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Silvicultural treatments for sapling mesquite (*Prosopis glandulosa* var. *glandulosa*) to optimize timber production and minimize seedling encroachment

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Abstract

To maximize lumber production and minimize weed problems with *Prosopis glandulosa*, silvicultural treatment methods were evaluated nine years after initiation. A randomized complete block design was used with four replicates and six treatments. Plots were shredder-harvested leaving sixteen 2-m squares on 10-m spacing that included a final rotation crop tree. In three of the treatments the crop trees were pruned to a single stem. To prevent re-establishment of mesquite in the interstitial areas, plots were spot sprayed with herbicides, disked, or disked and seeded with rye grass in 1986. Herbicide treatments and disking continued yearly through 1989. In 1991, disk treatments were repeated. After both 2.5 and 9 yrs, significant treatment differences were found for growth of basal diameter, growth of basal area, and growth of dry weight. The greatest crop tree growth occurred in treatments that were pruned with interstitial competition suppressed. Mortality was greatest in the dense treatments, while re-establishment of mesquite was greatest in the more open treatments. The greatest basal diameter growth of 1.21 cm $year^{-1}$ in the disked and pruned treatments is comparable to other fine hardwoods in temperate and dry tropical forests. © 1997 Published by Elsevier Science B.V.

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1. Introduction

Nitrogen-fixing trees and shrubs of the genus *Prosopis* (Felker and Clark, 1980) are native to the Western Hemisphere, Africa and Asia (Burkart, 1976) and they have become naturalized in Hawaii, Senegal, Sudan, South Africa, India, and Pakistan. *Prosopis* has been regarded as both an aggressive weed and as a vital resource for forage, fuelwood and soil improvement (Felker, 1990).

Dense stands of *Prosopis* often occur with as many as 10,000 small (1–2 cm diameter) stems ha^{-1} on recently colonized areas (less than 10–15 years). These multistemmed stands have hindered cattle management operations and reduced herbaceous forage production, much to the displeasure of ranchers. Accordingly these dense mesquite stands have been the object of intensive eradication efforts by bulldoz-

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ers with root plows and anchor chains (Mutz et al., 1978), tractor drawn mowers (Boyd et al., 1978) and herbicide application by both ground (Mayeux, 1987) and aerial application techniques. There have been serious *Prosopis* eradication programs in the United States, South Africa, Pakistan and the Sudan.

In spite of vigorous attempts at mesquite eradication since the 1940s in Texas, mesquite still occurred on 19.2 million ha, approximately 50% of the total Texas rangeland 40 yrs later (Texas State Soil and Water Conservation Board, 1991). Thus the management treatments employed were not sustainable.

In contrast to the problematic nature of dense stands of small trees, the occurrence of large (12-m canopy diameter), widely-spaced trees (10 m) has considerable agroforestry benefits (Stromberg, 1993). Soils under large *Prosopis* have nearly double the organic carbon and nitrogen as soils outside the canopy of the trees (Tiedemann and Klemmedson, 1973; East and Felker, 1993). Additionally, when highly productive forage grasses, i.e., *Panicum maximum* were planted under and away from the canopies of large mesquites, the productivity was significantly greater under the canopy of the mesquites. The approximately 13% protein, 35% sucrose pods have been important sources for human food (Felker, 1979; Bravo et al., 1994) and livestock food (Gomez-Lorence et al., 1970). *Prosopis* is the most important fuelwood species in Haiti (Wojtusik et al., 1993) and western India (G., Singh, 1996, pers comm.). Due to the attractive orange/red colgor, hardness greater than oak (Weldon, 1986) and lower volumetric shrinkage (4–5%) (Weldon, 1986; Tortorelli, 1956) than all other woods in the world (Chudnoff, 1984), high quality furniture and flooring industries have developed in both Texas and Argentina.

It is our observation that the dense stands of small mesquites are almost universally regarded as a liability, but that the large trees on wide spacings have been viewed in a positive fashion. Thus the issue becomes; (1) how does one convert dense stands of small trees into stands of large trees on wide spacings and (2) can the intraspecific competition demonstrated in other tree species be used to sustain the large trees on wide spacings after they have been established. Given the massive *Prosopis* eradication efforts by bulldozers and herbicides, which have not resulted in permanent reduction of mesquite stand densities, the sustainability issue is of considerable importance. Moreover, it would be highly desirable to avoid the environmental liabilities associated with massive bulldozing, root plowing, stacking and burning of mesquite brush and aerial spraying on thousands of hectares that has been so common in the past.

Ideally, *Prosopis* management programs should have two objectives. First, the management program must prevent the encroachment of dense stands of small trees in a sustainable fashion, with minimal use of herbicides and soil disturbance. Secondly, the management plan must capitalize on the economic benefits of *Prosopis*, i.e., soil fertility and ensuing forage production, pod production, firewood generation, lumber production that will generate revenue to provide a good return on the land investment and pay for the cultural practices necessary to maintain the ecosystem. The objective of this paper is to find a method that will simultaneously control the weedy issues and provide an income stream from as many products as possible.

It is possible that self-thinning observed in other tree species (Long and Smith, 1984; Smith and Hann, 1986; Hibbs, 1987) may be useful in controlling encroachment of mesquite. For example, Felker et al. (1990) examined *Prosopis* stands ranging from 6 to 19,000 stems ha^{-1} and found a negative logarithmic regression of stem density vs. tree size. This suggests that as natural thinning occurs in *Prosopis*, the surviving trees become larger, and provide intraspecific competition that prevents young *Prosopis* from colonizing the interstitial area. The self-thinning line produced in the Felker et al. (1990) study suggested that a 40-cm basal diameter could be obtained from 10 m spacing between trees. This size-density relationship could benefit both lumber and forage management objectives. Reducing tree density has been shown to increase herbaceous productivity (Jameson, 1967; Knoop and Walker, 1985).

This study is a continuation of one initiated in 1986, where a dense stand of mesquite saplings was thinned with a front-mounted flail shredder (Ulich, 1982). Herbicide and mechanical uprooting techniques (Ueckert, 1975; Boyd et al., 1978; McDaniel et al., 1982; Mayeux, 1987) were applied in combination with the shredder harvest to examine their influence on reduction of mesquite seedlings and coppice resprouts. Due to the importance of stem quality for lumber production, three treatments also had individual trees pruned to single stems.

2. Materials and methods

The study area, to maximize crop tree growth and minimize new mesquite development, was initially established in the fall of 1986 on 4 ha of mesquite brush 18 km south of Texas A&M University-Kingsville. The initial mean tree basal diameter, height and basal area ha^{-1} for the control treatment were 3.32 cm, 2.01 m, and 3.67 m^2, respectively. The age of the stand at initiation of the experiment was not known, but the trees were probably less than 10 years old. Soils and climate information are described in Cornejo-Oviedo et al. (1991).

In 1986, six treatments were established on 24 plots of 0.16 ha each. Each plot was designed to have four rows of four trees on a 10-m spacing. Eight-meter paths were cleared between the rows perpendicularly, leaving 16, uncut, 2-m squares in each plot (Fig. 1). If a tree was found in these spaces it was considered a crop tree. Only in a few cases were there 14 or 15 trees $plot^{-1}$.

A randomized complete block design with four replicates and six treatments was utilized for the treatments: (1) no manipulation (control); (2) strip harvested, using the Texas Tech biomass harvester

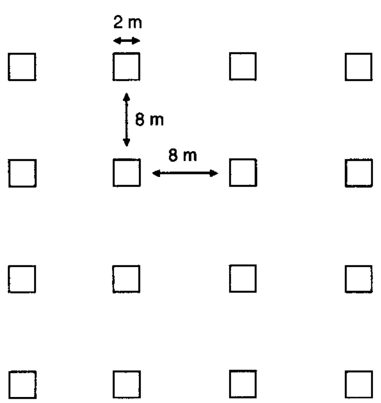

Fig. 1. Individual plot layout for thinning regime. 8-m strips were thinned in perpendicular directions leaving 2-m unthinned squares on 10-m centers. In some treatments, these 2-m squares were thinned to one tree with one stem.

(Ulich, 1982); (3) strip harvested followed by application of herbicides Grazon ET (3,5,6-trichloro-2-pyridinyloxyacetic acid) at the rate of 0.72 kg active ingredient (a.i.)/ha using a back-pack sprayer to treat individual trees; (4) strip harvested followed by pruning the 2-m × 2-m square areas to a single stem; (5) strip harvested, pruned, and interlying land moldboard plowed to a depth of 40 cm; (6) strip harvested, pruned, plowed, and seeded with rye (*Secale cereale*) grass.

In addition, live coppices were retreated with herbicide in the summer of 1987 and 1988. The plowed treatments (12-cm depth) were repeated in the winter of 1987, 1988, 1992 and 1994. Reseeding with winter rye grass was only conducted in the winters of 1987 and 1988. Native grasses, principally bermuda grass (*Cynodon dactylon*) overtook all disked plots when the rye grass was no longer seeded. In the spring of 1995 a second pruning was made on the crop trees that were initially pruned in 1986. This second severe pruning, to a single stem to about 2 m, occasionally removed 12-cm diameter stems to leave an approximate 3-m crown. The Texas A&M University-Kingsville biomass harvester (McLauchlan et al., 1994) was used to remove the above around biomass from seedlings and coppice resprouts in treatments five and six in the summer of 1995.

In the winter of 1995–96, basal diameters of the crop trees were remeasured, and this data were then compared with that of Cornejo-Oviedo in 1986–89. In the former study only trees that remained alive at the end of the 2.5 yrs were included in the initial means while in the current study, the initial means are for all trees in the stand in 1986.

Tree biomass was estimated with two sets of regression equations depending on the size of the trees. For trees with basal diameters less than 16 cm the following equation (Felker et al., 1983) was used:

$$\log_{10} W = 2.1905 \log_{10} BD \pm 0.98111 \ (R^2 = 0.83)$$

where W = stem dry weight (kg) and BD = stem basal diameter (cm).

If the basal diameters were greater than 16 cm the following regression equation developed by El Fadl et al. (1989) was used:

$$\log_{10} W = 1.05 \log_{10} A + 3.83 \ (R^2 = 0.80)$$

where W = stem fresh weight (kg); and A = stem basal area (m^2).

Based on earlier studies (Felker et al., 1983, 1989) we used a 60% dry weight/fresh weight ratio to convert fresh weight for trees with diameters greater than 16 cm to dry weight.

Analysis of variance was used to test for treatment differences in the crop tree mean annual growth of basal diameter, basal area, and dry weight estimates. Where treatment differences ($P < 0.05$) were detected, Tukey's HSD was used for mean separations. Where overall treatment differences were not detected, we examined pairwise T-tests for each pair of treatments (SAS, 1988).

In April, 1996, the total number of coppice and seedling trees were counted in the control plots and the plots in which a treatment was applied to inhibit seedling and resprout formation. Analysis of variance was also used to test treatment differences in coppice and seedling locations in four of the six treatments; control, harvest + herbicide, harvest + prune + plow, and harvest + prune + plow + rye. Tukey's HSD was used for mean separations.

The number of resprouts per tree in the three pruned treatments were measured and a 95% confidence interval (CI) generated. Percent crop tree mortality by treatment was also determined. Analysis of variance was used on the arcsine transformed mortalities. However, the statistical groupings are provided with untransformed percent mortality values.

3. Results

Annual diameter growth of trees in the control plots for the first nine years was significantly less ($P < 0.05$) than for all the other treatments. These results followed the same pattern as the results obtained in the first years of the study (Table 1). The harvest + prune + plow, and the harvest + prune + plow + rye treatments had a similar growth rate probably because the rye grass had not been planted since the winter of 1988.

The control basal area growth for nine years was significantly different ($P < 0.05$) from the basal area growth for the harvest, for the harvest + herbicide, for the harvest + prune + plow, and for the harvest + prune + plow + rye (Table 1). In contrast in 1989, none of the treatments were significantly different for basal area growth. The pruned treatments with reduced intraspecific competition had greater basal area growth than without reduced intraspecific competition.

The yearly basal-diameter increase remained rather similar between the initial three-year evaluation and the nine-year evaluation. In sharp contrast the yearly growth in basal area increased from 50% in the harvest + prune + plow + rye treatment to more than 100% in the harvest + herbicide treatment (Table 1). This result is attributable to the fact that a 1-cm diameter increase from a 12-cm to a 13-cm diameter tree is a much greater basal area increase

Table 1
Mean crop basal diameter growth rate and basal diameter growth rate in a mesquite sapling stand nine years after initiation of silvicultural treatments

Treatment	Initial basal diameter (cm)	3-yr basal diameter growth (cm yr^{-1})	9-yr basal diameter growth (cm yr^{-1})	3-yr basal area growth (cm^2 tree yr^{-1})	9-yr basal area growth (cm^2 tree yr^{-1})
Control	3.32	0.49 B	0.54 B	4.0 B	6.0 B
Harvest	3.69	0.97 A	1.04 A	9.6 AB	15.12 A
Harvest + herbicide	3.32	0.81 AB	1.13 A	7.0 AB	16.79 A
Harvest + prune	3.35	1.04 A	1.00 A	9.0 AB	13.49 AB
Harvest + prune + plow	3.73	1.16 A	1.21 A	10.9 A	18.12 A
Harvest + prune + plow + rye	3.56	1.25 A	1.20 A	12.0 A	18.87 A
P value	0.6632	0.0014	0.0002	0.0063	0.0022
MSE	0.2183	0.0429	0.0244	6.766	11.587

Table 2
Mean crop tree dry weight growth in a mesquite sapling stand in Ricardo, Texas, after silvicultural treatments. Results reported from 1989 (Cornejo-Oviedo et al., 1991) and 1995

Treatment	Initial dry [a] weight (kg)	3-yr dry [c] weight growth (kg $tree^{-1}$ yr^{-1})	9-yr dry [c] weight growth (kg $tree^{-1}$ yr^{-1})	Final dry [b] weight (kg)
Control	2.14	0.80 B	1.43 B	15.29 B
Harvest	2.61	2.02 AB	4.36 AB	41.74 AB
Harvest + herbicide	1.91	1.42 AB	4.79 A	45.28 A
Harvest + prune	1.91	1.83 AB	3.36 A	32.57 A
Harvest + prune + plow	2.58	2.08 A	5.22 A	49.45 A
Harvest + prune + plow + rye	2.34	2.51 A	5.27 A	54.59 A
P value	0.6469	0.0082	0.0017	0.0028
MSE	0.5690	0.3223	1.4514	130.9351

Means ($n = 4$) followed by the same letter are not significantly different ($P > 0.05$) as determined by Tukey's HSD.
[a] The initial dry weight was for all trees in 1986.
[b] The final dry weight was for only those trees that survived. Thus, initial dry weight plus annual growth may not equal final dry weight.
[c] Dry weight growth is (final measurement − initial measurement)/number of years of study (2.5 yrs in 1989, 9 yrs in 1995).

($19\ cm^2$) than a 1-cm increase in growth for a 6-cm to a 7-cm diameter tree ($10\ cm^2$).

The large yearly increase in basal area growth from the three- to the nine-year evaluation is paralleled by a large increase in yearly dry weight growth over the nine-year period (Table 2). Only the control dry weight growth for nine years was significantly different ($P < 0.05$) from the harvest, the harvest + herbicide, the harvest + prune + plow, and the harvest + prune + plow + rye (Table 2). The first three years dry weight growth did not differ significantly between the control and the harvest, the harvest + herbicide, or the harvest + prune treatments (Table 2).

After nine years, the number of coppiced and new seedlings in the control ($1045\ ha^{-1}$) was significantly different ($P < 0.05$) from only the harvest + prune + plow ($650\ ha^{-1}$) treatment (Table 3). Com-

Table 3
Mean number of live coppice and seedling locations in a mesquite sapling stand before (1986) and after silviculture treatments (1989, 1996) in Ricardo, Texas

Treatment	1986 [a] Coppice/ha	1989 [a] coppice ha^{-1}	1996 coppice ha^{-1}
Control	1739 A	1739 A	1045 A
Harvest	1088 AB	1142 B	no data
Harvest + herbicide	1016 AB	1019 BC	1016 AB
Harvest + prune	367 BC	656 BC	no data
Harvest + prune + plow	308 C	555 CD	650 B
Harvest + prune + plow + rye	441 BC	195 D	722 AB
P value	0.0001	0.0001	0.0226
MSE	105144.42	43933.20	30775.01

[a] 1986 (initial) and 1989 results reported from Cornejo-Oviedo et al. (1991).
Means ($n = 4$) within a column followed by the same letter are not significantly different ($P > 0.05$) as determined by Tukey's HSD.

Table 4
Mean crop tree mortality and percent crop tree mortality after nine years (1995) with *T*-test treatment comparison for each pair of treatments in Ricardo, Texas

Treatment	Percentage crop tree mortality	Treatments with significant difference	*P* value
Control	32.3	H + P + P	0.0279
		H + P + P + R	0.0313
Harvest	25.9	none	
Harvest + herbicie	18.2	none	
Harvest + prune	19.0	none	
Harvest + prune + plow	8.2	Control	0.0279
Harvest + prune + plow + rye	8.8	Control	0.0313
MSE	105144.42	43933.20	30775.01

No overall significant difference in means ($n = 4$) for ANOVA of all treatments for either percentage transformed ($P = 0.1042$) or percentage untransformed ($P = 0.1697$) data.

paring the 1996 data to the earlier data (Cornejo-Oviedo et al., 1991) it appears that natural thinning has occurred in the control plots. In the harvest + herbicide there was no change in the number of coppice locations. In the plow treatments mesquite encroachment has taken place in the interstitial areas.

The nearly four-fold increased mortality of the control crop trees over the crop trees in the harvest + prune + plow + rye was significantly different using a pairwise *T*-test (Table 4). This is indeed a very important finding as it confirms the presence of intraspecific competition-induced mortality in these plots.

4. Discussion

After nine years the probability for statistically significant differences among all treatments increased for basal diameter growth, basal area growth, and dry weight growth respectively.

The control continued to have the slowest growth, and the two treatments that received disking had the greatest diameter and basal area growth. Other treatments besides disking that decreased competition, i.e., elimination of mesquite in interstitial areas with herbicides also stimulated growth of the crop trees. The continued significance in treatment differences over time suggests that these management practices continue to affect stand-dynamics years after initiation. With more frequent disking and perhaps fertilization, presumably even greater growth rates could be achieved.

Cornejo-Oviedo et al. (1991) found the basal diameter mean annual increment for the most successful treatment (harvest + prune + plow + rye grass) was 1.25 cm $tree^{-1}$ yr^{-1}. After nine years this treatment had a mean annual increment of 1.20 cm $tree^{-1}$ yr^{-1} suggesting that three years data may be capable of predicting results from much longer and costly trials. Hopefully the mean annual increment of 1.2 cm yr^{-1} for the first nine years can be maintained to achieve a 46-cm basal-diameter tree in a 30-yr rotation.

The greatest basal diameter growth rates after nine years in this study (harvest + prune + plow, 1.21 cm $year^{-1}$), favorably compares with many high value lumber species. For example, five years after a thinning and pruning of a 12-yr-old Appalachian coppice stand Lamson (1983) reported growth rates of 1.12, 1.12, 0.76, and 0.66 cm $year^{-1}$ for thinned yellow poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), red maple (*Acer rubrum*), and red oak (*Quercus rubra*), respectively. These mesquite growth rates also compared favorably to 0.79 cm $year^{-1}$ for a 14-year-old (6–10 cm diameter) teak (*Tectona grandis*) plantation in the dry tropics of Northern India (Karmacharya and Singh, 1992).

As might be expected, mesquite mean annual growth rates from non-irrigated stands were less than growth rates obtained for valuable hardwoods under irrigation. For example, Jain (1994) measured diameter growth of an irrigated rosewood (*Dalbergia sissoo*) plantation in an arid zone of India and found the mean annual increment for the treated plots was

2.74 cm year^{-1}. In all cases, pruning stimulated diameter growth as the unpruned treatments had a mean annual increment of 1.73 cm year^{-1}. Annual diameter growth rates after nine years that approach 45% of irrigated hardwoods is remarkable.

The annual growth rates for *Prosopis* even compare favorably to average annual growth rates of a native forest with 195 species, 32 of which are commercial species, in the Brazilian Amazon, thirteen years after logging (Silva et al., 1995). From 1987–1992, all species had an average annual increment of 0.3 cm year^{-1}, the commercial species had an annual growth increment of 0.4 cm year^{-1}.

While diameter growth of mesquite has been favorably compared to other fine hardwoods, the potential for even greater growth exists. In two other studies within 25 km of this study (Felker et al., 1989; Duff et al., 1994) basal diameter growth year^{-1} for plantation grown *Prosopis* exceeded the basal diameter growth in the current study. Duff et al. (1994) found the mean annual basal diameter growth of nine *Prosopis glandulosa* var *glandulosa* families over a nine-year period to be 1.67 cm tree^{-1} year^{-1}. While no irrigation was provided in this study, substantial weed control occurred in the first four years. This management was a significant factor in the high productivity of the native *Prosopis* species.

Felker et al. (1989) found the annual basal diameter growth rate over a three-year period for a *Prosopis alba* (B2V50) clone was 2.56 cm tree^{-1} year^{-1}. The authors felt that the high productivity found in their study resulted more from intensive management practices than genetics. The greatest basal diameter annual growth in the current study was 1.21 cm tree^{-1} year^{-1} for the harvest + prune + plow treatment. Only disking was performed in 1992 and 1994. Annual cultivation, including the control of resprouts in the interstitial areas would possibly increase productivity and decrease mortality. The growth rates obtained for *Prosopis* in the more intensively managed plantations (Felker et al., 1989; Duff et al., 1994) are closer to the growth rates achieved for plantation grown *D. sissoo* in India (Jain, 1994).

In contrast to *P. glandulosa* diameter growth rates of 0.5 to 1.2 cm year^{-1} in this study and 1.69 cm year^{-1} in the Duff et al. (1994) study, much lower annual diameter growth rates of 0.26 to 0.61 cm year^{-1} were measured in a mature *Prosopis* stand where initial mean stem basal diameter was 16.4 cm with a diameter range from 15.7 cm to 17.9 cm (Cornejo-Oviedo et al., 1992). While thinning and understory removal appeared to significantly increase the diameter growth from 0.26 cm year^{-1} to 0.54 cm year^{-1}, these growth rates are much lower than obtained in this sapling stand. Perhaps cultivation and further thinnings will be required to obtain comparable basal diameter growth rates in natural stand that were achieved in the plantation grown trees.

Growth rates for thinned and pruned yellow poplar, black cherry, red maple, and red oak were 1.12, 0.91, 0.61, and 0.56 cm year^{-1}, respectively (Lamson, 1983). The author suggested that pruning live branches can cause a temporary reduction in diameter growth because some of the photosynthetic capability of the tree is removed. Meyer and Felker (1990) obtained different results. In their study pruning significantly ($P < 0.05$) increased diameter growth. In the current study pruning resulted in lower diameter growth only in the treatment where interstitial competition was not controlled.

The highest percentage mortality occurred in the control and the treatments that did not control competition, suggesting that natural self-thinning may have taken place. Felker et al. (1990) developed a self-thinning regression equation for mesquite, by plotting the log of biomass vs. the log of stem density ha^{-1}. This equation can be used to estimate the mortality we should have observed at given tree sizes.

The initial mean dry weight of the trees in this study was 1.61 kg tree^{-1} (2.68 kg fresh weight) which would correspond to a density of about 10,000 stems ha^{-1}. The self-thinning line of Felker et al. (1990) predicted that a final dry weight in the control of approximately 14 kg stem^{-1} (24 kg fresh weight) would correspond to a stand density of about 1600 stems ha^{-1}. The actual number of trees (not stems) in the control plots was 1200 trees ha^{-1} at the end of nine years. Thus, the regression correctly predicted an increased mortality, as stem diameter increased. The regression equation underestimated the mortality that was observed from a density of 1740 trees (8700 stems) ha^{-1} to what was observed (1200 trees ha^{-1}). Under natural conditions the dry weight in the harvest + prune + plow + rye grass treatment of 42 kg stem^{-1} (70 kg fresh weight) would correspond to a density of approximately 500 stems ha^{-1}. The number of stem ha^{-1} in this treatment was approximately 80, which is much lower than a natural stand. In an agroforestry situation where both rangeland and forest productivity is the objective, 80 trees ha^{-1} may be appropriate since these trees would have a maximum diameter of about 50 cm. However a higher density would be optimum for forest productivity alone.

Self-thinning pressure was apparently exerted in the control and treatments where interspecific competition existed. The more intensively managed treatments were maintained at a density lower than that found in a natural untreated stand, resulting in decreased mortality due to self-thinning pressures. The control had a 32.3% mortality, while the lowest density treatments had a mortality of 8.2 and 8.8%. Initial mean stand diameters were greater when calculated without the trees that eventually died (Cornejo-Oviedo et al., 1991), indicating that the smaller, more suppressed stems succumbed to self-thinning pressures.

There is other evidence of self-thinning in mesquite. At the Santa Ana Wildlife Refuge in the Rio Grande Valley, Texas (Vora and Messerly, 1990), 13 of 28 mesquite trees (46%) with crowns below the dominant overstory died over the five-year study period. The overstory in the Santa Anna study was 70% mesquite with approximately 230 trees ha^{-1}.

The coppice and seedling locations also appeared to follow a natural self-thinning process. The control coppice locations diminished over time as diameter increased, while coppice locations increased in the low density treatments. It was particularly interesting to note that the number of coppice and seedling locations remained stable in the unpruned treatments. This may be due to the large crowns maintained on the multiple stemmed trees. The greater shade and stem density may have inhibited mesquite resprouting. A more complete kill of the harvested trees from the herbicide application any have also affected the number of coppice locations.

While this study did not specifically address the issue of stem quality we recognize that stem quality is an important consideration when managing trees for a high value furniture and flooring market. The objective for this market is to grow single-stem trees free of lower branches to a height of at least 2 m. Rosen et al. (1980) have demonstrated that logs of sizes typical for mesquite, i.e., 58–204 cm long and 13–46 cm diameter, contain material suitable for furniture. Other milling techniques have been developed to utilize short logs for dimension stock (Dunmire et al., 1972; Rosen et al., 1980; Reynolds and Gatchell, 1982; Wiedenbeck and Araman, 1995). Species considered in the Rosen et al. (1980) study include black walnut (*Juglans nigra*), black cherry (*P. serotina*) and yellow poplar (*L. tulipifera*). Mesquite has been favorably compared to these species in terms of wood quality and growth (Tortorelli, 1956; Weldon, 1986; Panshin and de Zeeuw, 1980; Lamson, 1983).

To achieve good stem-quality for lumber it is critical to control resprouts that commonly occur after pruning (Meyer et al., 1971; Sosebee and Wan, 1987). Trees were originally pruned to one single stem, but pruning along the stem did not occur until the summer of 1995, when pruned trees had a mean basal diameter of 14.02 cm. This pruning eliminated all branches to 2-m height. Prunings to 2 m height should probably be conducted in the fifth or tenth year. New chemical and barrier treatments that greatly inhibit resprout formation from pruned surfaces should be helpful in resprout management (Patch and Felker, 1996, unpublished data).

For example a 20%-solution of the herbicide Remedy (triclopyr) in diesel fuel successfully inhibited resprouts along the stem and on the stumps of multiple stemmed trees. A formulation of the growth hormone naphthalene acetic acid (Tre-hold), and a physical shade barrier were also successful in inhibiting resprouts (Patch and Felker, 1996, unpublished data).

The 100-tree ha^{-1} crop tree objective developed in previous studies (Felker et al., 1990) appears justified in this rainfall regime. In retrospect, it would have been desirable to have reduced the stand density from 1700 trees ha^{-1} to 100 trees ha^{-1} in several intermediate stages. Unfortunately, when this trial was initiated this option was not available. A greater density in the young stand would maintain a closer relation to a natural self-thinning process, possibly inhibiting stem and coppice resprouts and seedling establishment. An intermediate cut would produce firewood and some boltwood for use in the furniture and flooring markets.

5. Conclusions

The *Prosopis* basal diameter growth rates three and nine years after treatment were very similar to other hardwoods in the U.S., India and tropical rainforests. However, the *Prosopis* basal area was much lower.

While only 8% mortality of crop trees occurred in the less dense treatment plots, a 32% crop tree mortality occurred in the dense control plots. This is indicative of intraspecific competition and also suggests that intraspecific competition might be used to hinder invasion of *Prosopis* into new locations.

The number of coppice and/or seedling locations declined in the dense control plot but coppice, seedling locations increased in the interstitial spaces between trees. This indicates that after nine years the crop trees do not exert sufficient intraspecific competition to keep out the seedlings. Annual disking or spot treatment with herbicides will continue to be required to prevent encroachment by young *Prosopis* on this relatively wide 10×10 m spacing, until crown size expands to limit regeneration.

Many factors which make *Prosopis* competitive in the hardwood lumber market provide ample incentive for management to be a consideration in all *Prosopis* dominated areas. Factors include: current wholesale prices of US$428/cubic meter for *Prosopis* lumber; the comparable *Prosopis* diameter growth rates to other temperate and tropical hardwoods; *Prosopis* induced mortality from intraspecific competition; and the possibility of integrating lumber management with intercropping, pasture improvement and wildlife.

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