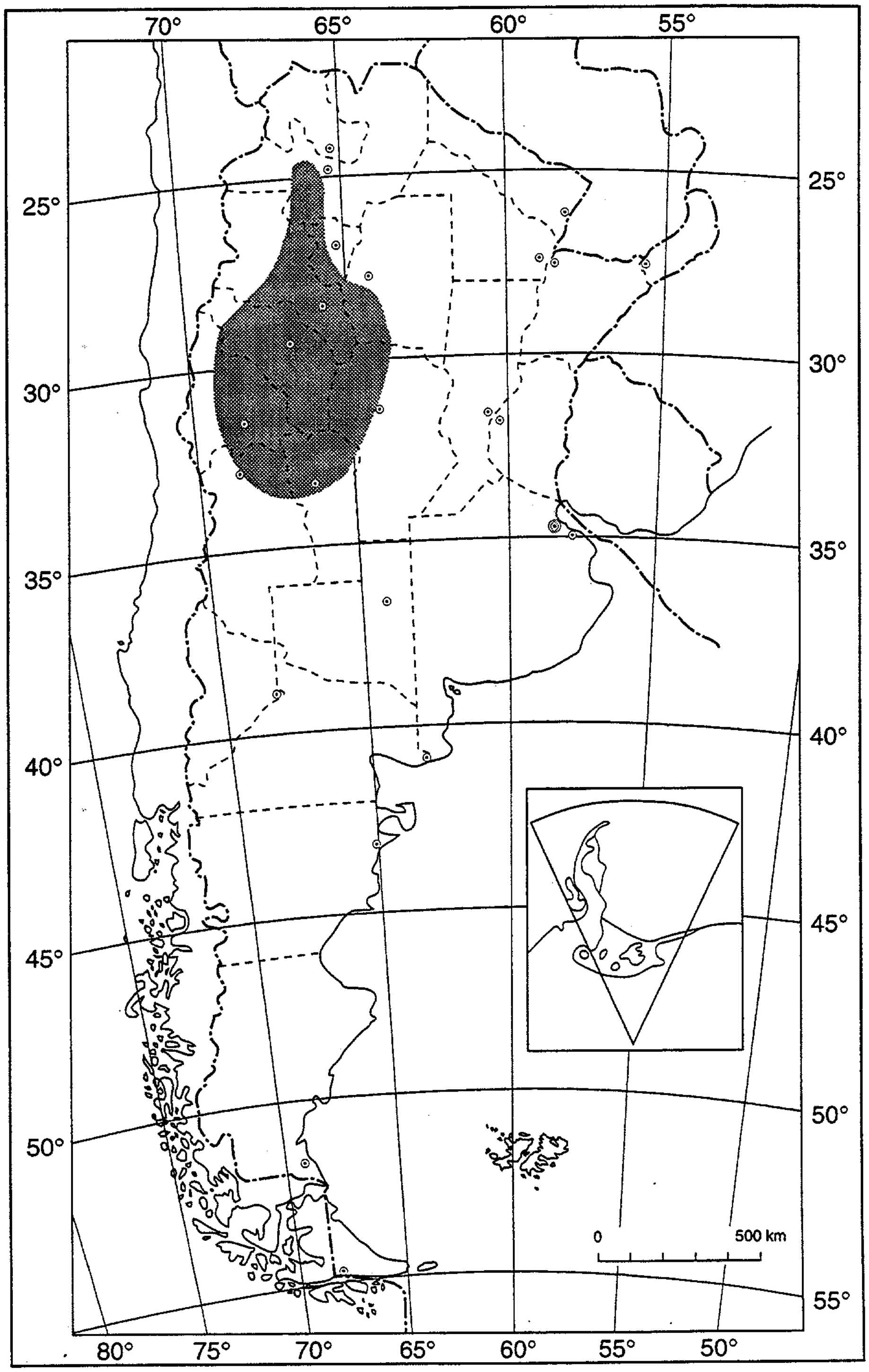

Figure 4. *Prosopis chilensis* Distribution in Argentina

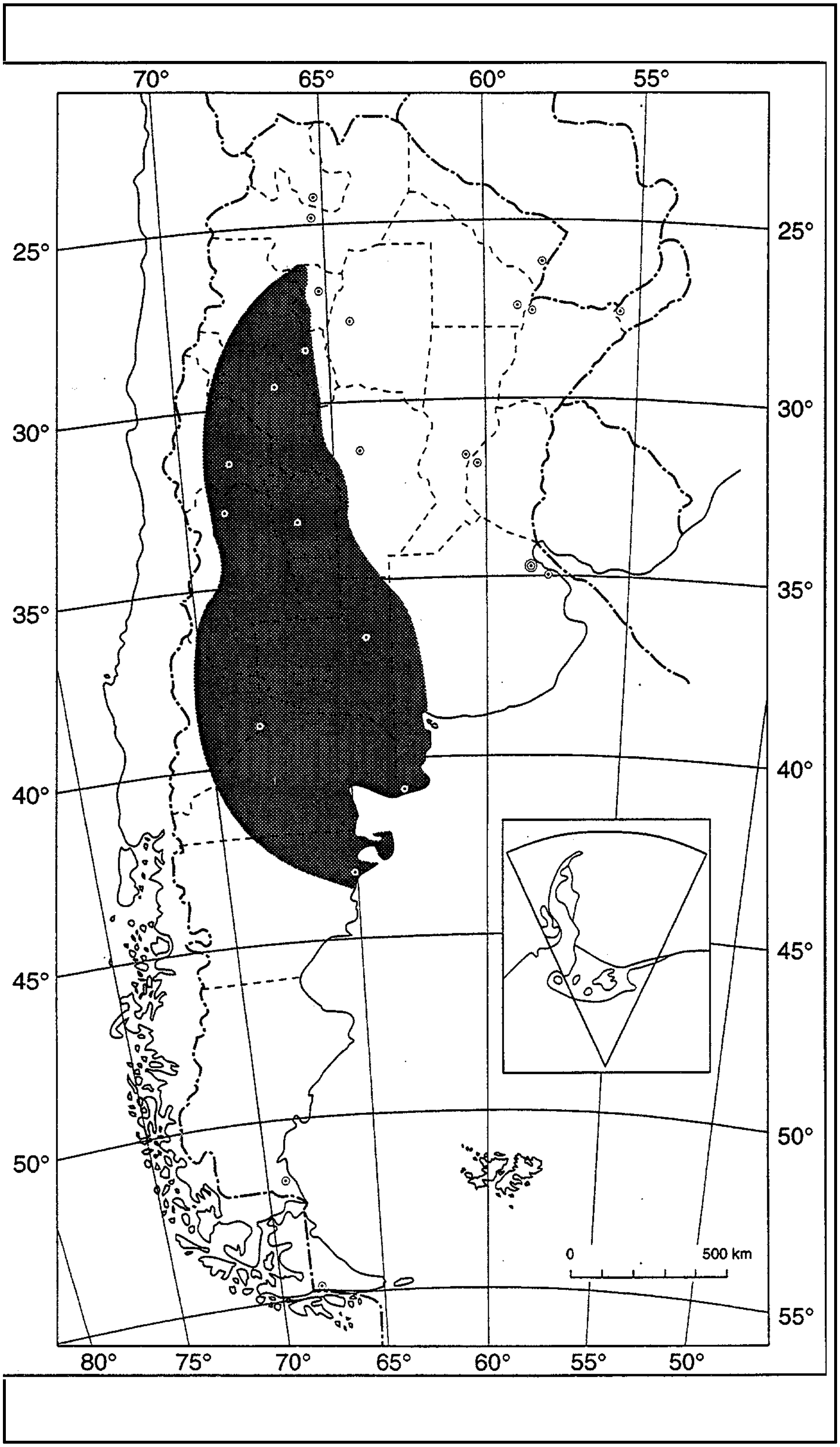

Figure 5. *Prosopis flexuosa* Distribution in Argentina

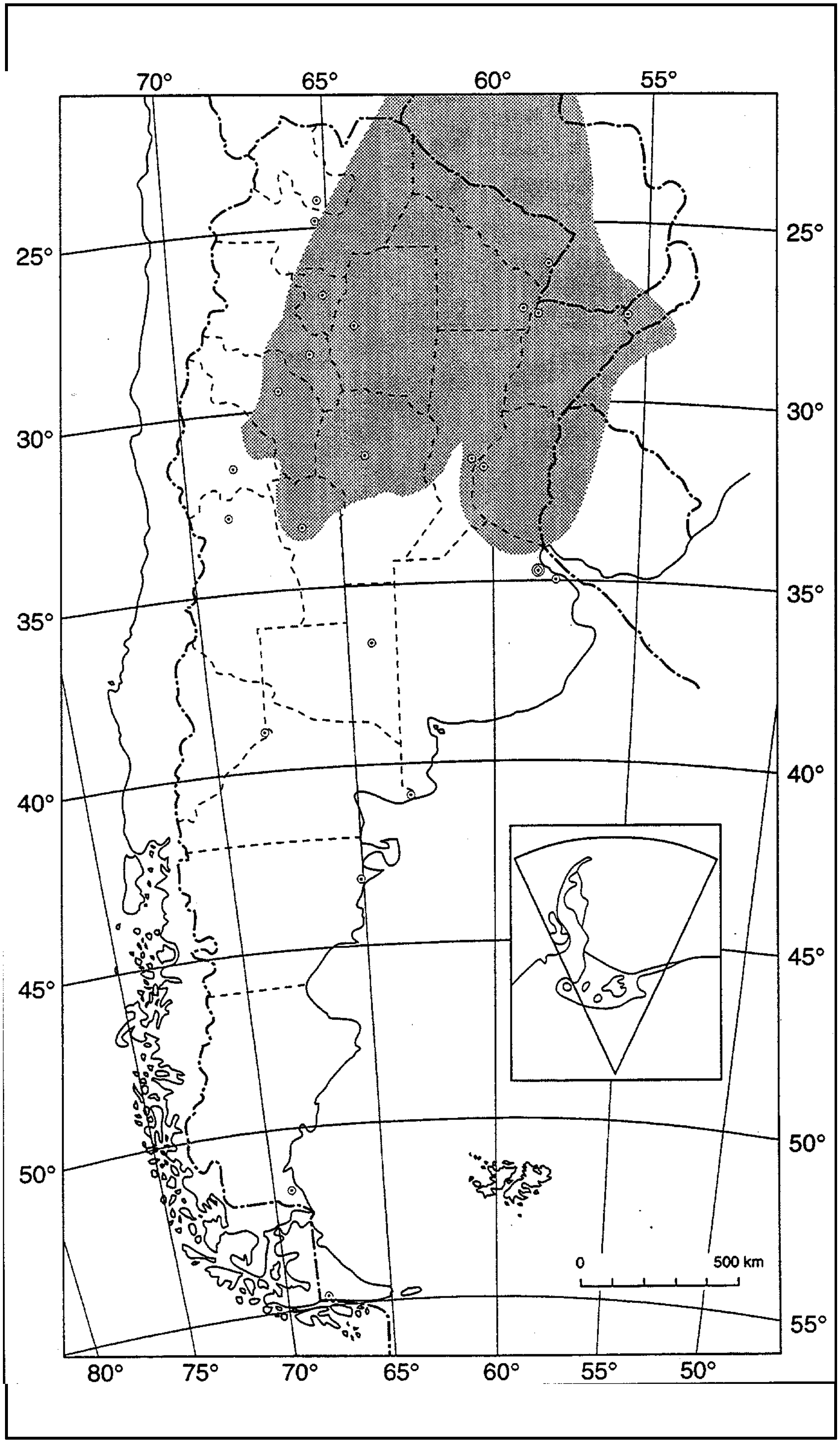

Figure 6. ***Prosopis nigra*** **Distribution in Argentina**

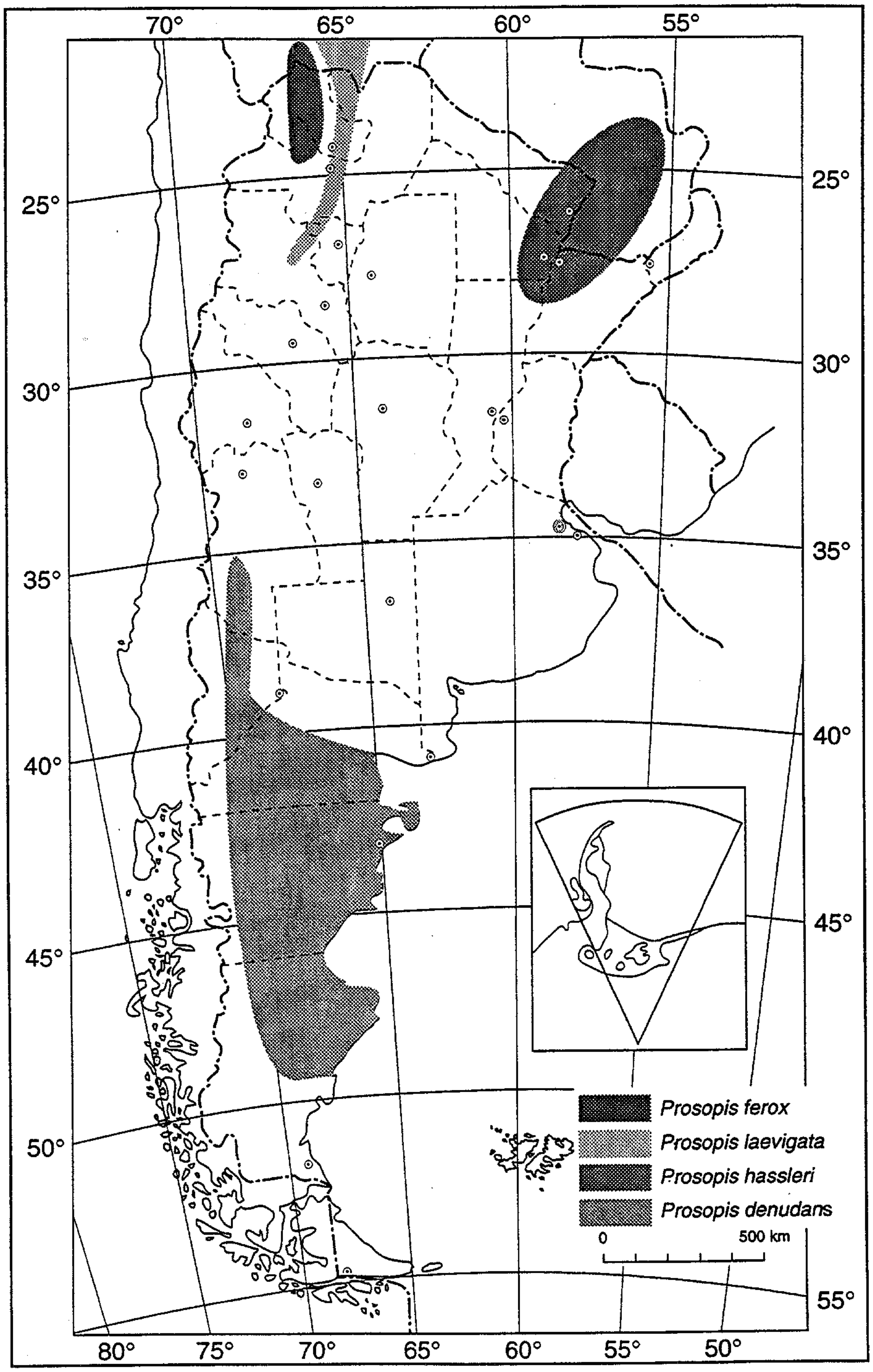

Figure 7. *Prosopis ferox, P. laevigata, P. hassleri,* and *P. denudans* Distribution in Argentina

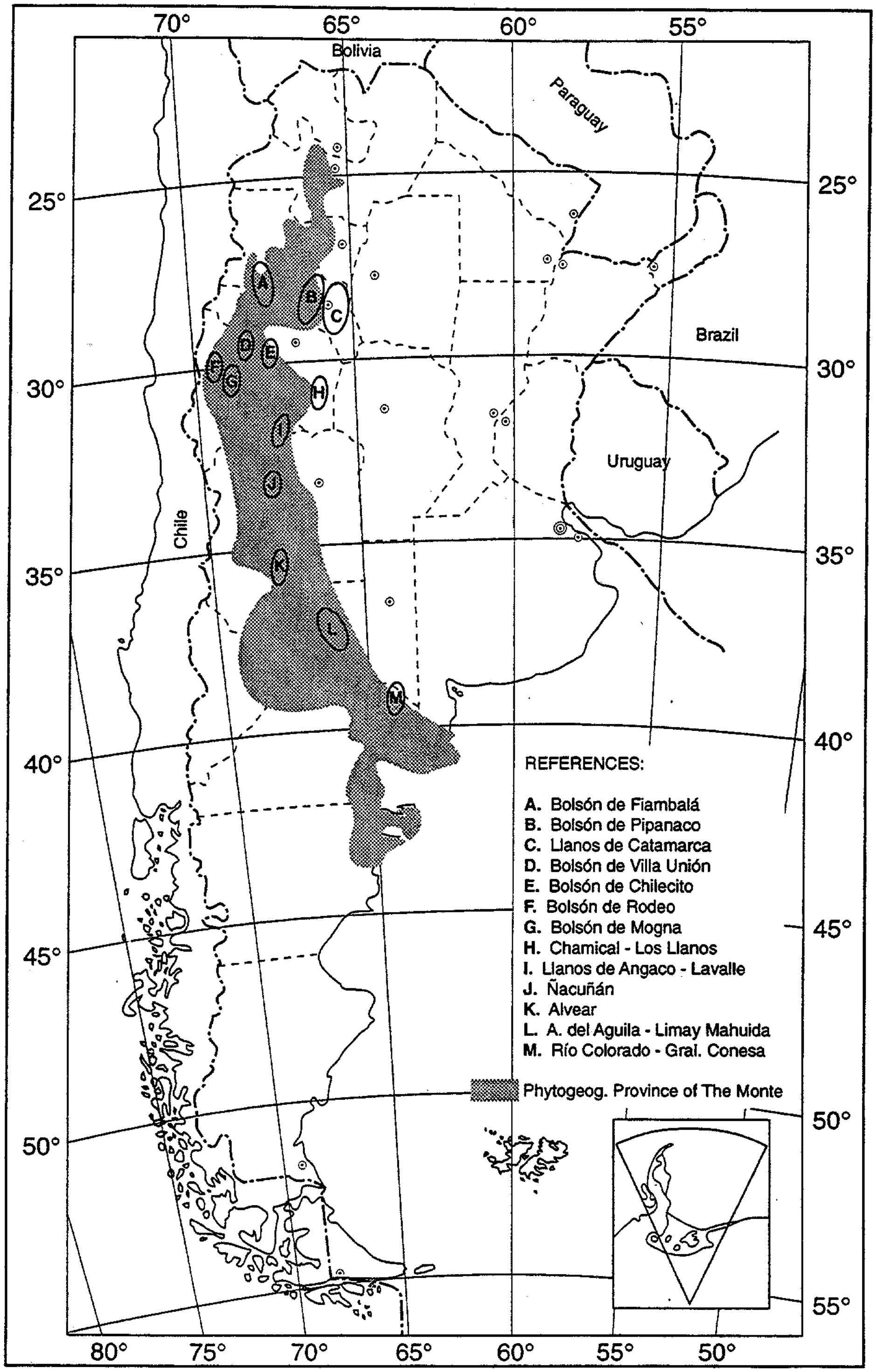

Figure 8. *Prosopis flexuosa* and *P. Chilensis* Genetic Material Areas in The Monte Phytogeographic Province

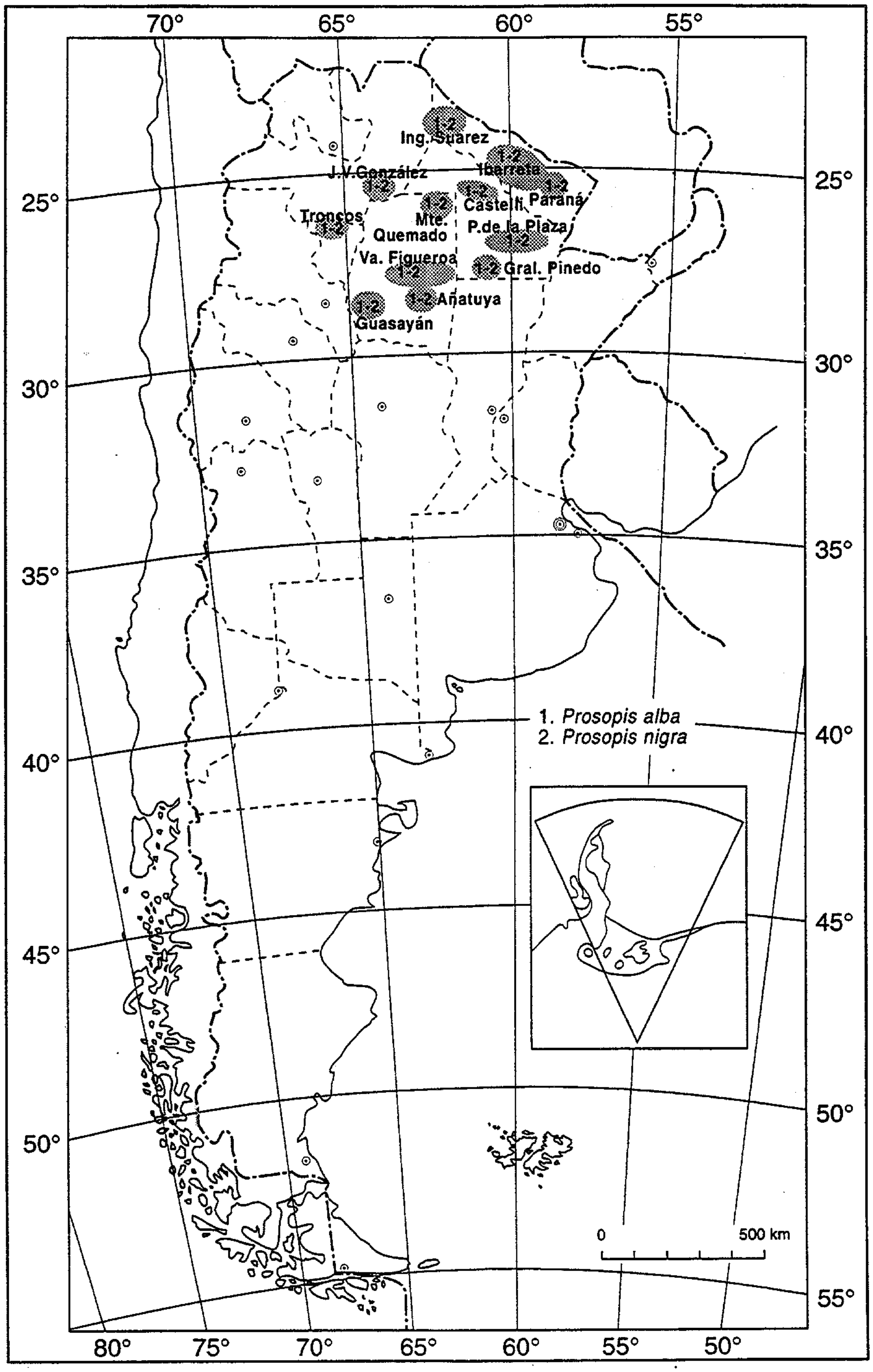

Figure 9. *Prosopis alba* and *P. nigra* Genetic Material Areas in the Chaco Phytogeographic Province

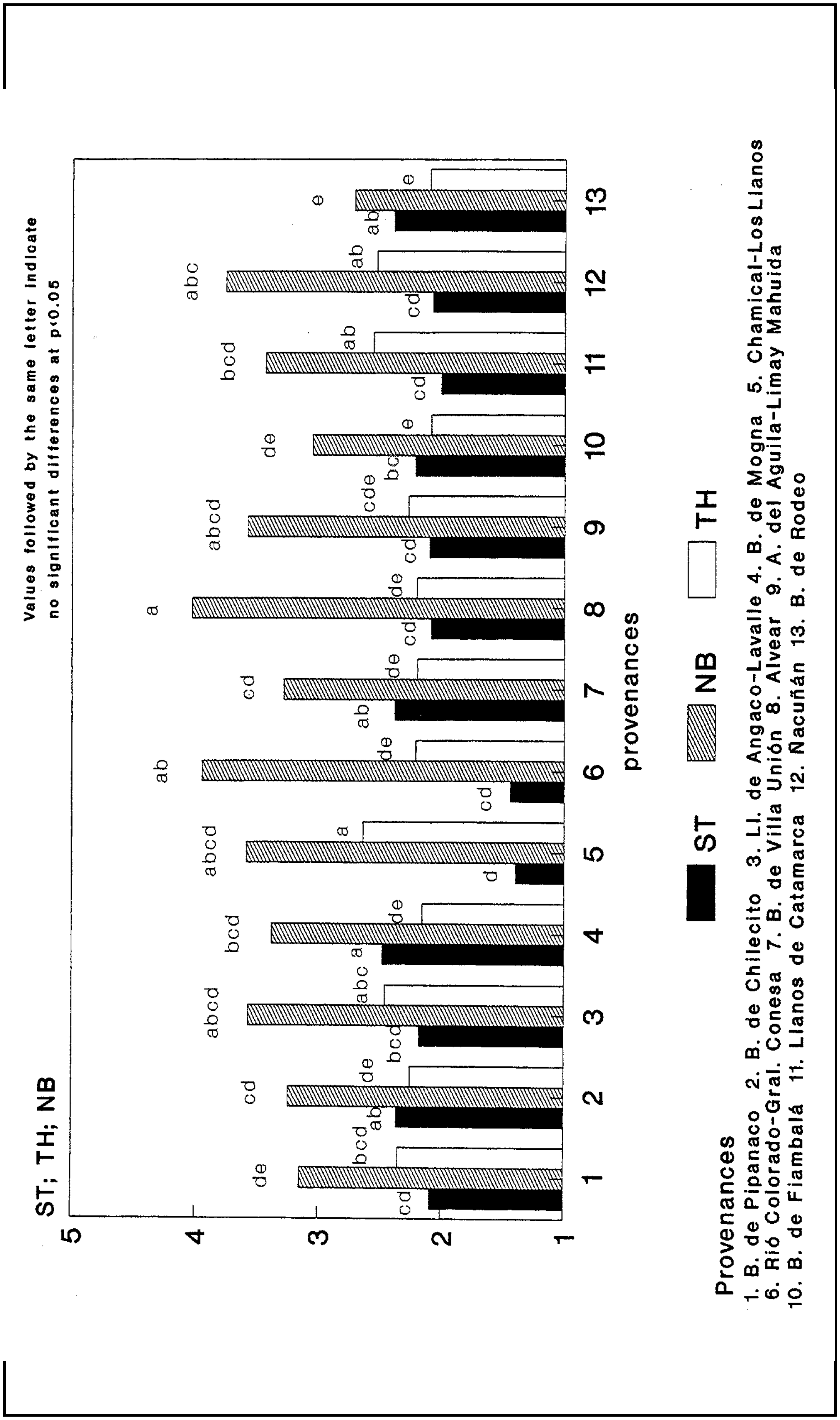

Figure 10. Straightness (ST), Number of Branches (NB), and Thorniness (TH) From Different *P. flexuosa* Provenances

Table 1. Ranking of Provenances for 34-Month Heights and Duncan Groupings in *Prosopis flexuosa*

Provenances	Mean Height (m)	Duncan Grouping*	Rank	Total Number of Families per Provenance
Bolsón de Fiambalá	1.23	a	1	6
Bolsón de Pipanaco	1.22	a	2	8
Bolsón de Mogna	1.07	b	3	12
Bolsón de V. Unión	1.06	b	4	5
Chamical-Llanos de La Rioja	1.03	bc	5	9
Llanos de Catamarca	1.02	bc	6	3
Bolsón de Chilecito	1.01	bcd	7	6
Llanos de Angaco-Lavalle	1.00	bcd	8	7
Alvear	0.94	bcde	9	5
Ñacuñán	0.93	bcde	10	5
A. Aguila-Limay Mahuida	0.89	cde	11	10
Bolsón de Rodeo	0.86	e	12	2
Río Colorado-Gral. Conesa	0.84	e	13	8

*** Values followed by the same letter indicated no significant differences at $p<0.05$.**

Table 2. Ranking of Provenances for 34-Month Basal Diameter and Duncan Groupings in *Prosopis flexuosa*

Provenance	Mean Basal Diameter (cm)	Duncan Grouping	Rank	Total Number of Families per Provenance
Bolsón de Fiambalá	1.40	a	1	6
Llanos de Catamarca	1.31	a	2	3
Chamical-Llanos de La Rioja	1.26	abc	3	9
Bolsón de Mogna	1.24	abcd	4	12
Alvear	1.19	bcde	5	5
Bolsón de Pipanaco	1.16	bcde	6	8
Llanos de Angaco-Lavalle	1.16	bcde	7	7
Ñacuñán	1.14	bcde	8	5
Bolsón de Villa Unión	1.08	cde	9	5
A. Aguila-Limay Mahuida	1.07	cde	10	10
Río Colorado-Gral. Conesa	1.07	cde	11	8
Bolsón de Chilecito	1.03	de	12	6
Bolsón de Rodeo	1.01	e	13	2

* Values followed by the same letter indicated no significant differences at $p<0.05$.

Table 3. Ranking of Provenances for 42-Month Heights and Duncan Groupings in *Prosopis chilensis*

Provenance	Mean Height (m)	Duncan Grouping*	Rank	Total Number of Families per Provenance
Bolsón de Pipanaco	1.83	a	1	13
Chamical-Llanos de La Rioja	1.76	ab	2	19
Bolsón de Fiambalá	1.68	ab	3	10
Bolsón de Rodeo	1.64	ab	4	1
Llanos de Catamarca	1.57	ab	5	9
Bolsón de Chilecito	1.53	ab	6	7
Bolsón de Villa Unión	1.50	ab	7	8
Bolsón de Mogna	1.50	ab	8	15
Llanos de Angaco	1.39	b	9	2

* Values followed by the same letter indicated no significant differences at $p<0.05$.

Table 4. Ranking of Provenances for 42-Month Basal Diameter and Duncan Groupings in *Prosopis chilensis*

Provenance	Mean Basal Diameter (cm)	Duncan Grouping*	Rank	Total Number of Families per Provenance
Bolsón de Pipanaco	2.74	a	1	13
Chamical-Llanos de La Rioja	2.42	ab	2	19
Bolsón de Rodeo	2.41	ab	3	1
Llanos de Catamarca	2.28	ab	4	9
Bolsón de Fiambalá	2.27	ab	5	10
Bolsón de Villa Unión	2.09	ab	6	8
Bolsón de Chilecito	2.04	ab	7	7
Bolsón de Mogna	1.98	b	8	15
Llanos de Angaco-Lavalle	1.87	b	9	2

* Values followed by the same letter indicated no significant differences at $p<0.05$.

Table 5. Spread of Family Ranking Within Provenances for 34-Month Heights in *Prosopis flexuosa*

Provenance Ranking	Provenance	Spread of 86 Family Rankings for Heights						
1	Bolsón de Pipanaco	2	3	8	16	21	23	28
		30						
2	Bolsón de Fiambalá	1	5	7	18	19	48	
3	Bolsón de Mogna	9	10	13	14	22	25	28
		43	55	63	66	76		
4	Bolsón de Villa Unión	12	26	34	40	68		
5	Chamical-Llanos de La	4	20	24	42	51	53	60
	Rioja	62	69					
6	Llanos de Catamarca	27	46	52				
7	Bolsón de Chilecito	17	29	45	47	54	71	
8	Llanos de Angaco-Lavalle	6	15	32	35	49	72	85
9	Alvear	11	56	67	70	82		
10	Ñacuñán	36	50	58	64	75		
11	A. del Aguila-Limay-	33	39	44	61	65	73	74
	Mahuida	77	78	80				
12	Bolsón de Rodeo	57	79					
13	Río Colorado-Gral.	31	37	59	81	83	84	86
	Conesa							

Table 6. Spread of Family Ranking Within Provenances for 42-Month Heights in *Prosopis chilensis*

Provenance Ranking	Provenance	Spread of 84 Family Rankings for Heights						
1	Bolsón de Pipanaco	1	3	4	10	16	19	25
		30	38	52	65	67	75	
2	Chamical-Llanos de La Rioja	5	6	7	8	9	11	20
		22	23	34	37	43	44	47
		48	49	58	72	79		
3	Bolsón de Fiambalá	2	13	27	28	40	42	54
		61	66	68				
4	Bolsón de Rodeo	41						
5	Llanos de Catamarca	12	18	31	35	57	60	64
		70	81					
6	Bolsón de Chilecito	15	17	26	35	46	74	83
7	Bolsón de Villa Unión	21	29	33	53	59	63	69
		84						
8	Bolsón de Mogna	14	24	32	36	45	51	55
		56	62	71	73	76	77	78
		80						
9	Llanos de Angaco	50	82					

Table 7. Proportion of the Genetic Variation Components for Height (H) and Basal Diameter (BD) Traits in 34-Month *Prosopis flexuosa* and 42-Month *Prosopis chilensis* Populations Growing in the Monte Zone

Genetic Variation Component	*P. flexuosa*		*P. chilensis*	
	H	BD	H	BD
V_p	45	36	29	33
$V_{f(p)}$	55	64	71	66

Table 8. Extreme Values for Familiar and Individual Means for Height (H) and Basal Diameter (BD) in 34-Month *Prosopis flexuosa* and 42-Month *Prosopis chilensis* Trees

Means and Values	*P. flexuosa*		*P. chilensis*	
	H (m)	BD (cm)	H (m)	BD (cm)
M.F.M.	1.42	1.64	2.52	4.70
m.F.M.	0.52	0.79	0.60	0.88
M.I.V.	3.00	8.84	4.10	20.20
m.I.V.	0.17	0.11	0.20	0.35

M.F.M.: Maximum familiar mean
m.F.M.: Minimum familiar mean
M.I.V.: Maximum individual value
m.I.V.: Minimum individual value

Table 9. Heritabilities at Individual and Familiar Level for Height (H), Basal Diameter (BD), Straightness (ST), Branching (NB), and Thorniness (TH) in 34-Month-Old *Prosopis flexuosa* Trees

Trait	H	BD	ST	NB	TH
Heritability at individual level	0.68	0.22	0.43	0.24	0.85
Heritability at familiar level	0.67	0.40	0.61	0.45	0.76

Table 10. Heritabilities at Individual and Familiar Level for Height (H) and Basal Diameter (Bd) in 42-Month-Old *Prosopis chilensis* Trees

Traits	H	BD
Heritability at individual level	0.39	0.36
Heritability at familiar level	0.41	0.40

Table 11. Estimation of Genetic and Phenotypic Correlations For Height (H), Basal Diameter (BD), Straightness (ST), Branching (NB), and Thorniness (TH) in 34-Month-Old *Prosopis flexuosa* Trees

Trait	Correlation Coefficient	BD	ST	NB	TH
H	r_F	0.61*	0.39*	–0.24*	0.04 NS
	r_A	0.65*	0.37*	–0.42*	–0.14*
BD	r_F	-	–0.16*	0.13*	0.21*
	r_A	-	0.13*	0.07 NS	0.02 NS
ST	r_F	-	-	–0.42*	–0.56*
	r_A	-	-	–0.61*	–0.69*
NB	r_F	-	-	-	0.40*
	r_A	-	-	-	0.49*

*$p<0.01$; NS: Not significant
r_F = estimate of the phenotypic correlation coefficient
r_A = estimate of the additive genetic correlation coefficient

IFS And Its Programme In Dryland Forestry Research

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1. The International Foundation for Science (IFS)

A small international group of scientists who were concerned about the problem of building indigenous science capacity in developing countries founded IFS in 1972. Their idea was to support young researchers of merit at the beginning of their scientific career in order to encourage them to stay in research and to establish themselves as members of the scientific community so that they might become leading scientists in their nations. IFS aims at the advancement of good scientists who can do relevant research of high quality in agricultural and related natural resources management sciences. Even if IFS puts the individual scientist at the centre of its focus, it encourages and supports team work and interdisciplinary research.

IFS is an international, nongovernmental, nonprofit organization. Its Secretariat is located in Stockholm, Sweden. The Foundation has a membership of some 92 national academies of sciences and research councils from 79 countries, whereof two-thirds are in developing countries. IFS is governed by an international Board of Trustees.

The yearly budget of IFS is approximately 40 million SEK, equivalent to around 5,5 million USD. In 1995 core contributions came from governmental sources or through IFS Member Organizations in Australia, Belgium, China R, Denmark, Finland, France, Germany, Japan, Netherlands, Norway, Sweden, and Switzerland. In addition contributions to the granting and supporting programme come from a number of national and international development agencies, including the World Bank, UNDP, UNEP, UNESCO, ISESCO, CTA-EEC, ODA, and SIDA.

2. The Granting And Supporting Programme

2.1 IFS Research Grants

The kind of support that IFS provides is mainly financial and in the form of research grants for specific research projects. The grants amount up to USD 12,000 per research period. The duration of a research period is normally between one to three years, depending on the kind of project. The grant may be renewed two times.

The grant is intended for the purchase of equipment, expendable supplies and literature, and, in well justified cases, for local travel and extra manpower. This implies that the applicant's salary, the basic infrastructure for the experimental work and technical assistance are made available by the researcher's institution.

Equipment purchased from the grant money becomes the property of the grantee's institution once the project is terminated.

2.2 Additional Support

Besides financial support, IFS can assist its grantees in the following ways:

- **The purchase of equipment, supplies and literature on behalf of grantees can be taken care of by the IFS Purchasing Department when grantees opt for leaving all or part of the grant with IFS. This service is of particular importance for grantees in countries where it is**

difficult to make purchases in foreign currency. Moreover, grantees will benefit from IFS's contacts to suppliers all over the world and the discounts IFS has with its major suppliers.

- **Travel grants may be awarded for participation in relevant scientific meetings and conferences.**

- **Scientific contacts can be arranged with IFS Scientific Advisers and other scientists working in the field of the grantee's project.**

- **Workshops and training courses are organized by IFS for its grantees. These provide the opportunity to present research results, to share experiences, to keep up-to-date with new techniques, and to establish new working contacts.**

- **IFS's project, "Service and Maintenance of Scientific Equipment," organizes training courses to assist grantees in Southern Africa Development Community (SADC) countries in the management and repair of laboratory equipment and connects them to the Network of Users of Scientific Equipment in southern Africa (NUSESA).**

2.3 Research Areas

IFS accepts applications from scientists in the following research areas: Aquatic Resources, Animal Production, Crop Science, Food Science, Forestry/Agroforestry, and Natural Products. A small pilot project was started in 1994 in selected environmental sciences that considers proposals dealing with water resources, biodiversity, and global climatic change.

Research on most aspects of the above areas is considered. It should be pointed out, however, that the projects should be relevant to developing countries, and they have to be research-oriented and not a transfer of technology. The proposals should aim at contributing to ecologically, socially, and economically sustainable development.

2.4 Criteria for Grants

Applicants for an IFS grant have to be native to a developing country in Latin America, Africa, or Asia[1]. They have to have an academic degree of not less than an MSc, or the equivalent. At the time they submit their first proposal to IFS, they have to be younger than 40 years[2] and at the beginning of their research career. Applicants must be employed at a university or research institution in a developing country.

The proposed research has to be carried out in a developing country and must fall within the IFS research areas as listed above.

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[1] Countries of the former Soviet Union and in eastern and southeastern Europe do not fall within the IFS programme.

[2] Chinese applicants have to be younger than 30.

2.5 The Selection Process

About 900 applications reach the IFS Secretariat every year. Available funds do not allow for funding of more than 200 grants per year—a situation which calls for a rigorous selection process. IFS relies on a worldwide network of around 1,000 Scientific Advisers to review the proposals and provide scientific advice and guidance to the grantees. The Advisers are specialists in their respective fields and assist IFS on a voluntary and nonpaid basis. The IFS programme could not exist without this contribution. I take this opportunity to thank all IFS Advisers for their valuable work.

The criteria that are applied for evaluating the applications are the candidate's qualification, the feasibility and scientific quality of the proposed research, and the relevance of the expected results to the needs of the country or region. Each application is evaluated by five to eight reviewers and discussed at the Scientific Advisory Committee meetings that take place twice a year for each research area. The final decision is taken by the IFS Board of Trustees, based upon the recommendations of the Scientific and Grants Committee.

2.6 Grantees and Grants

Since the IFS granting programme started in 1974 some 2,500 young scientists in 95 countries have received IFS support. Some 38% of the grantees work in Africa, 35% in Asia/Pacific, and 27% in Latin America. Almost 4,000 grants have been awarded so far.

About 55% of the total expenditures of IFS goes directly to the grantees in the form of grant money, 30% is spent on supporting activities (workshops, courses, recruitment, purchasing), 10% on administration, and 5% on other costs such as publications.

3. The IFS Forestry/Agroforestry Research Area

Forestry/Agroforestry is among the smaller areas in the IFS programme, considering the number of grantees. This is a reflection of the neglect of forestry research in many countries. We are trying to assist in changing this attitude and to encourage the researchers.

The programme covers all aspects of forestry and agroforestry research, both basic and applied, and thus concerns itself with the parts of the world's land area covered with forests and also with the use of trees and other woody perennials in all of the various different types of land use systems.

Even if all aspects of forestry and agroforestry research are considered, there are a number of subjects that we would like to emphasize, and we wish to concentrate the research activities of the IFS grantees on some key areas that are summarized in Annex 1.

4. Forestry in Dry Regions

Research on aspects of forestry in dry regions has been supported by IFS over many years. In 1992, the Swedish International Development Cooperation Agency (Sida) started to emphasize this area and, in the second half of 1993, they provided special funds to IFS for capacity-building efforts. It was realized that dryland forestry research is not given the attention that it should have when taking into consideration the land and forest area and the percentage of the population that is affected by dry conditions. This point was also strongly stressed during the IUFRO/IFS Workshop and the IUFRO World Congress in Finland last year. The prestige connected to research in these areas and the funds available for it are considerably lower than for research in more productive areas. Relatively few researchers, in particular, young researchers, are, therefore, willing and able to devote their time to projects in these areas. The special attention that the Sida initiative through the IFS programme is giving to research on aspects of forestry in dry regions means a lot to the scientists, and it is very encouraging for efforts in these areas in general.

Funding of SEK 5.2 million has been made available for three years, and we expect that the contract will be renewed. These funds have enabled us so far to award 31 research grants within this programme. A number of grantees have obtained travel grants to attend conferences, and two scientific meetings have been financed.

In June 1994 an international symposium was held in Nairobi on Supporting Capacity Building in Forestry Research in Africa. It was jointly organized and sponsored by IFS and the African Academy of Sciences (AAS), in technical cooperation with FAO. Some 80 participants included grantees of IFS and AAS, researchers from many African forestry research institutions and faculties, as well as from international institutions and organizations such as IUFRO, CIFOR, ICRAF, CIRAD-Forêt, Oxford Forestry Institute, and CABI.

The IUFRO/IFS workshop on Dryland Forestry Research took place in Finland in connection with the IUFRO World Congress beginning in August 1995. Some 55 participants from 30 countries shared their experiences regarding subjects such as ecology and silviculture in different dryland ecotones, dryland afforestation, utilization of indigenous knowledge, and application of research results for local-level development planning. The resolution of the workshop is available here. The proceedings have been published.

5. IFS Grantees' Research on Aspects of Forestry in Dry Regions

The projects supported by IFS in the field of dryland forestry research cover a wide range of subjects: genetic resources; adaptation of tree species to different ecological zones; reactions to drought stress; plant-soil relationships including aspects of water use efficiency and nutrient cycling; the role of rhizobium and mycorrhiza associations; control of pests and diseases; selection for use in agroforestry systems; potential for different purposes such as fuelwood or poles; productivity; propagation, regeneration, and afforestation; changes of vegetation due to human or animal impact; but also projects with more socioeconomic focus, e.g., about the role of nontimber forest products as sources of income. Grantees and their project titles are available from IFS.

Let me present to you a few of the grantees and their projects that IFS has supported or is still supporting. The projects are in different stages; some have started only recently and may not have given results yet; others are more advanced or have been terminated and results have been published in reports to IFS and in articles in scientific journals.

One of the projects has been presented to you earlier during this workshop—Dr. Ousman Diagne reported about his work with *Prosopis* in Senegal. Yet, *Prosopis* species have not been the subject of many IFS grantees' projects. I hope that this will change after this workshop, and I invite you to spread information about the IFS programme.

In Ethiopia, Mr. Tesfaye Abebe at the Awassa College of Agriculture has investigated the growth performance of some multipurpose trees and shrubs in the semiarid areas of southern Ethiopia to select those suitable for agroforestry purposes. He found *Acacia nilotica*, *A. cyanophylla*, *A. seyal*, *Cassia siamea*, and *Prosopis juliflora* to have the best performance in terms of rates of survival and growth rates (height and diameter growth) indicating a great potential for large biomass production in these areas. Studies of the potentials of these species for soil fertility improvement and agroforestry management techniques suitable for each species and desired products were suggested.

In Argentina, Dr. Marta de Viana at the Universidad Nacional de Salta investigates the cactus *Trichocereus pasacana* in order to find out what role dispersal and predation have for distribution and recruitment of this species. This columnar cactus grows in high altitudes and arid regions of northwestern Argentina. It is exploited as one of the main sources of wood in building, for furniture making, and for art and crafts. Dr. de Viana studies the distribution of the species in relation to the

available space and the seed bank at two sites that differ with regard to the density of this species, their plant diversity and altitude. Dr. de Viana noticed that 96% of the cacti were associated with other shrub species.

Dr. Oscar Eyog Matig, soil scientist and ecophysiologist with the Institute of Agricultural Research in Cameroon, has been supported by IFS for his work on the 'Hardé' soils at Maroua with respect to the relation of soil to plants and in view of establishing plantations. During the rainy season these compacted, denuded, and sterile soils take up water only in the upper 40 cm, the rest of the water runs off. The effect of different soil preparation techniques on the water reserve in the soil were tested. Dr. Eyog Matig found that the soil profile's water recharge was very small throughout the rainy season in the treatment where the digging of planting holes was not associated with any other soil preparation technique. It was also noted that the effects of bulldozer ploughing very quickly disappeared with time. The technique of using dikes to retain water made it possible for an important quantity of water to be stored in the soil, up to and above the depth of 1.70 m. This method is acceptable for farmers, and it has shown to be most efficient also with respect to the establishment of a herbaceous cover and the tree growth. Species showing potential under these conditions were *Eucalyptus camaldulensis*, *Azadirachta indica*, **and** *Acacia nilotica* **ssp** *adstringens*. **Also,** *Acacia senegal* **developed well and was considered of interest for the production of gum arabic.**

In Peru, Dr. Niels Valencia is studying regeneration and phenology of a dry cloud forest on the steppe, like western slopes of the Peruvian Andes. The study areas are at altitudes of 2500S3500 m where isolated patches of evergreen forest occur depending on locally favourable moisture conditions caused by persistent clouds in the wet season. The floristic composition differs largely between forests in the north and the south, but Dr. Valencia found the structure and the physiognomy of the forests to be the same. Inventories of the vascular flora of the dry-cloud forests have indicated 119 families, 392 genera, and 801 species. Trees and shrubs were represented by 40 families: for trees, in particular Araliaceae and Proteaceae; for shrubs, in particular Melastomataceae, Cactaceae, Ericaceae, Berberidaceae, Celastraceae, and Sapindaceae. The rate of regeneration of trees and shrubs species is decreasing from north to south. In northern Peru most species were found to regenerate, with trees having notably better rates than shrubs. In central Peru regeneration was very poor, a result probably of higher grazing pressure and the drier climatic conditions. The present phase of the project aims at using the native trees and shrubs of the dry-cloud forests for afforestation in order to prevent soil erosion.

A final report has recently been submitted to IFS by Dr. Emmanuel Rincon of Mexico concerning his research on the ecophysiology of tropical dry forest legumes. In the tropical dry forest at the Pacific Coast of Mexico legumes are very abundant and diverse. Dr Rincon carried out a screening programme on 10 species that were considered to have potential as sources of tubers, timber, forage, or fruits, and to reduce soil erosion. The germination, growth, and establishment of woody seedlings, as well as the influence of mycorrhizae on seedling growth were studied. The project has resulted in a number of publications. Dr. Rincon also looked at *Pachycereus pecten-aboriginum*, **an arborescent cactus of arid and tropical dry forests in Mexico that is associated with vesicular-arbuscular mycorrhizal fungi. The mycorrhiza infected seedlings had significantly higher dry-matter production, root/shoot ratios, and specific root length than noninfected seedlings. This suggests a more efficient exploitation of soil resources by the mycorrhiza cacti, and indicates an important role of the mycorrhiza fungi in the establishment, growth, water relations, and nutrition of cacti in the arid tropics.**

"Miombo trees and mycorrhiza" is the title of an IFS supported project carried out by Dr. Esron Munyanziza in Tanzania. Miombo woodlands are the largest type of vegetation in Tanzania and widely occur in several other African countries. The project focuses on the main miombo tree species, namely, *Afzelia quanzensis*, *Brachystegia microphylla*, *Brachystegia spiciformis*, *Julbernardia globiflora*, **and**

Pterocarpus angolensis **and aims at contributing to a proper management of miombo woodlands, to the silviculture of miombo tree species, and to afforestation of dry areas. Aspects included in the project are natural and artificial regeneration, fertilization, artificial inoculation of seedlings, and natural occurrence of mycorrhizae on field-grown seedlings. One of the objectives of the studies was to understand the constraints and ecological strategies of the miombo trees. Dr. Munyanziza mentioned as the main constraints the harsh climate, poor soils, and wildfires. Irregular and insufficient rains following seed dispersal constitute major constraints to natural regeneration. Bush fires not only result in erosion that washes away nutrients, but also kill seeds and damage most seedlings under 4 meters and even mature trees. Miombo trees have different strategies to improve their chance of survival and to reduce risks. The number of seeds produced, the way they are dispersed and the time of germination play an important role, as does the association with mycorrhiza fungi.**

Annex 1

The IFS Forestry/Agroforestry Research Area

IFS will consider applications for projects dealing with research on all aspects of forestry and agroforestry. We wish, however, to concentrate the research activities of the IFS grantees on the following key areas[3]:

1. Exploration, conservation and utilisation of biological diversity

- **Quantitative resource assessment ranging from remote sensing to field-based studies**
- **Characterisation of the soil environment in forestry systems (physical, chemical, and biological)**
- **Definition of minimal areas for effective** *in situ* **conservation and management for conservation**
- **Characterisation of genetic diversity using classical methods together with advanced techniques of molecular and biochemical techniques**
- **Development of** *ex situ* **conservation management and practices, including seed banks (where appropriate), cryopreservation, and tissue-culture genebanks**

2. Sustainable forest management (silvics)

2.1 Natural forest systems

- **Botany and ethnobiology of indigenous forests**
- **Edaphic factors and their interactions including nutrient cycling, physical structure, dynamics of nutrient, carbon partitioning and water movement and the biological functioning of forest rhizospheres**
- **Local knowledge of management of forest resources**
- **Autecology and synecology of important species of the forest including studies on phenology, seed recalcitrance, and whole-tree physiology**
- **Dryland ecology and range management**
- **Natural forest dynamics (succession, regeneration patterns in relation to site factors)**
- **Development of methods for forest management planning, especially for multiple use of forests**

2.2 Plantation forest systems

- **Silvics of indigenous and exotic species for use in plantations including mixed plantations**

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[3]Many thanks to Peter Wood, Sinclair Mantell, François LeTacon, Olavi Luukkanen, and Ivan Nielsen for setting up this list.

- **Development of plantation technology for production of nontimber forest products**

- **Population genetics of plantation species**

- **Tree planting patterns for watershed management**

- **Genetic improvement of plantation species using integrated conventional and advanced** *in vitro* **transformation methods**

- **Assessment of weediness with introduced species**

- **Enhancing cost effectiveness in plantation systems**

- **Studies on improved budding, grafting and propagation techniques to take advantage of genetic gains**

- **Appropriate phenology studies in indigenous fruit and other trees**

3. Agroforestry

- **Above- and below-ground interactions between tree and crop excluding simplistic research on alley cropping but emphasising more the interactions between soil microorganisms in the rhizosphere**

- **Development of symbiotic microbial associations which will improve sustainability**

- **Impact of agroforestry systems on physical soil properties and control of soil erosion on sloping lands**

- **Genetic improvement of fruit and multipurpose trees using integrated traditional and advanced modern methods**

- **Improved modified orchard systems for agroforestry**

- **Rationalisation of the use of chemical inputs for sustained yield and adequate pest and disease control leading to increased use of integrated pest and disease management, using biological control where possible**

- **Improvement of range management practices**

- **Rural appraisal for developing research programmes and on-farm research**

- **Evaluation of factors in the uptake of stabilisation practices including windbreaks, shelterbelts, etc.**

4. Forest products

- **Increasing added value to nontimber products from managed natural forests**
- **Increasing added value to timber products from natural and plantation forests**
- **Improvements and harvesting technologies for all forest products**
- **Marketing studies for small-scale rural producers**
- **Improved utilisation, coupled with sustainability, of underutilised forest products**
- **Improved postharvest handling of forest products**

Other cross-cutting issues which must be emphasized include:

- **Need for rural people to participate in the planning and management of research**
- **The need for some social and economic studies to be incorporated in any scientific research activity on tropical forestry systems**
- **It is expected that in choosing research topics national needs are taken into account**

Special funding is available for research proposals on aspects of forestry in dry regions.

Overview of Use of *Prosopis juliflora* for Livestock Feed, Gum, Honey, and Charcoal as Well as Its Role in Combating Drought and Desertification: Regional Case Studies from Gujarat, India

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Introduction

Prosopis juliflora is an aggressive and invading species that has spread rapidly due to its great tolerance to the extremely refractory conditions in the northwestern arid zone of the Gujarat state. Consequently, it constitutes about 30% of the vegetation cover in this unique and diverse ecosystem. It is the only promising species capable of supplying a renewable source of raw materials used in various cottage and small-scale industries. The high inherent coppicing capacity of *Prosopis* is a major factor contributing to the renewable nature of this resource. Regarding the use of *Prosopis juliflora*, some studies have been conducted for livestock feed by Gujarat Agriculture University, Anand,, and Vivekanand Research and Training Institute, Mandvi-Kachchh. Gujarat State Forest Development Corporation, Ltd. (GSFDC), has used this species since 1981 for forest products: pods, gum, honey, wax, and charcoal. Moreover, this species has been chosen by the Forest Department for intensive afforestation programmes under different schemes to check desertification in the refractory areas.

Use of *Prosopis juliflora*

The usefulness of *Prosopis juliflora* has long been recognized (Muthana and Arora, 1983; Silva, 1986; Silva, et al., 1986). It is considered to be a valuable tree species of the desert ecosystem. Its multiple-use possibilities have attracted growing interest in this species, especially in arid zone covering eight districts of the northwestern region of the Gujarat state (Singh, et al., 1996). This arid zone occupies a geographical area of about 3,500,000 ha, of which, a large portion is covered by a saline desert called the Rann of Kachchh. Here, *Prosopis juliflora* constitutes a large percentage of vegetative cover, extending over an area of about 500,000 ha. In this desert ecosystem, this species is one of the most efficient species to convert energy into biomass as a primary producer. It produces about 25 to 30 tons/ha/year at the short rotation age of 4 to 5 years (Patel, 1986), It is, therefore, necessary to improve the management of this natural resource through scientific and technical studies to obtain various raw materials in perpetuity for agro-industrial utilization. GSFDC, Gujarat Agricultural University, Anand, Vivekanand Research and Training Institute, Mandvi-Kachchh have been active in developing management techniques for this species. For example, GSFDC has undertaken a programme of collection, processing, and marketing of various minor forest products from different parts of *Prosopis juliflora*. The following forest products have been collected from different parts of the northwestern arid zone of Gujarat: pods, gum, honey, and wood for charcoal production. *Prosopis* has also been used to combat desertification.

Pods collection for livestock feed

Prosopis juliflora trees have a tremendous potential for pod production. The pods are collected twice a year (winter and summer). The maximum pod production is between March and June. GSFDC has collected about 2000 metric tons of pods and generated about 100,000 man-days (a man-day refers to a daily wage of Rs.40.00, equivalent to US$1.20) of labour (approximately US$125,000) during the last five years (GSFDC, Vadodara's records). Pod production is estimated to be about 20 kg/tree/year (Shukla et al., 1984), thus, about 10 metric tons/ha (500 trees/ha). It is estimated that about 5 million metric tons of pods could be collected from an estimated area of about 500,000 ha in the entire northwestern arid zone of Gujarat. If 40% of the pods were actually collected, the estimated yield would be about 2 million metric tons, which could provide employment to millions of people and earn hundreds of millions of Rupees as state income. Vivekanand Research and Training Institute, Mandvi-Kachchh, has installed a livestock-feed manufacturing plant. The Institute has succeeded in preparing highly nutritive livestock feeds from these pods after seed separation. The whole project provides employment to the rural poor through collection of pods. The project also provides a highly nutritive cattle feed that is cheaper than other available cattle feeds.

Regarding the composition of dried pods, Vimal and Tyagi (1986) have reported that the pods contain: protein, 16.5%; fat, 4.2%; carbohydrate, 57%; fibre, 16.8%; ash, 5.4%; calcium, 0.33%; and phosphorus, 0.44%. Moreover, Gujarat Agricultural University, Anand,, determined the trace-element composition of *Prosopis* pods as 12.46 to 15.51 ppm copper, 22.11 to 22.30 ppm manganese, 18.30 to 28.01 ppm zinc, and 203 to 638.8 ppm iron (Shukla, et. al., 1984).

Because of the high carbohydrate content and good amount of protein, the spongy walls of ripe pods are highly nutritive and used in making meal for humans (pinole) and alcoholic beverages (Mesquitabole, mesquite wines, etc.). The husk of pods is used for dying; they contain tannin (1.9%). Raizada and Chatterjee (1959) have noticed that the ripe pods are said to have high nutritive value, i.e., rich in sugar and nitrogen and are greedily eaten by most of the herbivorous animals and livestock. Further, the pods may yield a substitute for wood shavings used in various industries for thermal insulation and acoustic control (Narayanmurti, 1955). Studies on palatability and nutritive value of pods and their source as livestock feed and milk production, particularly goats, sheep, and camels, have been conducted by Gujarat Agricultural University, Anand,.

Prosopis pods provided good fodder without causing any digestive adverse effect. For cattle and buffaloes, the pods were not regarded as good fodder because of the high sugar content and indigestibility of raw seeds. (Shukla, et al., 1984). When fed in the dried and crushed state in the form of powder, the pods did not show any deleterious effect on cattle and, in fact, resulted in good animal performance.

Further, 50% wheat and rice-straw, molasses and ground-nut cake can also be mixed with this powder to make it more nutritious, palatable, and valuable. This powder contains 13% glucose which can be utilized in making biscuits after adding to it 50% wheat fine flour. During drought and scarcity, the pods are even used as food items by poor people. (VRTI, Kachchh-Mandvi).

To use *Prosopis juliflora* pods as a livestock feed, GSFDC has proposed a scheme for manufacture of livestock feed in Kachchh district to take advantage of the quantities of pods that are available. The seeds will be sold to the Forest Department and other agencies for raising plantations.

Gum production

Prosopis juliflora exudes gum from the sap wood. On average, about 40 g of gum is produced from one plant. However, under drought conditions more gum is exuded. During 1991-1992, the maximum production of more than 1000 metric tons was obtained. This compares to the normal yield of about of about 300 metric tons/year (GSFDC, Vadodara's records). In the last five years, the corporation has collected about 2000 metric tons of gum and generated more than 1 million man-days of labour (approximately US$1 million). The gum forms an adhesive mucilage, with favourable physical and chemical properties, that can be used as an emulsifying agent. Prosopis gum also finds use in confectionery, mending pottery, and as an adulterant and substitute for gum arabic. (Krochmal et al., 1954). Owing to the high content of arabinose, which is easily separable, the gum has proved to be an excellent source of this sugar. Moreover, the gum is used in industries, etc. If additional utilization of this gum can be found, it would further enhance the value of this already economically important tree (Ganguly and Kaul, 1961). Furthermore, the gum contains: D-galactose, 45%; L-arabinose, 24%;

L-rhamnose, 13%; and glucuromic acid, 13.7%. It possesses fairly good adhesive strength and can be used as paper adhesive for brown paper and wall paper. The gum has also been used in treating eye infections (Vimal and Tyagi, 1986).

Honey collection

Prosopis juliflora **flowers profusely twice a year and produces sweet nectar that gives excellent honey. In the last five years, about 300 metric tons of honey has been collected, processed, and marketed by GSFDC, which has generated about a half million man-days of labour.** ***Prosopis*** **honey accounts for about 90% of the total production of the state in the Kachchh district (GSFDC records). The honey is produced by a rare species of honeybee,** ***Apis floriea,*** **that is found in large numbers in Kachchh district due to its peculiar climatic and environmental conditions. The honey produced by** ***Apis floriea*** **is regarded as one of the best quality of honey from the medicinal point of view, with an "A" grade by researchers at the Central Bee Research & Training Institute (CBRTI) in Pune.**

In view of the increasing honey demand, the corporation has proposed a scheme for honeybee rearing to increase honey production in the Kachchh district. GSFDC honey enjoys high acceptability in the local market due to its purity and reasonable price. By rearing the domesticated variety of honeybee in selected areas of Kachchh district, the production can be increased. In this new process, modern methods of extraction from combs will be applied using new technology developed by CBRTI.

During purification of the honey, the wax is separated though filtration. In the last five years, about 15 metric tons of wax have been collected by GSFDC that has found good markets for creams, pain balms, and medicines.

Charcoal preparation

GDFDC has been entrusted with manufacturing charcoal from ***Prosopis juliflora*** **by the government of Gujarat. This activity has given significant employment opportunities to the local people. In the last five years, the corporation has manufactured about 300,000 bags of charcoal (1 bag = 30 kg) and generated about 300,000 man-days of labour (approximately US$350,000). The corporation has also delivered charcoal to the Forest Department for meeting the bonafide needs of the local population of the district. As a result, with its one million population, Katchch is the only district in India that is self-sufficient in its fuelwood requirements.** ***Prosopis*** **charcoal from Kachchh is also sent to other districts of Gujarat state to meet their fuelwood requirements.**

It is useful to estimate the total resources potential from ***Prosopis*** **charcoal in the entire northwestern arid zone of Gujarat.**

Assuming that

> **500 trees/ha produce 24 kg dry biomass at end of five years (12 dry metric tons/5 years = 2.4 tons/year)**
>
> **16.6% wood-to-charcoal yield for 0.4 tons of charcoal/ha-year**
>
> **100,000 of the 500,000 ha of the area covered by** ***Prosopis*** **is harvested and processed into charcoal each year**

then, the approximately 500,000 ha of ***Prosopis juliflora*** **would yield about 200,000 metric tons of charcoal per year in perpetuity on a five-year cycle. Thus, annually 6.66 million bags of charcoal worth Rs. 500 million (approximately US$15 million) would be available (one 30-kg bag of charcoal costs Rs.75). In this way, millions of man-days of labour could be generated for employment.**

Charcoal is prepared by burning thick stems and roots of trees under anaerobic conditions. Only one-third of the total quantity of fuelwood processed becomes charcoal. The wood is hard and heavy

(specific gravity 0.70). It is excellent firewood (calorific value is 4800 k cal/kg) that burns slowly and evenly and holds heat well. Because of its superior quality, it is considered to be one of the best charcoals (Vimal and Tyagi, 1986). Dry wood, on destructive distillation gives 33.9% charcoal, 1.24 methanol and 124.8 litre/kg of gas. *Prosopis* wood, together with rice husk and other agro-wastes, can be briquetted to form a good quality white coal. Other forms of charcoal can be used for household purposes. The pellets are prepared from twigs, powder from *Prosopis* pods, and charcoal waste particles. This mixture is bound together with a mixture of agro-wastes under specific temperature and pressure conditions. Briquettes are prepared from crushed green, dried (with supplemental heat) twigs that are mixed with *Prosopis*-pod powder, wooden chips and a binding material like rice husk and other agro-wastes. When hydraulic pressure is applied to this mixture, gum contained inside the wood chips comes out and mixes with the rice husk layer surrounding the wood chip. The resultant product is a briquette, in which Prosopis wood forms a core and rice husk forms an outside layer. These briquettes have better breathing action, and hence, better combustion characteristics than those of other types, and are used in furnaces.

Charcoal-manufacturing activities have been carried out in remote and backward areas of the districts like Kachchh, Banaskantha and Surendranagar by forming co-operatives and societies. The District Rural Development Agency, Banaskantha, has sponsored the scheme of Development of Women and Children in Rural Areas (DWACRA) to generate employment and income for poor people. Under this scheme, thousands of families have been benefitted by preparing charcoal in *Prosopis juliflora*-dominated areas.

Combating drought and desertification

The entire northwestern zone of Gujarat is facing the grim prospect of drought and desertification. A recent survey has revealed alarming facts about border areas that the process of desertification, which is, by and large, man-made, can play havoc with the ecological order (Varshney, 1995). The data collected from local inhabitants and government records show that the neglect of popular mechanisms had paved the way for the fast movement of the desert at an alarming rate of about a half-kilometer a year (Varshney, 1995). Consequently, the villages bordering western Rajasthan and Rann of Kachchh were the worst hit. The once fertile lands of those border areas have turned into barren wastelands. Over exploitation of ground water and vegetation, as well as mining activities, have resulted in a sharp increase in salinity levels. The study further revealed that the soil thermal regime, frequencies of salt sprays, and change in rainfall patterns have affected the soil moisture. Rapidly disappearing forest cover, lack of environmental consciousness among the people, accompanied by a blind race for rapid economic returns, have aggravated the situation in this zone. Some of the main reasons for desertification, outlined in the report were:

- Escalation in population of both humans and livestock
- Mobility of saline dust from the broken and cracked coastal area
- Salt spray and velocity of the wind during summer
- Increased salinity due to submergence of the fertile areas of this arid zone with saline water during the rainy season.

All these factors have contributed to the relentless march of the desert. Additionally, the Aravali hills have also been eroded and denuded, but due to different causes of over-grazing and other biotic pressures.

To combat desertification and check drought, afforestation programmes have been carried out under different schemes, viz. Desert Development Programme, Afforestation on Desert Border, and Border Area Plantation. These schemes have created shelterbelts and windbreaks on the periphery of agricultural land and wasteland as well as barren and saline areas under forests. No doubt, due to its tolerance to refractory environmental conditions, after successful introduction, *Prosopis juliflora* has been spread extensively and given excellent results in plantation activities carried out in about 20,000

ha in desert areas of Banaskantha and Mehsana district under the Desert Development Programme in the last 18 years. The practice of nomadic pastoralism with free grazing has stimulated the distribution of this species because the undigested, but treated seeds, pass through the digestive system of the livestock and are disseminated by migratory animals. This seed dispersal on vast areas has helped natural regeneration and naturalization of this species. Consequently, the desert is blooming and eroded, denuded Aravalli Hills are also becoming green due to its fast growth and drought-hardy inherent capacity. Further, a 4- to 6-year-old stand of *Prosopis juliflora* has reclaimed salt affected soils by enriching them with 6 to 8 tons/ha of air-dry leaf litter containing sufficient quantities of both macro- and micro-nutrients (Forest Department records). Last, but not the least, the seed cakes of this tree species that have been sown on contour trenches and excavated soil of water-retaining structures, such as check dams across the desert lands, have produced significant results in creating green belts and windbreaks to check the rapidly spreading devil of desertification - a problem of international dimensions.

Future Prospects

***Prosopis juliflora* is the only tree species utilized for its each and every part in various ways on a commercial basis. Due to its multiple uses, it has gained public acceptance as a plant of recognized economic value. This inherent capacity and potentiality of *Prosopis* can be converted into an even greater asset through application of scientific and technical methods. These new *Prosopis* technologies can accrue numerous benefits besides generating tremendous local employment opportunities.**

It is necessary to explore the feasibility of obtaining new products from *Prosopis* such as activated carbon, gas, organic acids, acetic acids, methanol, acetone, etc. through wood distillation. There is also a possibility of extracting carotene from its green leaves. The foliage, along with other organic matter, could be used as a green manure or compost. In summary, this tree has played a pivotal role in combating desertification and drought through its intensive plantation on refractory areas to enhance their ecostability. Hence, time has come to pool the scientific and research findings for multiple agro-industrial uses of *Prosopis juliflora* and to name it "KALP-VRAKSH", i.e., a tree that fulfills each and every desire and demand.

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Overview of Past, Current and Potential Uses of Mesquite in Mexico

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INTRODUCTION

In developing countries, forestry activities have not generated sufficient income to become an important influence in the development and welfare of the population. This is primarily due to the situation in these countries where forestry activities are usually focused on competing food production needs where agriculture and animal husbandry are the principal players. Developing countries are generally characterized by having a large variety of renewable natural resources which are little known and underutilized and a small number of well-known resources which are over exploited.

Regarding forest resources, most developing countries have historically been guilty of a lack of management planning, which is a consequence of a lack of technical knowledge as well as the intense pressures placed on forests such as the creation of new human settlements; growth of agricultural and ranching lands; development of an infrastructure, such as roads, water projects, electric lines, and railroads; and the use of products including firewood, medicinal plants, and food sources. Mesquite is a case in point.

1. MEXICAN FOREST RESOURCES

Mexico is located between longitude 87º W and 117º W and latitude 14° N and 32° N and has 200 million hectares of surface area. Of this area, 60% is mountainous and 40% ranges from hilly to flat. The Mexican climate is also varied with 60% of the country being arid or semiarid and 40% being divided between temperate and tropical climates. The mean annual precipitation varies from 0 to 500 mm in the most arid regions, 500 to 1500 mm in temperate regions, and from 1600 to more than 3000 mm in tropical zones.

These characteristics, together with the geology and soil of the country, have created a great diversity of vegetation. According to the Sub Secretaria Forestal y de Fauna Silvestre (1994), there are 138.65 million hectares suitable for silviculture, of which 56.87 million hectares are forested and 58.44 million are covered with shrubs and nonwoody vegetation, mostly from the Cactaceae family. There are also 22.23 million hectares of disturbed areas and 1.11 million hectares of aquatic vegetation (Table 1).

Mexican forest resources can be divided into three groups according to climate: temperate forests, tropical forests, and desertic vegetation.

Table 1. Areas Covered by Forest Ecosystems in Mexico

Ecosystem Type	Area	
	Millions of ha	Percentage
Temperate Forest	30.43	21.94
Tropical Forest	26.44	19.06
Shrub Lands	6.94	5.00
Drylands Vegetation	51.50	37.14
Disturbed Areas	22.23	16.03
Aquatic Vegetation	1.11	0.83
Total	138.65	100.00

1.1 Temperate Forests

Temperate forests consist of pure conifer stands, mixed conifer and hardwood stands, and pure hardwood stands. These forests are found in the mountainous regions of the country, in altitudinal bands ranging from 800 to 3,300 meters above sea level. Mexico has a wide variety of coniferous genetic material, principally in the genus *Pinus*. **Martínez (1945) listed 39 species, 18 varieties, and 9 forms; these numbers have increased recently with new research (Eguiluz, 1978). The following genera (among others) are also found in these forests:** *Abies*, *Cupressus*, *Taxodium*. **The hardwoods are represented by the** *Quercus*, *Arbutus*, **and** *Alnus* **genera.**

The regional distribution of temperate forests is very important in the Sierra Madre Oriental, Sierra de Chiapas, and the Baja California peninsula mountain systems. This forest class has a total surface area of 30.43 million ha. Chihuahua, Sonora, Durango, Sinaloa, Jalisco, Michoacán, Guerrero, Oaxaca, and Chiapas have the largest area of temperate forest.

1.2 Tropical Rainforests

Tropical rainforests are characterized by the diversity of their ecosystems which can reach 60 tree species and more than 100 plant species per ha. The commercially most important timber genera are *Cedrela*, *Swietenia*, *Platymiscium*, *Buscida*, *Piscidia*, **and** *Calophyllum*. **The natural distribution of the tropical rainforests is the coastal flatlands of the central and southern regions of the country below 800 meters above sea level. Jungles occupy 11.4 ha of the country, including the states of Campeche, Yucatán, Quintana Roo, Chiapas, Tabasco, Oaxaca, Veracruz, Puebla, San Luis Potosí, Hidalgo, Tamaulipas, Guerrero, Michoacán, Jalisco, Nayarit, Sinaloa, and Colima.**

1.3 Desertic Vegetation

Desertic vegetation consists of scrub land, desert brushwood, chaparral, and members of the Cactacea family. This type of vegetation is found throughout coastal Mexico, in the northern desertic regions, and in other regions in central and southern Mexico with similar arid characteristics. This ecosystem occupies 58.44 million ha, of which 51.50 million ha are legally required to be forest lands due to the topography which has more than 15% slope. This type of vegetation is utilized as an energy source in the form of firewood and charcoal, and several genera, such as *Euphorbia*, *Parthenium*, *Opuntia*, **and** *Agave*, **are used in domestic industries and food production.**

In conclusion, it can be stated that the largest vegetation area is 58.44 million ha (42.14%), which is made up of shrubs and scrub vegetation. Shrubs occupy 6.94 million ha (5.00%) and scrub occupies 51.50 million ha (37.14%).

The second largest vegetation area is forest land which consists of 56.87 million ha (41.01%) of which 30.43 million ha have temperate forests (21.94%) and 11.4 million ha are tropical rainforests (8.22%). The remaining 15.04 million hectares correspond to tropical dry forest (10.84%).

2. THE HISTORY OF MESQUITE IN MEXICO

The uses of mesquite in Mexico have changed over time due to cultural and technological advances. However, some of the most important uses have remained constant even to the present time.

The common name, mesquite, is actually derived from the Aztec language ?Nahuatl", in which the plant was called *mizquitl*, **or ?bark used for tanning." The genus name,** *Prosopis*, **comes from ancient Greek which means bark used for tanning sheep skins.**

In Mexico's history, it is possible to separate and observe several eras associated with mesquite use as summarized in Table 2.

Table 2. Forested Areas at Different Times During Mexico's History*

Era	Year	Temperate Forest (millions of ha)	Decreasing Rate (%)	Tropical Forest (millions of ha)	Decreasing Rate (%)
Prehispanic	1500	126.6		28.9	
Spanish Conquest	1800	120.6		18.4	
Independence	1825	123.1		20.8	
Revolution	1900	48.8		20.7	
Postrevolution	1940	40.8	0	20.4	1.4
Current	1950	39.5	3.18	19.8	2.9
	1960	33.3	15.6	17.7	10.6
	1975	29.5	11.4	15.2	14.1
	1976	28.7	2.7	15.0	1.3
	1986	27.5	4.1	11.4	24.0
	1996**	30.4		26.4	

* Data were derived from a map integrated by Moncayo (1981) under the title "General distribution of vegetation in prehispanic Mexico acerca 1521", and a table showing forested areas until 1976 (Moncayo, 1981). Finally, it was updated by the authors.

** Forested area increased because of a very detailed forest inventory (completed in 1994) that includes forest plantations for temperate forest areas, and mangrove areas, savannas, and riparian areas with tree cover in tropical forest areas.

2.1. Prehispanic Era

Before the Spanish conquerors arrived, ancient cultures in Mexico tried to keep a balance between extraction and production of forest resources, due to the religious base of these cultures.

Historical records of ancient cultures in Mexico show that they used forest resources for building homes, firewood, making weapons, for medicinal purposes, fruit harvesting, and religious uses. The ancient cultures involved with mesquite in Mexico are discussed below.

2.1.1 Seri and Yaqui Cultures

These cultures were located in the Mexican northwest in the states of Baja California and Sonora. They used mesquite for food, firewood, housing, weapons, tools, fibers, and medicine. They used every part of the plant.

The Seri culture used heat to kill a beatle from the bruquidae family in mesquite pods and to facilitate grinding the fruit. The powder obtained from pods was mixed with water to produce a kind of bread or a beverage called atole (Felger *et. al***., 1979).**

2.1.2 Purepecha Culture

This indigenous group settled at the edges of Paztcuaro Lake, and spread over the current states of Michoacan, Guanajuato, Queretaro, Guerrero, Colima, Jalisco, and Nayarit. This culture used firewood for religious ceremonies and wood for carving religious figures (Moncayo, 1981).

2.1.3 Chichimeca Culture

The Chichimeca lived in central Mexico in temperate forest areas. Due to their hunter-based culture, they developed a deep respect for nature. They used mesquite for weapons, mainly because of its durability and strength.

2.2. Spanish Conquest

After the Spanish conquerors arrived in New Spain, and following bloody battles, the indigenous cultures were conquered, and a new era for Mexico was born. At the same time as Spanish settlement advanced, gold and silver explorations were carried out as a result the discovery of huge ore deposits in Taxco, Zumpango del Río, Zacualpan, Sultepec, Temascaltepec, Espiritu Santo, Tlalpujahua and Zacatecas (Moncayo, 1981). Mining operations required different wood products throughout the mining process. Those wood products were poles, firewood, and charcoal. These mining activities were responsible for forest destruction, the change of forest lands to agriculture and animal husbandry activities, and establishment of new settlements (Moncayo, 1981; Sanchez *et. al.,* **1990).**

It was during this period that the genus *Prosopis* **was reported for the first time in 1651 by Hernández. Later, in 1767, Solís, a catholic friar, who was visiting the missions located in the northern part of New Spain, described the presence of the genus** *Prosopis* **(González, 1979). Finally, Clavijero, in his study of California's flora, mentioned the genus** *Prosopis***.**

2.3. Independence

After Mexico won independence from Spain, anarchy reigned in Mexico, causing a great decline in economic and productive activities. All agricultural activities were reduced to simple self-sufficiency levels.

It was during this time that private ownership started to be recognized, and forests were cut down in Mexico's tropical regions, mostly for wood exportation to Europe. The use of forest resources at this time was without any technical criteria, and with very severe overuse.

2.4. Revolution

With the stabilization of the economic, social, and political conditions after Mexico's civil war, the use of forest resources was based on the idea that they were infinite, and foreign investment was promoted for building railroads and to facilitate the transportation of minerals and raw lumber.

In conclusion, the decreasing rate of Mexican forest resources in an area can be observed for the different eras of Mexico's history.

3. MESQUITE IN MEXICO

Although it has been subjected to irrational human action since the Spanish conquest, which has caused a striking deterioration in natural population, mesquite remains a biological resource with a wide distribution in arid and semiarid zones in Mexico. Ecologically, *Prosopis* **species and varieties play a very important role in the food chains of the ecosystems where they are found. Mesquite serves as a food source and refuge for wildlife, stabilizes the soil and prevents erosion, and protects watersheds. In short, it is a prime candidate for integrated management. However, as with the rest of the flora of arid regions, mesquite has not been given the economic importance that it deserves.**

In most arid regions, mesquite is found as a shrub, only in ecosystems with an abundance of water does it grow into trees. It grows better near deep river pools, in valleys with deep soil, and places where the water table is high. Mexico has a wide variety of native mesquite species (Tables 3 and 4). In many arid regions in Mexico, mesquite is the most common vegetation for many kilometers forming forests called ?mezquitales."

Table 3. Native Mexican Species of the Genus *Prosopis*

SPECIES
1. *Prosopis laevigata* **var.** *laevigata*
2. *P. glandulosa* **var.** *glandulosa*
P. glandulosa **var.** *torreyana*
P. glandulosa **var.** *prostrata*
3. *P. juliflora* **var.** *juliflora*
4. *P. velutina*
5. *P. reptans* **var.** *clonerascens*
6. *P. pubescens*
7. *P. articulata*
8. *P. tamaulipana*
9. *P. palmeri*
10. *P. pazensis*
11. *P. bacharis*

Adapted from Maldonado-Aguirre (1991).

Table 4. Distribution of Mesquite Species in Mexico

Species	Distribution in Mexico
1. *Prosopis laevigata* **var.** *laevigata*	**San Luis Potosi, Central and Southern Tamaulipas**
2. *P. glandulosa* **var.** *glandulosa*	**Northeast**
P. glandulosa **var.** *torreyana*	**Pacific Northwest**
3. *P. juliflora* **var.** *juliflora*	**Baja California**
4. *P. velutina*	**Northeast**
5. *P. reptans* **var.** *clonerascens*	**Northeast**
6. *P. pubescens*	**Baja California**
7. *P. articulata*	**Guaymas, Sonora Tamaulipas; Veracruz; Baja California**
8. *P. tamaulipana*	**Tamaulipas; Veracruz**
9. *P. palmeri*	**Baja California**
10. *P. pazensis*	**Baja California**
11. *P. bacharis*	**Altar Desert, Sonora**

Adapted from Maldonado-Aguirre (1991), Piña-Puente (1981), and Ezcurra, et al. (1981).

Prosopis articulata, *P. tamaulipana*, **and** *P. palmeri* **are considered endemic to Mexico. Based on the absence of reproductive barriers and on numerical taxonomy, it can be concluded that there is natural hybridization between the populations of** *P. laevigata* **and** *P. glandulosa* **var.** *glandulosa* **.**

Prosopis laevigata **var.** *laevigata* **is typical of central Mexico. It can be found in the precipitation range from 300 mm to 900 mm and at altitudes up to 2300 meters above sea level. Industrial uses have not been developed for** *P. laevigata* **wood, but it is commonly used as domestic firewood. The fruit is used intensively as livestock forage as well as for human consumption.**

Prosopis glandulosa **is one of the most common mesquite species in Mexico. It is further taxonomically divided into two varieties:** *glandulosa*, **which is found in Texas and northeastern Mexico, and** *torreyana*, **which grows near the Pacific northwest coast. The latter is the most aggressive mesquite variety and is known as a pest on livestock ranges.**

Prosopis juliflora **var.** *juliflora* **is found in clearings, on slopes, and along stream beds. The species name comes from ?Julus" which means inflorescence in the shape of a whip.**

Prosopis veluntina **is a species which presents a short pubescence in the foliage and stems. It has a distribution in northeastern Mexico and grows in alluvial soils, low beaches, and in riparian zones.**

Prosopis pubescens **is found in northern Mexico in the states of Baja California, Chihuahua, and Sonora. It grows in deep alluvial soils. The species name refers to the fruit which is covered in fuzz.**

Prosopis reptans **var.** *cinerascens* **is a short species that is primarily distributed in northeastern Mexico in alluvial soils with a layer of calcium carbonate. The species name** *reptans* **means to crawl, a characteristic which can be observed in the growing plant.**

Prosopis articulata **is found only in a small area near Guaymas, Sonora, and in the states of Tamaulipas and Veracruz. It also grows in rocky mesas and clearings throughout Baja California.**

Prosopis tamaulipana, **an endemic Mexican species, is distributed along the eastern slope of the Sierra Madre Oriental mountains in the states of Tamaulipas and Veracruz. It grows in clay soils at low altitudes.**

Prosopis palmeri **is also an endemic species. Its distribution is limited to the Baja California peninsula and grows near dry creek beds and desert beaches.**

Mesquite species can be found throughout Mexico, concentrated as shown in Table 5.

Table 5. Mexican States With Mesquite Species

State	Mesquite Area (hectares)
Aguascalientes	279
Baja California	219
Baja California Sur	75,387
Coahuila	178,731
Chihuahua	126,787
Durango	559,878
Guanajuato	62,294
Hidalgo	962
Jalisco	2,575
Michoacan	427
Nuevo Leon	587,849
Puebla	4,547
San Luis Potosi	116,257
Sinaloa	5,862
Sonora	1,888,044
Tamaulipas	457,568
Zacatecas	14,512
Total	4,092,178

4. VALUE AND USES OF MESQUITE

Mesquite, due to its many different properties, has been used in different forms in many regions of Mexico. It can either be used directly or transformed. It is a magnificent soil builder, mesquite leaves deposit an important layer of organic material, it fixes atmospheric nitrogen, its roots control the movement of dunes, it is used for forage for domestic animals, it serves as habitat for wildlife, it produces nectar which is then converted into bee's honey, mesquite fruit serves as a human food source, mesquite wood is used for rustic construction projects, railroad ties and posts, and, of course, for domestic firewood. In some areas of Mexico, such as the northwest state of Sonora, mesquite is viewed as a plague, due to the intensive use of the range for livestock.

4.1. Human Consumption

Mesquite seed pods are eaten as fresh fruit or they are dried and pulverized. Candy, cookies, and bread are made from the seed pods and sold locally. Mesquite seed-pod powder is used as a coffee substitute and an alcoholic beverage is distilled from the sugars. Mesquite's abundant nectar is used in raising bees.

The protein content of mesquite seed pods is similar to soy beans and higher than many other legumes. Mesquite also has high sugar, alcohol, fiber, calcium, magnesium, potassium, iron, and zinc content (Table 6 and Table 7).

Table 6. Chemical Composition of *Prosopis*

Component	Percent of Total
Crude protein	12.12
Ether	2.73
Crude fiber	21.80
Ash	4.00
Calcium	2.20
Phosphate	0.30

Source: Franco de la Cruz (1980)

Table 7. Fractions of *Prosopis* **Seed Pod**

Fraction A	Fraction B	Fraction C	Fraction D
Exocarp 55%	Endocarp 25%	Endosperm 10%	Cotyledon 10%
Sugars 30-40% Fiber 10-20%	Fiber 35-40% Protein 8-12%	Sugars 50-70%	Protein 60% Fat 8-12%
Production of ethanol	Food production	Gum	Concentrated protein
Sugar extraction Food production			

Source: Maldonado-Aguirre (1991).

4. 2. Traditional Medicine

Mesquite plants offer a cornucopia of medicines. An extract of the seed pods as well as the fermented leaves of the mesquite plant have antibacterial effects against both *Staphylococus aureus* **and** *Escherichia coli***. An infusion made from the bark is used to cause vomiting. Resin from the trunk helps a sore throat, aids in the treatment of dysentery, strengthens the teeth, and helps with stomach problems. The leaves are also used as eye compresses to combat infections.**

4. 3. Forage

The flowers and pods are eaten by domestic animals. The flowers are only available for a short time, but the fruit has a longer viability; rural people collect the seed pods, then dry and crush them to store during dry periods. This powder is fed to livestock. Castro-Gil (1980) reports harvests of up to 25 metric tons/ha of mesquite fruit. Although domestic stock is not enamored of mesquite leaves, they are rich in nitrogen and other nutrients.

4. 4. Forestry Uses

Mesquite wood has a variety of uses ranging from its use as fence posts, furniture, firewood, parquet floors, handicrafts, cart wheels, and for rustic buildings. The native Seri people use the fibrous root (soaked in water) to make rope. Two different types of resin are extracted from mesquite: an amber one from the bark that is similar to arabic resin, and a black one used as a dye. However, the main use of mesquite in Mexico traditionally has been as firewood (Table 8).

Table 8. Firewood Characteristics

Region	Cooking Style		Most Frequently Used Species	Distance Traveled to Collect Wood		Rural Firewood Consumption
	Fire	Stove		Max.	Min.	
	(%)	(%)		(km)	(km)	(kg/month/person)
Baja California	84.54	15.46	Mesquite, Ironwood	34.17	1.73	64.819
North Pacific	83.41	16.59	Mesquite, Oak	18.62	1.50	29.635
North	17.70	82.30	Mesquite, Oak	32.00	0.92	70.906
Northern Gulf	93.31	6.69	Mesquite, Oak, Huizache	5.41	0.30	58.481
North Central	36.81	63.19	Mesquite, Huizache	12.75	1.00	38.125
Pacific Central	53.85	46.15	Huizache, Mesquite, Oak	5.95	0.33	42.438
Central	99.84	0.16	Oak, Mesquite, Pine	4.00	0.41	42.058
Central Gulf	99.22	0.78	Guisimo	3.41	0.83	90.987
South Pacific	100.0	0.00	Cualote, Oak	6.87	0.72	69.106
Yucatan Peninsula	96.45	3.55	Habin, Tzalam, Catzin	5.49	1.04	54.026

Adapted from: Secretaria de Energia, Minas e Industria Paraestatal (Nacional) (1988).

Mesquite wood, with a specific weight of 0.88 gr/cm^3 makes an excellent charcoal with a specific weight of 0.41 gr/cm^3 and a caloric value of 29.7 kj/g (Maldonado-Aguirre 1991; Wolf 1986). Annual charcoal production in Mexico is approximately 80,000 metric tons. Mesquite charcoal is highly prized for the flavor it gives the roasted food.

Studies conducted on the sapwood, heartwood, and internal and external bark of *Prosopis laevigata* **have shown that the wood is hard and durable and has many physical qualities that make it apt for furniture. This same hardness, however, makes it extremely difficult to work. The wood fibers are libriform, are moderately short, have a small diameter, and a thick wall. These fibers are suitable for high grade, medium quality paper (Table 9).**

Table 9. Microscopic Characteristics of *Prosopis laevigata* **Wood**

Fiber Length (μ) Diameter (μ) Thickness(μ)	Libriform	Moderate cut x = 887 Min. 114 Max. 1523 D = 239	Thin cut x = 11 Min. 7 Max. 21 D = 2.9	Very thick cut x = 4 Min. 2 Max. 9 D = 1.4
Cell content	Gum vessels	Axial and radial parenchyma rhomboid crystals		Fibers absent

Source: Maldonado-Aguirre (1991).

The main source of extracts in *Prosopis laevigata* **is the inner bark (Table 10).**

Table 10. Analysis of Extracts from Phloem, Sapwood, and Heartwood from *Prosopis laevigata*

Solvents	Floem	Sapwood	Heartwood
Benzene	1.623	2.684	3.109
Chloroform	0.507	1.000	0.836
Ether	0.779	0.313	0.934
Acetone	12.856	0.878	8.573
Ethanol	10.779	4.660	5.501
Water-ethanol	16.413	2.300	3.700
Water	3.000	0.500	2.050
Sum	45.955	11.837	24.704
Sum (4+5+6)	40.042	7.387	17.774

Source: Maldonado-Aguirre (1991).

The tannin content in the wood and inner bark is presented in Table 11.

Table 11. Tannin Content in Laboratory Extracts of *Prosopis laevigata*

Component	Total Extract (%)	Strasny Number (%)	Tannins (%)	Total Extract Tannins
Inner bark	9.75	62.22	6.07	0.62
Wood	8.00	37.17	3.10	0.37

Percent based on stove-dried sample.
Source: Maldonado-Aguirre (1991).

4. 5. Environmental Improvement

Mesquite trees provide shade for livestock, shelter for wildlife, and nesting sites for birds. The plants improve the soil by adding organic matter in the form of leaves, by fixing nitrogen, and by adding sulfur and soluble salts. A mesquite tree can fix up to 11.2 g/m^2 of nitrogen (Maldonado-Aguirre (1991).

4. 6. Reforestation

Mesquite trees have been used for firewood in reforestation projects in different regions throughout Mexico. Due to the species' ability to adapt to different conditions, they have been used in urban forestry projects in different cities in northern Mexico. The genus has also been used as wind breaks, and is a candidate for controlling dune movement.

5. MESQUITE'S POTENTIAL IN MEXICO

It is evident that the growing demand for mesquite wood, as well as the growing population, overgrazing, insect infestation, disease, and fire all contribute to the deterioration of this important resource. Therefore, it is necessary to develop restoration, conservation, and sustainable-use technologies in order to provide for these growing demands into the future.

Priority should be placed in the following areas: taxonomy, determination of the limits of the ecosystems where mesquite species are found, development of plans for the conservation of the biodiversity of the genus *Prosopis* **for current and future use, as well as genetic improvement programs. Aspects of domestication and planting should be considered for each region. Efficient methods of inventory need to be developed for mesquite. It is also important to define the different production systems that mesquite can take part in, such as windbreaks, soil improvement, forage, firewood, and as a drought-resistant plant.**

All of this should be undertaken keeping in mind the need for diversity of employment and income in rural areas as well as the need for technology development and integrated management that includes wildlife.

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The Potential of Prosopis in the Conservation and Development of Drylands: the FAO Perspectives

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1. INTRODUCTION

The International Convention to Combat Desertification was signed in October 1994 in Paris. It triggered a renewed dynamism in initiatives regarding the conservation and development of drylands and, in particular, in the view to combating desertification and promoting social and economic development of societies in dry lands. Drylands occupy about 3400 million hectares of emerging lands, which harbour over 500 million people who are among the poorest communities and who are among the 800 million people exposed to a number of survival problems, including food insecurity, inadequate access to drinking water and sanitation facilities, inadequate energy supply and heat from fuelwood, etc. Forestry has an important role to play in the conservation and development of drylands. It uses, preferably, multipurpose species that have a role to play in the social, economic, and economic aspects of the conservation or restoration of land productivity. These species, growing under harsh conditions, must resist drought, winds, and strong transpiration and should be adapted. *Prosopis* species are among those species that hold, as abundantly documented, great promise for the conservation and development of drylands. FAO has always given great importance to drylands and under its mandate has developed a number of initiatives to gather and disseminate information concerning multipurpose species for drylands, supported research and networking, and has promoted/implemented projects aimed at developing technologies and training people for a better use of these species in dryland development and conservation.

2. OBJECTIVES IN DRYLAND DEVELOPMENT AND CONSERVATION AND THE ROLE OF MULTIPURPOSE DROUGHT-RESISTANT SPECIES

The use of trees and shrubs in the conservation and development of drylands aims has these major objectives:

- Improve the socioeconomic conditions of dryland communities
- Restore and maintain the productive capacity of drylands
- Restore and maintain the ecological balance

2.1 Improving the Socioeconomic Conditions of Dryland Communities

The major problems in the solution of which forestry or tree planting are needed are numerous but the most important ones relate to supplying energy resources to population, complementing their direct food consumption, and providing fodder to their livestock.

[1] With inputs from Dr. F. Riveros, Chief AGPP and documentation from C. Palmberg-Lerche, Chief FORM.

2.1.1 Energy

The survey of fuelwood needs made in 1982 with projections to the year 2000, indicated 2400 million people will be either unable to meet their minimum energy requirements or will be forced to literally deplete any renewable forest resources as they will be cutting the forest faster than it is being grown. This situation was especially difficult in dry areas, most of which were under prospective deficit or in deficit or acute scarcity. The consumption of fuelwood in the early 1980s was about 1800 million m^3; it is projected at 2400 million m^3 in year 2010; most of these needs will concern dryland communities while the natural formations in these areas are limited and their productivity very low at less than 1 m^3 per ha per year. There is an evident need for important investment in tree planting within land-resources management programmes; there is need for researching the adequate species that are drought resistant and reasonably productive.

2.1.2 Trees and Food Production in Drylands

Dryland communities usually know periods of difficult food situation and recurrent food insecurity. In the corresponding countries, daily calorie intake per capita often ranges from 2000 to 2300 calories (2200 calories are necessary to meet basic nutrition needs) and the worst cases in which intake is under 2000 calories usually arise in dryland countries, especially in those in which poverty is compounded by situations of war and civil strife. In many cases, the direct contribution of plant species critically complement food availability in lean periods. The cases are many in which the gaps are filled with products from the trees the processing of which has accumulated a wealth of technological practices. Indeed, trees and shrubs of drylands have been constantly used for food production, be it as occasional snacks that can provide some support to herders or food items that can substantially complement the diet. Acacias in Australia and in some parts of Africa have been known to provide valuable food. Many other species provide direct food supply or a number of other products (gums, incense, and dyes) that may be tapped and sold for money that contributes to the restoration of food supplies. In selecting tree species for planting in dry areas, this element of contribution to food security should always be taken into great consideration.

2.1.3 Provision of Fodder for Livestock

Raising livestock is the major farming system in drylands. Pastures in these areas tend to be overwhelmed by overstocking and degraded by inadequate practices of lopping and desertification processes. In areas of seasonal rainfalls, bushfires, often cause, even during years of good rainfall, important biomass losses and the initiation of debilitating processes that ultimately may reduce the tree stocking of the pastures. The complement provided by tree browse to the feeding of livestock has been amply documented, especially in dry tropical ranges. There are also a number of trends toward less extensive husbandry modes that call for more feed inputs in which the pods of legume trees can play an important role. All these developments call for more and more fodder trees in pastoral environments.

2.2 Maintaining or Restoring the Productive Capacity of Drylands

A number of dryland species have pioneering capabilities and can be established under harsh or degraded conditions. They then serve as pioneers helping to build up soils and establish or restore new conditions more favourable to biological processes. A number of *Prosopis* and *Acacia* species are suitable for such biological missions and *Prosopis* species have been actually used under such situations.

2.3 Restoring the Ecological Balance

The plantation of resistant species can contribute to the restoration of natural vegetation in many cases in the areas surrounding or neighbouring these plantations as local conditions improve in aspects relating to reduced wind velocity, buffered temperatures, improved water economy at local levels, etc. In many cases the restoration of wild fauna has been noted, especially in small rodents, small carnivores, and bird populations. All these elements help restore ecological processes.

Conversely, cases exist in which the introduction of nonindigenous species has created a number of ecological setbacks that has been resented by local populations and thus created social dissatisfaction. The vicinity of wetlands has been up to now regarded as calling for careful consideration before introducing *Prosopis*, especially *Prosopis juliflora*; but it has been noted active regeneration of *Prosopis* associated with the migration of livestock along transhumance treks in Sahelian grasslands and steppes. The use of *Prosopis* species should consider these possible elements of rejection in some areas.

3. THE CHARACTERISTICS OF SPECIES FOR PLANTATION IN DRYLANDS AND *Prosopis* SUITABILITY

The above developments help highlight a number of characteristics that are needed for plantation in drylands. With the new guidelines promoted by the Convention on Desertification, initiatives should be taken and matured by or with the populations at grass-roots level, conducted in a truly participatory ways, and address the true needs of communities. This means that species and technologies to establish them should be socially acceptable and easily accessible to people. The species that are selected should at least have these characteristics:

- Species adapted to harsh arid conditions and to occasional occurrences of drought:
- Multipurpose species should be recommended that are:
  - Suitable for soils conservation practices;
  - Contributors to the production of service timber (building poles, posts, the important small pieces of wood needed to build sheds and prepare other implements for livestock management and shelters)
  - Suitable for producing fuelwood and charcoal, especially for the need of artisans; for fodder production be it from leaves or pods
  - Eventually, producers of direct food items or other products that can be marketed, thus contributing to income generation and improving livelihood systems in dry areas
  - Favourable to landscape beautification, ecologically suitable, and not critically harmful to the environment.

Prosopis species usually respond to these characteristics. The abundant documentation has shown a large array of services rendered by a number of *Prosopis* species including the American ones, *Prosopis africana* (especially for hardwood for "heavy duty" charcoal and various service timber and material for handicraft), *Prosopis cineraria* in Asia and the Near East whose formations constitute in many areas of this region the last refuge of remaining wildlife species and which still maintain special ecosystems that have been drastically reduced during the last 50 years.

It is under these considerations that FAO has devoted special interest to those multipurpose dryland plant species by supporting them in many field programmes and devoting a sizeable amount of its Regular Programme to their knowledge, handling, and conservation technology.

4. A SHORT REVIEW OF FAO WORK ON *Prosopis*

4.1 Supporting Cooperation and Exchange of Experiences among *Prosopis* Researchers and Developers

Since the late 1970s, FAO (especially the Grassland Group and the Forest resources Division) has been interested in the potential role of *Prosopis tamarugo* in the rehabilitation of arid and desert area in northern Chile. A study was commissioned by FAO to describe in detail the programme the Chilean government developed in the "Pampa del Tamarugal" during 1960 through 1976. This study was intended to illustrate the potential of the species in growing under very difficult conditions (2 mm annual rainfall and high significant rainfall about 250 mm once every 60 to 80 years). The limitations of *Prosopis tamarugo* under strictly dry tropical conditions were perceived later.

An international meeting on *Prosopis tamarugo* was organized in Chile in June 1984 with 18 countries participating due to the interest raised by the above mentioned study. The meeting whose proceedings were published as "The Current State of Knowledge on *Prosopis tamarugo,"* led to setting up a number of national associations dealing with the genus *Prosopis* in Latin America and the idea of establishing an "International Prosopis Association."

In 1986, FAO and the Brazilian Government organized a second International Conference on *Prosopis juliflora* in Recifé, Brazil. The 200 participants from 26 countries established an "International Prosopis Association" based in Recifé. The proceedings were published as "The Current State of Knowledge on *Prosopis juliflora*."

A Prosopis symposium was organized jointly by the Centre of Overseas Research and Development (CORD), University of Durham, in 1992, with co-sponsorship of FAO, and support from the UNESCO MAB Programme, the Technical Centre for Agricultural and Rural Cooperation and the International Prosopis Association. The proceedings were published as "Research and Development Strategies for *Prosopis*," providing guidelines to appropriate and sustainable use of *Prosopis* species in drylands.

These three events have contributed to the creation of national *Prosopis* associations in Argentina, Peru, and Brazil. These events have also served to increase awareness of the value and potential of the genus *Prosopis* when properly introduced and managed into arid, semiarid, and subhumid regions, those areas especially targeted by the Convention on Desertification.

A number of national and subregional events are regularly supported to share experience gained in development operations. In West Africa, a national symposium opened to Sahelian countries was organized in November 1993 by Cabo Verde with the support of FAO to draw national and subregional lessons from the project "Development and Utilization of Forest Resources in Cabo Verde," which accumulated large experience on the establishment, management, and use of Prosopis plantations for more than 15 years. Similar events for stock-taking are envisaged for Mauritania and Niger.

4.2 Work Supported to Better Handle *Prosopis* Species and Their Genetic Resources for Forestry Initiatives

Other activities were and are being developed to promote better knowledge and use of the species suitable for drylands, among which are *Prosopis* species.

The Forest Resources Division (Forest Resources Development Service) has developed since 1979, and upon recommendation of the FAO Panel of Experts on Forest Gene Resources, an international project on the Conservation and Better Utilization of Genetic Resources of Arboreal Species for the Improvement of Rural Living. The general objectives of the project were the conservation and improved utilization of genetic resources of multipurpose arboreal species growing in arid and semiarid areas. The priority of the project had initially gone to the genera *Acacia* and *Prosopis* and these species still remain very strong in the priorities of the Forestry Department. One of the first products of the project were the publication of two booklets on the "Collection, Handling, Storage and Pre-treatment of *Prosopis* Seeds in Latin America" and on "Seed Insects of *Prosopis* Species." A number of specific activities have been conducted through cooperation with the national institutions with catalytic funding and advice.

The FAO Panel of Experts on Forest Gene Resources continues monitoring and updating the list of priority species, among which species of the genus *Prosopis* are featured regularly.

A recent review of the role of *Acacia* species in the rural economy of Africa and the Near East included the very important *Prosopis cineraria* for the Near East.

4.3 Support to Prosopis Work for Animal Husbandry

FAO through its Grassland Group, which deals with fodder production has also provided funds and guidance to national institutions active in applied research on topics relating to better management and sustainable utilization of *Prosopis* species for fodder production. Among these, the following initiatives should be noted:

Argentina: Support was provided in the evaluation of 12 species of *Prosopis*; the development of grafting techniques for various species; taxonomic studies on the genus *Prosopis* in Chile and Argentina; management studies on natural *Prosopis* formations.

Brazil: Studies on the vegetative propagation of *Prosopis juliflora* in northeastern Brazil; use of irrigation techniques in *Prosopis* plantations; provision of processing units to prepare compound feed stuff in three regions of northeastern Brazil.

Chile: Support to the University of Tarapacà with research on pruning of *Prosopis tamarugo*; management of *Prosopis tamarugo* plantations.

Italy: Cooperation with university of Genoa through a research project in some aspects of responses to drought and salinity on *Prosopis juliflora*, *Prosopis tamarugo*, and *Prosopis cineraria.*

Mexico: Support to Centro de Investigación y de Estudios Avanzados del IPN to study quick-growing species of *Prosopis juliflora* through Letter of Agreement arrangements.

4.4 Development of Field Activities for Integrated Uses of *Prosopis* Species and Formations

Activities are developed in many countries to restore fertility on degraded lands, to stabilize moving sand dunes, and to improve the livelihood of rural communities. Three countries that exemplify these activities, undertaken mostly with *Prosopis juliflora*, are Cabo Verde, Mauritania, and Niger in dry western Africa.

In Cabo Verde, a series of projects have worked since 1978 with a number of dryland species, but particularly with *Prosopis juliflora*, to implement soil and water conservation tasks and provide fuelwood to the populations. More than 15,000 ha of plantations were established, mainly with *Prosopis juliflora.* A number of socioeconomic and ecological positive returns were observed, such as improved availability of fuelwood, with attached income generation through trading wood and charcoal needed by urban communities, to improved fodder production. However, some reservations have been expressed on ecological grounds, which are not ignored, but which will have to be monitored on a continuing basis in close cooperation with the people of this area.

In Mauritania, drought and desertification trends and high utilization pressure have depleted the *Acacia* steppes in many parts of the countries while blowing sand has threatened a number of human settlements since the early 1970s. A programme of sand dune stabilization and regeneration of agricultural lands was started with mainly *Prosopis* species, especially *Prosopis juliflora.* Experience was gained in sand-dune-stabilization techniques, use of many local and introduced species and the organization and participation of people in this process. The project also resulted in diversification of rural activities for income generation. The Manager of this project, who is presenting a paper at this workshop, will provide additional details on the status of this project.

In Niger an integrated project in the Keita valley has abundantly used *Prosopis juliflora* in a number of rehabilitation activities, including water and soil conservation, sand-dune stabilization, windbreak establishment, and establishment of small woodlots for fuelwood. These plantations were only part of a complete land-use planning, restoration, and valuation aimed at conserving productive lands and turning abandoned plateau wastelands back to production. More than 16,000 hectares established within the various "revegetation" models for various objectives, have become intimately integrated in the rural life of the local population.

All these activities are complementary and support the many functions and roles of FAO in its responsibility to support technology development, collect and disseminate information regarding identification, conservation, development, and use of plant genetic resources.

5. FUTURE PERSPECTIVES

Many countries are developing, or will be developing soon, their work programmes to implement the International Convention to Combat Desertification. As already indicated, this Convention, while making restoration of drylands mandatory to parties, stresses participation, local planning, and decentralization. More consultation and consideration in detail of the needs, doubts, and reservations of the major actors and partners, that is, the populations, will be an absolute necessity. These deliberations also involve the choice of species to be used in operations aiming at introducing forest and range species. Then, there will be increased need for hardy and resistant species to use but, at the same time, more say on species selection by local people. This entails a number of important considerations, among which are:

- The information flow on adequate species for multipurpose activities in drylands must be maintained and increased.

- It is absolutely necessary to draw from past experiences to avoid repeating mistakes and to give the most suitable advice to populations who will be gaining higher awareness on their needs and who will be probably showing greater dedication to and appropriation of, dryland restoration activities. In this connection it is essential that all research and development projects in their final phase synthesize in an handy and usable form the research results and/or technologies and methodologies they have come up with for the benefits of extension services and other development agents.

- Concentrating on particular species is alright to promote the whole potential of single species or genera, but there will be more need to promote a larger group of species and to give greater chance to diversity, use of local species, and related local technical knowledge and culture.

- It is important to associate and further involve institutions of developing countries, especially those from affected countries in a view to strengthening their institutional set up and support capacity building and local, national, and regional initiatives.

- Follow up to the present meeting should consider the elements above and especially to build on and help revive what has already been established with new concerted initiatives and resources. In other words, we are not starting from scratch. The networks that have been established (including the International Prosopis Association, the Dryland Conservation and Development Network in Latin America, the groups around the Desert Development Conference, etc.) should be sensitized, if needed, re-energized, expanded, and used. Thus, the focus could, while continuing to promote single species or genera, highlight the importance of promoting "flexible" multipurpose groups of various species with a view to providing a diversified set of species handy for use in desertification activities most likely to expand considerably in the coming years. Within the activities to be undertaken in the near future the following are important to deliver soon:

- Coordinating efforts between this initiative and the previous ones to see how to conduct business in the future and pool forces.

- Identifying major areas of cooperation especially in further investigating the *Prosopis* species especially those insufficiently known like *Prosopis africana*, and looking at the equitable share and custody of *Prosopis* genetic resources.

- Collecting information and organizing data bases on capabilities and human resources for technical cooperation on *Prosopis* species.

FAO has a broad mandate and experiences on all these issues; such capital is at the disposal of countries and organizations and could provide the general forum that would valorize all initiatives including this and help develop synergical linkages from which all will equitably benefit.

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