

An Investment-based Approach to *Prosopis* Agroforestry in Arid Lands

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Abstract: This paper suggests that many of the social goals of agroforestry in arid lands, i.e., soil improvement, provision of firewood and income generation, etc., can be accomplished with *Prosopis* plantations used to produce lumber for fine furniture and flooring. *Prosopis* lumber compares favorably in color, hardness and shrinkage values to the world's finest timbers that also belong to the legume family such as padauk (*Pterocarpus soyauxii*), purpleheart (*Peltogyne* spp.), cocobolo (*Dalbergia retusa*), Indian rosewood (*Dalbergia latifolia*), and Brazilian cherry (*Hymenaea courbaril*). Data from various field trials was combined to produce the scenario of a *Prosopis alba* plantation on a 10 x 10 m spacing that was annually intercropped. These trees were predicted to achieve 38 cm in diameter in 30 years with a sawn lumber volume of 15.9 m³ ha⁻¹ worth \$ 856 m⁻³. After the cost of sawing the trees into lumber (\$ 107 m⁻³) and the total plantation costs of \$ 2135 over the 30 years was deducted, the net profit was predicted to be \$ 9,774 ha⁻¹ and the internal rate of return was calculated to be 9.3% using an interest rate of 8%. No value was ascribed to the high sugar content in the pods, of value to both humans or livestock, to soil improvement from N fixation or to provision of firewood from prunings. Thus, the 9.3% internal rate of return should be considered a minimum value. Due to the long term nature of the investment, plantations for fine lumber may be outside the financial capabilities of rural poor. As a result it may be necessary to attract investors from large investment firms that have a portion of their funds in long term investments.

Key words: *Prosopis*, agroforestry, lumber, timber, algarrobo plantations, tree plantation, economic evaluation.

It is probably fair to say that most of the world's agroforestry programs originate from institutional and government agencies and that altruistic objectives such as the need to conserve soils, provide fuelwood to the poor, and create jobs, are the basis for these programs. Large-scale extension programs are often coupled with subsidies in the form of reduced seedling prices, or direct payments to farmers to achieve wide scale adoption of agroforestry programs. Unfortunately, after the government programs end, many of the altruistically driven agroforestry activities also end.

In contrast, private enterprises with good investment returns often undergo very rapid expansion. The immense influx of capital into mutual funds and the stock market in the mid 1990's and the expansion of the world area planted to cotton following good prices in the early 1990's (FAPRI, 1998) are examples of rapid adoption of activities that have a good return on the investment. Investment consultants usually offer a variety of investment programs ranging from long-term, moderate return with little risk, to high return potential with substantial risk.

It appears as if the lack of widespread implementation of agroforestry programs is due to lack of adequate return on investments into agroforestry activities. There appears to be two possibilities for this lack of investment into agroforestry of arid lands. Either there are no products from arid agroforestry capable of generating a good return on the investment, or what is lacking is development of detailed business plans and markets for the products.

Of all the agricultural products from arid lands, fine hardwood lumber and value added products from hardwood lumber such as flooring and furniture has one of the greatest prices per unit weight. For example, in 1999, a cubic meter of *Prosopis alba* lumber that weighed 784 kg (@ 12% moisture), had a price of \$ 856 in Argentina and the United States (@ \$ 2 bd⁻¹ ft and 428 bd ft m⁻³) and thus had a price of \$ 1090 per metric ton. In comparison, 1999 prices

were \$ 90 t⁻¹ for maize and \$185 t⁻¹ for soybeans (CBOT, 1999).

Of fundamental importance to the development of any business enterprise is the long-term demand for the product at good prices and the lack of potential competing products from other international sources. Fine hardwood lumber is one of the few commodities that have had a long history of increase in demand. The long term increase in the price of cherry logs is one indicator of the stability of hardwood lumber prices (Fig. 1). Another indication of the growing demand for hardwoods is that from 1975 to 1986 US exports increased by nearly 300% from 487,000 m³ in 1975 to 2,605,000 m³ 1986 (value of \$ 516 M) (Araman, 1987). Ten years later in 1996 this export nearly doubled again to \$ 1,200 M (US Department of Commerce, 1996). The top ten countries

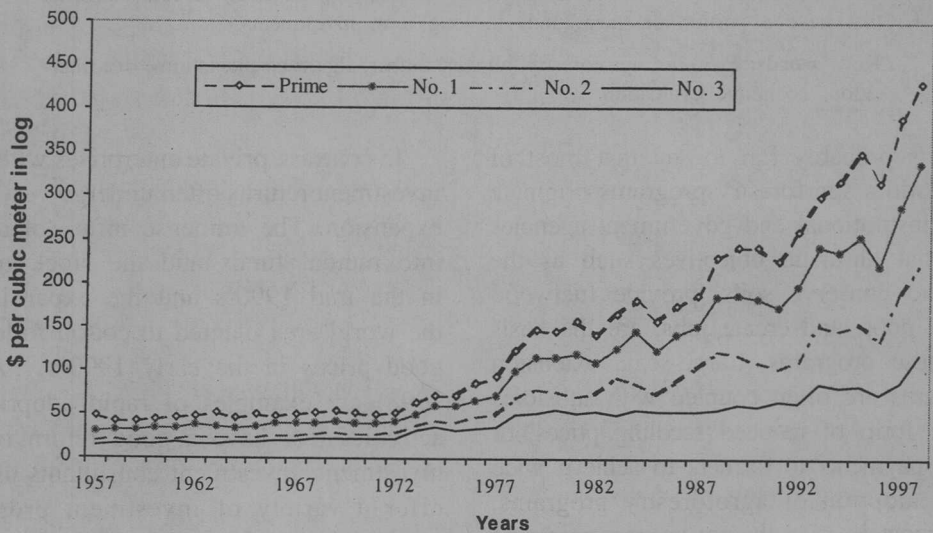


Fig. 1. Cherry (*Prunus serotina*) log prices (\$ per cubic meter) in Indiana for Prime, No 1, No 2 and No 3 logs which decrease in quality, respectively. Data courtesy of Hoover (1999).

that purchased US hardwoods were: Canada \$ 262 M, Japan \$ 136 M, Italy \$ 88 M, West Germany \$ 86 M, United Kingdom \$ 70 M, Mexico \$ 66 M, Spain \$ 64 M, Taiwan \$ 60 M and Korea \$ 54 M (US Department of Commerce, 1996).

To provide a market-driven incentive to sustainable tropical forest management, the Forest Stewardship Council was formed to provide a process for ecological certification (Merry and Carter, 1997). While wood products from plantations that have been ecologically certified only have marginally higher prices, it has been suggested that they should lead to a much greater market share on the international wood market. The certification criteria include considerations of land tenure, respect for indigenous people's rights, use of multiple products and services and management in an environmentally friendly manner (Merry and Carter, 1997). Other organizations such as the World Wildlife Fund (www.panda.org/forests4life), Smartwood (kbatch@smartwood.org), and the Certified Forest Products Council (www.certifiedwood.org) promote ecological certification and market development of products from ecologically certified forests.

It is the intent of this communication to point out the advantages of an agroforestry program in which the production of fine hardwood lumber is the economic driving force.

Results of this economic assessment will show that *Prosopis* plantations are a moderate return, stable, and long term investment. This emphasis on hardwood lumber production is not to belittle social goals such as alleviation of rural poverty or the enhancement of the environment, but rather to provide a market-driven approach to

fulfilment of social goals that will be economically sustainable.

Comparison of Algarrobo Lumber to Other Fine Timbers

Substantial documentation exists that *Prosopis* has been one of the most important sources of charcoal and firewood in diverse arid regions of the world such as Haiti (Lea, 1996), Mexico (Rodriguez-Franco and Maldonado-Aguirre, 1996), India (Varshney, 1996; Singh, 1996) and Argentina (Ochoa, 1996). Undoubtedly *Prosopis* also provides significant quantities of firewood and charcoal in other arid regions where it is abundant, i.e., Sahelian Africa, Chile, Ecuador, Peru and Pakistan. While utilitarian household furniture has been made from *Prosopis* in parts of Mexico and Argentina, the vast difference in value between *Prosopis* charcoal (\$ 100 t⁻¹) and fine timber, as described above (\$ 1000 t⁻¹), has not been recognized. To gain a perspective on the value of *Prosopis* lumber, it is useful to compare its technical characteristics to other timbers of comparable technical quality and appearance.

Many of the highly colored, dense furniture woods of the world's tropical rainforests belong to the legume family. These include padauk (*Pterocarpus soyauxii*) (crimson red), purpleheart (*Peltogyne* spp.) (purple), cocobolo (*Dalbergia retusa*) (deep red), Indian rosewood (*Dalbergia latifolia*) (dark violet), Brazilian cherry (*Hymenaea courbaril*) (reddish brown) as well as *Prosopis*. Generally speaking, these tropical legume hardwoods are harder and have greater densities than common temperate and tropical non-legume hardwoods such as Honduran mahogany (*Swietenia macrophylla*), teak

Table 1. Comparison of *Prosopis alba* (algarrobo blanco) wood physical - mechanical characteristics to other fine hardwoods

Properties	Legumes						Tropical non-legumes		Temperate non-legumes		
	Algarr- obo (1)	Brazi- lian cherry (2)	Coco- bolo (3)	Indian rose- wood (4)	Padauk (5)	Purple heart (6)	Hond- uran mah- ogany (7)	Teak (8)	Black cherry (9)	Walnut (10)	White Oak (11)
Density (kg m ⁻³)	750- 850	—	1000- 1245	850	670- 820	800- 1060	480- 830	640	560	630	760
Bending strength (MOE x 10 ³)	1380	2160	1880	1780	5560	2000	1500	1450	1490	1680	1780
Shrinkage (%) volumetric	4.8	12.7	8.5	8.5	7.6	9.9	7.8	7.0	11.5	12.8	16.3
Tangential (%)	2.9	8.5	4.6	5.8	5.2	6.1	4.1	5.8	7.1	7.8	10.5
Radial (%)	1.8	4.5	2.9	2.7	3.3	3.2	3.0	2.5	3.7	5.5	5.6
Side Hardness (kg)	1060	1070- 1490	1240	1440	—	845	380	450	430	460	620

1. *Prosopis alba*, 2. *Hymenaea courbaril*, 3. *Dalbergia retusa*, 4. *Dalbergia latifolia*, 5. *Pterocarpus soyauxii*, 6. *Peltogyne* spp., 7. *Swietenia macrophylla*, 8. *Tectona grandis*, 9. *Prunus serotina*, 10. *Juglans nigra*, 11. *Quercus alba*.

Values for *Prosopis alba* are from Turc and Cutter, 1984.

(*Tectona grandis*), Black cherry (*Prunus serotina*), walnut (*Juglans nigra*) and white oak (*Quercus alba*) (Table 1). For example, *Prosopis alba* has about twice the hardness of mahogany, teak, white oak and walnut. The hardness of *Prosopis alba* and other tropical hardwoods allows use of finer sandpaper that in turn leads to smoother and higher quality finishes. The greater hardness also leads to less wear for flooring and furniture that is subject to continual use.

In what is perhaps the most important physical characteristic for fine furniture and flooring, i.e., radial, tangential and volumetric contraction with respect to changing wood moisture, *Prosopis* has the lowest and thus most desirable values (Table 1). Since the

radial and tangential shrinkage values of algarrobo are almost equal, the wood shrinks equally in all directions. This lack of shrinkage is of importance when furniture is moved from a high humidity region to low humidity region or when seasonal changes result in air humidity changes.

Since many of the highly colored legumes described above are from tropical rainforests, there is significant public concern in use of these woods. In contrast, as *Prosopis* occurs naturally on millions of hectares of semi-arid regions of the world, there is little danger of the populations being radically reduced. However, there is a concern in its native habitat in Argentina that the largest trees are being harvested first leading to erosion of the gene pool for erect tall trees.

Government incentives to plant algarrobo in Argentina (ca. \$ 300 ha⁻¹) have stimulated establishment of new plantations (1400 ha in the Province of Santiago del Estero for 1999) that will help guarantee the sustainability of this resource. Not only can algarrobo substitute for the world's finest furniture timbers on the basis of its physical properties, but substitution of algarrobo for these fine timbers can also reduce the pressure on tropical rainforest species.

Plantation Techniques and Annual Growth Rates

In order to arrive at the economic analyses, it is necessary to know the operations that are required for the plantation and the annual growth rates that will result from these operations. At this time, no *Prosopis* plantations have been harvested at 25 years of age to know with certainty the long-term growth rates. However, data are available for 10 years' growth from native *P. glandulosa* managed stands (Patch and Felker, 1997) and from young plantations (3 years of age) that were intensively managed for bioenergy production (Felker *et al.*, 1989). These intensively managed plantations achieved a yield of 20 dry Mg ha⁻¹ in the third growing season without irrigation at transplant or any other stage of the plantation. Three years after planting these trees had mean basal diameters of 7 cm and heights of 6 m. Data on tree diameter/spacing relationships is available from native stands (Felker *et al.*, 1990).

The operations described below result from a synthesis of the best practices from many trials, i.e., weed control (Felker *et al.*, 1986), container sizes (Felker *et al.*, 1987) and fertilization (Wightman and Felker,

1990), and are designed for a commercial plantation to achieve sufficiently rapid growth to generate an economically viable return on the investment. If rapid growth rates, high seedling survival and good investment returns are not required, critical plantation establishment procedures such as weed control and subsoiling could be eliminated.

Plantation Requirements and Procedures

While algarrobo plantations do not require irrigation, they require fields that have been subsoiled, that are free of weeds and that have been treated with pre-emergence herbicides. The soil salinity should be less than 12 mhos cm⁻¹ (Rhodes and Felker, 1987) and the pH should be less than 8.5 (Cline *et al.*, 1986). The rainfall should be at least 500 mm y⁻¹. In the rainy season prior to planting the field should be cultivated and subsoiled. These operations increase the ability of roots to quickly penetrate moist zones and to capture stored moisture for the next growing season. When considering that 1 mm of stored rainfall ha⁻¹ is equivalent to 10,000 L of water ha⁻¹, the benefits of site preparation the season before planting are obvious. Inexpensive pre-emergence herbicides such as karmex (diuron) or Lorox (linuron) at rates of 2 kg ha⁻¹ or surflan (oryzalin) at high rates of 2.5 kg ha⁻¹ offer good season-long control of most weeds (Felker *et al.*, 1986).

Seedlings are best grown in long (35 cm), narrow (3.5 by 3.5 cm) cardboard containers with open bottoms (Felker *et al.*, 1987). These seedling containers provide air pruning of the roots and avoid spiral root systems. The seedlings are planted with the containers still on. A heavy-duty tree transplanter, adapted from a subsoiler, is

used to plant 300 trees ha^{-1} , all 40 cm deep.

It is convenient to plant the trees on a 10 x 10 m spacing to allow for intercropping with plants such as maize and sorghum. It would be possible to plant algarrobo at higher densities, but the lower rainfall in arid regions does not permit mature trees with 40 cm diameters on spacings less than 10 m (Felker *et al.*, 1990). At 10 m spacings, annual diameter increases by 1.25 cm y^{-1} have been obtained over a 9 year period (Patch and Felker, 1997). Thus, it appears possible to obtain a 38 cm diameter tree in 30 years. A stand of 100, 38 cm diameter trees are predicted to have a sawn lumber volume of 6800 bd ft (15.9 m^3) (Felker *et al.*, 1990) for an annual increase of $0.53 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$.

The landowner should consider purchasing a sawmill or paying to have the logs sawn to add value to the logs. To illustrate the difference in annual returns from a *Prosopis* plantation with and without sawing the trees into lumber, consider that the average prices for *Prosopis* logs in Argentina are about $\$ 100 \text{ t}^{-1}$. Since a cubic meter of *Prosopis alba* containing 428 board ft weighs 784 kg (@ 12% moisture), at 1998 prices of $\$ 2 \text{ bd}^{-1} \text{ ft}$ ($\$ 856 \text{ m}^{-3}$), algarrobo lumber is worth $\$ 1090$ per metric ton (12% moisture). As described later, there would be 15.9 m^3 of lumber from this plantation at 30 years. If the landowner sawed these trees himself, at a lumber price of $\$ 856 \text{ m}^{-3}$ the annual increase in value would be $\$ 453 \text{ ha}^{-1} \text{ y}^{-1}$. However, if the logs were sold without being sawn into lumber, they would be only worth about $\$ 45 \text{ y}^{-1}$.

It is clearly to the landowner's advantage to saw the trees into lumber to obtain the value added possibly from the lumber.

Efficient Utilization of all Algarrobo Size Classes

Even with pruning, *Prosopis* trees will not be as straight as pine trees and they will have significant large side branches. To obtain the greatest value for the entire tree, it is important to maximize the value of each of the fractions. The most valuable fraction is long wide ($2 \times 0.25 \text{ m}$) clear straight lumber (up to $\$ 1200 \text{ m}^{-3}$), followed by small lumber ($0.50 \times 0.10 \text{ m}$) for flooring ($\$ 800 \text{ m}^{-3}$), followed by wood for charcoal and firewood (about $\$ 50 \text{ m}^{-3}$).

Thus, whenever possible, it is economically advantageous to convert logs to flooring rather than firewood or charcoal. Lumber is traditionally obtained from logs, a minimum of 30 cm in diameter and 1 m in length. New sawmill systems, called Scragg Mills, are now available to efficiently produce flooring from logs that are only 22 cm in diameter and 50 cm in length. In this sawmill, a chain with clips is used to push small logs through 2 blades that are spaced 10 to 15 cm apart. About 3 small logs (25 cm diameter and 40 cm long) can be processed per minute (Morgan Saw, Sarepta, LA pers. comm., 1998). As there is no equipment to produce high value solid products from logs less than 20 cm in diameter they can only be used for firewood and charcoal.

To summarize, logs greater than 30 cm in diameter and 1 m in length should be sawn on conventional sawmills to produce lumber worth up to $\$ 1200 \text{ m}^{-3}$. Logs from about 20 to 30 cm in diameter and 50 cm

Table 2. Plantation costs and economic returns for a hypothetical *Prosopis* plantation in Santiago del Estero, Argentina

Time	Operation	Total
Year before planting	Disk field 2 times (\$ 44); subsoil (\$ 20); and apply Diuron at 2 kg ha⁻¹ (\$ 25)	\$ 89
Year of planting	- Mark field for 10 by 10 m plantings 2 man-hour (\$ 4) - Transplant 100 trees ha⁻¹ with tractor (\$ 15) and 3 man team (\$ 6) for \$ 21 total for transplanting - Seedling costs 100 @ 0.15 each (\$ 15) - Apply preemergence herbicide Diuron at 3 kg ha⁻¹ (\$ 38 ha⁻¹) on 1.5 m both sides of trees (0.3 ha) (\$ 11) - Apply soil insecticide to control boring insects (\$ 23) - Rodent control (\$ 28). - Sweep cultivator for weed control (\$ 22) (3 times y⁻¹ with 2 passes each time) 6 times y⁻¹ (\$ 132 ha⁻¹ or \$ 40/3 m strips) - Stake trees and prune side branches to 2 m height 3 times (\$ 18)	\$ 160
1st year after planting	- Replant the dead (10%) seedlings (\$ 2 per seedling) & 3 h (\$ 6) for \$ 8 total - Cultivate the field 3 times y⁻¹ with 2 passes each (\$ 40). - Apply diuron and simazine at 1.5 kg ha⁻¹ each in 3 m strips (\$ 11) - Prune the trees to 3 m height (\$ 18).	\$ 77
2nd & 3rd year after planting	- Cultivate the field 3 times y⁻¹ with 2 passes each (\$ 40) - Apply diuron and simazine at 1.5 kg ha⁻¹ each in 3 m strips (\$ 11) - Prune the trees to 3 m height (\$ 18)	\$ 138 (for both years)
4th year after planting to 29 years after planting	- Cultivate the field 3 times y⁻¹ with 2 passes each (\$ 40) - Apply diuron and simazine at 1.5 kg ha⁻¹ each in 3 m strips (\$ 11) 25 years @ \$ 51 y⁻¹ = 1275 - In addition in years 10, 15 and 20 prune trees @ \$ 18 - Total direct costs. - Plus overhead charges of 19.1%	\$ 54 \$ 1,793 <u>\$ 342</u>
	TOTAL	\$ 2,135
Income	Total sawn lumber 15.9 m ³ @ \$ 856 m ⁻¹ Cost to saw lumber @ \$ 107 m ⁻³ Net sales of lumber Total plantation costs Net profit	\$ 13,610 \$ 1,701 \$ 11,909 <u>\$ 2,135</u> \$ 9,774

in length should be processed on a Scragg Mill to produce flooring worth \$ 800 m⁻³. Logs less than 20 cm in diameter can only be processed into firewood or charcoal.

Costs of Plantation Establishment and Maintenance

The plantation costs described in Table 2 are for Santiago del Estero, Argentina in 1999 and are in US dollars using the 1 to 1 exchange rate of Argentine pesos to US dollars. The plantation design assumed 100 trees per hectare on a 10 x 10 m spacing that was intercropped. Pre-emergence weed control assumed a 1.5 m strip on both sides of the trees. Thus 7 m was available for intercropping between the rows. Labor costs assumed \$ 1.50 h⁻¹ direct labor charges and \$ 0.54 h⁻¹ benefit charges for a total of \$ 2.04 h⁻¹ labor charges. Supervision/technical direction in the field and administration in the office were calculated to be 19.1% of total costs.

Economic Analyses

The internal rate of return for these costs and revenues was 9.31% using an interest rate of 8%. It is interesting that the thesis of Benjamin (1996) on a walnut agroforestry system in Indiana also used annual diameter increases of 1.25 cm y⁻¹ and achieved internal rates of return from about 9 to 18% depending on the intercrop and rotation age. Due to the greater rainfall they were able to achieve greater final densities of about 350 trees ha⁻¹. The internal rate of return for the *Prosopis* system we have described must be considered a minimum value, since this analysis does not ascribe any value to any other products from this plantation, i.e., pods,

firewood, charcoal, or soil nitrogen increases as described below.

Other Useful Economic Products

In addition to the economic returns from production of fine lumber from *Prosopis*, these plantations produce other valuable products such as high sugar content pods and branches for firewood and charcoal production. Unfortunately, quantitative data is not available to include the returns from these products in the economic assessment. Nevertheless, it is important to briefly describe the importance of these other products.

Starting at about 5 years of age, *Prosopis* produces pods with about 30% sucrose and 10% protein (Oduol *et al.*, 1986) that have no toxic constituents and that are a valuable resource for livestock. Pod production is highly variable from tree to tree and from year to year. In good years small trees (15 cm trunk diameter) may produce 5 to 10 kg of pods while large trees (40 cm trunk diameter) may produce 40 kg of pods (Felker *et al.*, 1984).

These pods were an important component of the diets of indigenous people in south-western United States (Felger, 1979) as well as Argentina (Ochoa, 1996) and to the early European settlers and their livestock. Contemporary research focusing on production of refined flours and syrups from algarrobo pods for human food applications is highly promising (Grados and Cruz, 1996). It seems probable that a program to combine food technology research with a program to select trees with consistently high pod production and to develop efficient harvesting techniques could result in a significant industry from *Prosopis* pods.

Firewood and charcoal is an important commodity in most arid lands. Due to the above-average density of algarrobo (750 kg m^{-3}), it is a very good firewood and it makes charcoal that is in high demand. Unfortunately, the prices of charcoal and firewood are low (\$ 80 to 100 t^{-1}) compared to the lumber (\$ 1000 t^{-1}). Thus firewood and charcoal production from algarrobo plantations are best viewed as a non-cash benefit to those caring for the plantation or possibly for minimal sales to recover the costs of the pruning operations.

Environmental Benefits

The soils of the world's arid regions have some of the lowest organic carbon and nitrogen contents of any ecosystem (Jenny, 1944). This can be attributed to high air temperatures and low soil moisture contents that result in high soil temperatures and thus rapid organic matter degradation rates (Katterer *et al.*, 1998). Soil organic carbon and nitrogen are critically important as these constituents increase soil water infiltration, the ability of the soil to store nutrients and the ease with which roots can penetrate soils (Breman and Kessler, 1997; Charreau and Vidal, 1965). Recent studies on N fixation in mature *Prosopis* stands using natural abundance $\text{N}^{15}/\text{N}^{14}$ isotopes found that soils under the canopies of large *Prosopis glandulosa* (60 cm in diameter) had 14 t ha^{-1} more soil C and 3.5 t ha^{-1} more soil N than soils outside the canopy (Geesing *et al.*, 1999). Thus algarrobo plantations will greatly increase the soil chemical and physical properties so critical to the environment of arid lands.

Locations Where Investment into Algarrobo Plantations Appear Feasible

The north-western provinces of Argentina, i.e., Santiago del Estero, Chaco, Cordoba and Santa Fe, are highly promising for these *Prosopis* plantations due to: (1) greater acceptance by the people of the importance of this tree, (2) the fact that *Prosopis* is well adapted to the climate, insects, and diseases of its native habitat, (3) the combination of low land prices (\$ 50 ha^{-1}) and abundant inexpensive labor (\$ 15 d^{-1}), and (4) favorable government policies that currently subsidize planting up to \$ 340 ha^{-1} .

In addition to rainfed areas of north-western Argentina where these data were developed, plantations of algarrobo should be a good investment in other areas as well. For example,

- In north central India (Haryana) where irrigation mismanagement has resulted in vast areas of alkaline soils/sodic soils with pH values too high, i.e., 10.4 for traditional crops. Here Singh (1996) has found that after 20 years *Prosopis* plantations changed the pH from 10.3 to 8.03 and the soil C from 0.12 to 0.58%. To illustrate the value of lumber in arid regions, when the trees from a research plot, to control high pH, were auctioned off at the Central Soil Salinity Research Institute at Karnal, India, Rs. 412,000 (about \$ 10,000 US) were obtained (G. Singh, 1999 pers. comm.). These trees were 28-year-old and the research plot contained 394 trees, including 191 *Eucalyptus*, 122 *Prosopis*, 41 *Terminalia*, 20 *Albizia*, 16 *Acacia* and 4 *Azadirachta indica*. In the case of *Prosopis*, 113 trees had

diameter from 20 to 120 cm and 9 trees had a diameter between 120 and 180 cm.

- In Pakistan, considerable research has been conducted to find *Prosopis* species capable of moderate growth with irrigation from highly saline groundwater (Ahmad *et al.*, 1994, 1996). Much of this work has been directed at growing plantations of *Prosopis* along the desertic coastline of Pakistan. In addition, Moid Ahmad, Geology Department, Ohio University, Athens, Ohio (pers. comm.), has strongly advocated use of *Prosopis* to lower the saline water table in the irrigated areas along the Indus River. In these areas purchase of the currently unusable land at very low prices and planting of salt-tolerant algarrobo should provide good return on the investment as well as recover the soil.
- In both India and Pakistan, sissham (*Dalbergia sissoo*) is very highly regarded as a furniture wood due to its orange/red color, its hardness and its ability to take a fine finish. Unfortunately, sissham has a slow growth rate in relation to more common timber trees, i.e., pine, eucalyptus. The form of sissham leaves much to be desired. While shrinkage data are not available for *D. sissoo*, the shrinkage data for closely related *D. latifolia* would suggest (Table 1) that *Prosopis alba* lumber is more dimensionally stable than sissham. Lumber hardness and shrinkage data for *Prosopis juliflora* taken from the Island of Vieques near Puerto Rico, were very similar to the excellent properties of Texas *Prosopis glandulosa* and *P. alba* (K. Rogers, Texas Forest Products, Lab Lufkin, TX pers. comm.).
- Thus, it appears possible to use *Prosopis juliflora* that is so widespread in India and Pakistan, as a replacement for sissham.
- In spite of the low annual rainfall in the northern deserts of Peru (ca 70 mm y^{-1}), due to periodic intense rains from El Nino years (2000 mm) that recharge the water table, there is estimated to be 150,000 ha of *Prosopis pallida/juliflora* near Piura, Peru (N. Grados, pers. comm.). Intensive efforts at the University of Piura have resulted in new food products and processing systems for *Prosopis* pods for human food uses. A World Bank project has been proposed using city sewage water to establish *Prosopis* plantations (E Loayza, World Bank, pers. comm.). In addition, plantations where groundwater is close to the surface should be feasible.
- In the semi-arid central plateau of Mexico, i.e., Guanajuato, San Luis Potosi, *Prosopis* has been an important resource for centuries (Franco and Maldonado, 1996; Silbert, 1996). In this region, many of the window frames and doors of homes and churches were made from *Prosopis*, but now few trees of the sizes required are available. Due to low land prices, abundant labor and low and uncertain yields from traditional crops, *Prosopis* plantations for lumber should be a good investment.

Ecological Certification

To provide a market driven incentive to improved tropical forest management, the Forest Stewardship Council was formed to provide a process for ecological certification (Merry and Carter, 1997). The certification

criteria include considerations of land tenure, respect for indigenous people's rights, use of multiple products and services and management in an environmentally friendly manner (Merry and Carter, 1997). Wood products from plantations that have been ecologically certified command greater price and appeal on the international wood market. Although algarrobo is not certified, plantations of algarrobo should be easily certifiable as they benefit the environment and provide multiple products and services.

The long-term world wide increase in demand for furniture quality hardwoods, combined with public concern for the over-harvest of tropical rainforest timbers suggests that the demand for fine hardwoods, from sources other than tropical rainforests, is very likely to continue. The excellent shrinkage values of *Prosopis*, combined with above average hardness values and excellent finishing characteristics, suggests that *Prosopis* has excellent long term potential in the world, fine hardwood market.

When the moderate *Prosopis* growth rates ($0.5 \text{ m}^3 \text{ y}^{-1}$) are combined with low land values and low labor costs, good rate of internal returns (about 9%) appear possible. As *Prosopis* is native, or has been naturalized for many decades to many of the world semi-arid regions, the biological risks in the growth of the tree in plantations are minimal. In many of the world semi-arid regions, where *Prosopis* is native, i.e., Argentina, Peru and Mexico, the tree has been highly valued by original inhabitants and later Europeans for centuries, and a *Prosopis* plantation project would enjoy widespread public support. In some areas where it has become naturalized, i.e., India, Pakistan and Brazil, it is also highly regarded and would

also enjoy support from the local community. The environmental aspects of an algarrobo plantation would be highly positive and beneficial to the environment.

Reforestation of arid lands has been a high priority for many non-governmental organizations and multinational aid agencies for many decades and tens of millions of dollars have been spent trying to achieve this objective. It now appears possible to fund the reforestation of arid lands, that will result in many benefits for some of the world's poorest people, solely based on private investments into fine lumber production from *Prosopis*.

References

- Ahmad, R., Ismail, S. and Khan, D. 1996. Use of *Prosopis* in Arab/Gulf states, including possible cultivation with saline water in deserts. In *Prosopis: Semi-arid Fuelwood and Forage Tree* (Eds. P. Felker and J. Moss), pp. 1.41-2.1. Building Consensus for the Disenfranchised. Center Semi-Arid Forest Resources Publication, Kingsville. www.tamuk.edu/webuser/symposium.
- Ahmad, R., Ismail, S., Moinuddin, M. and Shaheen, T. 1994. Screening of mesquite (*Prosopis* spp.) for biomass production at barren sandy areas using highly saline water for irrigation. *Pakistan Journal of Botany* 26: 265-282.
- Araman, P.A. 1987. New patterns of world trade in hardwood timber products. *Annual Agricultural Outlook Conference*, Outlook 88, Session 22, pp. 391-401. USDA Washington, DC.
- Benjamin, T.J. 1996. Financial analysis of a black walnut and corn agroforestry system. Unpublished M.S. Thesis. Department of Forestry & Natural Resources, Purdue University W. Lafayette, IN. 109 p.
- Breman, H. and Kessler, J.J. 1997. The potential benefit of agroforestry in the Sahel and other semi-arid regions. *European Journal of Agronomy* 7: 25-33.
- CBOT, 1999. *Chicago Board of Trade*. www.cbot.com/mplex/vendors.

- Charreau, C. and Vidal, P. 1965. Influence de l'Acacia albida sur le sol, nutrition minerale et rendements des mils Pennisetum au Senegal. *L'Agronomie Tropicale* 6-7: 600-625.
- Cline, G., Rhodes, D. and Felker, P. 1986. Micronutrient, P and pH influences on growth and leaf tissue levels of *Prosopis alba* and *Prosopis glandulosa*. *Forest Ecology and Management* 16: 81-93.
- FAPRI, 1998. *World Agriculture Outlook*. March 1998. World Cotton Prices.
- Felger, R.S. 1979. Ancient crops for the Twenty-first century. In *New Agricultural Crops* (Ed. G.A. Ritchie), pp. 4-19. American Association for the Advancement of Science Symposium Volume.
- Felker, P., Clark, P.R., Osborn, J.F. and Cannell, G.H. 1984. *Prosopis* pod production - A comparison of North American, South American, Hawaiian, and germplasm in young plantations. *Economic Botany* 38: 36-51.
- Felker, P., Meyer, J.M. and Gronski, S.J. 1990: Application of self-thinning in mesquite (*Prosopis glandulosa* var. *glandulosa*) to range management and lumber production. *Forest Ecology and Management* 31: 225-232.
- Felker, P., Smith, D. and Wiesman, C. 1986. Influence of chemical and mechanical weed control on growth and survival of tree plantings in semi-arid regions. *Forest Ecology and Management* 16: 259-267.
- Felker, P., Smith, D., Wiesman, C. and Bingham, R.L. 1989. Biomass production of *Prosopis alba* clones at 2 non-irrigated field sites in semiarid south Texas. *Forest Ecology and Management* 29: 135-150.
- Felker, P., Wiesman, C. and Smith, D. 1987. Comparison of seedling containers on growth and survival of *Prosopis alba* and *Leucaena leucocephala* in semiarid conditions. *Forest Ecology and Management* 24: 177-182.
- Franco, C.R. and L. Maldonado, A. 1996. Overview of past, current and potential uses of mesquite in Mexico. In *Prosopis: Semi-arid Fuelwood and Forage Tree* (Eds. P. Felker and J. Moss), pp. 6.41-6.53. Building Consensus for the Disenfranchised. Center Semi-Arid Forest Resources Publication, Kingsville, TX. www.tamuk.edu/webuser/symposium.
- Geesing, D., Felker, P. and Bingham, R.L. 1999. Influence of mesquite (*Prosopis glandulosa*) on soil nitrogen and carbon development: implications for global carbon sequestration. *Journal of Arid Environments* (in press).
- Grados, N. and Cruz, G. 1996. New approaches to industrialization of algarrobo (*Prosopis pallida*) pods in Peru. In *Prosopis: Semi-arid Fuelwood and Forage Tree. Building Consensus for the Disenfranchised*. (Eds. P. Felker and J. Moss), pp. 6.41-6.53. Center Semi-Arid Forest Resources Publication, Kingsville, TX. www.tamuk.edu/webuser/symposium.
- Hoover, W.L. 1999. *Indiana Forest Products Price Report and Trend Analysis*. Annual Report. Department of Forestry, Purdue University, W. Lafayette, IN, USA.
- Jenny, H. 1944. *Factors of Soil Formation*. New York: McGraw-Hill Book Co., Inc., USA.
- Katterer, T., Reichstein, M., Andren, O. and Lomander, A. 1998. Temperature dependence of organic matter decomposition: a critical review using literature data analyzed with different models. *Biology and Fertility of Soils* 27: 258-262.
- Lea, J.D. 1996. A review of literature on characoal in Haiti. In *Prosopis: Semi-arid Fuelwood and Forage Tree. Building Consensus for the Disenfranchised* (Eds. P. Felker and J. Moss), pp. 2.33-2.45. Center Semi-arid Forest Resources Publication, Kingsville, TX. www.tamuk.edu/webuser/symposium.
- Merry, F.D. and Carter, D.R. 1997. Certified wood markets in the US: Implications for tropical deforestation. *Forest Ecology and Management* 92: 221-228.
- Ochoa, J. 1996. A review of the social and economic opportunities for *Prosopis* (algarrobo) in Argentina. In *Prosopis: Semi-arid Fuelwood and Forage Tree* (Eds. P. Felker and J. Moss), pp. 5.19-6.1. Building Consensus for the Disenfranchised. Center Semi-arid Forest Resources Publ. Kingsville, TX. www.tamuk.edu/webuser/symposium.
- Oduol, P.A., Felker, P., McKinley, C.R. and Meier, C.E. 1986. Variation among selected *Prosopis* families for pod sugar and pod protein contents. *Forest Ecology and Management* 16: 423-424.
- Patch, N.L. and Felker, P. 1997. Evaluation of silvicultural treatments of sapling mesquite

- (*Prosopis glandulosa* var. *glandulosa*) to optimize timber and pasture improvement nine years after initiation. *Forest Ecology and Management* 96: 231-240.
- Rhodes, Dwight and Felker, P. 1987. Mass screening *Prosopis* (mesquite) seedlings for growth at seawater salinity. *Forest Ecology and Management* 24: 169-176.
- Silbert, M.S. 1996. A mesquite pod industry in Central Mexico: An economic development alternative. In *Prosopis: Semi-arid Fuelwood and Forage Tree. Building Consensus for the Disenfranchised* (Eds. P. Felker and J. Moss). Center Semi-arid Forest Resources Publ. Kingsville, TX. www.tamuk.edu/webuser/symposium.
- Singh, G. 1996. The role of *Prosopis* in reclaiming high pH soils and in meeting firewood and forage needs of small farmers. In *Prosopis: Semi-arid Fuelwood and Forage Tree. Building Consensus for the Disenfranchised* (Eds. P. Felker and J. Moss), pp. 6.53-6.41. Center Semi-Arid Forest Resources Publication, Kingsville, TX. www.tamuk.edu/webuser/symposium.
- Turc, C.O. and Cutter, B.E. 1984. Sorption and shrinkage studies of six Argentine woods. *Wood and Fiber Science* 16: 575-582.
- US Department of Commerce, 1996. *Wood Import and Export Statistics*. USDA Bureau of Statistics, Washington, DC.
- Varshney, A. 1996. Overview of the *Prosopis juliflora* for livestock feed, gum, honey and charcoal as well as combating drought and desertification: A regional case study from Gujarat, India. *Prosopis: Semi-arid Fuelwood and Forage Tree* (Eds. P. Felker and J. Moss), pp. 6.35-6.41. Building Consensus for the Disenfranchised. Center Semi-Arid Forest Resources Publication, Kingsville, TX. www.tamuk.edu/webuser/symposium.
- Wightman, S.J. and Felker, P. 1990. Soil and foliar characterization for *Prosopis* clones on sites with contrasting productivity in semi-arid south Texas. *Journal Arid Environments* 18: 351-365.