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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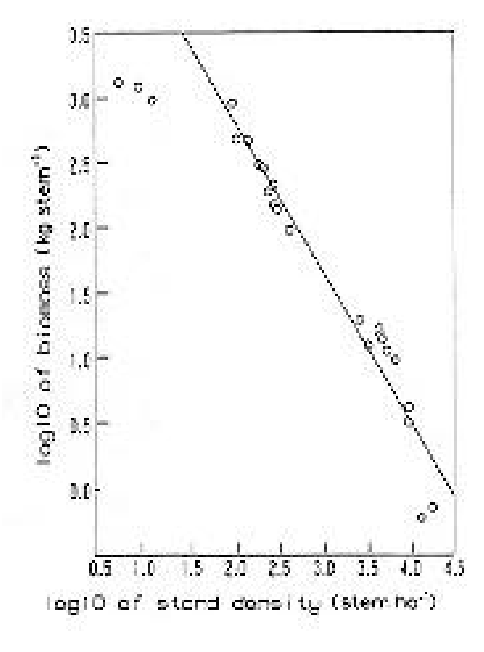

Figure 1. Self-thinning Line for Mesquite (*Prosopis glandulosa* var. *glandulosa*) Stands in Texas

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

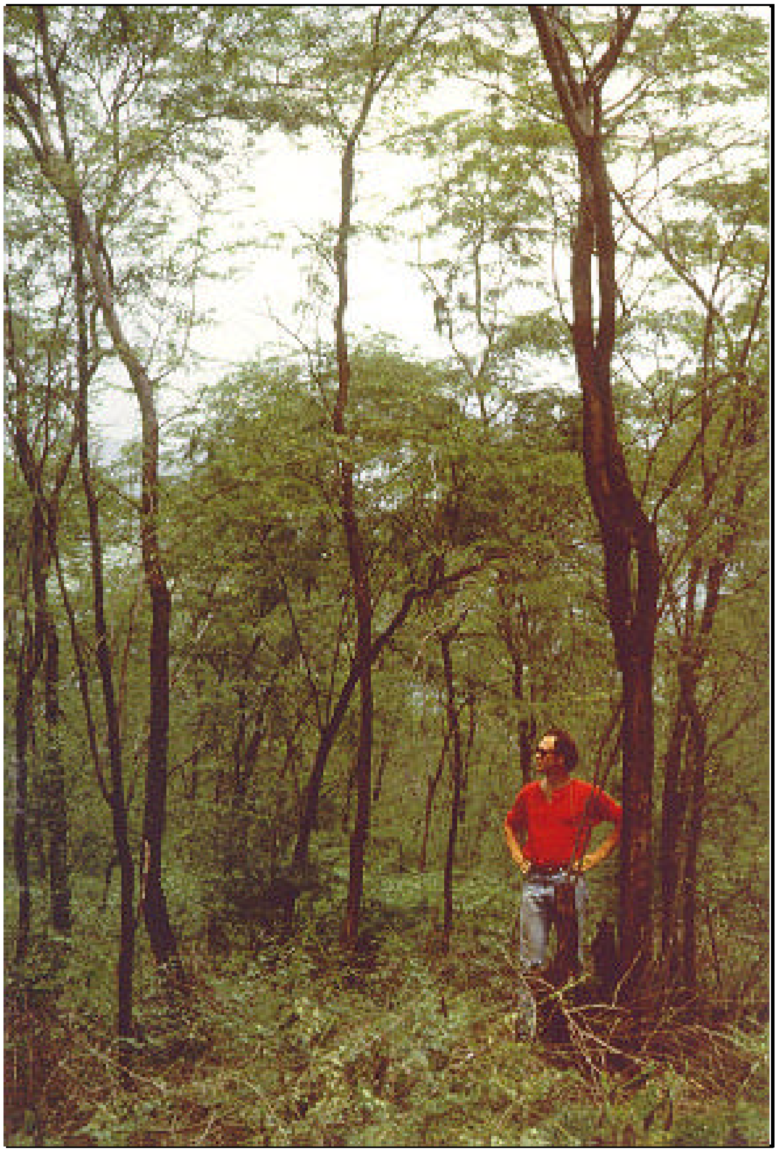

Figure 6. Coppiced Stems of *P. juliflora* in Haiti in Which Coppiced Stems Have Been Pruned to a Single Stem

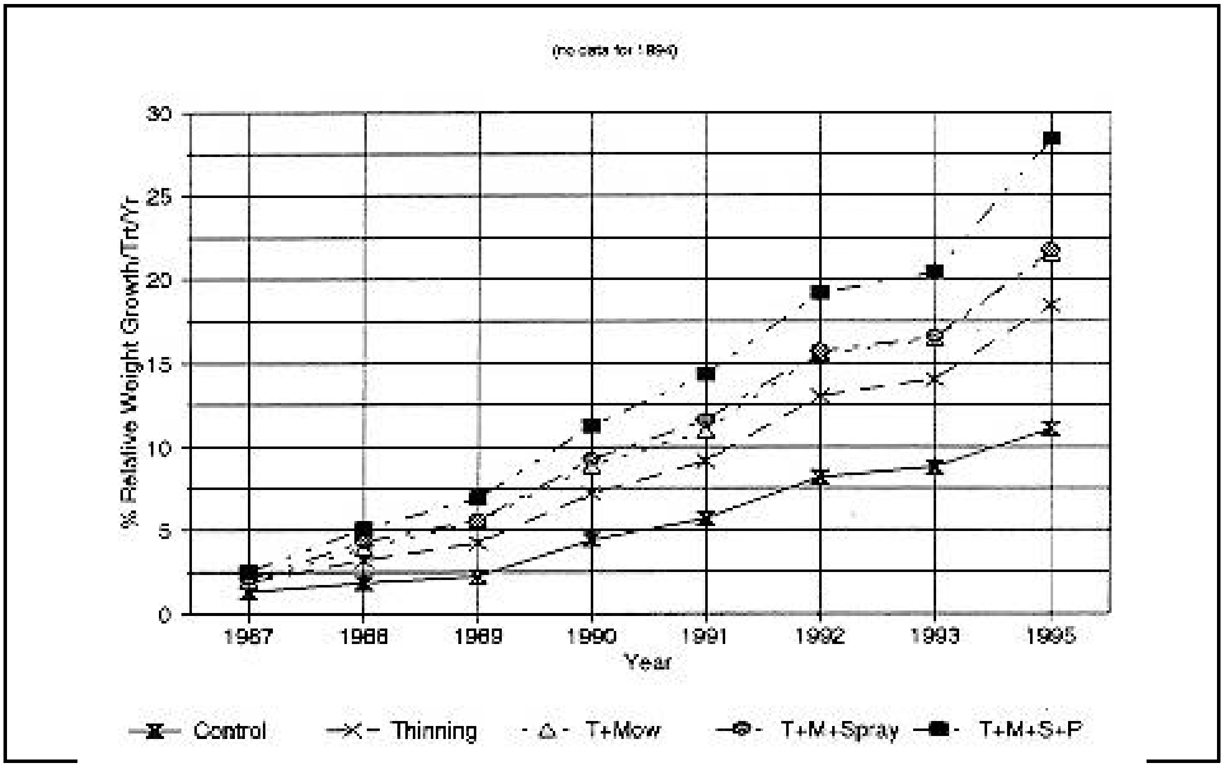

Figure 7. Growth of Mature Stand of *P. glandulosa* in Texas Following: no treeatment (control); thinning multiple-stemmed trees to single-stemmed trees (thinning); thinning multiple-stemmed trees and manually eliminating shrubby understory (T+Mow); thin trees, eliminate understory, and spray shrub resprouts with herbicides (T+M+Spray); thin, eliminate understory, spray resprouts and apply 100 kg/ha P fertilizer (T+M+S+P)