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Biomass Production of *Prosopis alba* Clones at Two Non-Irrigated Field Sites in Semiarid South Texas

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ABSTRACT

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The biomass productivity of three *Prosopis* clones and an open-pollinated *Prosopis* family, which were previously identified as high-biomass producers, were compared in two Texas field trials. A 3-m × 3-m spacing was used and two border rows were established around each of the 25-tree plots to avoid border effects on the biomass estimates. The sites had mean annual rainfalls of 525 mm and 700 mm. At the drier site, survivals of 88%, 91%, 96% and 98% occurred 2 years after establishment, without irrigation at any phase of the planting. This is quite exceptional given the fact that a 70-year-record freeze of $-12\,^{\circ}C$ occurred the first winter, and that a drought occurred the second growing season in which the trees were without rain for 6 months in the hottest part of the year. After 3 seasons growth ($2\frac{3}{4}$ years) at the drier site, a hybrid thorny, multi-stemmed *P. alba* × *P. glandulosa* var. *torreyana* clone B9V18 had the greatest standing biomass of 7.39 t[1]/ha. A thornless erect clone, *P. alba* B2V50, had the next-greatest biomass of 4.75 t/ha. The same thornless clone had the greatest production of 39 t/ha after three seasons at the wetter site, while the thorny hybrid clone B9V18 had only 16.6 t/ha at the end of three seasons' growth. Two principal reasons seem responsible for the differences in productivity. Clone B9V18, being thorny and multi-stemmed, was undamaged from deer browse and deer scrapes at the drier site, while the thornless erect clone was heavily browsed at the drier site, but not at the wetter site. Clone B9V18 experienced considerable damage from blister beetles (*Epicauta nigritarsus*) at the wetter site, while clone B2V50 was undamaged. The 1st, 2nd and 3rd-season dry-matter growths for the wet site were 3.5, 14.1, and 21.7 t/ha for clone B2V50, which compare favorably to the greatest growth-rates for pines and hardwoods in the United States. The 6-fold difference in the productivity of clone B2V50 between sites may be caused by fertility deficiencies. During adverse conditions of drought and freezing weather the clones produced no growth, but neither was there a loss in biomass or survival. Under favorable rainfall conditions exceptional growth rates were obtained.

[1]t, metric tonne, 1000 kg (Mg).

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INTRODUCTION

Prosopis has been reported to be a promising genus for reforestation in semiarid regions (Burley and von Carlowitz, 1984) since it can fix nitrogen (Felker and Clark, 1980) and produce pods for livestock or human consumption (Oduol et al., 1986).

Previous studies examined 55 open-pollinated families of *Prosopis* from Africa, North America and South America for growth under heat/drought stress in the California Imperial Valley (Felker et al., 1983b). This location was chosen since it was the hottest experiment station in the country, with mean July daily maximum temperatures of 42 °C. Due to the low rainfall at this location (less than 80 mm/year), supplemental irrigation was necessary.

Over a 100-fold range in the family means for biomass production occurred at this site. The fastest-growing trees each achieved basal diameters over 6 cm the first growing-season, basal diameters over 14 cm the second growing-season, and dry-weights of 30–40 kg the second growing-season. These exceptional trees were cloned by rooted-cutting techniques (Klass et al., 1984). The most productive clones were from the taxa *P. alba* and *P. chilensis*. Clones were also made of some putative naturally occurring interspecific hybrids *P. alba*×*P. glandulosa* var. *torreyana*.

The biomass productivity of selected clones was evaluated in Texas at one location (Zachry Ranch) with about 525 mm/year rainfall, and another location at Kingsville with about 700 mm/year rainfall. Seedlings were planted without irrigation and harvested after two and three seasons growth, for biomass measurements. Stem diameter and weight measurements were taken on some of these trees to develop regressions for future studies.

MATERIALS AND METHODS

Rooted cuttings were prepared as described by Klass et al. (1984). The cuttings and seedlings were inoculated with a *Prosopis* rhizobia strain (Felker and Clark, 1980) and grown in the greenhouse for 4 months before transplant to the field. An artificial peat/perlite/vermiculite soil mix amended with macro and micronutrients was used. Ray-Leach 'super-cell' dibble tubes were used in the clonal comparison portion of the Zachry trial, while 3.8-cm×3.8-cm×38-cm cardboard plant-bands were used for the remaining seedlings and for the trial at Kingsville (Felker et al., 1988).

The basic design for these plots was a 5×5 array of trees, on a 3-m×3-m spacing, with two additional border rows surrounding each sample plot. Due to the difficulty in propagating the clones, the border rows were raised from the fastest-growing family from seed, i.e. *P. alba* 0166.

Two sites were established in successive years. The H.B. Zachry Ranch site has hotter temperatures and lower annual rainfall. The long-term July daily maximum temperature for Laredo (50 km from Zachry) is 38.1 °C versus 36.1 °C for Kingsville (Anonymous, 1965). There was no groundwater at either site, and irrigation was not used in any phase of these plantings.

The rainfall in Kingsville was 495 mm in 1984, 1026 mm in 1985, and 682 mm in 1986 (cf. annual mean of about 700 mm; Anonymous, 1985). Rainfall data for the Zachry Ranch was extrapolated from the nearest three official weather stations in Hebbronville, Zapata, and Laredo about 50 km away. The mean rainfall for these three locations was 399 mm in 1983, 325 mm in 1984, and 799 mm in 1985 (Anonymous, 1985). The Zachry Ranch manager measured 230 mm of rain in 1984 and 560 mm of rain in 1985. In 1984 he observed that no rain occurred from April through October.

The soil at the Zachry site belonged to the Copita series, i.e. a fine-loamy soil of the mixed hyperthermic family of Ustollic Calciorthids, pH 7.4 and $NaHCO_3$-extractable-P of 1.9 μg/g. Two soil series occurred at the Kingsville site. The predominant soil was the Hidalgo series, a fine-loamy mixed hyperthermic family of Typic Calciustolls. The minor soil type at Kingsville was the Palobia series which belonged to the fine-loamy, mixed, hyperthermic family of Aquic Natrustalfs. These soils ranged in pH from 6.6 to 8.2, and in extractable P from 1.2 to 1.5 μ/g (Wightman and Felker, 1990).

The trees were harvested at ground-level with a chainsaw, and weighed with precalibrated scales. The dry-matter percentage was determined by reducing 3–4 entire trees of each clone to 10-cm lengths and drying in burlap bags at 70 °C until equilibrium was reached. After drying, some of the trees were separated into the leaf fraction and the woody fraction, consisting of main stem, branches and small twigs. Paired basal stem diameter and weight measurements were taken on some of the trees harvested in 1985 and 1986 to develop regressions for future non-destructive biomass estimates. The diameter and biomass were recorded for individual stems of multi-stemmed trees. Since regression equations were available for 1st-year trees (Felker et al., 1983a) data for these trees was not taken.

Zachry Ranch site-preparation and field-plot design

Two trials were conducted at the Zachry Ranch. One trial was designed to compare the relative performance of three of the most productive clones (identified in the California studies) to that of an open-pollinated family (*P. alba* 0166). This comparison trial used three replicates of 25 trees/replicate.

A second trial was used to obtain more-precise biomass-production estimates with larger plots of only one family (*P. alba* 0166). This trial had six identical plots, three harvested at the end of the 2nd and three after the 3rd season. Each replicate consisted of 12 rows of 12 trees per row, but only the inner 10 rows of 10 trees were harvested. Herbicide contamination (bromacil) in the spray equipment before planting reduced one plot to 60% of its intended size.

The clonal-comparison trial at Zachry Ranch used a randomized complete-block design with four genetic strains, three replications/year and harvests at two successive years. In January 1984 (approximately 9 months after transplant), the equation (Felker et al., 1983a):

$$\log_{10} \text{dry-weight (kg)} = 2.1905\ (\log_{10} \text{stem diameter (cm)}) - 0.9811$$

was used to estimate the dry biomass of all the trees at the Zachry Ranch. The biomass estimate per clone at the end of the 1st growing-season was the mean of six plots of 25 trees (150 trees). Three replicates of 25 trees each were harvested at the end of the 2nd season (December 1984) and the 3rd season (December 10, 11, 12 1985). Thus 12 plots were harvested at the end of year 2 and at the end of year 3. During the harvests, basal-diameter measurements and fresh weights were taken for approximately 50 trees of each clone or seed lot, to develop regression equations for future use.

The three clones at the Zachry Ranch, *Prosopis alba* B2V50 (thornless), *P. alba*×*P. glandulosa* var. *torreyana* B5V20 (thorny), and *P. alba*×*P. glandulosa* var. *torreyana* B9V18 (thorny), were compared with the seed-propagated accession with the greatest biomass productivity, *P. alba* 0166 (Felker et al., 1983b). The female parent of *P. alba* 0166 was thornless but, evidently due to outcrossing with thorny native *P. glandulosa* var. *torreyana*, the progeny were highly variable in leaf morphology, presence of thorns, form, and date of bud burst. Clone B9V18 was selected from *P. alba* 0166, and thus a comparison of clone B9V18 and *P. alba* 0166 suggests the genetic gains possible through cloning.

The site was initially fenced with 60-cm-high chicken-wire and 4 strands of barbed wire, to keep out rabbits and cattle, respectively. It was necessary to erect a 2.5-m-high, 15-strand solar-powered fence in the spring of 1984 to reduce deer browse to negligible levels.

The Zachry site was prepared by cutting the grass, cactus, and small trees, by spraying perennial-grass resprouts with glyphosate, and by disking twice, followed by applying 2.8 kg oryzalin (Surflan) a.i./ha. A previously described heavy-duty mechanical tree-planter (Felker et al., 1984) was used to plant the seedlings 40 cm deep. The seedlings were side-dressed with liquid ammonium-phosphate fertilizer (10:34:0) at the rate of 60 kg P/ha during the transplanting. The 20-cm-long 'dibble tubes' were removed from the clones and the seedlings in the clonal comparison trial, but in the accompanying 1-ha *P. alba* 0166 plot, the cardboard plant-bands were left on at planting. A substantial rain occurred only 2 days after these seedlings were planted.

Cultivation was provided with a disk harrow and with a custom cultivator with four 66-cm-wide sweeps pulled by a low-profile 18-hp. tractor. This provided weed control in a 2.5-m-wide swath with only 1.5 m of canopy opening.

Chemical weed-control during the 2nd growing-season with a simazine/diuron combination was not particularly effective. Norflurazon was used for weed control beginning on 12 February 1985, at 5 kg a.i./ha, since it controls annual grasses, annual forbs, nightshades, nutsedges (*Cyperus* spp.) and problem perennial grasses such as bermuda grass (*Cynodon dactylon*) and johnsongrass, *Sorghum halepense* (Felker et al., 1986). For unknown reasons, weed control was not as good on the Zachry site as on the Kingsville site. Survival of these trees was assessed 5 weeks after planting, and the dead trees were replaced.

Kingsville site-preparation and field-plot design

In the fall of 1983, this site was a grassy field with small trees. The trees were uprooted, the site mowed, sprayed with glyphosate to kill perennial grasses, mouldboard-plowed, and disked several times. Two days prior to planting, oryzalin was applied at a rate of 2.4 kg a.i./ha. The heavy-duty mechanical tree-planter was used to plant this trial on 16 March 1984. Before planting, the tree-planter and attached row-marker were used to create parallel ridges, 3 m apart, perpendicular to the direction of planting. This permitted the planting of trees in a precise grid-pattern which allowed mechanical cultivation down the rows and perpendicular to the rows, to eliminate weeds in the rows. The 38-cm-long plant-bands were used, and no irrigation was used at any phase of the planting. After planting, a 50-cm-high chicken-wire fence was placed around the planting to reduce rabbit browse.

The spring of 1984 was unusually hot and dry. In January, 125 mm of rainfall occurred but no more rain occurred till mid-May. Thus the Kingsville trial received no rain during either the 6 weeks prior to planting or the 8 weeks after.

Temperatures of 38.9 °C and 40.5 °C occurred after the planting but before the rains. Only 3 trees out of 225 had to be replaced (98.7% survival); no leaf-loss or other sign of stress appeared on the other trees.

In the summer of 1984, the field was cultivated perpendicular to the rows with a 2-m-wide disk harrow. The trees were also cultivated over the top with a single-row, sweep cultivator. The field was hand-hoed once to remove large vines that escaped the mechanical cultivation. By late summer, these trees were sufficiently large to prevent cultivation with a tandem disk-harrow and an 80-hp tractor, so a low-profile sweep cultivator was used.

In December of 1984, the trees were approximately 2.5 m tall, and three B2V50 plots were harvested. Rainfall during the 2nd year's growth was higher than normal (1026 mm), especially in the spring and fall, and it is unlikely that the trees experienced water-stress. In the spring of 1985, these plots were disked; norflurazon, applied at 5 kg/ha, provided excellent weed control throughout the spring and summer.

After the December 1985 harvest, the herbicide norflurazon was again applied in January 1986 at 5 kg/ha. In the spring of 1986, the plots were cultivated twice and hand-weeded once. Foliar data from the previous season indicated a high probability of a copper deficiency (and possibly other micronutrients). Therefore a foliar micronutrient application of 'Soluble Trace Element Mix (STEM)' was made on 22 May, at a concentration of 8.8 g/l having an elemental composition of 28% S, 8% Fe, 8% Mn, 5% Zn, 3% Cu, 2% B, and 0.05% Mo; this application was repeated in June. A soil copper application, made in early June at 6 kg/ha, was injected into the soil at a depth of 30 cm as copper sulfate solution (275 l/ha). The 25-hp tractor used to inject this solution inadvertently destroyed several of the trees that should have been harvested in December 1986, which caused a decrease in the yields reported for one plot.

During the 2nd week of December 1986, the trees for the 3rd-year harvest were cut with a chainsaw and suspended from a fork-lift to measure the weight. Many of the stems weighed 60–70 kg and were at the limit of what could be handled manually.

RESULTS

Regression-equation development

The regression equations relating biomass to basal stem diameter are presented in Tables 1 and 2. With the exceptions of the 3rd-season *P. alba* 0166 at Zachry, and clone B9V18 the 3rd season at Kingsville, all equations had an r^2 greater than 0.91 and were significant at the 0.0001 level. These equations may be useful in future studies where it is not desirable to harvest the trees.

The woody fraction and dry-matter percentage increased with successive harvests. Percentage dry-matter for clone B2V50 at Kingsville was 42.5 ± 1.9%, 50.6 ± 1.6%, and 54.1 ± 2.8% at the end of the 1st, 2nd and 3rd harvests, respectively, paralleling the increase of the woody fraction of 78.5 ± 5.5%, 91% (only 1 large tree analyzed), and 95.5 ± 1.3% at the end of the 1st, 2nd and 3rd year for clone B2V50 at Kingsville. Substantial leaf-drop occurred in the winter, which may explain the low leaf percentages observed.

Zachry biomass studies

Survivals for 1983 (Table 3) were based on the trees to be harvested in 1984 and 1985, while in 1984 they were only for the trees harvested that year. This accounts for the small discrepancies between 1983 and 1984. The initial survivals were excellent, since 3 of the 4 accessions had greater than 94% survival. The planting stock for clone B2V50 was smaller than desirable, which may account for their lower survival. Between planting in the spring of 1983 and the survival measurement in 1984, a 70-year-record freeze of −12°C occurred in December 1983 and a 20-year-record drought (230 mm rainfall) occurred in the 1984 growing-season. As negligible changes in survival occurred between these dates, these accessions appear to be well adapted to these conditions.

TABLE 1

Regression equations relating basal stem diameter to fresh weight for Zachry Ranch clones

Variable	*Prosopis alba* clone B2V50 Year		*P. alba*×*P. glandulosa* Torr. clone B9V18 Year		*P. alba*×*P. glandulosa* Torr clone B5V20 Year		*P. alba* 0166 (from seed) Year	
	2nd	3rd	2nd	3rd	2nd	3rd	2nd	3rd
Stems (no.)	81	69	139	73	116	74	90	59
Slope (m)	2.5746	2.2902	2.2380	2.5655	2.5440	2.2316	2.5932	2.3680
SE	0.0850	0.0839	0.0581	0.0562	0.0601	0.0712	0.0759	0.1211
Intercept (*b*)	−1.1029	−0.9552	−0.9648	−1.0535	−1.1258	−0.9142	−1.1323	−1.0997
SE	0.0362	0.0494	0.0353	0.0349	0.0285	0.0378	0.0366	0.0644
r^2	0.91	0.92	0.92	0.97	0.94	0.93	0.93	0.87
P value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Stem wt (kg)								
mean	1.20	2.82	3.01	4.54	1.58	2.23	1.81	2.11
minimum	0.04	0.20	0.19	0.10	0.10	0.40	0.04	0.10
maximum	3.90	6.10	9.80	13.60	8.90	7.60	7.45	10.00
Stem diam. (cm)								
mean	2.63	3.90	4.10	4.24	2.99	3.42	3.02	3.44
minimum	0.80	1.50	1.20	1.40	1.10	1.70	0.90	1.00
maximum	4.60	5.90	7.50	7.60	6.20	6.40	5.90	7.80

Regressions were computed for the equation: $\log_{10}y = m\log_{10}x + b$
where y = fresh weight (kg) and x = basal stem diameter (cm).

Biomass productivity at the Zachry site for the 1st, 2nd and 3rd growing-season is presented in Table 3. Clone B9V18 had greater biomass production than any other clone or seed-lot in all three growing-seasons. The 1st-season productivity of clone B9V18 was 3.56 t/ha, quite substantial given the wide (3-m×3-m spacing). The other varieties had considerably lower productivities of 1.68, 1.60, and 1.40 t/ha for clone B2V50, seedlot 0166 and clone B5V20, respectively. Almost no production occurred the 2nd year, but substantial production occurred again the 3rd season.

The reason for the lack of growth in 1984 was simply a lack of rain. While 140 mm of rain occurred prior to April 1984, no additional rain occurred till October of 1984. Nearly 200 consecutive days occurred during the spring and summer without rain. The long-term average daily maximum temperatures obtained from a nearby site in Laredo were 31°C in April, 34°C in May, 37°C in June, 38°C in July and August, 34°C in September, and 30°C in October, when another 100 mm of rainfall occurred, bringing the yearly total to approximately 230 mm. Unfortunately, the later rainfall occurred in cooler weather when *Prosopis* grows poorly.

TABLE 2

Regression equations relating fresh biomass to basal stem diameters for *Prosopis alba* clone B2V50 and *P. alba* by *P. glandulosa* var. *torreyana* clone B9V18 at Kingsville site

	Prosopis clone and age		
	B2V50		B9V18
	2nd year	3rd year	3rd year
Stems (no.)	62	195	232
Slope (m)	2.4036	2.7027	2.4829
SE	0.1030	0.0414	0.0623
Intercept (*b*)	−0.9359	−1.1085	−1.0050
SE	0.0830	0.0360	0.0441
r^2	0.9022	0.9569	0.8742
P value	0.0001	0.0001	0.0001
Stem wt. (kg)			
mean	13.74	25.30	8.08
minimum	0.70	0.41	0.18
maximum	45.00	90.72	45.36
Stem diam. (cm)			
mean	6.6	7.7	5.2
minimum	2.2	2.1	1.0
maximum	12.4	16.4	11.0

The regression coefficients were estimated for the equation
$\log_{10}$ fresh wt (kg) = m$\log_{10}$ diameter (cm) + *b*.

While little or no growth occurred in 1984, no tip die-back occurred because of lack of water, and no trees died. Thus *Prosopis* clones tested appear capable of waiting-out the drought, with neither growth nor loss in survival.

The 3rd-year's growth increments, obtained from the differences in biomass at the end of years 2 and 3, were 3.31 t/ha for clone B9V18, 3.22 t/ha for clone B2V50, 1.56 t/ha for clone B5V20, and 1.72 t/ha for seed-propagated accession 0166. Thus, clone B9V18 had the greatest standing dry-biomass in all 3 years, and the greatest growth in year 3. However, clone B2V50 had a 210% increase in biomass over the previous year, while clone B9V18 had only an 81% increase. Perhaps clone B2V50 would catch up in subsequent years. It is noteworthy that clone B9V18 had about a 220% increase in biomass over its parent family 0166.

Clones B9V18 and B2V50 are vastly different in plant architecture, thorns, and resistance to deer and insects. In the fall and winter of 1983/1984, deer damage was severe on many of the thornless B2V50 clones (when it was below head-height) both from browsing and from use as deer scrapes to rub the velvet

TABLE 3

Dry-biomass (t/ha; mean ± SE) and survival (%) for Zachry Ranch clonal comparison trial

Species	1983		1984		1985
	Biomass	Survival[1]	Biomass	Survival[2]	Biomass
Prosopis alba × *P. glandulosa* var. *torreyana*, clone B9V18					
	3.56 ± 0.41	100	4.08 ± 0.13	96	7.39 ± 0.50
P. alba clone B2V50					
	1.68 ± 0.22	95	1.53 ± 0.06	96	4.75 ± 0.48
P. alba 0166, seed-propagated					
	1.60 ± 0.12	94	1.89 ± 0.52	91	3.61 ± 0.78
P. alba clone B5V20					
	1.40 ± 0.24	87	1.86 ± 0.13	88	3.42 ± 0.47

[1]Percent survival measured 5 weeks after planting for all trees to be harvested in 1984 and 1985. Dead trees were replaced after survival measurements.
[2]Percent survival in 1984 based only on harvested blocks.

off their antlers. Clone B9V18, being thorny and more bushy, received no noticeable damage from deer browse and deer scrapes, which no doubt contributed to its higher productivity. After the erection of the 2.4-m-high electric fence, negligible deer damage occurred and clone B2V50 produced many new shoots.

When the 3rd-season growth was harvested, clone B2V50 was about 3 m tall and it was possible to move moderate-sized equipment down the rows. In contrast, clone B9V18 was less than 2 m tall, and it was not possible to walk down the 3-m-wide rows without moving 5 or 6 thorny branches at each tree. The B2V50s had just begun to capture the site by achieving full canopy cover at the time they were harvested. It is possible that, if they were put on a longer rotation, they could shade-out the weeds, or reduce the weed population through root competition for moisture and nutrients.

The performance of clone B2V50 at the drier site was disappointing (especially given the outstanding performance at Kingsville), but may not reflect its true biomass productivity. Clone B2V50 was more difficult to propagate and consequently smaller, weaker plants were used for the planting than for B9V18.

Unlike clones B2V50, B9V18 and B5V20 which exhibited no damage from the Christmas 1983 freeze, many of the thornless *P. alba* 0166 progeny experienced considerable dieback, while the thorny progeny were nearly undamaged. None of the 150 trees of thorny hybrid clone B9V18 selected from *P. alba* 0166 exhibited any freeze damage. This complicates comparisons of the biomass productivity between these clones and seedlots.

Dry-biomass production from the large blocks of seed-propagated *P. alba*

0166 at the Zachry site was 2.6±0.7 and 4.5±0.6 t/ha in 1984 and 1985, respectively. The range in biomass productivity per tree in 1984 was surprisingly large, i.e. from 1.0 kg to 22.3 kg/tree. The larger trees seemed to fill in the voids created by small or stunted trees. It is unclear how much of large-tree growth can be attributed to genetics versus lack of competition.

Dry-biomass of *P. alba* 0166 at the end of the 2nd year was 2.6 t/ha for the 100-tree plots and 1.9 t/ha in the 25-tree plots in the clonal-comparison section. At the end of the 3rd growing-season, the mean dry-weights were 4.5 and 3.6 t/ha for the large and small plots, respectively. Thus the biomass of the larger plots was greater at the end of the 2nd and 3rd growing-season.

The soils throughout this field were remarkably constant, suggesting that edaphic factors were not responsible for this difference in productivity. A consistent difference between the two sections was that the seedlings for the smaller plots were grown in the 'supercell' dibble tubes, while the seedlings for the larger plots were grown in the 38-cm-long plant-bands. Previous field comparisons between these seedling containers found a significant increase in growth of *Prosopis* with the plant-bands (Felker et al., 1988). The larger plots were located on a slight downward slope (to the east) which may have served to catch additional water or to be partially shaded from the afternoon sun.

Kingsville biomass productivity

Mean fresh weights per tree and dry-weights for each of the three growing-seasons for *P. alba* clone B2V50 in Kingsville are presented in Table 4. Fresh weight of 7.3 kg and dry-weight of 3.1 kg are quite substantial for the 1st-year's growth. For example, in a Pennsylvania study even with plant spacings as close as 0.3 m × 0.3 m, the most productive *Populus* clone achieved a stem dry-weight of only 1.3 t/ha at the end of the 1st growing-season (Bowersox and Ward, 1976).

The 2nd-year's growth at the Kingsville site saw an appreciable increase, with a standing dry-weight of 17.6 t/ha and production of 14.1 t/ha. At the time of harvest, the trees had lost an appreciable quantity of their leaves due to cool weather; the wood-plus-stem fraction of one tree separated by hand was 91% of the total dry-weight.

In the 3rd growing-season, the three plots of *P. alba* clone B2V50 had dry standing biomass of 31.4, 40.0, and 46.5 t/ha (mean of 39.3). The plot with 40.0 t/ha had several trees killed the 3rd season during the soil copper application; this analysis makes no compensation for that loss. Thus, clone B2V50 more than doubled in biomass the 3rd season, with production of 21.7 t/ha.

The three plots of *P. alba* × *P. glandulosa* var. *torreyana* clone B9V18 had standing dry-biomass of 11.9, 17.9 and 20.1 t/ha at the end of the 3rd growing-season, (mean 16.6±4.2). Clone B9V18 had a slightly greater dry-matter percentage (59.4%) than clone B2V50 (54.1%).

TABLE 4

Biomass productivity of *Prosopis alba* clone B2V50 and *P. alba*×*P. glandulosa* var. *torreyana* clone B9V18 at Kingsville

Year	Row[1]	Mean tree fresh wt. (kg)	Dry-weight (t/ha)	Annual growth (t/ha)
1984	Inner B2V50	7.3±0.3[2]	3.5±0.2[1]	3.5
1985	Inner B2V50	31.4±1.3	17.6±0.7	14.1
	Border 0166	25.0±2.7		
1986	Inner B2V50	65.4±7.3	39.3±4.4	21.7
	Border 0166	37.4±7.4		
	Inner B9V18	25.1±3.8	16.6±2.4	
	Border 0166	38.7±8.2		

[1]The 'inner' sample plots consisted of 25 trees on a 3-m×3-m spacing for a plot size of 225 m^2. Each plot was surrounded by two border rows (on a 3-m×3-m spacing) of *Prosopis alba* 0166 from seed. The weight of the 'border' row closest to the clonal plots is presented for comparative purposes (24 trees).
[2]Mean ± SE.

It is interesting to compare the productivity of clones B2V50 and B9V18 to the border-row of *P. alba* 0166; these border-rows had nearly identical fresh-weight/tree for clones B2V50 and B9V18 in their respective field positions (40.1 vs. 39.5; 28.1 vs. 29.2; 56.4 vs. 60.0). On average, clone B2V50 had 74% greater biomass than the adjacent border-row of seed-propagated *P. alba* 0166. In contrast, clone B9V18 had 35% less fresh weight than the border-rows. Thus the border-rows have served as a control on the productivity comparisons for these two clones. In both the poorest field position and in the best position, clone B2V50 had nearly 240% greater production than clone B9V18.

DISCUSSION

In Kingsville, *Prosopis alba* clone B2V50 had standing dry-weights of 3.5, 17.6 and 39.3 t/ha at the end of the 1st, 2nd and 3rd years' growth, respectively; thus, respective growth was 3.5, 14.1 and 21.7 t/ha. The high productivity for the 3rd-year's growth looks especially promising. These productivities are comparable to many short-rotation systems on much closer spacings, i.e. about 1.2×1.2 m, with a density of 6944 trees/ha (Bowersox and Ward, 1976; Zavitovski, 1981).

Other workers have also reported high productivity for *Prosopis* in plantations. Ahmed (1961) evaluated the productivity of seven *Prosopis* accessions in several regions in Pakistan after 12–15 years growth. Assuming for the clear bole a specific gravity of 0.7, his yields for *Prosopis* productivity ranged from 13 to 8000 kg/ha/year at 250-mm annual rainfall. The highest biomass productivity reported was from a high-rainfall area (1220 mm/year) in Mombasa, Kenya, where ground-water was near the surface. Here Maghembe et al. (1983) reported a dry-biomass of 216 t/ha at the end of six growing seasons, for a yearly productivity of 36 t/ha/year.

Prosopis biomass productivity studies in California (Felker et al., 1983a,b) reported high maximum yields of 13–15 t/ha/year. However, data from these plots was only of a preliminary nature, due to poor control over border influences of the smaller plots, use or prime agricultural land, and the use of partial irrigation. The studies reported here had adequate control over border influences, were non-irrigated, and were conducted of good pastureland. Thus this data should be applicable to the millions of hectares of land with annual rainfalls of 650 mm and above in Texas. Given the high productivities obtained here, biomass-energy farms should be possible in Texas.

The concept of biomass-energy farms using *Prosopis* clones, as suggested for use in Texas by Felker (1984), is compatible with the results obtained here. The 3-m$\times$3-m spacing appears sound in minimizing seedling costs while still allowing high productivity. Simazine has been shown to be phytotoxic to *Prosopis* and so should be replaced by a linuron/norflurazon combination (Felker et al., 1986). A 6-month field-evaluation of the proposed biomass-harvester (Felker, 1984) found it to be commercially unacceptable (Felker, unpublished observations, 1986). Other harvesters have been developed (see e.g., Stokes et al., 1986) that might be acceptable.

The last two growing-seasons in Kingsville have been high-rainfall years, so substantially lower productivities may have occurred if the rainfall had been closer to the long-term average. Furthermore there is need for improvement in the management of weed control, fertilization, and pesticide application during mid-rotation. This is because, unlike *Leucaena*'s dense canopy, the *Prosopis* canopy is not dense enough to shade out weeds, even when the trees have grown close enough to prevent a 30-hp tractor penetrating the stand (for cultivation), without causing excessive damage.

The productivity of clone B2V50 at Kingsville is so much greater than at the Zachry site that it would appear that factors in addition to rainfall limit its growth. For example, during the 3rd growing-season, clone B2V50 produced 21.7 t/ha growth in Kingsville with 682 mm rainfall, while it only produced 3.22 t/ha during the 3rd growing-season at the Zachry Ranch with 560 mm rainfall.

During the 2nd season, a no-growth drought occurred at the Zachry site, while an exceptionally high-rainfall year occurred in Kingsville.

Companion studies (Wightman and Felker, 1990) suggest that copper and possibly other micronutrients may be limiting growth at the Zachry site. Research is needed to predict soil types conducive to the high productivities that occurred at Kingsville. After nutrient deficiencies are corrected, the productivity of the Zachry site should approach that of the Kingsville site, i.e. about 10 t/ha in good-rainfall years.

While clone B2V50 had 140% more biomass than clone B9V18 at Kingsville, partially due to the lack of deer damage, B9V18 produced the greater biomass at Zachry partially because blister beetles (*Epicauta nigritarsus*) were not a problem there. These insects heavily defoliated the native mesquites in Kingsville, whereas they caused little damage to *P. alba* clones. The resistance of the hybrid clone to blister beetles more closely resembled the native *P. glandulosa* than the female *P. alba* parent. These plots were sprayed with an orthene/pydrin mixture in 1985 to control both psyllids and blister beetles, but this was not possible in 1986 due to the large size of the trees.

Clone B2V50 had the lowest survival (88%) of all the clones at the Zachry Ranch in a year in which 38 mm of rain occurred 1 day after planting. In contrast, it had 99% survival the following year at Kingsville when rain did not occur within 8 weeks of planting. The difference seems attributable to use of larger planting-stock and the technique of planting recently watered seedlings with the plant-bands still on (Felker et al., 1988).

Thorniness and cold-tolerance in the progeny of *P. alba* 0166 appear to be derived from the native mesquite, since the *P. alba* female parent was thornless and *P. alba* in general is not cold-hardy (Felker et al., 1981). None of the native mesquites suffered from this freeze. Since *P. alba* and the California native mesquites (*P. glandulosa* var. *torreyana*) naturally form interspecific hybrids, and since they have been grown in close proximity for several generations, it is possible that clone B2V50 may represent an F_2 progeny with *P. alba* leaf morphology and native cold-tolerant genes.

While almost no growth occurred on the Zachry trees during their 2nd growing-season, they survived a 70-year-record freeze and a 20-year-record drought with no loss in survival or biomass. Long-term survival in the face on natural disasters is a very important asset for biomass plantations, and these *Prosopis* clones appear well suited to adverse conditions.

The southwestern United States was highly recommended for biomass-energy feedstock production in early studies (Alich and Inman, 1974). Later studies by Solar Energy Research Institute (SERI) consultants (Salk and Folger, 1987) came to the opposite conclusion. However, the latter consultants failed to recognize the exceptionally high productivity that can occur in the southwestern U.S.A. when the high solar intensities and long growing-seasons are combined with either high rainfall (greater than 650 mm) or ground-water sources within several m of the surface. Furthermore, *Prosopis* and other arid-adapted biomass producers such as *Atriplex* are exceptionally salt-tolerant (Felker, 1984). Water that is too saline for traditional agriculture could be used for irrigation in areas of the United States where the rainfall is too low to achieve economically acceptable production levels of other crops. Moreover, some areas such as California's San Joaquin valley are in need of deep-rooted, salt-tolerant plants to lower water-tables and reduce pumping costs to dispose of irrigation drainage-water (Felker, 1984).

In semiarid developing countries where fuelwood is in short supply (Eckholm, 1975), such as India, the Sahel and Latin America, plantations of these trees could be very useful. DeTroyer (1986) of the World Bank has stressed the need for technologies to markedly improve fuelwood productivity in semiarid regions of the Sahel.

It is our feeling that the high productivities obtained in this study are more a result of intensive management, especially weed control, than genetics per se. *Prosopis alba* 0166 plantations that were initiated 3 years before these plantings, but later abandoned because of poor weed control, have not visibly grown in 4 years. Introduction of these clones to developing countries with high expectations but without the management capability for site preparation, weed control and fertility assessment would be inviting disaster. In developing countries, the most likely successful adaptation of these clones will probably be where they are grown in farmers' fields and routinely weeded with the farmers' crops.

While these studies have emphasized the biomass productivity of *Prosopis* for fuel, *Prosopis* plantations could also be developed for luxury-quality lumber. *Prosopis* has outstanding cabinet-quality wood, with an attractive orange/red color, a high specific gravity (0.7) and one of the lowest volumetric shrinkage values, 4% (Weldon, 1986).

CONCLUSIONS

The *Prosopis* clones examined here had excellent survival at transplant (greater than 95%), without irrigation, even when no rain occurred for 8 weeks after planting. During adverse conditions, such as a 20-year-record drought and a 70-year-record freeze, no growth occurred, but neither was there any loss in survival. However, when favorable rainfall conditions occurred (greater than 550 mm for 2 years) truly exceptional dry-matter productivities of 20 t/ha were achieved. Productivity at the Zachry site appeared to be limited by some variable in addition to rainfall, perhaps fertility. A better understanding of the relationship between growth, water-stress and soil/plant nutrient relationships on sandy calcareous soils is required for exploitation of these tree legumes. Nevertheless, the clones and management systems reported here have greatly improved productivity over previous systems, and appear to have great potential to relieve fuelwood shortages in many of the world's semiarid regions.

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