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SCREENING *PROSOPIS* (MESQUITE) SPECIES FOR  
BIOFUEL PRODUCTION ON SEMI-ARID LANDS

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## ABSTRACT

Arid adapted nitrogen fixing trees and shrubs of the genus *Prosopis* (mesquite) have been examined for woody biomass production on semi-arid lands of southwestern United States. A germplasm collection of 900 accessions from North and South America and Africa was assembled. Field studies screening for biomass production, frost tolerance, response to irrigation, pod production and heat/drought tolerance involved a total of 80 accessions including *Leucaena leucocephala* (Hawaii Giant K-8), *Parkinsonia aculeata*, *Cercidium floridum*, and *Olneya tesota*. *Prosopis* species of South American origin had the highest dry matter production of all genera, were 20-30 fold more productive than many range species and possessed genetic variability for lack of thorns and erect tree shape. Selections made from survivors of cold/frost screening trial had more frost tolerance and biomass productivity than prostrate selections from the ranges of Arizona, New Mexico and west Texas. Thirteen *Prosopis* species were found to nodulate, reduce acetylene to ethylene, and grow on a nitrogen free media in greenhouse experiments. The salinity tolerance of six *Prosopis* species was examined on a nitrogen free media in greenhouse experiments. No reduction in growth occurred for any species tested at a salinity of 6,000 mg NaCl/L which is considered too saline for normal agricultural crops. *P. pallida*, *P. articulata* and *P. tamarugo* grew well on a nitrogen free media equivalent to  $\frac{1}{2}$  seawater and grew slightly in full seawater. A 44% sugar pod

producing *Prosopis* was identified that produced 73 kg of pods. These pods were easily fermented to ethanol by cooperators at MIT. Individual trees have grown 5 to 7 cm in basal diameter, and 2.0 to 3.7 meters in height per year and have achieved 50 kg oven dry weight per tree in 2 years with 600 mm water application per year. Vegetative propagation techniques have been developed and clones of these highly productive trees have been made. Small plots on a 1.5 x 1.5 m spacing in the California Imperial Valley had a first and second season dry matter production of 11.7 and 16.9 T/ha for *P. chilensis* (0009), 7.1 and 6.9 T/ha for *P. glandulosa* var. *torreyana* (0001), 9.8 and 19.2 T/ha for *P. alba* (0039) and 7.9 and 14.5 T/ha for progeny of a California ornamental (0163). The projected harvested costs of \$25.00 per oven dry ton or \$1.50 per million Btu's compare favorably with coal and other alternative fuel sources in South Texas.

## INTRODUCTION

Mesquite (*Prosopis spp*) is a heat/drought resistant, nitrogen fixing (Felker and Clark, 1970), leguminous tree that occurs on 30 million hectares of marginal semi-arid land in southwestern United States (Parker and Martin, 1952). By using groundwater accumulated from runoff from nearby mountains mesquite occurs on many miles of sand dunes in Death Valley, California where the mean annual precipitation is 45 m (1.78") and the mean daily July maximum temperature is 46.7°C (116°F). Energy can be obtained from mesquite from woody biomass and from fermentation of its high sugar content (33-43%) pods to alcohol.

On 1 April 1978 work was initiated under this Department of Energy grant to evaluate *Prosopis* as an energy crop through greenhouse and field plot research and through economic and cost considerations. The following research activities were carried out to meet these objectives: (1) a germplasm collection representing North and South American and African accessions was established, (2) thirty-two representative accessions from this collection were screened for growth rate under controlled moisture treatments such that the plants were watered when the soil moisture levels reached a 0.6 Bar (wet), 2.0 Bar (medium) or 5.0 Bar (dry treatment). This work was carried out on the University of California, Riverside (UCR) experiment station, (3) fifty-five accessions representing the most productive accessions in the UCR moisture treatment plots, and accessions collected first year in California



FIGURE 1 - Mesquite in Death Valley sand dunes

Note man lower right

desert were screened for biomass production and heat/drought tolerance in the hot (July daily max of 107° F) California Imperial Valley, (4) the water use efficiency was determined and biomass production in kg/ha was estimated for four of most productive accessions in the Imperial Valley location, (5) portions of first and second season Imperial Valley plantings and of all third season UCR trees were harvested, green and dry weight measured and regression equations developed for estimating fresh and dry biomass, (6) the cold/frost tolerance of 30 *Prosopis* accessions was determined with field plantings at 1520 m (5000 ft) elevation by monitoring temperatures and measuring percent survival. An environmental assessment report was prepared and approved prior to establishing these plantings, (7) pod production (yield/plant) and pod characteristics were determined for selected species at all locations, (8) cultural practices including weed and insect control measures were developed, (9) effective vegetative propagation techniques for *Prosopis* were developed and (10) *Prosopis* was evaluated as an energy crop by estimating costs to establish field plots and commercial sized stands, and by examining environmental assessments and land availability.

This final report is divided into chapters which specifically address the objective described above. As this is the only applied work on *Prosopis*, sufficient detail in experimental methods has been provided for others to easily repeat these procedures. Additional sections such as breeding mechanism and taxonomy have

been included to provide a comprehensive final report that could stand alone.

Sections of this report have been condensed from journal articles, manuscripts, and symposium proceedings listed in the Appendix. Copies of all these items may be obtained from the DOE/Technical Information Center, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

## I. Breeding Structure, Taxonomy, and Germplasm Acquisition

### Breeding Structure

Simpson (1977) conducted pollen compatibility studies on *P. velutina* in Arizona, and *P. chilensis*, *P. flexuosa*, and *P. torquata* in northern Argentina. Three branches were covered by nylon netting to exclude pollinators. One unmanipulated branch and one artificially self-pollinated branch served as controls. Without presenting quantitative data Simpson states that the above species were self-incompatible. This would require out-crossing and should result in high variability among seedling propagated progeny from the same female parent (half-siblings). This prediction of high variability among half-siblings is amply verified throughout all experimental portions of this report.

In contrast *Leucaena leucocephala* which is highly self-compatible (J. L. Brewbaker pers. comm.) is highly regular in leaf and pod morphological characters and at least for biomass productivity has smaller coefficients of variation than *Prosopis*.

Both morphological (Burkart, 1976) and cytogenetic (Hunziker, 1975) evidence suggest that obligate outcrossing occurs to such an extent that interspecific hybrids occur naturally. Different kinds of observations from our field trials indicate interspecific hybridization easily occurs between the South American introduced ornamental *Prosopis*, probably species *alba*, and the southern California native *P. glandulosa* var. *torreyana*. A

South American ornamental tree designated accession 0166 was thornless, had 2 pair of pinnae with 30-50 pairs of finely divided leaflets and flat curved pods and was growing within 200 meters of southern California native species. Some of the progeny of 0166 had thorns of the native species; a leaflet number, size, and spacing intermediate between the native and female parent; and straight pods intermediate between the two species. Progeny of another South American ornamental (0163) showed segregation in spring bud burst as well as segregation for leaf morphological characters and presence of thorns. In the mountain cold screening trial progeny of ornamental 0163 were intermediate between *P. alba*, with nearly no survival, and California native species with high survival.

In some cases progeny of South American ornamentals with intermediate botanical characteristics have exceptionally high and low biomass producing trees. Four progeny of ornamental 0285 harvested after two growing seasons had a range in oven dry biomass of 0.1 to 56.3 kg. All four harvested trees were alive but the small trees were severely disfigured and stunted with no typical "first year stem growth". Throughout several sucking insect infestations in the field the disfigured characteristic of the stunted tree was never transmitted to another plant and we assume the condition is not a disease and must be of genetic origin. This disfiguration is readily apparent when the first true leaves emerge above the cotyledons. A possible explanation could be

varying degrees of gene complementation resulting from heterozygous parents entering the interspecific hybridization.

Most cases of this hybridization are apparent when the ornamental is the female parent. The exception results from an analysis of progeny from accession 0216 (*P. glandulosa* var. *torreyana*) which had an ornamental of South American origin growing nearby. Progeny of 0216 had the highest biomass production of any native species in the second season Imperial Valley trials and were just below the productivity of South American ornamentals. The coppicing ability of 0216 progeny resembled the *P. alba* species more than the native species, and the 0216 progeny showed more psyllid resistance (but less than *P. alba*) than any other California native. The leaf and thorn morphology of 0216 progeny resembled the female parent but their biomass productivity, coppicing ability, and insect resistance more closely resembled *P. alba* taxa.

#### Taxonomy

The botanical nomenclature of Burkart's (1976) second revision of the genus *Prosopis* is used here. *Prosopis* taxonomy is difficult because of the putative interspecific hybrids with intermediate characters especially within Burkart's section algarobia series *chilensis*. Species in other sections such as *P. kuntzei*, *P. pubescens*, *P. ruscifolia*, and *P. tamarugo* are readily identifiable. Some of the plant materials came from South America courtesy of Prof. O. T. Solbrig of Harvard University who worked with Burkart and who is an authority on *Prosopis*. Con-

sequently, we have used the *P. alba* taxonomic identification of materials supplied by Solbrig without reservation.

Ornamental *Prosopis* introduced into North America several decades ago are widely used in the southern California high and low deserts and in Tucson and Phoenix, Arizona. Sunset garden book lists these "Reese hybrids" as being of uncertain origin (Sunset, 1981), but they are known in southern California deserts as "Chilean mesquite". These ornamentals are definitely not North American taxa or *P. chilensis* typical of the region near Santiago Chile from which the type specimen originated, or *Prosopis* in the Salar de Pintados near Iquique, Chile (Felker unpubl. obs.). The *Prosopis* in the vicinity of San Pedro d'Atacama Chile are similar in leaf, thorn, pod, and gross tree morphology to southern California ornamentals. Chilean botanists have classified this species as *P. atacamensis* but Burkart (1976) rejected this taxa in favor of *P. alba*. Unlike *P. alba* obtained from Solbrig, the ornamental South American derived *Prosopis* will be identified with a parenthetical question mark as *P. alba* (?).

Earlier workers have used the taxon *P. juliflora* for mesquite in Texas, Arizona, N. Mexico and California but as reviewed by Burkart (1976) *P. juliflora* is a truly tropical species that does not exist in continental U.S.A. *P. chilensis* is another confused taxon that except for our *P. chilensis* (0009) accession received from Buenos Aires probably does not exist in the United States. *Prosopis* accessions similar to *P. chilensis* observed

by Felker in the type locality near Santiago Chile were not observed among *Prosopis* in the Sudan or Senegal despite widely held beliefs to the contrary.

The term accession is used to denote single tree seed collections (half-siblings) whose taxonomic identity is or might be uncertain. Tree to tree variability in natural populations is so large that accessions (half-siblings) that have been bulked from a similar geographic region (provenances) have not been used.

#### Germplasm Acquisition

In developing any new crop plant it is imperative to obtain as much genetic diversity as possible to be able to provide products of various qualities, and to be able to adapt to stress conditions such as heat, drought, insect predation, frost and salinity. Our *Prosopis* collection consists of: approximately 150 accessions obtained from Professor Solbrig which were used in the IBP project comparing North and South American deserts; of 150 collections of native *Prosopis* collected on a 3,000 mile field trip through the California desert; of 300 Peruvian collections obtained through contract with Dr. Alva of Lima, Peru; of approximately a dozen *tamarugo* (*P. tamarugo*), *algarrobo* (*P. alba*?) and *chanar* (*Geoffrea decorticans*) collections made by Felker in Chile; of several hundred second generation progeny of UCR and Imperial Valley grown trees; of miscellaneous collections from Argentina, Hawaii, the Caribbean, Senegal, Sudan

and South Africa, and of a very limited number of cuttings of approximately a dozen clones.

The following species and origins are represented; *P. africana*, West Africa; *P. alba*, Argentina; *P. articulata*, Baja, Mexico; *P. chilensis*, Argentina; *P. kuntzei*, Argentina; *P. laevigata*, San Luis Potosi, Mexico; *P. nigra*, Argentina; *P. pallida*, Hawaii; *P. pubescens*, California; *P. ruscifolia*, Argentina; *P. tamarugo*, Chile; *P. glandulosa* var. *glandulosa*, Texas; *P. glandulosa* var. *torreyana*, California; and *P. velutina*, Arizona.

Seeds and pods of this collection have been stored in a 8' x 8' x 10' walk-in freezer after having been catalogued, indexed and records made of information accompanying the shipment. USDA clearance and permits have been obtained to import all *Prosopis* species except *P. ruscifolia*. No remaining seed of *P. kuntzei* and *P. laevigata* exist but most accessions have a sufficient number of pods to obtain several hundred viable seeds. Pods containing 40,000 seeds are available for several South American ornamental accessions.

Extraction and separation of *Prosopis* seeds from the pods is made difficult by the pliable leathery capsule surrounding the seed which is in turn embedded in a 17-40% sugar pod mesocarp. An evaluation of 5 seed separation devices fabricated and/or purchased at UCR, including the Texas Tech (Flynt and Morton, 1969) design, with a Hobart Model 275 coffee mill located at the USDA lab in San Francisco indicates the coffee mill produces less

broken seeds in approximately the same milling time as any device. We have not yet located a Hobart mill to purchase as they have been out of production so long most Hobart dealers have never seen them.

Large numbers of seed requests have come from developing countries but because of limited seed supplies and difficulty in cleaning seeds only a small portion of them have been filled.

Accessions that occur in specialized ecological niches, such as high elevation/cold winter climates or in proximity to salt water bodies may possess specialized genetic attributes that confer exceptionally useful characteristics and are individually discussed in subsequent sections of this report.

## II. Methods of Biomass Estimation

In the initial grant application height measurements were used to screen *Prosopis* selections for biomass productivity. As shown in Table 1 it soon became apparent that tall accessions such as *P. velutina* (0025) did not have nearly as large a stem diameter as accessions such as *P. alba* (0039) of the same height. Height (h) and basal stem diameter (2r) measurements were then incorporated into a single function which assumed the shape of a cone ( $\pi r^2 h/3$ ) for a non-destructive estimate of growth. A similar parabolic stem volume expression ( $\pi r^2 h/2$ ) has been reported by ecologists (Whittaker and Marks, 1975) to be the preferred expression for relating volume and biomass with linear expressions. After this work was completed a paper appeared which reported highly significant linear regressions for mesquite between fresh weight, canopy volume, basal area, and area 60 cm above ground level (Whisenant and Burzlaff 1978).

In 1979 four replicates of 55 accessions in Imperial Valley were harvested, weighed, stem diameter measurements taken and representative trees reduced in volume for moisture content determination. The stem diameters, heights, and fresh biomass for these trees ranged from 0.16 to 7.65 cm, 26 cm to 446 cm, and 0.04 kg to 17.8 kg respectively. Linear regressions of basal area versus fresh weight were significant (Table 2) ( $r^2=0.913$ ) but predicted that trees less than 1.3 cm in diameter had a negative biomass and indicated that equations of higher power were

Table 1. Height, stem diameter, and stem volume 1½ years after transplanting *Prosopis* in Riverside Orchard Study trees

Accession		Origin	(a) Height (cm)	(b) Diameter (cm)	(c) Main Stem Volume (cm <sup>3</sup> )
<i>P. chilensis</i>	(0009)	Argentina	355	4.9	3150
<i>P. alba</i>	(0039)	Argentina	286	5.3	2270
<i>P. alba</i>	(0037)	Argentina	310	3.9	1420
<i>P. alba</i>	(0035)	Argentina	280	4.0	1200
<i>P. spp</i>	(0025)	Mexico	304	3.3	940
<i>P. nigra</i>	(0038)	Argentina	199	2.6	420
<i>P. chilensis</i>	(0010)	Argentina	189	2.7	380
<i>P. spp</i>	(0022)	Arizona	123	2.1	240
<i>P. velutina</i>	(0031)	Arizona	170	1.5	110
<i>P. spp</i>	(0026)	New Mexico	125	1.9	110
<i>P. ruscifolia</i>	(0033)	Argentina	149	1.5	88
<i>P. spp</i>	(0030)	Arizona	132	1.3	63
<i>P. spp</i>	(0080)	Arizona	135	1.2	48
<i>P. spp</i>	(0028)	Texas	111	0.77	19
<i>P. spp</i>	(0074)	New Mexico	86	0.8	17

(a) Height from ground to tip of the longest branch.

(b) Diameter at ground level; where two trunks appeared at ground level with diameter greater than 1 cm, the diameter which yielded the sum of areas is given; where there were numerous branches less than 0.5 cm in diameter, only the largest was measured.

(c) Main stem volume calculated by assuming the volume of a cone, i.e.  $\pi r^2 h/3$  where  $r$  is the radius and  $h$  the height; mean stem volume is not calculated from mean height and mean stem diameter, but from individual stem volumes.

Table 2. Regression equations relating basal area, stem diameter and stem volume to fresh biomass in first season  
Imperial Valley

Species	Equation Parameter				
	X	Y	$r^2$	Y inter- cept	slope
South American <i>Prosopis</i>	Basal area	Fresh wt.	.900	-.379	.342
North American <i>Prosopis</i>	(cm <sup>2</sup> )	(kg)	.903	-.665	.366
Other species			.918	-.365	.404
All species			.913	-.537	.363
South American <i>Prosopis</i>	Log basal	Log fresh	.986	-.882	1.29
North American <i>Prosopis</i>	area	wt.	.936	-.989	1.42
Other species	(cm <sup>2</sup> )	(kg)	.946	-.683	1.19
All species			.959	-.863	1.30
South American <i>Prosopis</i>	Log stem	Log fresh	.986	-1.02	2.58
North american <i>Prosopis</i>	dia.	wt.	.936	-1.14	2.85
Other species	(cm)	(kg)	.946	-.807	2.38
All species			.959	-.999	2.60
South American <i>Prosopis</i>	Log stem	Fresh wt.	.724	-1.23	11.60
North American <i>Prosopis</i>	dia.	(kg)	.829	-3.99	13.51
Other species	(cm)		.849	-4.94	18.73
All species			.772	-3.63	14.22
South American <i>Prosopis</i>	Stem dia.	Log fresh	.870	-.965	.341
North American <i>Prosopis</i>	(cm)	wt.	.886	-.934	.371
Other species		(kg)	.922	-.649	.293
All species			.877	-.804	.324
South American <i>Prosopis</i>	Stem vol.	Fresh wt.	.902	-.974	.00302
North American <i>Prosopis</i>	(cm <sup>3</sup> )	(kg)	.860	-.097	.00390
Other species			.899	-1.19	.00290
All species			.902	-.770	.00312
South American <i>Prosopis</i>	Log stem	Log fresh	.986	-2.18	.920
North American <i>Prosopis</i>	vol.	wt.	.933	-2.72	1.11
Other species	(cm <sup>3</sup> )	(kg)	.931	-1.87	.827
All species			.953	-2.27	.948

Equation parameters are for equation  $y = mx + b$  where x and y are functions listed in the respective columns and r is the correlation coefficient. There are 63, 117, 32, and 212 trees harvested respectively for South America, North America, other and all species.

required. A linear regression of log-log transformed biomass and stem area had a higher  $r^2$  and a slope of 1.30 indicating that an expression intermediate between linear and quadratic provided a better fit of the data (Table 2). A linear regression of log (area x height) versus log (fresh weight) was no better than log area alone and therefore height measurements and cone volume estimates were discontinued. In summary the easiest and best estimate of fresh biomass was of the form log fresh weight = log basal diameter.

In 1979 the dry matter content of 4 *Prosopis* species and *Cercidium floridium*, *Leucaena leucocephala*, *Olneya tesota* and *Parkinsonia aculeata* were determined by reducing entire trees to 10-15 cm lengths and drying them in a 37°C forced air oven for 8 weeks until they came to equilibrium (Table 3). The largest pieces lost less than 1% when dried for an additional 24 hrs at 110°C. The native deciduous *P. glandulosa* var. *torreyana* was harvested in the winter when it lost most of its leaves and therefore had a significantly higher dry matter content than 3 evergreen *Prosopis* of South American origin (Table 3). *Parkinsonia aculeata* and *Leucaena leucocephala* had lower dry matter contents of 44 and 40% respectively. The 10% difference in dry matter content between *Leucaena* and *Prosopis* is a 25% difference relative to *Leucaena*.

Regressions for biomass estimation were expanded in 1980 with the complete harvest of the UCR differential irrigation

Table 3. Moisture content and leaf and stem dry matter for first season Imperial Valley tree legume genera

Accession	Dry matter %	Stem dry matter Stem + leaf dry matter %
<i>Prosopis alba</i> (0039)	49 <sub>+2</sub> bc	71 <sub>+2</sub> c
<i>Prosopis alba</i> (0163)	50 <sub>+2</sub> b	80 <sub>+3</sub> b
<i>Prosopis chilensis</i> (0009)	48 <sub>+1</sub> bc	76 <sub>+4</sub> bc
<i>Prosopis glandulosa</i> var. <i>torreyana</i> (0001)	56 <sub>+3</sub> a	95 <sub>+1</sub> a
<i>Cercidium floridum</i> (0324)	51 <sub>+1</sub> b	96 <sub>+2</sub> a
<i>Leucaena leucocephala</i> (0147)	40 <sub>+2</sub> d	70 <sub>+1</sub> c
<i>Olneya tesota</i> (0343)	50 <sub>+6</sub> b	78 <sub>+3</sub> bc
<i>Parkinsonia aculeata</i> (0322)	44 <sub>+3</sub> cd	81 <sub>+5</sub> b

Moisture content and dry matter partitioning was determined for four entire trees of each of the above species. Means followed by same letter are not significantly different at 5% level. The dry matter contents are expressed as percent of fresh weight.

treatment plots consisting of 935 trees and of harvest of 4 blocks of second season Imperial Valley trees consisting of 205 trees. Basal diameter and fresh weight measurements were taken for all these trees but height measurements were not taken because the previous year's data indicated that height measurements did not increase the accuracy of the biomass predictions.

Differences in dry matter content were expected for the 27 accessions in the UCR irrigation study but too many large trees were involved to dry entire trees. Use of a whole tree drum chipper was donated by Asplundh Tree Expert Company that allowed entire trees to be homogenised to allow subsamples to be taken for moisture content determination. This chipper was very fast but some small (1 cm) diameter stems resulted in 6-7 cm long pieces while 4 cm diameter stem sizes yielded 1-2 cm size chips. Thus large subsamples (1 kg) were required to achieve homogeneity for moisture content determination. Three 500-1500 g subsamples of each of two trees were obtained for most of the 81 plots for a total of 486 subsamples. These subsamples filled two pickups to over capacity. Considerable difficulty was obtained locating a 70°C drying oven large enough to process two pickup loads of subsamples to meet U.S. Forest Service/DOE recommended procedures for moisture content determination. We recommend these drying procedures be modified to allow use of 45°C forced air ovens that are commonly available in agricultural colleges in the 80 ft<sup>3</sup> capacity.

Mechanical difficulties were encountered with the chipper during harvest of the wet and dry irrigation treatments that delayed chipping some of the trees for 2 days after harvest and weighing. Trees in the wet irrigation treatment experienced longer delays than those in the dry treatments. In contrast all of the trees from the medium irrigation treatment were chipped within an hour after weighing. The mean dry matter content for the trees in the medium, dry, and wet irrigation treatments were 56.6%, 58.9%, and 61.0% respectively and follow the order of increasing duration between weighing and chipping. The dry matter contents in the medium treatment were used to calculate dry matter contents for all irrigation treatments; because these trees were chipped immediately, because there was only a several percent difference among treatments, and because dry matter contents in the medium treatment were most conservative (lowest).

These results are presented in Table 4.

A whole tree chipper was not available for the Imperial Valley harvests and thus representative trees were reduced to 10-15 cm lengths by hand and dried to equilibrium at 65°C. The standard deviations of the dry matter contents measured the previous year were small and therefore two whole trees instead of four were reduced to 10-15 cm lengths for moisture content determination. In general, the dry matter contents in 1980 were several percent lower than in 1979 (Table 5). *Leucaena leucocephala* went from 40% to 53% dry matter and was the major ex-

Table 4. Riverside irrigation study dry matter coefficients

<u>Variety</u>	<u>Species</u>	<u>Dry weight fresh weight (%)</u>	
		<u>Mean</u>	<u>Standard Deviation</u>
3	<i>P. alba</i> (0098)	56	1.2
4	<i>P. alba</i> (0037)	53	2.5
5	<i>P. alba</i> (0039)	57	2.0
6	<i>P. alba</i> (0132)	53	5.5
7	<i>P. alba</i> (0134)	55	2.2
8	<i>P. articulata</i> (0016)	54	1.6
9	<i>P. chilensis</i> (0009)	56	1.7
10	<i>P. kuntzei</i> (0130)	60	4.3
11	<i>P. laevigata</i> (0114)	58	2.5
12	<i>P. nigra</i> (0036)	56	2.2
13	<i>P. nigra</i> (0034)	61	0.0
14	<i>P. nigra</i> (0038)	55	2.6
15	<i>P. nigra</i> (0133)	56	1.2
18	<i>P. ruscifolia</i> (0131)	58	1.2
19	<i>P. tamarugo</i> (0042)	55	1.2
20	<i>P. velutina</i> (0020)	57	1.2
21	<i>P. velutina</i> (0032)	58	1.4
22	<i>P. velutina</i> (0025)	60	2.4
23	<i>P. glandulosa</i> var. <i>torreyana</i> (0001)	60	1.0
25	<i>P. glandulosa</i> var. <i>glandulosa</i> (0028)	63	0.2
26	<i>P. spp</i> (0080)	61	0.8
27	<i>P. spp</i> (0074)	60	0.0
28	<i>P. spp</i> (0108)	53	1.4
29	<i>P. spp</i> (0116)	53	0.6
30	<i>P. alba</i> (0013)	53	0.6
31	<i>P. alba</i> (0137)	53	3.1
32	<i>P. alba</i> (0138)	57	2.4
		Mean	56.6

Values are for trees harvested in medium irrigation treatment as described in text. Dry matter contents are means of 3,500-1,000 g subsamples from each of two homogenised (chipped) trees.

Table 5. Dry matter contents for Imperial Valley  
in 1979 and 1980

	<u>Dry weight</u> <u>fresh weight</u>	1979	1980
<i>Leucaena leucocephala</i> (0147)		40%	53%
<i>Parkinsonia aculeata</i> (0322)		44%	40%
<i>Olneya tesota</i> (0343)		50%	52%
<i>Cercidium floridium</i> (0324)		51%	45%
<i>P. alba</i> (?) (0163)		50%	47%
<i>P. glandulosa</i> var. <i>torreyana</i> (0001)		56%	49%
<i>P. chilensis</i> (0009)		48%	47%*
<i>P. alba</i> (0039)		49%	46%

\*extrapolated from *P. alba* (0039) and *P. alba* (?) (0163)  
from first and second year trends.

ception to this rule. Early in the second season *Leucaena* produced large quantities of pods and seeds then lost most of its leaves. At the time of the 1980 harvest the *leucaena* still had not regained full leaf cover which probably accounted for its high dry matter content. The dry matter content determined for the California native *P. glandulosa* var. *torreyana* (0001) was used for all North American deciduous species, and the dry matter content determined for the South American introduced ornamental (0163) was used for all nearly evergreen South American species.

The measured fresh weights for all harvested trees in the Imperial Valley plots were multiplied by a moisture content measured for each species to achieve a data set of stem diameter versus dry weight. A regression of log stem diameter versus log dry weight did not yield satisfactory results when comparing genera of greatly differing moisture contents (e.g. *Leucaena* and *Prosopis*) because the equation effectively used a weighted average dry matter content for all selections.

The preferred computation of dry biomass is achieved through the regression relating log stem diameter to log fresh weight and an individual dry matter coefficient for each genera or accession. In this report we have denoted this calculation as "coefficient calculated dry weight".

A summary of biomass regression equations for all three sites and for the combined equation for all sites is presented in

Table 6. The antilog of the tree size and biomass has been presented to allow a researcher to choose the regression most suited to his size class. It is important to realize the mean of the antilogs of X and Y are not identical to the means of the untransformed variables.

The first season Imperial Valley trees had the smallest stem diameters and fresh biomass. The UCR third season trees were intermediate and the second season Imperial Valley trees had the largest stem diameter and fresh biomass.

The antilog of the standard error of the Y (biomass) prediction is included in the table as it is often requested by reviewers. Calculation of this standard error assumes equal standard deviations (in absolute terms) over the range of the regression. We have measured stem diameter and biomass with calipers and scales of different capacity to attempt to achieve several percent accuracy in measurement over the entire range of the regression. This implies equal coefficients of variation and that the standard deviations increase in proportion to stem diameter and biomass. Since equal standard deviations are not present over the range, a calculation of standard error for the regression is invalid. Intuitively, it is unreasonable to assume constant standard error of Y when a constant percentage accuracy is obtained.

Little change in either the slope or standard error of Y occurs between the fresh and dry weight regressions for the

Table 6. SUMMARY OF BIOMASS REGRESSION EQUATIONS

	Field Study			
	1st Season Imperial Valley	2nd Season Imperial Valley	UCR-3rd Season	1st & 2nd Season-Im- perial Val- ley & UCR 3rd Season
$X = \log_{10}$ stem diameter (cm); $Y = \log_{10}$ fresh weight (kg)				
antilog mean $X \pm$ antilog STD DEV $X$	3.64 $\pm$ 1.53	6.08 $\pm$ 1.58	3.99 $\pm$ 1.67	4.18 $\pm$ 1.66
antilog mean $Y \pm$ antilog STD DEV $Y$	2.87 $\pm$ 3.12	10.2 $\pm$ 3.67	4.05 $\pm$ 3.33	4.41 $\pm$ 3.52
antilog standard error $Y$	1.38	1.52	1.71	1.66
slope (m)	2.5801	2.6758	2.116	2.2470
intercept (b)	-0.9908	-1.0908	-0.6609	-0.7538
n	212	205	935	1352
$r^2$	0.919	0.898	0.803	0.841
F	2370***	1781***	3808***	7126***
$X = \log_{10}$ stem diameter (cm); $Y = \log_{10}$ dry weight (kg)				
antilog mean $X \pm$ antilog STD DEV $X$	3.64 $\pm$ 1.52	6.08 $\pm$ 1.58	3.98 $\pm$ 1.67	4.19 $\pm$ 1.67
antilog mean $Y \pm$ antilog STD DEV $Y$	1.52 $\pm$ 3.07	4.89 $\pm$ 3.63	2.29 $\pm$ 3.29	2.41 $\pm$ 3.46
antilog standard error $Y$	1.39	1.51	1.70	1.66
slope (m)	2.5374	2.6582	2.0805	2.1905
intercept (b)	-1.2438	-1.3948	-0.8893	-0.9811
n	212	205	935	1352
$r^2$	0.913	0.899	.800	0.832
F	2197***	1810***	3739***	6681***

Values computed above are for the regression equation  $Y = mx + b$ .  $n$  is the number of observations,  $r$  is the correlation coefficient and  $F$  is computed from the analyses of variance.

same data set. The major change occurs in the Y intercept which is reasonable since logs are subtracted to achieve division by a constant factor such as is required to convert fresh to dry biomass.

A statistical comparison of the regression equation slopes and population means for the three data sets (1st season Imperial Valley, 2nd season Imperial Valley, and 3rd season UCR) was made to determine if the equations could be combined or used interchangeably (Table 7). The slopes of the regression equation for the first and second season Imperial trees were not significantly different although their mean stem diameters and biomasses were (Table 7). The slope of the regression for the UCR third season trees was significantly different from both Imperial Valley data sets despite the fact that the UCR trees were intermediate in diameter and biomass between Imperial Valley data sets. The spacing of the UCR trees (1.22 m) was narrower than the Imperial Valley trees (1.52 x 3.66 m) and perhaps forced the UCR trees into a different configuration. Most of the fast growing UCR trees were included in the Imperial Valley trials but none of the very slow growing UCR mesquite with prostrate tendencies were included in the Imperial Valley study which might account for differences observed in the regressions. The greatly differing UCR and Imperial Valley climates may also be responsible for part of this difference.

In order to estimate biomass production on first and second

Table 7. Comparison of means and slopes of regression equation  
 $\log_{10}$  dry biomass (kg) =  $m \log_{10}$  stem diameter (cm)  
- b for different field studies

Field Study Tested	Slope			Adjusted means		
	P <sup>1</sup>	F Value	Degrees Freedom	P <sup>1</sup>	F Value	Degrees Freedom
Imperial Valley Season 1	0.1%	35.21	2,1346	0.1%	21.93	2,1348
Imperial Valley Season 2						
UCR Season 3						
Imperial Valley Season 1	>10%	2.11	1,413	0.1%	14.73	1,414
Imperial Valley Season 2						
Imperial Valley Season 1	0.1%	27.09	1,1143	0.1%	32.46	1,1144
UCR Season 3						
Imperial Valley Season 2	0.1%	46.70	1,1136	0.1%	13.84	1,1137
UCR Season 3						

A comparison of adjusted means was computed even in the case where the slopes were found to be significantly different.  
1 indicates level of significant difference.

season UCR trees (which were not harvested) the regression equation for the Imperial Valley trees was combined with the UCR equation, in spite of the fact they were significantly different because the Imperial Valley trees had first season trees and more smaller trees. However, third season actual measured dry biomass was also presented and used for oven dry kg/ha calculations.

### III. Biomass Estimation in UC-Riverside Differential Irrigation Plots

The soil used for this study was a Hanford fine sandy loam (typic xerothent) and plants were transplanted on 28 June 1978. The accessions (Table 8) included representatives of each of the 12 species in our collection, some of which Burkart (1976) recommended as rapid in growth but non-invasive. Others were range species native to the U.S. These accessions were grown under wet, medium and dry water regimes to ensure that no promising accession was overlooked because it was grown with too much or too little water. In the three regimes 7.6 cm of water was applied to individual plots when the soil water potential at 30 cm depth, measured by tensiometers and resistivity blocks (Cannell and Asbell, 1964) reached -60, -200 and -500 kPA (-0.6, -2.0 and -5.0 bar). Each water regime was applied in one of three randomized blocks, each containing one plot of each accession, so that the water treatments were not replicated and their effects were wholly confounded with block differences. Valid estimates of error can however be made for water x accession interactions. Each plot contained 12 plants of each accession, spaced at 1.2 x 1.2m (4'x4') in a 4x3 array. Each plot was surrounded by an earthen berm with a separate valve and pipe opening (2.5cm). The seedlings of each accession were sorted so that the initial sizes were similarly distributed in each of three sets of 12 plants.

Table 8. Origin of *Prosopis* Germplasm

Species	Accession Number	Location of Origin
<i>P. africana</i>	0040	Upper Volta
<i>P. africana</i>	0045	Neur-Mactar, Senegal, W. Africa
<i>P. alba</i>	0098	Argentina
<i>P. alba</i>	0035	Poro del Tigre, Argentina
<i>P. alba</i>	0037	Cos los lomita, Argentina
<i>P. alba</i>	0039	Santiago del Estero, Argentina
<i>P. alba</i>	0132	Quimlo, Saer Pena, Argentina
<i>P. alba</i>	0134	Argentina
<i>P. alba</i>	0137	Argentina
<i>P. alba</i>	0138	Argentina
<i>P. alba</i> (?)	0013	South America
<i>P. articulata</i>	0016	Baja, Mexico
<i>P. chilensis</i>	0009	Buenos Aires, Argentina
<i>P. chilensis</i>	0010	La Pampa, Argentina
<i>P. glandulosa</i>		
var. <i>glandulosa</i>	0028	McNary, Texas
<i>P. glandulosa</i>		
var. <i>torreyana</i>	0001	Thermal, California
<i>P. juliflora</i>	0044	Ross-Bethio, Senegal, W. Africa
<i>P. kuntzei</i>	0130	Argentina
<i>P. laevigata</i>	0114	San Luis Potosi, Mexico
<i>P. nigra</i>	0034	Colonia Bard de Lostoses, Argentina
<i>P. nigra</i>	0036	Poro del Tigre, Argentina
<i>P. nigra</i>	0038	Los Lomitos, Argentina
<i>P. nigra</i>	0133	Argentina
<i>P. pallida</i>	0041	Hawaii
<i>P. pallida</i>	0140	University of Hawaii
<i>P. ruscifolia</i>	0033	Parada 6, Argentina
<i>P. ruscifolia</i>	0131	Argentina
<i>P. tamarugo</i>	0042	Chile
<i>P. velutina</i>	0020	Pima County, Arizona
<i>P. velutina</i>	0031	Pima County, Arizona
<i>P. velutina</i>	0025	Santa Ana, Mexico
<i>P. velutina</i>	0032	Benson, Arizona
<i>P. spp</i>	0022	Yuma, Arizona
<i>P. spp</i>	0026	Lordsburg, New Mexico
<i>P. spp</i>	0030	Stafford, Arizona
<i>P. spp</i>	0074	Mesquite, New Mexico
<i>P. spp</i>	0080	York, Arizona
<i>P. spp</i>	0108	Mexico
<i>P. spp</i>	0116	San Luis Potosi, Mexico

Basal stem diameter and height measurements were carried out on these plots at the end of the first growing season but only basal diameter measurements were made at the end of the second growing season. Fresh weight determinations, basal diameter measurements, and dry matter content determinations were made during the harvest of these trees at the end of the third growing season. The regression equation developed from third season UCR trees was highly significant but was not used on first and second season trees as the latter trees were smaller in diameter and of less biomass than 3rd season UCR trees. Consequently, the data set for the Imperial Valley trees which contained first season trees and smaller trees was merged with the data set for the 3rd season UCR trees. This "UCR-Imperial Valley merged regression" contained 212 first season Imperial Valley trees, 205 second season Imperial Valley trees and 935 third season UCR trees and was significantly weighted towards the UCR trees. The dry biomass per tree on the UCR plots was computed from the "merged UCR-Imperial Valley regression" for three seasons, three moisture treatments and 32 accessions (Tables 9, 10, and 11). Additionally, the measured fresh biomass and measured dry matter content were used to compute actual measured dry biomass in Table 12.

The ranked order and range of estimated biomass were approximately the same for the three growing seasons and for measured biomass at the end of the third season. A 15, 22, and 20 fold

Table 9. First Season Dry Biomass per Tree Estimated from the Combined UCR-Imperial Valley Regression Equation at UCR

Species	Accession Number	Irrigation Treatment			Biomass per tree (Kg)
		60kPa	200kPa	500kPa	
<i>P. chilensis</i>	0009	.19	.24	.43	.29
<i>P. alba</i>	0039	.43	.19	.25	.29
<i>P. alba</i>	0013	.16	.14	.30	.20
<i>P. pallida</i>	0041	.23	.17	.19	.20
<i>P. pallida</i>	0140	.17	.14	.20	.17
<i>P. glandulosa</i>					
var. <i>torreyana</i>	0001	.12	.15	.17	.15
<i>P. alba</i>	0132	.17	.16	.10	.14
<i>P. alba</i>	0037	.10	.13	.20	.14
<i>P. alba</i>	0137	.19	.07	.15	.14
<i>P. alba</i>	0098	.07	.10	.23	.13
<i>P. nigra</i>	0133	.13	.06	.17	.12
<i>P. articulata</i>	0016	.13	.14	.09	.12
<i>P. juliflora</i>	0044	.15	.13	.09	.12
<i>P. alba</i>	0138	.11	.11	.13	.12
<i>P. nigra</i>	0038	.09	.13	.12	.11
<i>P. spp</i>	0108	.14	.07	.06	.09
<i>P. velutina</i>	0020	.11	.06	.09	.09
<i>P. velutina</i>	0025	.08	.09	.09	.09
<i>P. nigra</i>	0036	.12	.07	.07	.09
<i>P. velutina</i>	0032	.06	.11	.09	.09
<i>P. spp</i>	0116	.07	.06	.10	.08
<i>P. alba</i>	0134	.07	.08	.08	.08
<i>P. laevigata</i>	0114	.04	.06	.07	.06
<i>P. nigra</i>	0034	.05	.04	.06	.05
<i>P. ruscifolia</i>	0131	.04	.04	.05	.04
<i>P. spp</i>	0080	.05	.03	.04	.04
<i>P. glandulosa</i>					
var. <i>glandulosa</i>	0028	.03	.02	.05	.03
<i>P. tamarugo</i>	0042	.03	.03	.04	.03
<i>P. spp</i>	0074	.03	.03	.03	.03
<i>P. kuntzei</i>	0130	.02	.02	.03	.02
<i>P. africana</i>	0045	.01	.01	.01	.01
<i>P. africana</i>	0040	.01	.01	.01	.01
Mean		.112y	.092x	.122y	.11

Means followed by the same letter are not significantly different at the 5% level as judged by the "student Newman-Keuls Procedure". The combined UCR-Imperial Valley regression equation  $\log \text{dry matter} = 2.1905 \log \text{diameter} - 0.9811$  was used to estimate the dry biomass per tree.

Table 10. UCR Second Season Dry Biomass per Tree Estimated from Combined UCR-Imperial Valley Regression Equation

Species	Accession Number	Irrigation Treatment			Biomass per tree (Kg)
		60kPa	200kPa	500kPa	
<i>P. chilensis</i>	0009	2.87	4.04	4.55	3.82
<i>P. alba</i>	0039	3.09	2.94	3.28	3.10
<i>P. alba</i>	0013	2.04	2.31	2.51	2.29
<i>P. alba</i>	0137	2.49	2.35	1.97	2.27
<i>P. alba</i>	0132	2.04	2.93	0.76	1.91
<i>P. alba</i>	0098	1.14	2.82	1.89	1.87
<i>P. alba</i>	0138	1.80	1.80	1.79	1.80
<i>P. glandulosa</i>					
var. <i>torreyana</i>	0001	1.25	1.73	2.17	1.72
<i>P. nigra</i>	0133	1.11	2.37	1.43	1.62
<i>P. alba</i>	0037	1.10	2.06	1.72	1.61
<i>P. articulata</i>	0016	1.70	1.80	1.31	1.60
<i>P. spp</i>	0108	1.71	1.99	0.93	1.54
<i>P. velutina</i>	0020	1.37	1.10	1.34	1.27
<i>P. nigra</i>	0038	0.82	1.50	1.23	1.19
<i>P. velutina</i>	0025	1.24	0.90	1.29	1.14
<i>P. spp</i>	0116	0.71	1.40	0.92	1.01
<i>P. alba</i>	0134	0.95	1.12	0.91	1.00
<i>P. velutina</i>	0032	0.74	1.41	0.73	.96
<i>P. nigra</i>	0036	1.00	0.78	0.74	.84
<i>P. laevigata</i>	0114	0.42	0.63	1.02	.69
<i>P. pallida</i>	0140	0.59	0.00	0.00	.59
<i>P. spp</i>	0028	0.42	0.72	0.61	.58
<i>P. tamarugo</i>	0042	0.41	0.51	0.73	.55
<i>P. spp</i>	0080	0.44	0.49	0.38	.44
<i>P. spp</i>	0074	0.21	0.61	0.44	.42
<i>P. ruscifolia</i>	0131	0.46	0.56	0.22	.42
<i>P. nigra</i>	0034	0.27	0.38	0.39	.35
<i>P. kuntzei</i>	0130	0.09	.19	.21	.17
<i>P. juliflora</i>	0044	0.00	0.00	0.00	0.00
<i>P. pallida</i>	0041	0.00	0.00	0.00	0.00
<i>P. africana</i>	0045	0.00	0.00	0.00	0.00
<i>P. africana</i>	0040	0.00	0.00	0.00	0.00
Mean		1.19y	1.52x	1.33xy	1.34

Means followed by same letter are not significantly different at 5% level as judged by the "student Newman-Keuls Procedure". The average biomass per tree is the average of all trees. In cases where mortality caused uneven sample sizes between treatments, the average is not the average of the 3 treatments.

Table 11. UCR Third Season Dry Biomass per Tree Estimated from Combined UCR-Imperial Valley Regression Equation

Species	Accession Number	Irrigation Treatment			Biomass per tree (Kg)
		60kPa	200kPa	500kPa	
<i>P. chilensis</i>	0009	6.96	8.15	7.34	7.49
<i>P. alba</i>	0039	7.44	5.55	5.85	6.29
<i>P. alba</i>	0098	4.08	6.73	6.44	5.58
<i>P. articulata</i>	0016	5.40	6.22	4.70	5.44
<i>P. alba</i>	0137	5.54	6.18	4.18	5.33
<i>P. alba</i>	0013	5.33	5.61	4.51	5.11
<i>P. nigra</i>	0133	3.71	5.55	4.02	4.45
<i>P. alba</i>	0132	4.24	7.00	2.07	4.44
<i>P. alba</i>	0138	5.28	4.24	3.43	4.32
<i>P. spp</i>	0108	5.48	5.60	1.79	4.26
<i>P. alba</i>	0037	4.04	4.76	3.98	4.25
<i>P. glandulosa</i>					
var. <i>torreyana</i>	0001	3.24	4.21	5.11	4.19
<i>P. velutina</i>	0025	3.08	3.82	3.46	3.45
<i>P. alba</i>	0134	2.98	4.08	3.28	3.45
<i>P. nigra</i>	0038	3.32	3.70	2.89	3.30
<i>P. velutina</i>	0020	3.94	2.25	2.83	3.00
<i>P. spp</i>	0116	2.15	3.18	3.72	3.00
<i>P. laevigata</i>	0114	2.03	4.07	2.40	2.87
<i>P. nigra</i>	0036	2.99	2.89	1.95	2.64
<i>P. velutina</i>	0032	2.38	4.09	1.44	2.64
<i>P. spp</i>	0028	1.42	2.22	1.39	1.69
<i>P. tamarugo</i>	0042	1.66	1.43	1.88	1.66
<i>P. spp</i>	0074	1.06	1.82	1.24	1.37
<i>P. spp</i>	0080	1.31	1.69	1.03	1.34
<i>P. nigra</i>	0034	0.83	1.36	0.95	1.05
<i>P. ruscifolia</i>	0131	1.01	1.80	0.39	1.05
<i>P. kuntzei</i>	0130	0.23	0.50	0.39	0.37
<i>P. juliflora</i>	0044	0.00	0.00	0.00	0.00
<i>P. pallida</i>	0140	0.00	0.00	0.00	0.00
<i>P. pallida</i>	0041	0.00	0.00	0.00	0.00
<i>P. africana</i>	0045	0.00	0.00	0.00	0.00
<i>P. africana</i>	0040	0.00	0.00	0.00	0.00
Mean		3.40y	4.03x	3.05y	3.49

Values followed by the same letter are not significantly different at 5% level as judged by "Student Newman-Keuls Procedure".

Table 12. UCR Third Season Measured Dry Biomass Per Tree<sup>a</sup>

Species	Accession Number	(Kg)			Average
		60kPa	200kPa	500kPa	
<i>P. chilensis</i>	(0009)	9.9	8.8	8.9	9.2
<i>P. articulata</i>	(0016)	7.9	9.0	6.4	7.8
<i>P. alba</i>	(0039)	9.6	4.9	5.9	6.8
<i>P. alba</i>	(0137)	9.0	7.1	3.7	6.7
<i>P. nigra</i>	(0133)	4.4	6.5	4.7	5.2
<i>P. alba</i>	(0098)	3.8	5.7	6.1	5.1
<i>P. alba</i>	(0037)	4.6	6.2	4.2	5.0
<i>P. nigra</i>	(0036)	6.7	4.1	3.5	4.9
<i>P. alba</i>	(0013)	6.2	5.3	3.3	4.9
<i>P. velutina</i>	(0025)	5.5	4.7	4.5	4.9
<i>P. glandulosa</i>					
var. <i>torreyana</i>	(0001)	4.2	5.3	5.1	4.9
<i>P. nigra</i>	(0038)	3.6	6.6	4.3	4.8
<i>P. alba</i>	(0134)	3.9	4.8	4.4	4.4
<i>P. alba</i>	(0132)	5.1	6.7	1.0	4.3
<i>P. spp</i>	(0116)	3.2	4.3	5.0	4.1
<i>P. spp</i>	(0108)	5.6	5.5	1.2	4.0
<i>P. alba</i>	(0138)	4.8	3.4	3.5	3.9
<i>P. laevigata</i>	(0114)	2.4	3.8	3.2	3.2
<i>P. velutina</i>	(0020)	4.1	2.3	2.7	3.0
<i>P. velutina</i>	(0032)	2.0	4.5	1.0	2.5
<i>P. spp</i>	(0028)	1.5	2.0	1.8	1.7
<i>P. tamarugo</i>	(0042)	1.6	1.7	1.8	1.7
<i>P. nigra</i>	(0034)	1.6	2.2	1.2	1.7
<i>P. spp</i>	(0080)	1.4	2.1	0.8	1.4
<i>P. spp</i>	(0074)	0.88	1.8	0.85	1.2
<i>P. ruscifolia</i>	(0131)	0.94	2.0	0.3	1.0
<i>P. kuntzei</i>	(0130)	0.31	0.54	0.46	0.4
<i>P. juliflora</i>	(0044)	0.0	0.0	0.0	0.0
<i>P. pallida</i>	(0140)	0.0	0.0	0.0	0.0
<i>P. pallida</i>	(0041)	0.0	0.0	0.0	0.0
<i>P. africana</i>	(0045)	0.0	0.0	0.0	0.0
<i>P. africana</i>	(0040)	0.0	0.0	0.0	0.0
Mean		4.27x	4.53x	3.31y	4.04

<sup>a</sup>Dry biomass is calculated from measured fresh biomass and an individual dry matter coefficient for each accession. Values followed by same letter are not significantly different at 5% level as judged by Student-Newman-Keuls procedure.

range in average biomass productivity among accessions was estimated for the first, second, and third growing seasons and an actual 23 fold range was measured at the end of year 3. *P. chilensis* (0009) had the greatest estimated biomass for all three seasons and the greatest measured biomass. *P. alba* (0039) had the second largest estimated biomass for all three seasons but *P. articulata* (0016) proved to have the second largest actual dry biomass per accession.

The first winter the five accessions *P. pallida* (0041), *P. pallida* (0140), *P. juliflora* (0044), *P. africana* (0040) and (0045) were eliminated from the study by an abnormally low frost of -5°C. One of the *P. pallida* (0140) trees resprouted from the stump and was included in the analysis the second season but not the third season even though it survived ensuing winters. The shrubby prostrate accessions 0074, 0080, and 0028 from New Mexico, Arizona, and west Texas were among the accessions with lowest productivity for all treatments, growing seasons and in both estimated and actual biomass production. The accession with lowest average biomass production, *P. kuntzei*, possesses only photosynthetically active stems and no true leaves in its mature form and might be expected to be a slow grower. *P. kuntzei* is of interest because of its high specific gravity of 1.25-1.30 (Burkart, 1976). Surprisingly when grown in the greenhouse nursery under continuous fluorescent lighting techniques described by Hanover and Reicosky (1972), the *P. kuntzei* had the

fastest height growth of all the accessions. The accession with the smallest production in the dry plot was *P. ruscifolia* that was the subject of a memo from Secretary Bergland to Secretary Schlesinger in early 1979 complaining about the potential of the species escaping to become a weed from our UCR plots.

The medium irrigation treatment in which water was applied when the soil moisture at the 45 cm depth reached 200 kPa (2 Bars), proved to be the best overall water regime in the second and third season's estimated growth and in the final measured growth. Surprisingly in the first season the wet and dry treatment were better than the medium treatment. The estimated and actual *P. chilensis* (0009) biomass production showed a surprising lack of response to water application. In the first season water was not applied to the dry (500 kPa) plot (other than 100 mm at transplant), 500 mm was applied in irrigation the second season and no additional water was applied in the third season. The rainfall for the 78-79 winter was 423 mm (16.6") and 370 mm (14.6") for the 79-80 winter. For the *P. chilensis* in the dry irrigation treatment, the total water application from irrigation and rainfall from June 1978 at the time of planting through November 1980 at the time of harvest was 1393 mm.

The biomass production for these plots was expressed in dry kg/tree because the small plot size of 12 trees on a 4x3 array cannot be unequivocally extrapolated to kg/ha due to border effects. Nevertheless it is useful to arrive at order of

magnitude estimates in kg/ha. In the 4x3 array, 2 trees were completely surrounded by one row of trees. These two trees had an average dry biomass of 6.0 kg and 6.2 kg in the medium and dry *P. chilensis* treatments respectively. These trees had 66% of the average tree dry biomass of the outer trees in the plot. This is a larger bordereffect than observed for second season Imperial Valley-water use efficiency *P. chilensis* trees (5x5 array on 1.5x1.5 m spacing) where the biomass per tree of the inner 9 trees was 73% of the outer trees. Since the UCR border effect is similar to Imperial Valley trees, for reasons described in section on "Biomass estimation-Imperial Valley water use efficiency study" we believe extrapolation of inner two UCR trees to biomass production in kg/ha is reasonable. Since the *P. chilensis* trees were on a 1.22 m (4 ft) spacing there were 6718 trees/ha for 40,300 dry kg/ha or  $13.4 \text{ T ha}^{-1}\text{yr}^{-1}$ . Similar calculations for *P. articulata* show a dry biomass of 49,700 and 27,500 kg  $\text{ha}^{-1}$  corresponding to  $16.6 \text{ T ha}^{-1}\text{yr}^{-1}$  and  $9.2 \text{ T ha}^{-1}\text{yr}^{-1}$  for the medium and dry irrigation plots respectively. By taking the total water application of 1393 mm described earlier, the *P. chilensis* can be seen to have an apparent water efficiency of 345 kg  $\text{H}_2\text{O}/\text{kg}$  dry matter. Apparent is used to qualify the water use efficiency since the trees may be acquiring water deep in the profile. Neutron probe data indicates little water within 4.2 m (14 ft) of the surface but the trees could be obtaining water at much deeper depths. Whatever the source of water, a 3

season total production (2½ years) of 40,000 kg/ha with less than 500 mm (20 inches) per year is remarkable.

#### IV. Heat/Drought screening of 55 Tree Legume Accessions in California Imperial Valley

Fifty-five accessions of the tree legumes listed in Table 13 were screened for biomass production under drought/heat stress in the California Imperial Valley at Brawley. The average daily July maximum temperature at this location is 108°F, 100 days of the year have temperatures of at least 100°F, and the mean annual rainfall is 65 mm (2.5").

Each accession was planted as a single tree replicate on a 1.5x3.6 m (5x12 ft) spacing in each of 16 blocks during 20-22 March 1979. A different random design was used to assign the position of the single tree replicates in all 16 blocks. As soil and neighboring tree interactions were completely random throughout the field, significant differences for ranked means of insect resistance, pod production or biomass production probably were genetically controlled.

Flood or basin irrigation was used to provide water for these trees as the 65 mm annual rainfall was insignificant. A 400 mm (16") irrigation was placed on this field 8 weeks prior to transplant. At the time of transplant a 100 mm irrigation was given and 2-150 mm irrigations were given the first season. In January of the second year a single 750 mm irrigation was made that carried the trees through the entire next year. The first year a block effect was observed with 4 blocks nearest the floodgates having the greatest diameter and the 4 blocks

Table 13

## INDEX TO ACCESSIONS IN IMPERIAL VALLEY SCREENING TRIALS

Variety	General Code	Originator's Code	Species	Origin
1	0001	Ruby	<i>P. glandulosa</i> var <u>torreyana</u>	Thermal, CA
2	0009		<i>P. chilensis</i>	Argentina
3	0013	P-12	<i>P. alba</i> (?)	Riverside, CA
4	0016		<i>P. articulata</i>	Baja, Mexico
5	0020	2201-4	<i>P. velutina</i>	Arizona
6	0032	2229-1	<i>P. velutina</i>	Cochise, AZ
7	0038	4258	<i>P. nigra</i>	Argentina
8	0041	Esbenshade	<i>P. pallida</i>	Hawaii
9	0037	4257	<i>P. alba</i>	Argentina
10	0044		<i>P. juliflora</i>	Senegal
11	0039	4272	<i>P. alba</i>	Argentina
12	0098	1040-1	<i>P. alba</i>	Argentina
13	0132	4273	<i>P. alba</i>	Argentina
14	0133	4274	<i>P. nigra</i>	Argentina
15	0137	4287-2	<i>P. alba</i>	Argentina
16	0163		<i>P. alba</i> (?)	Indio, CA
17	0147		<i>Leucaena leucocephala</i> (K-8)	Hawaii
18	0166		<i>P. alba</i> (?)	Thermal, CA
19	0168		<i>P. alba</i> (?)	Desert Shores, CA
20	0285		<i>P. alba</i> (?)	Harper Dry Lake, CA
21	0286		<i>P. alba</i> (?)	Harper Dry Lake, CA
22	0280		<i>P. spp.</i>	Trona, CA
23	0247		<i>P. velutina</i>	Westmoreland, CA
24	0322		<i>Parkinsonia aculeata</i>	Riverside, CA
25	0324		<i>Cercidium floridum</i>	Riverside, CA
26	0317		<i>P. tamarugo</i>	CORFO, Chile
27	0245		<i>P. pubescens</i>	Scissors Crossing, CA
28	0263		<i>P. pubescens</i>	Ash Meadows Nev
29	0343		<i>Ulnuya tesota</i>	Glamis, CA
30	0154	002	<i>P. glandulosa</i> var <u>torreyana</u>	Palm Springs, CA
31	0157	005	<i>P. glandulosa</i> var <u>torreyana</u>	Whitewater Cyn, CA
32	0165	012	<i>P. glandulosa</i> var <u>torreyana</u>	Thermal, CA
33	0239	081	<i>P. glandulosa</i> var <u>torreyana</u>	Thermal, CA
34	0250	092	<i>P. glandulosa</i> var <u>torreyana</u>	Mecca, CA
35	0171	018	<i>P. glandulosa</i> var <u>torreyana</u>	Harpers Well, CA
36	0170	017	<i>P. glandulosa</i> var <u>torreyana</u>	Harpers Well, CA
37	0246	088	<i>P. glandulosa</i> var <u>torreyana</u>	Julian, CA
38	0184	027	<i>P. glandulosa</i> var <u>torreyana</u>	Blythe, CA
39	0199	041	<i>P. glandulosa</i> var <u>torreyana</u>	Needles, CA
40	0258	100	<i>P. glandulosa</i> var <u>torreyana</u>	Mesquite Drylake, CA
41	0205	047	<i>P. glandulosa</i> var <u>torreyana</u>	Shoshone, CA
42	0216	058	<i>P. glandulosa</i> var <u>torreyana</u>	Death Valley, CA
43	0234	076	<i>P. spp.</i>	Bakersfield, CA
44	0255	097	<i>P. glandulosa</i> var <u>torreyana</u>	29 Palms, CA
45	0296	136	<i>P. glandulosa</i> var <u>torreyana</u>	Temecula, CA
46	0261	103	<i>P. glandulosa</i> var <u>torreyana</u>	Pahrump, Nev
47	0271	113	<i>P. glandulosa</i> var <u>torreyana</u>	Saline Valley, CA
48	0276	116	<i>P. glandulosa</i> var <u>torreyana</u>	Panamint Valley, CA
49	0289	129	<i>P. glandulosa</i> var <u>torreyana</u>	Harper Dry Lake, CA
50	0194	037	<i>P. alba</i> (?)	Nina's Trees
51	0190	033	<i>P. glandulosa</i> var <u>torreyana</u>	Twin Palms Trailer Park, CA
52	0186	029	<i>P. spp.</i>	Ehrenberg, AZ
53	0291	131	<i>P. glandulosa</i> var <u>torreyana</u>	Newberry, CA
54	0182	025	<i>P. glandulosa</i> var <u>torreyana</u>	Blythe, CA
55	0210	052	<i>P. glandulosa</i> var <u>torreyana</u>	Death Valley, CA

harvested the first and second year (which each contained one block near the floodgates) being slightly larger than remaining blocks.

This screening trial included the 15 most promising biomass producing accessions from the UCR differential irrigation plots, other leguminous trees of the California desert such as desert ironwood (*Olcneya tesota*), palo verde (*Cercidium floridium* and *Parkinsonia aculeata*) as well as an advanced strain of *Leucaena leucocephala* (Hawaii Giant K-8) developed by Dr. J. L. Brewbaker of the University of Hawaii. Approximately half of the accessions in this trial were collected on a 3,000 mile field trip in the summer of 1978 in the California deserts. Accessions were collected from a region 300 miles north to south (from El Centro to north of Death Valley National Monument) and 300 miles east to west (from Parker Dam to 10 miles west of Bakersfield). Mesquite pods were collected on the floor of Death Valley in July when the temperature was 49°C (120°F) as well as at 914 m (3,000 ft) elevation in the foot hills 100 km NE of San Diego where mesquite was growing in association with live oak, and chapparral type vegetation. Pods were also collected from *Prosopis* trees introduced from South America at least several decades ago for use as ornamentals. Using the taxonomy of Burkart (1976) these selections probably are *Prosopis alba* and are tentatively identified in this report as *P. alba* (?).

Four blocks of the Imperial Valley trees (approximately 220)

were harvested, weighed, stem diameter measurements taken, and whole trees of each genus manually reduced to six inch lengths for moisture content determination in November of 1979 and 1980. As described in the section on biomass estimation, regression equations between stem diameter and fresh and dry biomass were then computed.

Two complimentary methods for ranking the accessions in order of biomass production were then possible. Regression equations were used to predict biomass from stem diameter measurements of standing trees and those that were harvested. These predicted weights were compared with the fresh and dry weights of the trees actually harvested. Due to the large variation in seed propagated *Prosopis*, the ranked order of biomass production often changed between estimated and measured trees because of the 3-4 fold increase in sample size for the predicted biomass data set. The ranked biomass for first and second season predicted biomass (880 and 660 trees respectively) and for first and second season measured dry biomass (217 and 205 trees respectively) are presented in Tables 14, 15, 16, and 17.

The first season mean measured dry biomass per tree ranged from 0.05 kg for *Prosopis tamarugo* to 5.7 kg for *Parkinsonia aculeata* - a 180 fold range! The accessions *P. alba* (0166) ? and *P. alba* (0194) ? both had individual trees with greater dry biomass than the *Parkinsonia aculeata*. The *P. alba* (0194) tree with 8.9 kg dry biomass has been cloned. (See list of Imperial

Table 14

Coefficient calculated predictions of dry weights of first season (1979)  
Imperial Valley Trees

Species	Accession Number	Oven dry Biomass per tree (kg)	
		Mean	Range
P. <u>alba</u> (?)	0166	5.0	1.6-10.6
P. <u>chilensis</u>	0009	4.8	1.9-9.5
Leucaena <u>leucocephala</u> (k-8)	0147	4.5	2.3-6.4
P. <u>alba</u>	0037	4.3	1.2-9.3
P. <u>alba</u>	0132	4.1	2.3-5.7
Parkinsonia <u>aculeata</u>	0322	3.9	0.7-5.6
P. <u>articulata</u>	0016	3.8	1.5-7.7
P. <u>alba</u> x P. <u>glandulosa</u> var <u>torreyana</u>	0163	3.7	1.1-7.2
P. <u>alba</u>	0168	3.6	0.35-8.9
P. <u>glandulosa</u> var <u>torreyana</u>	0216	3.4	0.39-8.7
P. <u>alba</u>	0194	3.3	0.35-7.2
P. <u>glandulosa</u> var <u>torreyana</u>	0246	3.1	1.6-5.1
P. <u>alba</u>	0137	3.1	2.1-5.4
P. <u>alba</u> (?)	0285	3.1	0.01-8.3
P. <u>glandulosa</u> var <u>torreyana</u>	0184	3.0	0.39-6.1
P. <u>glandulosa</u> var <u>torreyana</u>	0157	2.8	1.3-6.6
P. <u>alba</u>	0039	2.8	1.3-5.5
P. <u>spp</u> (?)	0186	2.7	1.3-5.3
P. <u>glandulosa</u> var <u>torreyana</u>	0199	2.6	1.3-5.6
P. <u>glandulosa</u> var <u>torreyana</u>	0291	2.6	1.3-4.2
P. <u>glandulosa</u> var <u>torreyana</u>	0001	2.6	1.1-5.6
P. <u>juliflora</u>	0044	2.6	1.4-4.4
P. <u>glandulosa</u> var <u>torreyana</u>	0250	2.5	0.39-4.2
P. <u>glandulosa</u> var <u>torreyana</u>	0210	2.4	0.67-4.9
P. <u>glandulosa</u> var <u>torreyana</u>	0182	2.4	1.3-3.6
P. <u>glandulosa</u> var <u>torreyana</u>	0239	2.4	0.89-6.1
P. <u>alba</u> (?)	0286	2.3	0.08-6.9
P. <u>glandulosa</u> var <u>torreyana</u>	0190	2.3	0.09-4.7
P. <u>glandulosa</u> var <u>torreyana</u>	0165	2.3	0.81-3.3
P. <u>alba</u>	0098	2.2	0.04-4.8
P. <u>glandulosa</u> var <u>torreyana</u>	0205	2.1	0.26-3.8
P. <u>glandulosa</u> var <u>torreyana</u>	0296	2.1	0.44-4.7
P. <u>alba</u> (?)	0013	2.0	0.27-4.2
P. <u>glandulosa</u> var <u>torreyana</u>	0170	1.9	0.39-3.6
P. <u>glandulosa</u> var <u>torreyana</u>	0258	1.8	0.34-3.1
P. <u>glandulosa</u> var <u>torreyana</u>	0261	1.7	0.44-3.5
P. <u>glandulosa</u> var <u>torreyana</u>	0276	1.6	0.11-3.1
P. <u>pallida</u>	0041	1.6	0.08-4.2
P. <u>velutina</u>	0032	1.6	0.67-3.6
P. <u>glandulosa</u> var <u>torreyana</u>	0271	1.6	0.61-3.1
P. <u>velutina</u>	0020	1.5	0.03-2.9
P. <u>glandulosa</u> var <u>torreyana</u>	0154	1.5	0.19-2.8
P. <u>glandulosa</u> var <u>torreyana</u>	0171	1.4	0.16-3.1
P. <u>glandulosa</u> var <u>torreyana</u>	0255	1.3	0.01-2.1
P. <u>nigra</u>	0133	1.2	0.03-5.2
P. <u>nigra</u>	0038	1.1	0.31-2.8

continued

Table 14  
Oven dry Biomass per tree  
(kg)

Species	Accession Number	Mean	Range
P. spp	0234	1.0	0.22-2.2
P. spp	0280	0.93	0.03-3.42
P. <u>velutina</u>	0247	0.93	0.23-2.2
P. <u>pubescens</u>	0245	0.92	0.14-1.8
P. <u>pubescens</u>	0263	0.77	0.02-1.3
P. <u>glandulosa</u> var <u>torreyana</u>	0289	0.74	0.19-1.6
<u>Cercidium floridium</u>	0324	0.74	0.24-1.5
<u>Olneya tesota</u>	0343	0.11	0.04-0.17
P. <u>tamarugo</u>	0317	0.03	0.02-0.07
Overall		2.33	0.01-10.6

Table 15

Coefficient calculated predictions of dry weights of second season (1980)  
Imperial Valley trees

Species	Accession Number	Oven dry Biomass per tree (kg)	
		Mean	Range
P. <u>alba</u> (?)	0166	29.0	2.8-77.2
P. <u>articulata</u>	0016	18.5	2.2-48.2
P. <u>chilensis</u>	0009	18.3	6.2-39.6
P. <u>alba</u> (?)	0168	17.5	0.93-58.4
P. <u>alba</u> (?)	0285	16.8	0.01-83.3
P. <u>alba</u>	0132	15.9	8.7-28.8
P. <u>alba</u>	0037	15.8	7.8-28.8
Leucaena <u>leucocephala</u> (K-8)	0147	15.5	5.7-36.3
P. <u>alba</u>	0137	15.4	2.1-32.1
Parkinsonia <u>aculeata</u>	0322	13.0	4.5-24.5
P. <u>alba</u> x P. <u>glandulosa</u> var <u>torreyana</u>	0163	13.0	4.6-29.4
P. <u>glandulosa</u> var <u>torreyana</u>	0216	12.6	0.46-30.0
P. <u>alba</u> (?)	0194	11.6	1.9-23.9
P. <u>alba</u>	0039	10.6	1.6-26.9
P. <u>juliflora</u>	0044	10.4	2.4-20.6
P. <u>glandulosa</u> var <u>torreyana</u>	0184	9.3	3.0-17.9
P. <u>glandulosa</u> var <u>torreyana</u>	0246	8.7	2.1-17.9
P. <u>alba</u>	0098	8.6	0.06-22.8
P. <u>glandulosa</u> var <u>torreyana</u>	0001	8.1	1.2-17.4
P. <u>glandulosa</u> var <u>torreyana</u>	0239	8.0	1.1-24.9
P. <u>glandulosa</u> var <u>torreyana</u>	0157	7.8	3.5-27.4
P. <u>glandulosa</u> var <u>torreyana</u>	0182	7.6	1.9-13.0
P. <u>glandulosa</u> var <u>torreyana</u>	0199	6.6	2.1-17.4
P. <u>glandulosa</u> var <u>torreyana</u>	0165	6.3	2.8-10.4
P. spp	0186	6.1	2.2-16.4
P. <u>alba</u> (?)	0013	5.6	0.28-13.2
P. <u>alba</u> (?)	0286	5.6	0.08-21.1
P. <u>glandulosa</u> var <u>torreyana</u>	0210	5.6	0.63-9.0
P. <u>glandulosa</u> var <u>torreyana</u>	0190	5.5	1.5-13.0
P. <u>glandulosa</u> var <u>torreyana</u>	0250	5.5	3.1-9.0
P. <u>glandulosa</u> var <u>torreyana</u>	0291	5.1	1.5-11.1
P. <u>pallida</u>	0041	5.0	.05-13.6
P. <u>glandulosa</u> var <u>torreyana</u>	0205	4.2	1.3-7.5
P. <u>glandulosa</u> var <u>torreyana</u>	0170	4.1	1.7-7.5
P. <u>glandulosa</u> var <u>torreyana</u>	0255	3.9	.01-7.8
P. <u>glandulosa</u> var <u>torreyana</u>	0258	3.9	1.7-7.5
P. <u>velutina</u>	0020	3.7	0.04-7.0
P. spp	0296	3.5	1.1-6.7
P. <u>glandulosa</u> var <u>torreyana</u>	0271	3.3	1.3-8.4
P. <u>glandulosa</u> var <u>torreyana</u>	0261	3.1	1.7-5.0
P. <u>glandulosa</u> var <u>torreyana</u>	0154	3.1	0.37-11.1
P. <u>glandulosa</u> var <u>torreyana</u>	0276	3.1	0.10-8.1
P. spp	0280	3.0	0.18-9.6
P. <u>velutina</u>	0032	2.9	0.51-6.0
P. <u>glandulosa</u> var <u>torreyana</u>	0171	2.8	0.22-4.6
P. <u>pubescens</u>	0245	2.6	0.25-5.7
P. <u>nigra</u>	0038	2.5	0.44-10.6

continued

Table 15

Species	Accession Number	Oven dry Biomass per tree (kg)	
		Mean	Range
<u>P. pubescens</u>	0263	2.5	0.03-5.7
<u>Cercidium floridium</u>	0324	2.4	0.38-4.8
<u>P. velutina</u>	0247	2.2	0.35-4.4
<u>P. nigra</u>	0133	2.2	0.06-8.4
<u>P. spp</u>	0234	2.1	0.51-4.8
<u>P. glandulosa</u> var <u>torreyana</u>	0289	1.2	0.33-3.3
<u>Olneya tesota</u>	0343	0.30	0.07-0.66
<u>P. tamarugo</u>	0317	0.15	0.05-0.28
* Overall		7.7	0.01-83.3

Table 16

Ranked order of dry weights of trees harvested in 1979  
(first season) in Imperial Valley

Species	Accession Number	Biomass per tree (Kg)	
		Mean	Range
<i>parkinsonia aculeata</i>	0322	5.7	4.1-7.2
<i>P. chilensis</i>	0009	4.7	3.3-6.2
<i>P. alba (?)</i>	0194	4.5	2.4-8.9
<i>P. alba</i>	0037	4.4	3.7-5.5
<i>P. alba</i>	0166	4.4	1.7-8.4
<i>P. articulata</i>	0016	4.3	3.0-5.5
<i>P. juliflora</i>	0044	4.2	3.2-4.9
<i>P. alba (?)</i>	0286	4.1	2.1-7.0
<i>P. alba (?)</i>	0168	3.6	1.6-5.2
<i>P. alba</i>	0132	3.5	2.1-4.8
<i>eucaena leucocephala</i>	0147	3.4	2.3-5.4
<i>P. glandulosa</i> var			
<i>torreyana</i>	0246	3.4	2.9-3.6
<i>P. alba</i>	0039	2.9	1.2-3.9
<i>P. glandulosa</i> var			
<i>torreyana</i>	0182	2.8	1.9-3.8
<i>P. glandulosa</i> var			
<i>torreyana</i>	0157	2.8	1.7-3.9
<i>P. glandulosa</i> var			
<i>torreyana</i>	0250	2.8	1.6-3.5
<i>P. alba</i>	0137	2.8	2.2-3.6
<i>P. glandulosa</i> var			
<i>torreyana</i>	0291	2.7	1.3-4.5
<i>P. alba (?)</i>	0163	2.7	1.0-4.1
<i>P. glandulosa</i> var			
<i>torreyana</i>	0216	2.6	1.1-3.8
<i>P. glandulosa</i> var			
<i>torreyana</i>	0001	2.5	1.7-3.5
<i>P. alba</i>	0098	2.4	1.8-3.1
<i>P. glandulosa</i> var			
<i>torreyana</i>	0239	2.3	1.6-3.3
<i>P. pallida</i>	0041	2.3	1.8-2.6
<i>P. glandulosa</i> var			
<i>torreyana</i>	0184	2.2	1.3-2.9
<i>P. glandulosa</i> var			
<i>torreyana</i>	0154	2.1	1.6-2.7
<i>P. velutina</i>	0020	2.1	1.5-2.7
<i>P. glandulosa</i> var			
<i>torreyana</i>	0190	2.0	1.3-2.7
<i>P. spp.</i>	0280	2.0	0.55-4.5
<i>P. glandulosa</i> var			
<i>torreyana</i>	0165	1.9	1.1-3.4
<i>P. alba (?)</i>	0285	1.8	0.05-2.9
<i>P. nigra</i>	0133	1.8	0.95-3.2
<i>P. spp.</i>	0186	1.7	0.22-3.0
<i>P. nigra</i>	0038	1.7	0.35-3.6
<i>P. glandulosa</i> var			
<i>torreyana</i>	0171	1.6	0.39-3.4
<i>P. glandulosa</i> var			
<i>torreyana</i>	0170	1.5	0.28-3.6

continued

Table 16

Species	Accession Number	Biomass per tree (Kg)	
		Mean	Range
<i>P. glandulosa</i> var <i>torreyana</i>	0199	1.5	1.1-1.7
<i>P. glandulosa</i> var <i>torreyana</i>	0276	1.4	0.45-2.3
<i>P. glandulosa</i> var <i>torreyana</i>	0205	1.4	0.11-2.4
<i>P. glandulosa</i> var <i>torreyana</i>	0255	1.3	0.78-1.7
<i>P. alba</i>	0013	1.3	0.5-3.0
<i>Cercidium floridium</i>	0324	1.3	0.92-2.2
<i>P. glandulosa</i> var <i>torreyana</i>	0296	1.1	0.73-1.5
<i>P. pubescens</i>	0263	1.0	1.0-1.1
<i>P. glandulosa</i> var <i>torreyana</i>	0258	1.0	0.22-1.9
<i>P. spp.</i>	0234	1.0	0.22-1.3
<i>P. velutina</i>	0032	.95	0.78-1.2
<i>P. glandulosa</i> var <i>torreyana</i>	0210	.87	0.56-1.2
<i>P. glandulosa</i> var <i>torreyana</i>	0261	.76	0.28-1.6
<i>P. glandulosa</i> var <i>torreyana</i>	0271	.74	0.56-1.0
<i>P. glandulosa</i> var <i>torreyana</i>	0289	.73	0.62-0.78
<i>P. velutina</i>	0247	.45	0.15-0.85
<i>P. pubescens</i>	0245	.22	0.06-.34
<i>Qineya tesota</i>	0343	.20	0.10-0.25
<i>P. tamarugo</i>	0317	.05	
Total		2.28	0.05-8.9

One tree of each of the above accessions was harvested and weighed from each of 4 randomized blocks of 55 varieties. Four entire trees of each of the above genera were dried until equilibrium was achieved for moisture content determination. Fresh weights were multiplied by respective moisture contents to achieve dry biomass reported above.

Table 17

Ranked dry weights of trees harvested in 1980  
(second season) in Imperial Valley

Species	Accession	Dry biomass per tree (Kg)	
		Mean	Range
<u>P. articulata</u>	0016	36.8	22.2-50.7
<u>P. alba (?)</u>	0166	29.2	1.2-48.8
<u>P. alba (?)</u>	0137	29.1	23.9-32.8
<u>Parkinsonia aculeata</u>	0322	23.8	14.2-35.8
<u>P. alba (?)</u>	0285	23.4	0.1-56.3
<u>P. alba (?)</u>	0168	22.9	13.6-33.0
<u>P. alba</u>	0037	21.4	13.0-28.6
<u>P. juliflora</u>	0044	18.4	12.2-30.9
<u>P. alba</u>	0039	16.8	3.9-24.6
<u>P. alba</u>	0132	16.6	13.4-23.7
<u>P. chilensis</u>	0009	16.6	7.0-27.3
<u>P. glandulosa</u> var torreyana	0216	15.7	0.8-34.0
<u>P. alba (?)</u>	0163	14.1	6.9-21.3
<u>P. glandulosa</u> var torreyana	0246	14.1	7.6-24.9
<u>Leucaena leucocephala</u>	0147	12.0	4.1-17.1
<u>P. alba</u>	0098	11.5	0.06-20.0
<u>P. glandulosa</u> var torreyana	0182	10.1	2.4-17.3
<u>P. alba (?)</u>	0194	9.1	4.7-12.6
<u>P. alba (?)</u>	0286	7.6	0.8-24.3
<u>P. glandulosa</u> var torreyana	0184	7.6	3.1-18.5
<u>P. glandulosa</u> var torreyana	0001	7.4	2.9-13.6
<u>P. glandulosa</u> var torreyana	0239	7.4	5.3-9.1
<u>P. glandulosa</u> var torreyana	0165	6.8	4.2-11.3
<u>P. alba</u>	0013	6.5	0.9-16.2
<u>P. spp.</u>	0280	6.2	3.2-9.2
<u>P. glandulosa</u> var torreyana	0250	6.1	3.1-8.5
<u>P. glandulosa</u> var torreyana	0205	6.0	4.1-7.4
<u>P. velutina</u>	0020	5.4	2.4-7.8
<u>P. glandulosa</u> var torreyana	0157	5.0	3.3-7.6
<u>P. glandulosa</u> var torreyana	0291	4.9	1.3-9.3
<u>P. velutina</u>	0032	4.6	2.4-8.7
<u>P. glandulosa</u> var torreyana	0170	4.4	1.4-9.8
<u>P. spp.</u>	0186	4.3	2.9-5.3
<u>P. glandulosa</u> var torreyana	0255	4.2	0.1-10.5

continued

Table 17

Dry biomass per tree  
(Kg)

species	Accession	Mean	Range
<i>P. pallida</i>	0041	4.2	2.4-6.0
<i>P. glandulosa</i> var <i>torreyana</i>	0199	3.9	1.8-7.6
<i>P. glandulosa</i> var <i>torreyana</i>	0154	3.8	0.4-8.7
<i>P. glandulosa</i> var <i>torreyana</i>	0296	3.8	2.4-5.1
<i>P. glandulosa</i> var <i>torreyana</i>	0210	3.7	0.5-6.2
<i>P. spp.</i>	0234	3.6	2.4-4.7
<i>P. glandulosa</i> var <i>torreyana</i>	0258	3.4	2.1-4.2
<i>P. nigra</i>	0133	3.4	0.2-10.2
<i>P. pubescens</i>	0263	3.2	1.1-5.8
<i>Cercidium floridium</i>	0324	3.1	0.9-9.2
<i>P. pubescens</i>	0245	2.8	0.1-4.5
<i>P. glandulosa</i> var <i>torreyana</i>	0276	2.8	1.6-3.9
<i>P. glandulosa</i> var <i>torreyana</i>	0190	2.5	1.9-2.9
<i>P. velutina</i>	0247	2.4	1.7-2.4
<i>P. glandulosa</i> var <i>torreyana</i>	0289	2.4	1.0-4.7
<i>P. nigra</i>	0038	2.3	0.3-4.7
<i>P. glandulosa</i> var <i>torreyana</i>	0171	2.3	0.1-3.5
<i>P. glandulosa</i> var <i>torreyana</i>	0261	2.2	1.6-3.3
<i>P. glandulosa</i> var <i>torreyana</i>	0271	1.9	1.1-3.3
<i>Olneya tesota</i>	0343	.44	0.2-0.7
<i>P. tamarugo</i>	0317	.23	0.2-0.4
Total		9.2	.02-56.3

One tree of each of the above accessions was harvested and weighed from each of 4 randomized blocks of 55 varieties. Two entire trees of each of the above genera were dried until equilibrium at 65°C was achieved for moisture content determination. Fresh weights were multiplied by respective moisture contents to achieve dry biomass reported above.

Valley clones on Table 18.) The tree legume *Leucaena leucocephala* (0147) (Hawaii Giant K-8) had substantially lower biomass. Most of the high producing accessions were *P. alba* either obtained through Dr. Solbrig e.g. 0037 and 0132 or from ornamentals in southern California e.g. 0194, 0166, 0286, and 0168. The salt tolerant accession from Baja, Mexico *P. articulata* (0016) and *P. juliflora* (0044) from West Africa also had high biomass productivity.

The California native accessions *P. glandulosa* var. *torreyana* exhibited a wide range in productivity and fell just below the highest biomass producers and just above the lowest producers with the range of 0.73 to 3.4 dry kg per tree. Intermediate in biomass productivity was the *P. pallida* (0041) accession from Hawaii, and several *P. alba* and *P. nigra* accessions. The lowest producing accessions were a screwbean (*P. pubescens* 0245), desert ironwood (*Olneya tesota* 0343), and *P. tamarugo* 0317.

The data for measured biomass of second season trees (Table 17) had a similar order with a similar 160 fold range (0.23 to 36.8 kg) in biomass productivity per accession. Major changes were the drop in ranking of biomass production per accession of *Parkinsonia aculeata* and *Prosopis chilensis* from first to fourth and second to eleventh respectively and the increase in *P. articulata* from sixth to first. The *P. articulata* had a noticeably smaller range in biomass per tree (22.2 to 50.7 kg) than the California ornamentals 0166 and 0285 with 1.2 to 48.8 and 0.1

Table 18  
DESCRIPTION OF IMPERIAL VALLEY CLONES

Species	Parent Access- sion	Field Code	First Season	Second Season	Number Rooted Cuttings
			Basal Dia- meter (cm)	Dry <sup>1</sup> Wei- ght (kg)	
<u>P. chilensis</u>	(0009)	V <sub>2</sub> B <sub>9</sub>	7.3	13.4	5
<u>P. articulata</u>	(0016)	V <sub>4</sub> B <sub>6</sub>	6.7	12.6	40.0
<u>P. alba</u>	(0037)	V <sub>9</sub> B <sub>2</sub>	7.2	5.5	13
<u>P. alba</u>	(0037)	V <sub>9</sub> B <sub>13</sub>	7.5	8.6	2
<u>P. alba</u> (?)	(0163)	V <sub>16</sub> B <sub>9</sub>	6.8	9.5	5
<u>P. alba</u> (?)	(0166)	V <sub>18</sub> B <sub>9</sub>	7.9	17.2	14
<u>P. alba</u> (?)	(0168)	V <sub>19</sub> B <sub>11</sub>	7.4	15.5	23
<u>P. alba</u> (?)	(0285)	V <sub>20</sub> B <sub>5</sub>	7.2	17.7	56.3
<u>P. alba</u> (?)	(0285)	V <sub>20</sub> B <sub>9</sub>	6.8	7.3	
<u>P. alba</u> (?)	(0286)	V <sub>21</sub> B <sub>3</sub>	6.7	7.0	2
<u>P. glandulosa</u> var <u>torreyana</u>	(0216)	V <sub>42</sub> B <sub>13</sub>	7.0	9.8	3
<u>P. alba</u> (?)	(0194)	V <sub>50</sub> B <sub>2</sub>	6.8	8.9	15
<u>P. alba</u> (?)	(0194)	V <sub>50</sub> B <sub>12</sub>	6.5	9.9	6

<sup>1</sup>Dry weights listed are the products of actually measured fresh weights times dry matter coefficients determined on companion trees of the same species harvested the same date.

to 56.3 kg ranges respectively. This latter accession had the individual with the greatest dry biomass per tree (56.3 kg). All four harvested trees of 0285 were alive but the small trees were severely stunted and disfigured from the time the first pair of true leaves emerged in the greenhouse. As the disfiguration was never transmitted to another plant we assume it is not a disease and must be of genetic origin. As discussed in the section on breeding mechanism we believe this range is attributable to varying degrees of success in forming interspecific hybrids with the native mesquite.

The *Leucaena leucocephala* (Hawaii Giant K-8), a widely used tree legume for biomass production in the Philippines and moist tropics, dropped in rank to 15th. The California native *P. glandulosa* var. *torreyana* (0246) had high productivity among the native mesquite in both years.

*P. glandulosa* var. *torreyana* (0216) which had high biomass productivity for a native mesquite was collected from a large tree (50 cm DBH and 13 m (43 ft) tall). Perhaps the fast growth of this accession is the result of a potentially large tree achieving its unusually large size. Alternatively it is possible the fast growth of the 0216 progeny were in part due to hybridization with a recently planted ornamental *P. alba* (?) that was growing within 50 m. As discussed in the section on breeding structure this is the first evidence that hybridization has occurred with *P. glandulosa* var. *torreyana* as the female parent.

The ranked order of the coefficient calculated predictions of first and second season biomass per tree are similar to measured values for the smaller sample sizes of harvested trees. The major differences are presence of *P. alba* (0166) as the most productive tree in both years. This seems reasonable as unlike accessions such as *Parkinsonia aculeata* (0322) and *P. articulata* (0016), *P. alba* (?) (0166) had large trees in slightly higher elevation non-harvested blocks that were not adjacent to flood-gates.

The coefficient calculated biomass correctly predicted the upward move of *P. articulata* ranking in year 2 but appears to underestimate *Parkinsonia aculeata* production and to overestimate *Leucaena leucocephala* production. This is not particularly surprising as these trees are of different genera. The equation predicted a dry biomass of 83.3 kg for a tree of accession 0285 that actually was 56.3 kg. This large error is not particularly surprising as this was the largest tree measured and as prediction error of regression equations increase near the extremities of the data set.

#### Discussion of Imperial Valley Single Tree Biomass Screening

We feel that progeny of *Prosopis alba* ? accessions used for ornamentals are most promising for woody biomass production in arid lands despite impressive biomass production by both *Leucaena* and *Parkinsonia* for the following reasons. Despite our attempts and those of other workers (Roskoski et al., 1980)

*P. aculeata* has never been reported to nodulate. Though *P. aculeata* was not included in frost screening trials in the mountains, it was severely damaged by frosts in the Mojave desert near Barstow in December of 1978 in which *P. alba* (?) accessions remained undamaged. Our most serious objection to widespread development of *P. aculeata* is that there is only one species known and therefore little potential for breeding with other species with better frost tolerance, salt tolerance, etc.

Unlike *Parkinsonia aculeata*, *Leucaena leucocephala* (Hawaii Giant K-8) is an excellent nitrogen fixer. *Leucaena* growth is more dramatic than *Prosopis* because of more rapid height growth. In these Imperial Valley trials several shorter "bushy" *Prosopis* had greater dry matter contents and greater overall biomass productivity than *Leucaena*. However, *Leucaena* grew all winter and spring at temperatures too cool for semi-deciduous *Prosopis* strains to initiate new leaves. *Leucaena* should be considered for biomass production in arid climates where daily temperatures do not achieve 30-35°C temperatures required for mesquite. Presumably because of drought stress *Leucaena* set a large crop of seeds (1.8 kg were harvested from one tree) about 16 months from transplant and lost many leaves which it never regained. In contrast, a *Leucaena* harvested the first year which had no opportunity to flower and set seeds had tremendous coppice growth with one bushy coppice reaching 6 m in height a year from harvest. Compared to mesquite, *Leucaena* coppice regrowth is soft and succu-

lent and appears most appropriate for livestock forage. Although *Leucaena* is reported to be frost sensitive it survived without damage through two, albeit nearly frost free, California Imperial Valley winters. If above ground *Leucaena* portions were harvested prior to the winter frosts it might have excellent survival chances.

In both measured and predicted biomass production *P. alba* (?) (0166) and *P. articulata* (0016) had greater biomass production than *P. chilensis* (0009) which was the greatest biomass producer in the UCR plots. *P. chilensis* (0009) was included in the Imperial Valley companion study on water use efficiency because at the time of planting it was the greatest biomass producer known to us. Average seed propagated progeny of *P. alba* (0166) had 60-80% greater biomass than *P. chilensis* (0009) and appear promising. The *P. alba* (?) (0166) female parent is located along a Southern Pacific Railroad right of way and is currently being irrigated and fertilized to stimulate greater seed production. The maximum number of cleaned seed that could optimistically be expected from this tree is 150,000. Allowing for disfigured culls this would only be sufficient to plant 100 ha per year.

Reasonable biomass production goals in kg/ha can be projected from the single tree data developed here even though plant competition was random in all directions. The low estimate of productivity can be obtained using the average biomass

per tree of all harvested trees and the 1.52 x 3.65 m (5 x 12') spacing (1,798 trees/hectare). The average dry biomass the first year was 2.28 kg/tree or 4,100 kg/ha and 9.2 kg/tree the second year for 16,500 kg/ha. The second year's growth was 12,400 kg/ha. The upper estimate of productivity can be derived from maximum mean measured dry biomass per tree of 36.8 kg which would yield 66,000 kg/ha. This accession clearly experienced less competition than its neighbors because it was the largest tree and therefore a 66,000 kg/ha yield in two years is unreasonable.

Clones of *P. alba* (?) (0166) and (0285) have achieved actual or estimated 45 dry kg in two seasons (Table 18). It seems reasonable that 45 kg/tree could be expected from clonal material on large fields with a longer rotation of 3 seasons if a wider spacing of 3 x 3 m (9.8 ft) (1111 T/ha) were employed. Under this scenario 50 dry metric tons would be produced in three years for an annual production of 16.7 T/ha. These calculations are admittedly arbitrary but we believe they represent reasonable yield goals and management strategies. A wood density of 50 dry metric tons/ha should be sufficiently high to make effective use of harvesting and transportation equipment.



FIGURE 2 - Largest tree harvested in California Imperial Valley 1 3/4 years from transplant

## V. Biomass Estimation Imperial Valley Water Use Efficiency Plots

Three of the most promising biomass producing accessions in the first season UCR field trial i.e. *P. chilensis* (0009), *P. alba* (0039), and *P. glandulosa* var. *torreyana* (0001) were included with progeny from a 17 m tall (55'-25 year old) ornamental tree of South American origin (0163) to evaluate the water use efficiency and production in kg/ha in the California Imperial Valley. These accessions were examined in 3 replicates of 25 trees on a 1.5 x 1.5 m spacing in a 5 x 5 array. A basin irrigation system was used as described elsewhere in this report.

Basal stem diameter measurements were made for all 300 trees (4 varieties of 3 reps of 25) to calculate oven dry biomass using individually determined dry matter coefficients for each accession, and the 2 season combined-Imperial Valley stem diameter-fresh weight regression equation.

Total dry matter per plot was estimated to compare with total applied water per plot as discussed in the section on water use efficiency. An estimation of the dry matter production in kg/ha was also made after correcting for the edge effect of the outer trees in the 5 x 5 array. The three replicates contained a total of 48 (3x16) outer trees and 27 (3x9) inner trees. An F was used to compare all outer trees per accession with inner trees (Tables 19 and 20). A significant edge effect was observed at the end of the first and second season for *P. alba*

BIOMASS ESTIMATION FIRST SEASON WATER USE STUDY  
IMPERIAL VALLEY

Variety	Trees	Dry Weight <sup>1</sup> tree (kg)	P <sup>2</sup>	Standard error	Dry Weight <sup>3,4</sup> (kg/ha)
<u>P. chilensis</u> (0009)	Outside	3.62	.003	.19	15,600
	Inside	2.73		.15	11,700 x
	Total	3.30		.14	14,200 a
<u>P. glandulosa</u> var <u>torrey-</u> <u>ana</u> (0001)	Outside	2.36	.002	.15	10,200
	Inside	1.64		.11	7,100 z
	Total	2.10		.11	9,000 c
<u>P. alba</u> (0039)	Outside	3.14	.011	.23	13,500
	Inside	2.27		.18	9,800 xy
	Total	2.82		.16	12,100 b
<u>P. alba x P.</u> <u>glandulosa</u> var <u>torrey-</u> <u>ana</u> (0163)	Outside	2.09	.546	.19	9,000
	Inside	1.83		.24	7,900 yz
	Total	2.00		.15	8,600 c

1. "Coefficient calculated dry weights" computed as described in biomass estimation section.
2. Level of probability for significant differences between outside row and inner trees.
3. Using 1.52m (5') spacing.
4. Inside trees followed by same letter are not significantly different at 5% level and total trees followed by same letter are not significantly different at 5% level.

Table 20  
BIOMASS ESTIMATION SECOND SEASON WATER USE STUDY  
IMPERIAL VALLEY

Variety	Trees	Dry Weight <sup>1</sup> tree (kg)	P <sup>2</sup>	Standard error (kg)	Dry Weight <sup>3,4</sup> (kg/ha)
<u>P. chilensis</u> (0009)	Outside	9.13	.030	.74	39,300
	Inside	6.64		.73	28,600 x
	Total	8.23		.55	35,400 a
<u>P. glandulosa</u> var <u>torrey-</u> <u>ana</u> (0001)	Outside	5.14	.001	.36	22,100
	Inside	3.27		.25	14,000 y
	Total	4.47		.27	19,200 c
<u>P. alba</u> (0039)	Outside	9.06	.050	.79	39,000
	Inside	6.72		.70	29,000 x
	Total	8.22		.57	35,400 a
<u>P. alba</u> x <u>P.</u> <u>glandulosa</u> var <u>torrey-</u> <u>ana</u> (0163)	Outside	6.66	.154	.61	28,700
	Inside	5.21		.76	22,400 x
	Total	6.16		.48	26,500 b

1. "Coefficient calculated dry weights" computed as described in biomass estimation section.
2. Level of probability for significant differences between outside row and inner trees.
3. Using 1.52m (5') spacing.
4. Inside trees followed by same letter are not significantly different at 5% level and total trees followed by same letter are not significantly different at 5% level.

(0039), *P. chilensis* (0009) and *P. glandulosa* var. *torreyana* (0001). One entire replicate of accession 0163 had 50% of the first season biomass production of the other two replicates (which we attribute to field position) that obscured the statistical comparison of edge effects for this accession. With the exception of accession (0163) the inner 9 trees generally had 30-40% less biomass than the outer row in the plot. The border effect possibly could extend further than the second row, but this hypothesis cannot be tested since 5 x 5 array plots only have one tree for the third row. In an analyses of border effects on small plot work, Zavitkovski (1981) found the border effect could extend into the 6th row on closely spaced (0.3 m x 0.3 m) *Populus* plantings but that the border effect did not extend past the outer row in 1.2 m x 1.2 m plantings. As all the *Prosopis* in this study were on a 1.5 x 1.5 m (5 ft) spacing there is reason to believe the edge effect was minimal for the inner nine trees.

Based on the inner trees, the first and second season oven dry biomass production was 11.7 and 16.9 T/ha for *P. chilensis*, 7.1 and 6.9 T/ha for *P. glandulosa* var. *torreyana*, 9.8 and 19.2 T/ha for *P. alba* (0039) and 7.9 and 14.5 T/ha for *P. alba* x *P. glandulosa* var. *torreyana* respectively. The ranked order of biomass production in season one and two were not significantly different (5% level) but large relative increases occurred for *P. alba* (0039) and *P. alba* x *P. glandulosa* var. *torreyana* (0163)

in the second season.

Plant competition at the 1.5 m spacing seems to be pronounced in both year one and year two. A comparison of the average dry biomass per tree for *P. chilensis* (0009) in the companion screening trial at a wider (1.5 x 3.65m) spacing, with outer and inner trees in the water use study were 4.8 kg, 3.6 kg, and 2.7 kg in year 1 and 18.3, 9.1, and 6.6 kg for year 2. Trees in the water use study were basin irrigated with water originating in the center of the plot, making it unlikely that water was limiting growth of the inner trees. As plants in the screening trial (1.5 x 3.65 m spacing) had less applied water, sunlight appears to be limiting in the close (1.5 x 1.5 m) spacing.

In summary, substantial plant competition occurs the first and second season when *Prosopis* is grown on a 1.5 x 1.5 m spacing. Reduction in growth of inner trees is most attributable to light competition. *P. chilensis* in adjacent 1.5 x 3.65 m screening plots had 2.8 times biomass per tree suggesting that wider spacings be employed. When corrected for one row of edge effect, the maximum production of 14.5 oven dry T/ha/yr was obtained by both *P. chilensis* (0009) and *P. alba* (0039).

## CHAPTER VI.

IRRIGATION AND WATER USE STUDIES AT THE  
BRAWLEY FIELD STATION

A water use efficiency study was initiated at the U.S.D.A. Brawley Field Station during 20-22 March 1979. Mesquite, P. alba (0039), P. chilensis (0009), P. glandulosa var. torreyana (0001) and P. spp (0163) were transplanted on a 1.5 m x 1.5 m grid and randomized in 12 plots (basins 9.1 m x 9.1 m). The basins on each side were separated by a 3.0 m space and a 0.6 m berm surrounded each basin. The irrigation system was designed to measure the total water applied to each plot and to apply water at the center of the plot when the soil suction reached -3 to -5 bars at 0.46 m depth (measured by resistance blocks calibrated in band suction). Two 3.0 m neutron tubes were placed in each plot in early July at 15.2 cm and 30.4 cm from the base of one plant (average in size) of the inside 8 plants surrounded by the 16 outside plants. Another neutron tube approximately 6 m in length was placed 46 cm from the same plant in 1980.

The soil on which the mesquite plots are located is a Holtville clay, a fine textured soil that exhibits surface cracking of 4-8 cm in width and may extend to 30 cm in depth between irrigations. This has created a problem in determining the soil water evaporation from the soil surface and also in maintaining the water applied to the basin. During irrigations an attempt was made to close the cracks on the inside edge of the berms as the water approached through the cracks to the edges of the basins. Some water applied to the basins was lost

from the plots through the deep cracks. Because of this loss and the slow rate of water movement through the clay, the penetration of water at each irrigation ranged from 0.6 to 0.9 m even though the basins were filled to capacity by a slow rate of water application. The water used within the profile depth as measured to 6 m by the neutron equipment between irrigations was not replaced. This is discussed at a later part in this section but is clearly shown in Graphs 3 to 6.

In determining the water use during the two years of the Brawley study, an attempt was made to correct for the soil evaporative losses. The following study was conducted during the summer of 1980.

A bare surface plot outside but adjacent to the mesquite plots was constructed to determine evaporation from the soil surface. The plot was 3 x 3 m with one neutron tube placed in the center and one at the corner to a depth of 1.5 m. The center tube was used to develop an evaporation equation that was used to evaluate water loss due to evaporation. The plot was irrigated the same time as the test plots were irrigated. The loss of moisture was evaluated from July to the middle of September, a period of 62 days and for an eight day period in September. The longer period (see Graphs 1 and 2) of 62 days was used to develop the evaporation equation used in determining evaporation for the total growing period. The equation used was  $Y = .8821X^{-.5525}$ , where Y equals the rate of loss of water over the time (days) between irrigations. X in the equation is the time in days (24 hours) and to determine the total loss over this period the rate of loss per day (Y) times the days (X) gives the loss in inches (later converted to mm) for the period. The equation is only good when applied to the soil

surface after irrigation. Evaporation over the test period (286 days) was 455.42 mm. Rainfall fell in small amounts during the period from 11/29/79 to the first reading in 3/5/80 but was not included in the total evaporation because the plants were dormant during this part of the season.

Shading and wind protection within the mesquite plots reduced the rate of evaporation compared to the bare soil evaporation plot. This was observed by visually checking the drying conditions with time between mesquite plots and the evaporation plot. At the end of the 62 day period used for the bare soil evaporation plot, the soil surface conditions and soil cracking appeared to be about the same for both the mesquite plots and the bare soil plot. For the data presented it is postulated that the total evaporation for the 62 day period was similar and evaporation measurements made on the bare soil plot have been directly applied to the mesquite plots. Some measurements relating the neutron data obtained in mesquite plots and those in the bare soil plot are being investigated during the 1981 season in an attempt to better define the evaporative losses in the mesquite plots.

Neutron measurements were made in 1980 at 15 cm increment depths using the 3 neutron tubes. Readings at these depths to 3.0 m (depths of tubes placed close to the plant in 1979) were almost identical and indicates that the root systems within this volume of soil were similar throughout the interior part of the plots. This lends credance to the neutron measurements used to determine the soil water volume changes during the season. Neutron measurements were made prior to irrigation,

immediately following irrigation, when the water on the soil surface had moved into the soil and one or two times between irrigations. The latter measurements were used to check the water movement into the soil following irrigation.

The studies on the evaporation process of the clay soil are being continued during the 1981 season. This is believed to be critical to the water use studies and more information is needed to arrive at a final value to be used in this study. The soil physical properties are also being studied in terms of plant growth and root development during the 1981 season. These two studies should provide needed information in developing water use values that can be used with confidence.

In the meantime the data in the following tables and graphs should be considered only as preliminary since final corrections to the data cannot be made until the data is further refined during the 1981 season.

Graphs 3 through 6 show selected moisture depletion curves for four plots, one of each variety of *Prosopis*. The first and last readings are shown for 1979 and the first two readings and last reading for 1980. The graph shows that depletion of moisture occurred largely in the upper 3 m through the 1979 season. Even though depletion occurred throughout the 1980 season in this portion of the profile, it was not of the same magnitude. Since irrigation was only effective in recharging the upper 0.9 m of the profile, the remaining 5 m were not recharged at any time. The extreme variation of moisture differences in the deeper part of the soil profile are probably due to thin layers of clay or silt. These were not so strongly delineated when measurements were made at 30 mm depth increments during the 1979 season.

Water use in the top 0.9 meters of the profile averaged 53% of the total water used while 46% of the moisture used came from .9 m to 6 m.

Table 21 shows evapotranspiration, evaporation, water use and cubic centimeters of water to produce one gram of dry biomass for 1980. The table also shows the dry biomass production expanded to metric tons per hectare ( $MT\ ha^{-1}$ ). This calculation is based on the mean of either the inner nine trees or all trees. Table 22 shows the evapotranspiration, water use and dry biomass production for the 1979 and 1980 seasons combined.

Some previous studies on water requirements by McGinnies and Arnold (1939) on range plants in Arizona included velvet mesquite, Prosopis Velutina. Large containers were used for these studies and the experiments were conducted for 390 days. The average water requirement for these studies was  $1671\ cm^3$  of water used to produce one gram of dry matter. Dwyer and De Garmo (1970) in greenhouse studies on mesquite Prosopis Juliflora showed an average value of  $4,818.7\ cm^3$  of water to produce one gram of dry matter for pots controlled at field capacity, 1/2 field capacity, 1/3 field capacity and 1/4 field capacity. There was no significant difference between treatments. Both of these studies show high water requirement to produce the crop when compared to field crops and range grasses (McGinnies and Arnold, 1939). Water requirements for most of these crops were in the  $400-700\ cm^3$  of water to produce a gram of dry matter.

In the studies for 1980 the average water use values are  $535.3\ cm^3$  for P. chilensis,  $1150.3\ cm^3$  for P. glandulosa var. torreyana,  $478.3$

$\text{cm}^3$  for P. alba and  $760.8 \text{ cm}^3$  for P. alba x P. glandulosa var. torreyana.

The water use values for 1979 and 1980 (combined) show relatively the same magnitude as for 1979. The most efficient mesquite varieties are the larger and faster growing plants P. chilensis and P. alba. The water use for all the varieties are well within the magnitude of most field crops.

Table 21. Dry biomass production and water use, 1980.

Species	Accession Number	Plot	kg/plot Dry Matter	Neutron Measured cm H <sub>2</sub> O (ET)	cm <sup>3</sup> H <sub>2</sub> O gm <sup>-1</sup> Dry Matter	b E (cm)	Inner 9 Trees MT ha <sup>-1</sup>	All Trees MT ha <sup>-1</sup>
<u>P. chilensis</u>	(0009)	I	86.7	74.8	714.4	45.5	8.6	15.0
		V	133.1	77.1	479.7		22.2	23.4
		IX	150.0	74.6	411.8		20.0	23.4
					535.3 (Av.)			
<u>P. glandulosa</u>	(0001)	II	43.2	79.3	1520.1	45.5	7.6	7.5
var. <u>torreyana</u>		VII	59.5	73.6	1024.3		7.0	10.3
		XII	74.9	82.0	906.6		6.6	13.0
					1150.3 (Av.)			
<u>P. alba</u>	(0039)	VI	122.8	64.8	437.0	45.5	16.2	21.3
		VIII	119.0	79.2	551.0		22.2	20.6
		X	163.1	88.0	446.8		19.4	28.2
					478.3 (Av.)			
<u>P. alba</u> x	(0163)	III	71.6	78.8	911.4	45.5	6.6	12.4
<u>P. glandulosa</u>		IV	76.6	83.5	902.7		11.0	13.3
var. <u>torreyana</u>		XI	147.7	83.5	468.2		21.3	25.3
					760.8 (Av.)			

a Water applied as evaluated with neutron probe

b Soil evaporative losses

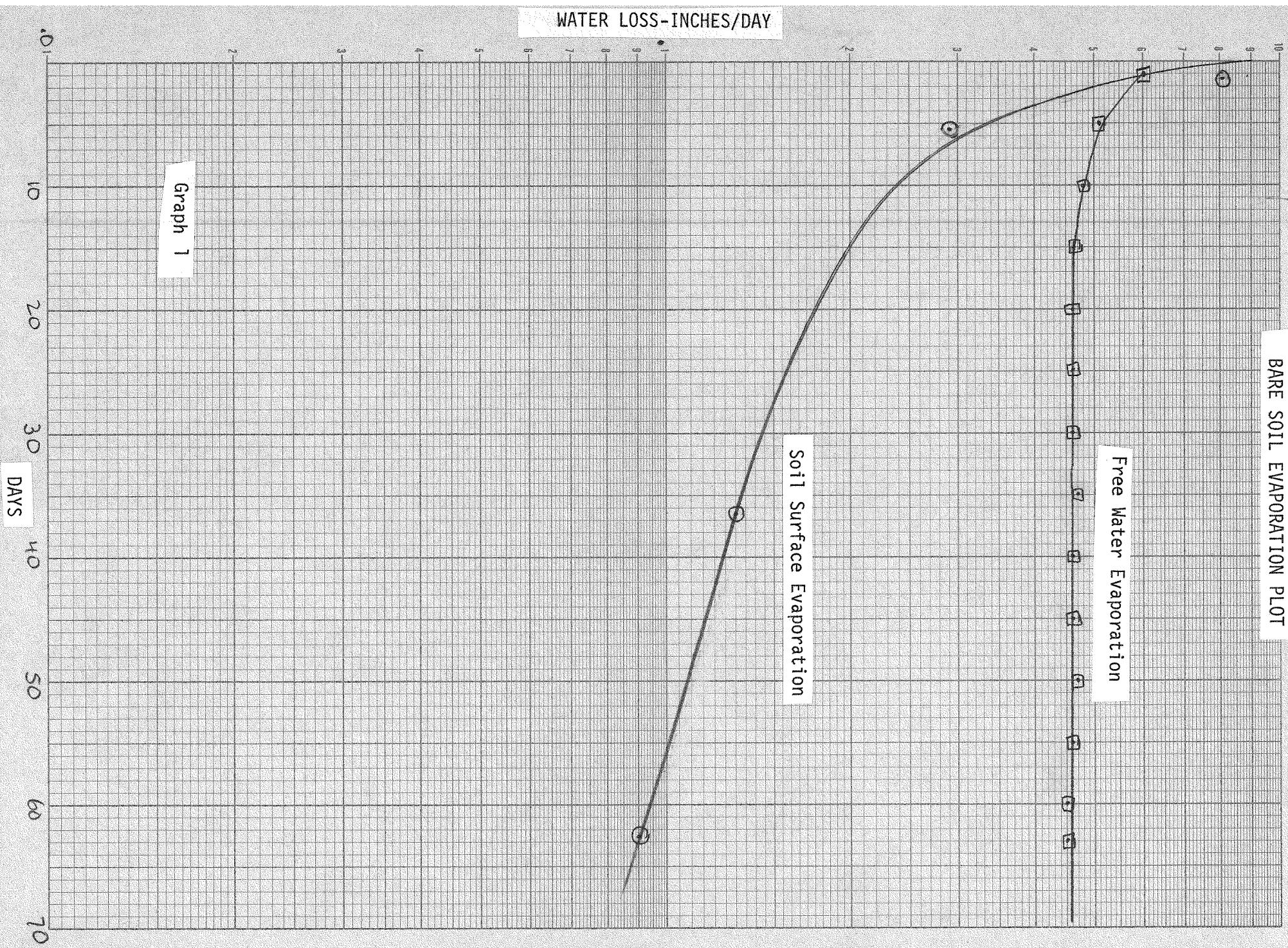
Table 22. Dry biomass production and water use, 1979 and 1980 total.

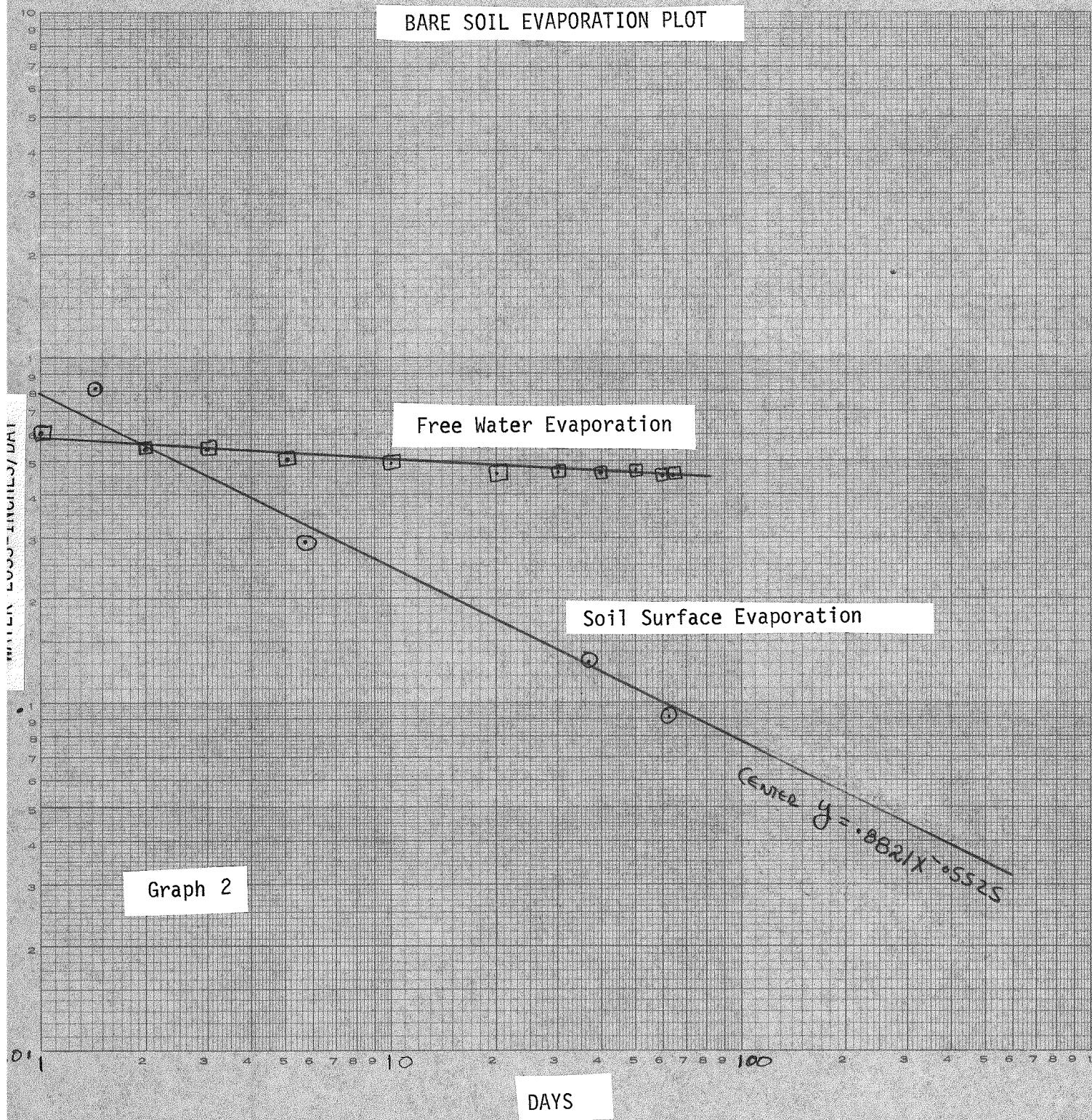
Species	Accession Number	Plot	kg/plot Dry Matter	Neutron Measured cm H <sub>2</sub> O (ET)	cm <sup>3</sup> H <sub>2</sub> O gm <sup>-1</sup> Dry Matter
<u>P. chilensis</u>	(0009)	I	169.7	112.9	550.9
		V	214.8	115.2	444.1
		IX	232.8	112.7	400.9
					465.3 (Av.)
<u>P. glandulosa</u> var. <u>torreyana</u>	(0001)	II	81.1	117.4	1198.8
		VII	122.7	111.7	753.9
		XII	131.1	120.1	758.6
					903.8 (Av.)
<u>P. alba</u>	(0039)	VI	176.8	102.9	482.0
		VIII	195.0	117.3	498.1
		X	244.8	126.1	426.6
					468.9 (Av.)
<u>P. alba</u> x <u>P. glandulosa</u> var. <u>torreyana</u>	(0163)	III	94.8	116.9	1021.1
		IV	135.8	121.6	741.5
		XI	212.5	121.6	473.9
					602.2 (Av.)

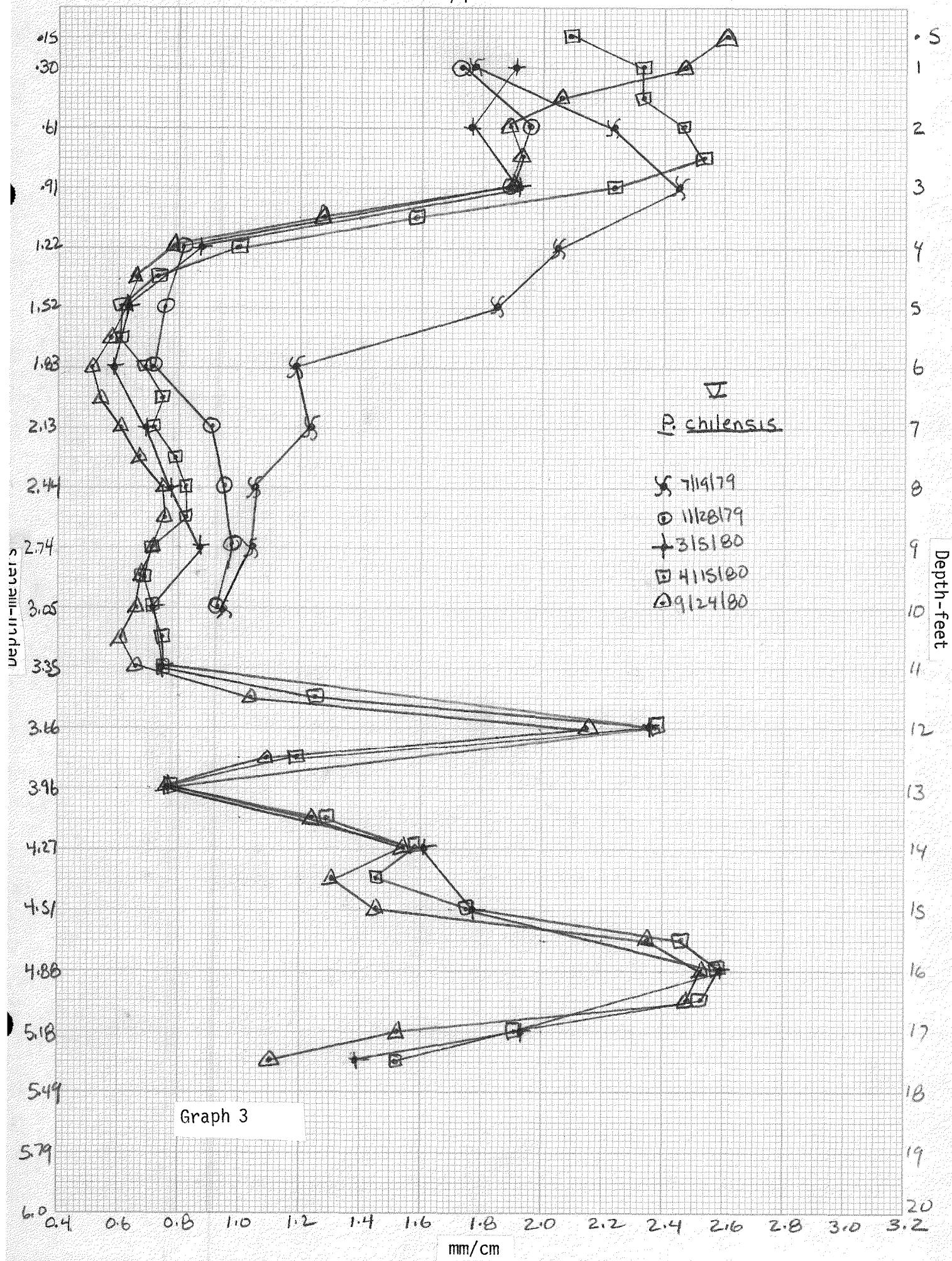
## LITERATURE CITED

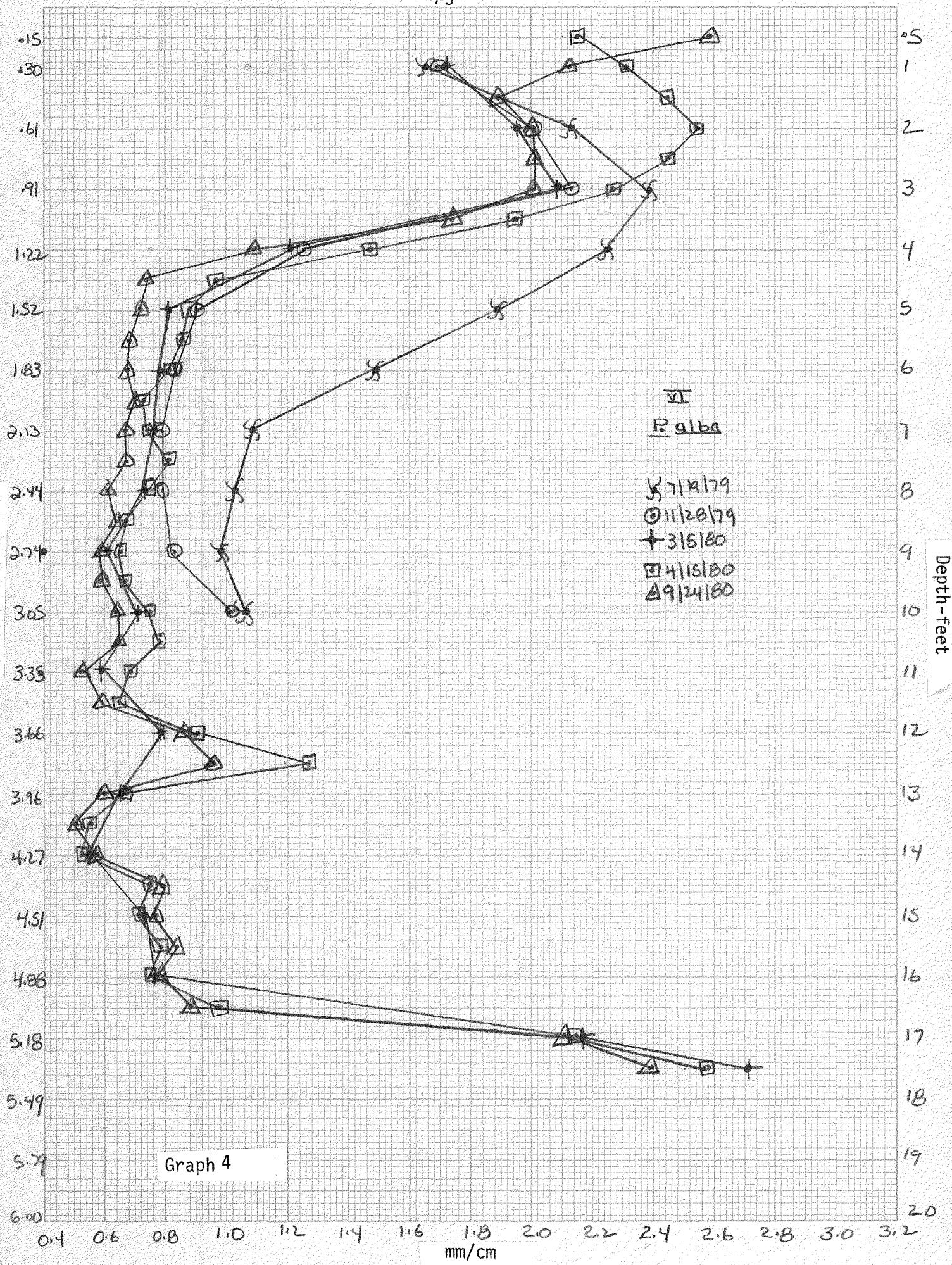
- McGinnies, W. G. and J. F. Arnold. 1939. Relative water requirements of Arizona range plants. Tech. Bul. No. 80, Arizona Agric. Expt. Sta.
- Dwyer, Don D. and Harlan C. De Garmo. 1970. Greenhouse productivity and water-use efficiency of selected desert shrubs and grasses under four soil moisture levels. Tech. Bul. No. 570, New Mexico Agric. Expt. Sta.

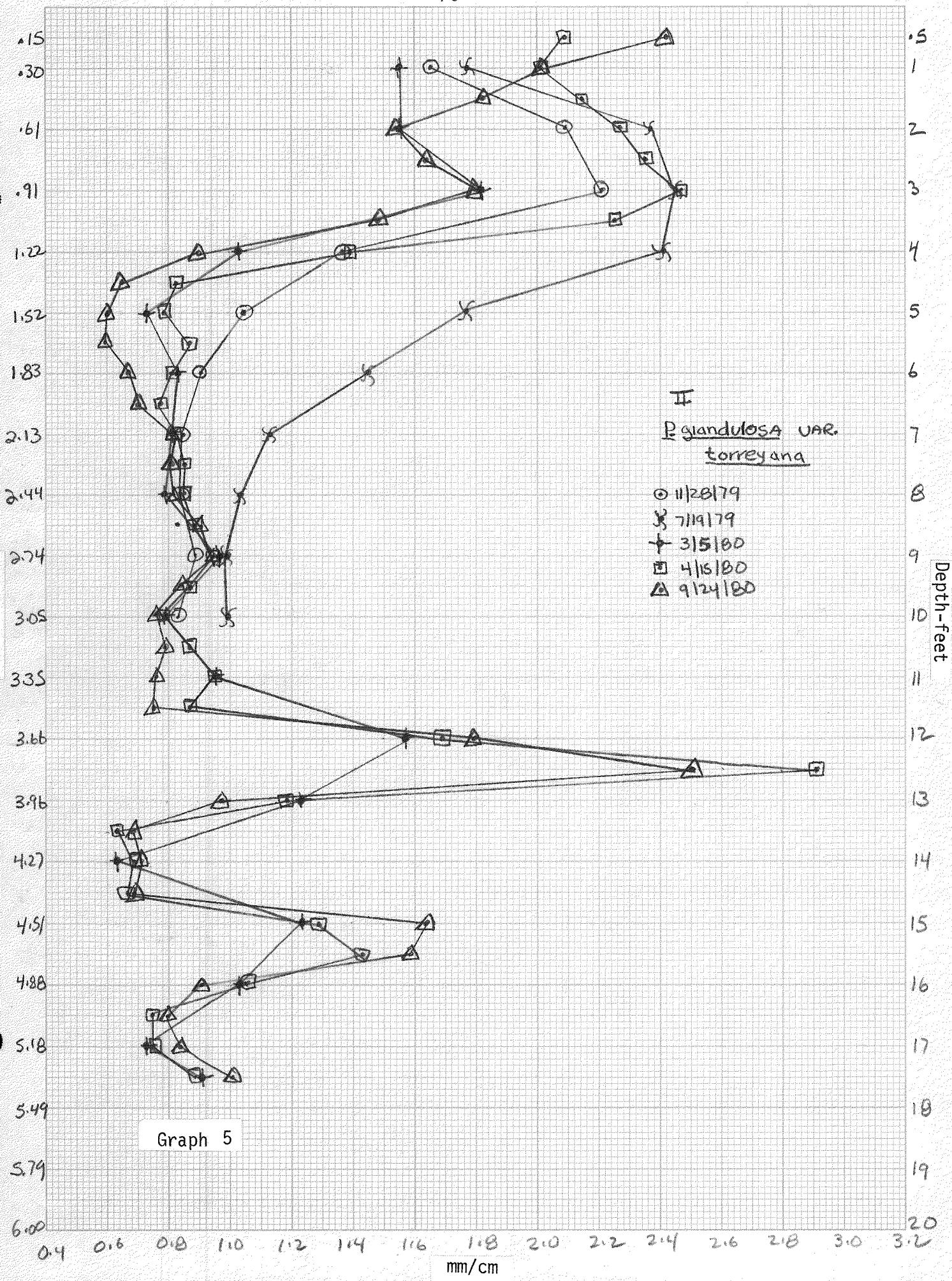
## BARE SOIL EVAPORATION PLOT

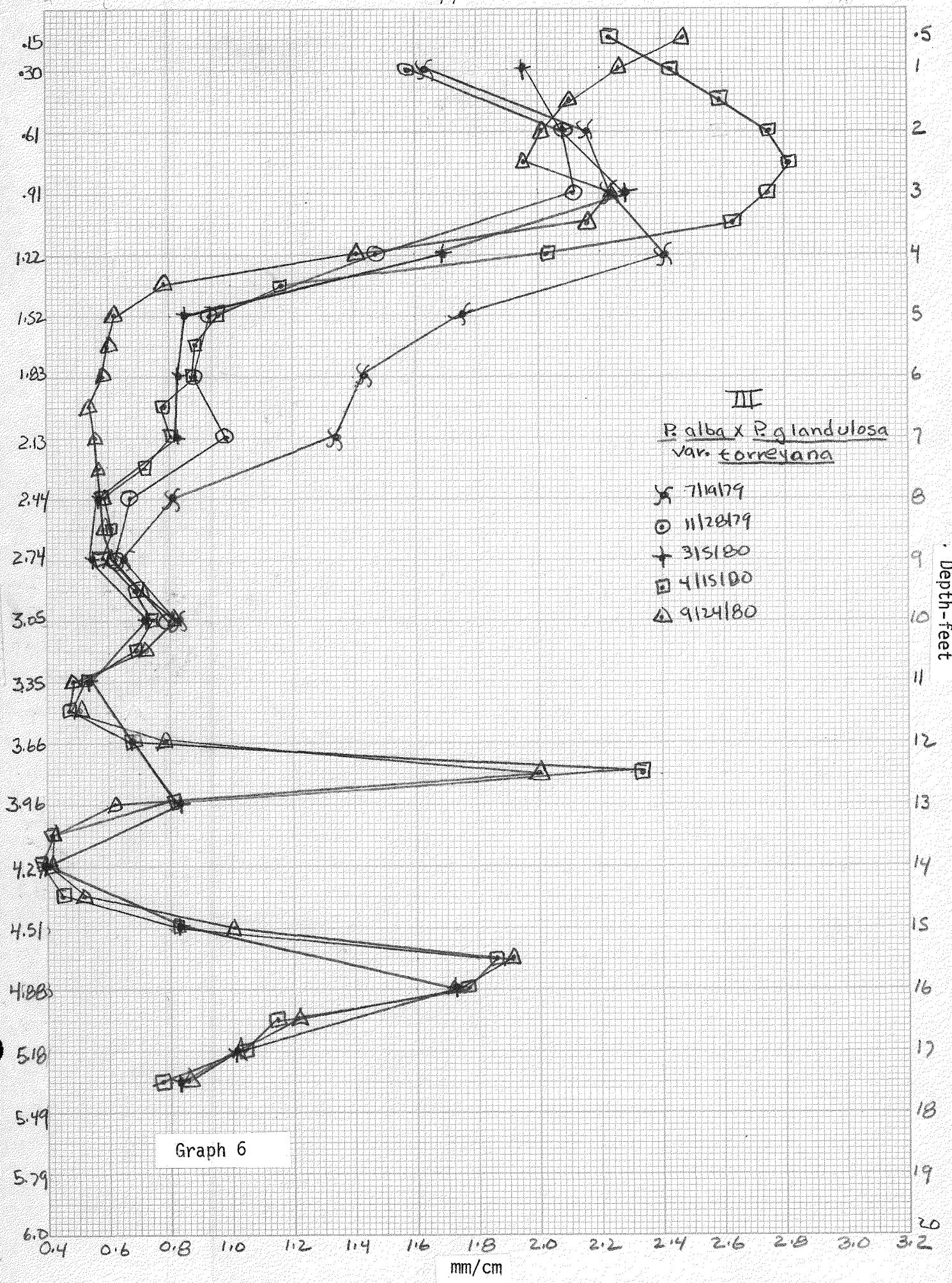












## 2. Irrigation Studies at Riverside

Tables 23 through 26 show the total irrigation water applied in millimeters for all plots and moisture treatments for 1978, 1979 and 1980. When the soil moisture potential at the specified control depth reached 0.6, 2.0, or 5.0 bars in M1, M2, and M3 respectively, irrigation water was applied. Due to small effects of irrigation on productivity the control depth was increased from 30 cm (12") to 46 cm (18") to 61 cm (24") in season 1, 2, and 3 respectively.

Table 23

## Key to Plot Numbers

Plot Number	Species	Accession Number
1	<i>P. africana</i>	0040
2	<i>P. africana</i>	0045
3	<i>P. alba</i>	0098
4	<i>P. alba</i>	0037
5	<i>P. alba</i>	0039
6	<i>P. alba</i>	0132
7	<i>P. alba</i>	0134
8	<i>P. articulata</i>	0016
9	<i>P. chilensis</i>	0009
10	<i>P. kuntzei</i>	0130
11	<i>P. laevigata</i>	0114
12	<i>P. nigra</i>	0036
13	<i>P. nigra</i>	0034
14	<i>P. nigra</i>	0038
15	<i>P. nigra</i>	0133
16	<i>P. pallida</i>	0041
17	<i>P. pallida</i>	0140
18	<i>P. ruscifolia</i>	0131
19	<i>P. tamarugo</i>	0042
20	<i>P. velutina</i>	0020
21	<i>P. velutina</i>	0032
22	<i>P. velutina</i>	0025
23	<i>P. glandulosa</i> var. <i>torreyana</i>	0001
24	<i>P. juliflora</i>	0044
25	<i>P. glandulosa</i> var. <i>glandulosa</i>	0028
26	<i>P. sp.</i>	0080
27	<i>P. sp.</i>	0074
28	<i>P. sp.</i>	0108
29	<i>P. sp.</i>	0116
30	<i>P. alba</i> (?)	0013
31	<i>P. alba</i>	0137
32	<i>P. alba</i>	0138

Table 24. Riverside mesquite plots (water applied)

based on tension reading  
of -.5 - -.7 bar at  
control depth.

Control Depth	(M1)					
	12"		18"		24"	
	1978	1979	1979	1980	1980	1980
Plot no.	Inches	mm	Inches	mm	Inches	mm
1	3	76.2	Dead		Dead	
2	3	76.2	Dead		Dead	
3	3	76.2	27	685.8	12	304.8
4	6	152.4	19	482.6	34	863.6
5	9	228.6	36	914.4	24	609.6
6	6	152.4	39	990.6	44	1117.6
7	3	76.2	27	685.8	34	863.6
8	3	76.2	27	685.8	26	660.4
9	3	76.2	35	889.0	40	1016.0
10	3	76.2	4	101.6	18	457.2
11	-	-	12	304.8	18	457.2
12	3	76.2	24	609.6	34	863.6
13	3	76.2	16	406.4	28	711.2
14	3	76.2	24	609.6	32	812.8
15	3	76.2	24	609.6	34	863.6
16	6	152.4	Dead		Dead	
17	6	152.4	Dead		Dead	
18	3	76.2	19	482.6	36	914.4
19	6	152.4	12	304.8	20	508.0
20	6	152.4	27	685.8	26	660.4
21	3	76.2	16	406.4	26	660.4
22	6	152.4	28	711.2	42	1066.8
23	6	152.4	27	685.8	40	1016.0
24	3	76.2	Dead		Dead	
25	-	-	8	203.2	18	457.2
26	3	76.2	20	508.0	18	457.2
27	3	76.2	8	203.2	26	660.4
28	6	152.4	19	482.6	20	508.0
29	3	76.2	16	406.4	18	457.2
30	6	152.4	31	787.4	26	660.4
31	6	152.4	36	914.4	32	812.8
32	3	76.2	19	482.6	26	660.4

Not included is 423 mm (16.6") rainfall the 1978-1979 winter and 370 mm (14.6") the 1979-1980 winter.

Table 25. Riverside mesquite plots (water applied)

based on tension reading  
of -2 bar at control depth.

Control Depth	(M2)		1979	1980		
	12"					
	1978	mm				
Plot no.	Inches	mm	Inches	mm		
1	-		Dead	Dead		
2	-		Dead	Dead		
3	3	76.2	16	406.4		
4	3	76.2	23	584.2		
5	3	76.2	16	406.4		
6	3	76.2	23	584.2		
7	3	76.2	11	279.4		
8	3	76.2	19	482.6		
9	3	76.2	23	584.2		
10	-	-	-	12.0		
11	3	76.2	11	279.4		
12	-	-	12	304.8		
13	3	76.2	8	203.2		
14	3	76.2	23	584.2		
15	-	-	19	482.6		
16	-	-	Dead	Dead		
17	-	-	Dead	Dead		
18	-	-	12	304.8		
19	-	-	12	304.8		
20	3	76.2	11	279.4		
21	3	76.2	20	508.0		
22	3	76.2	15	381.0		
23	3	76.2	23	584.2		
24	3	76.2	Dead	Dead		
25	-	-	4	101.6		
26	-	-	8	203.2		
27	-	-	8	203.2		
28	-	-	8	203.2		
29	-	-	15	381.0		
30	-	-	12	304.8		
31	-	-	16	406.4		
32	-	-	20	508.		
				39.3		
				998.2		

Not included is 423 mm (16.6") rainfall the 1978-1979 winter  
and 370 mm (14.6") the 1979-1980 winter.

Table 26. Riverside mesquite plots (water applied)

based on tension reading  
of -5 bar at control depth.

Control Depth	(M3)		18" 1979	24" 1980
	12" 1978	Inches mm		
Plot no.	Inches	mm	Inches	mm
1	0	0	Dead	
2	0	0	Dead	
3	0	0	4	101.6
4	0	0	16	406.4
5	0	0	20	508.0
6	0	0	8	203.2
7	0	0	-	-
8	0	0	8	203.2
9	0	0	20	508.0
10	0	0	-	-
11	0	0	8	203.2
12	0	0	8	203.2
13	0	0	8	203.2
14	0	0	12	304.8
15	0	0	12	304.8
16	0	0	Dead	
17	0	0	Dead	
18	0	0	-	-
19	0	0	12	304.8
20	0	0	12	304.8
21	0	0	-	-
22	0	0	8	203.2
23	0	0	20	508.0
24	0	0	Dead	
25	0	0	4	101.6
26	0	0	8	203.2
27	0	0	8	203.2
28	0	0	12	304.8
29	0	0	4	101.6
30	0	0	23	584.2
31	0	0	8	203.2
32	0	0	8	203.2

Not included is 423 mm (16.6") rainfall the 1978-1979 winter  
and 370 mm (14.6") the 1979-1980 winter.

## VII. Coppicing ability

Woody biomass production costs for plantation grown trees can be greatly reduced if the trees resprout from the stump (coppice) after the first harvest. Coppice regrowth avoids costs associated with land preparation, seedlings, transplanting, and first year herbicide applications. Projected production costs (on the stump) are \$23.36 per dry ton for first harvest from tissue cultured seedlings and \$5.00 per dry ton for subsequent coppice regrowth harvests.

One year after 4 blocks of 55 tree legumes were harvested for biomass determination, the stumps were examined for presence or absence of coppice regrowth. The results of this examination are presented in Table 27. The primary objective of the harvest was to determine total above ground dry biomass and thus the trees were harvested with a chain saw at ground level. A greater percent coppice might have been observed if higher cuts had been made above more stem bud primordia.

In general the South American *P. alba* and *P. nigra* have greater ability to coppice than the North American natives. Most trees in the productive woody biomass accessions 0009, 0166, 0168, 0039, and 0190 coppiced. The amount of woody biomass was not estimated but was substantial in many cases. A one year old coppice of accession 0194 was 5.4 tall (17'8") (Figure 3). Nearly all of the trees of the genera *Parkinsonia*, *Leucaena*, and *Olneya* coppiced while none of the *Cercidium floridium*

coppiced.

The coppicing ability of the highest woody biomass producing accessions appears promising but studies are needed to determine the optimum height of harvest, coppice biomass production levels, and the number of coppice rotations that are possible.

Table 27

Coppicing ability of tree legumes in Imperial Valley varietal trial

Variety Number	Accession Number	Species	Number of trees which coppiced
1	0001	P. <u>glandulosa</u> var <u>torreyana</u>	2
2	0009	P. <u>chilensis</u>	3
3	0013	P. <u>alba</u>	1
4	0016	P. <u>articulata</u>	1
5	0020	P. <u>velutina</u>	3
6	0032	P. <u>velutina</u>	1
7	0038	P. <u>nigra</u>	3
8	0041	P. <u>pallida</u>	0
9	0037	P. <u>alba</u>	3
10	0044	P. <u>juliflora</u>	1
11	0039	P. <u>alba</u>	4
12	0098	P. <u>alba</u>	4
13	0132	P. <u>alba</u>	4
14	0133	P. <u>nigra</u>	4
15	0137	P. spp.	3
16	0163	P. <u>alba</u> x P. <u>glandulosa</u> <u>torreyana</u>	4
17	0147	Leucaena <u>leucocephala</u>	3
18	0166	P. <u>alba</u>	3
19	0168	P. <u>alba</u>	4
20	0285	P. spp.	1
21	0286	P. spp.	2
22	0280	P. spp.	3
23	0247	P. <u>velutina</u>	1
24	0322	Parkinsonia <u>aculeata</u>	4
25	0324	Cercidium <u>floridium</u>	0
26	0317	P. <u>tamarugo</u>	4
27	0245	P. <u>pubescens</u>	1
28	0263	P. <u>pubescens</u>	2
29	0343	Olneya <u>tesota</u>	3
30	0154	P. <u>glandulosa</u> var <u>torreyana</u>	2
31	0157	P. <u>glandulosa</u> var <u>torreyana</u>	3
32	0165	P. <u>glandulosa</u> var <u>torreyana</u>	2
33	0239	P. <u>glandulosa</u> var <u>torreyana</u>	2
34	0250	P. <u>glandulosa</u> var <u>torreyana</u>	2
35	0171	P. <u>glandulosa</u> var <u>torreyana</u>	1
36	0170	P. <u>glandulosa</u> var <u>torreyana</u>	0
37	0246	P. <u>glandulosa</u> var <u>torreyana</u>	1
38	0184	P. <u>glandulosa</u> var <u>torreyana</u>	1
39	0199	P. <u>glandulosa</u> var <u>torreyana</u>	0
40	0258	P. <u>glandulosa</u> var <u>torreyana</u>	0
41	0205	P. <u>glandulosa</u> var <u>torreyana</u>	0
42	0216	P. spp.	3
43	0234	P. spp.	2
44	0255	P. <u>glandulosa</u> var <u>torreyana</u>	0
45	0296	P. <u>glandulosa</u> var <u>torreyana</u>	0
46	0261	P. <u>glandulosa</u> var <u>torreyana</u>	0
47	0271	P. <u>glandulosa</u> var <u>torreyana</u>	1
48	0276	P. <u>glandulosa</u> var <u>torreyana</u>	1

continued

Table 27

<u>Variety Number</u>	<u>Accession Number</u>	<u>Species</u>	<u>Number of trees which coppiced</u>
49	0289	P. <u>glandulosa</u> var <u>torreyana</u>	2
50	0194	P. <u>alba</u>	4
51	0190	P. <u>glandulosa</u> var <u>torreyana</u>	0
52	0186	P. spp.	2
53	0291	P. <u>glandulosa</u> var <u>torreyana</u>	0
54	0182	P. <u>glandulosa</u> var <u>torreyana</u>	0
55	0210	P. <u>glandulosa</u> var <u>torreyana</u>	1

Four trees of each of 55 varieties were randomly replicated in 4 blocks. The 9 month old trees were harvested with a chain saw at ground level in November 1979 and observed for presence or absence of coppice on 20 November 1980. The maximum number of coppiced trees per variety is 4.

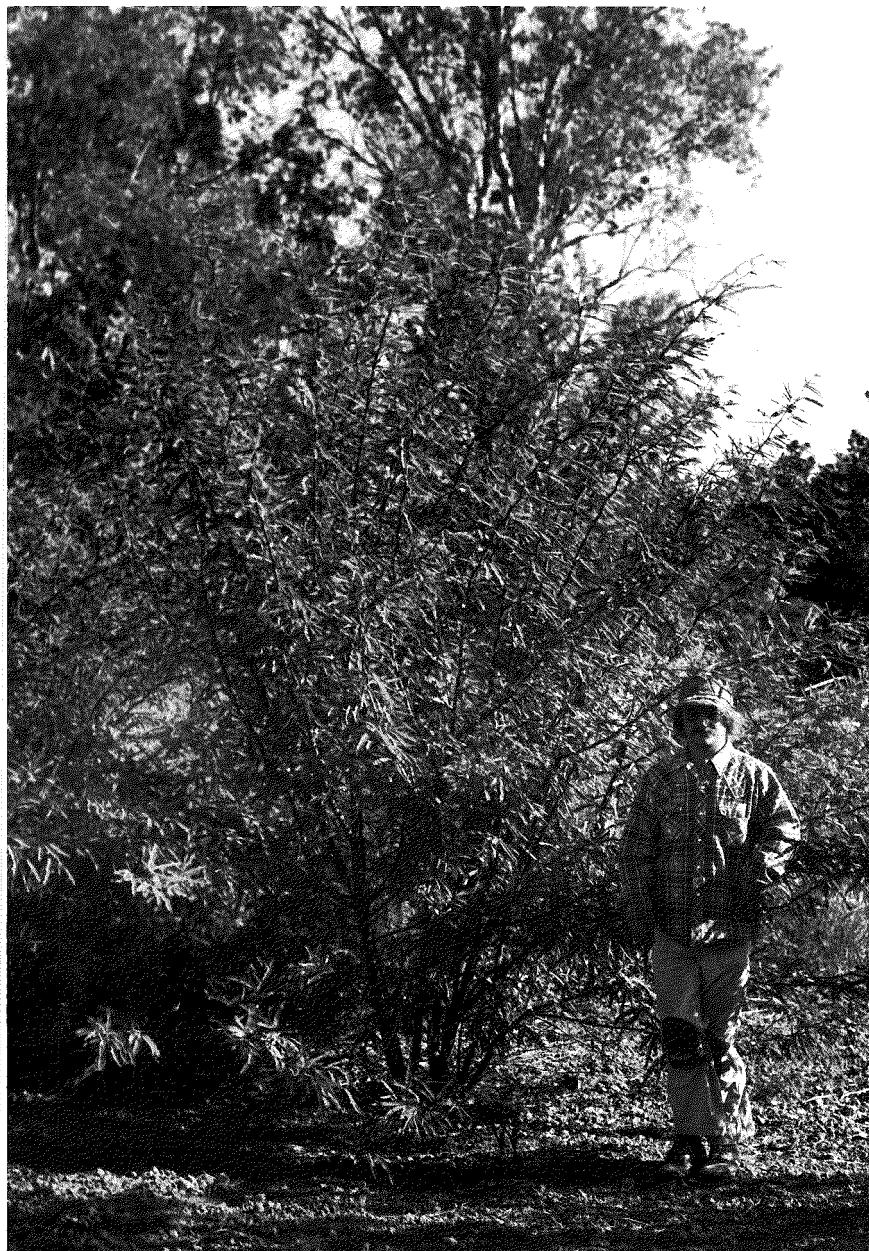


FIGURE 3 - Largest one year old coppice of *P. alba* (0194)  
Imperial Valley

## VIII. Mesquite Pod Production

### A. Mesquite pod production from immature field trees

Pod yield data has been collected from three field plots in southern California. The oldest field plot designated as the Riverside orchard study has 25 randomly replicated accessions and was established in June 1977. This plantation was initially conceived as a nursery so that the trees are widely spaced (4.5 x 6.1 m) and in the summer the trees are irrigated every three weeks by furrow irrigation.

A second planting, designated as the Riverside irrigation study, was established in July 1978 at Riverside and included 32 accessions representing 12 species. Twelve trees of each accession were grown in three different basins where water was supplied when the soil water potential reached 0.6, 2, or 5 bars. A third planting was established in March 1979 in the California Imperial Valley to screen for biomass production, pod production, and to conduct a water use efficiency study. The Riverside climate is cooler (daily July maximum of 34.6°C) than the Imperial Valley climate (daily July maximum of 41.7°C) with the result that mesquite growth is nearly half as rapid in Riverside as it is in Imperial Valley.

Pod yield data for third and fourth season "Riverside orchard setting trees", for second and third season "Riverside irrigation study trees" and for first and second season Imperial Valley trees are presented in Tables 28, 29, 30, 31, 32, and 33.

Table 28

MESQUITE POD YIELD FOR RIVERSIDE ORCHARD SETTING  
TREES AT END OF THIRD GROWING SEASON (1979)

Species	Accession Number	Origin	Avg. Yield/ Tree (grams)	Range in Yield/ Tree (grams)	Total Yield/ Accession (grams)
<i>Prosopis velutina</i>	0020	Arizona	1650	0-4797	8248
<i>P. spp.</i>	0025	Sonora, Mex.	1291	226-2913	5164
<i>P. spp.</i>	0032	Arizona	1267	268-4709	6337
<i>P. glandulosa,</i> var. <i>torreyana</i>	0001	California	996	0-3864	9957
<i>P. velutina</i>	0031	Arizona	75	0-230	301
<i>P. alba</i>	0039	Argentina	44	0-250	262
<i>P. spp.</i>	0030	Arizona	31	0-115	125
<i>P. spp.</i>	0027	New Mexico	26	0-102	102
<i>P. juliflora</i>	0007	Unknown	10	4-19	30
<i>P. spp.</i>	0029	Arizona	7	0-21	21
<i>P. spp.</i>	0028	Texas	17	0-17	17
<i>P. chilensis</i>	0010	Argentina			
<i>P. alba</i>	0163	S. America			
<i>P. nigra</i>	0038	Argentina			
<i>P. nigra</i>	0036	Argentina			
<i>P. alba</i>	0035	Argentina			
<i>P. ruscifolia</i>	0033	Argentina			
<i>P. spp.</i>	0026	New Mexico			
<i>P. spp.</i>	0024	Mexico			
<i>P. spp.</i>	0023	Arizona			
<i>P. spp.</i>	0022	Arizona			
<i>P. spp.</i>	0021	N. America			
<i>P. chilensis</i>	0009	Argentina			
			Unassigned:	281	
			Total:	30,845	or 68 lbs

During the summer months, these accessions are irrigated every 3 weeks by furrow irrigation. Plot yield previous year was 1 pod or 2.5 grams. Moisture content is approximately 10%.

Table 29  
MESQUITE POD YIELD FOR RIVERSIDE ORCHARD SETTING  
TREES AT END OF FOURTH SEASON (1980)

Species	Accession Number	Origin	Number of Trees with Pods	Average Yield per Tree (grams)	Range in Yield per Tree
P. sp.	0029	Arizona	2	906	18-1796
P. spp.	0007	N. America	1	493	493
P. <u>glandulosa</u> , var. <u>torreyana</u>	0001	Thermal, CA	7	373	33-1210
P. spp.	0028	Texas	2	360	261- 459
P. <u>velutina</u>	0032	Arizona	4	273	16- 635
P. <u>velutina</u>	0025	Sonora, Mex.	5	251	30- 616
P. <u>alba</u>	0039	Argentina	4	210	13- 533
P. <u>chilensis</u>	0010	Argentina	1	148	148
P. spp.	0027	New Mexico	1	140	140
P. <u>nigra</u>	0034	Argentina	1	102	102
P. <u>alba</u>	0037	Argentina	3	100	8- 247
P. <u>alba</u> (?)	0163	Indio, CA	1	93	93
P. <u>velutina</u>	0020	Arizona	4	76	44- 110
P. spp.	0026	New Mexico	2	55	37- 72
P. spp.	0030	Arizona	3	43	24- 77
P. <u>velutina</u>	0031	Arizona	3	39	18- 80
P. <u>alba</u>	0035	Argentina	2	30	3- 56
Total				10,326	

The trees were individually picked and the pods dried, weighed, catalogued, and stored as single tree selections. Pod weights presented here are after drying in a forced air 50°C oven for a minimum of 6 hours. This reduces the harvested mature pod from approximately 13% moisture to 6% moisture and does not affect seed germination.

No pods were produced the first year in either of the Riverside studies while six trees of the Riverside accessions produced pods in their first Imperial Valley growing season. The second season one pod (2.5 g) was produced in the Riverside orchard setting trees, 2.4 kg of pods were produced in the Riverside irrigation study trees, and 5.3 kg were produced in the Imperial Valley study. The third season 30.8 kg were produced in Riverside orchard setting trees and 48.7 kg were produced in the Riverside irrigation study. Imperial Valley trees have not yet reached the third season. The only trees in the fourth season were Riverside orchard setting trees which produced 10.3 kg or only one-third of the previous years production. This drop in production might be due to alternate bearing or it might be the result of over watering as discussed later.

The consistently high pod production for several selections from Arizona and nearby Mexico such as *P. velutina* (0020), *P. velutina* (0025), *P. velutina* (0032), and *P. sp* (0080) among all sites and all years is particularly noteworthy.

In the Riverside irrigation study little differences in

pod production were noted among moisture treatments for trees in their second season. Despite approximately 33% less overall biomass production in the third season dry plot (see section on biomass estimation in these plots) the 5.0 Bar treatment (which received no irrigation in season three) produced nearly twice as many pods as the wet irrigation treatment. Water stress evidently stimulates pod production at the expense of woody biomass production in many selections of *Prosopis*.

In some of the dry irrigation plots an abnormally high pod/woody biomass ratio was present on small water stressed trees. Accession 0080 had an average dry matter of 1.4, 2.1, and 0.8 kg per tree in the wet, medium, and dry irrigation plots respectively. The total dry matter for accession 0080 in the dry plot was 9.6 kg and the total pod production was 4.97 kg. Thus the pods constitute 52% of the above ground biomass (excluding pods) in the plot. Tree number ten in the 0080 dry plot had a pod production in the third season of 1.438 kg and a measured dry biomass of 2.4 kg for a pod production/above ground biomass percentage of 60%. Regression equations predicted a dry biomass of 0.7 kg for tree ten at the end of the previous year. Thus a 1.4 kg non-fruit biomass growth and 1.44 kg of pod production occurred in the third season so that 50% of yearly dry matter production was partitioned into pod production. This is higher than expected of typical forest fruiting dry matter partitioning and higher than the harvestindex of most agricultural crops.

Table 30

MESQUITE POD PRODUCTION FOR SECOND GROWING SEASON  
(1979) RIVERSIDE IRRIGATION STUDY TREES

Species	Accession Number	Origin	Moisture Treatments									
			Wet (0.6 bar) treatment			Medium (2.0 bar) treatment			Dry (5.0 bar) treatment			
			Number of trees w/pods	Range pod yield/ tree w/pods (grams)	Total prod. (grams)	Number trees w/pods	Range pod prod./ tree (grams)	Total prod. (grams)	Number trees w/pods	Range pod yield/ tree (grams)	Total prod. (grams)	
<u>Prosopis</u> <u>velutina</u>	0020	Arizona	9	0-530	920	7	0-177	216	6	0-218	488	
<u>Prosopis</u> <u>spp.</u>	0032	Arizona	1	-	89	6	0-116	207	5	0-276	339	
<u>Prosopis</u> <u>spp.</u>	0025	Sonora, Mex.	1	-	5	-	-	-	1	-	25	
<u>Prosopis</u> <u>spp.</u>	0080	Arizona	1	-	17	-	-	-	2	0- 29	34	
<u>Prosopis</u> <u>nigra</u>	0038	Argentina	-	-	-	3	3- 14	21				
TOTAL:					1031			444			886	
						Grand total: 2361 grams						

Only 5 of 27 varieties at Riverside produced pods second growing season.

There are 12 possible pod producing trees per moisture treatment on a 4 x 4 ft spacing.

The basin size is 12 x 16 ft ( $5.2 \times 10^{-3}$  acre).

Table 31

MESQUITE POD PRODUCTION FOR THIRD GROWING SEASON (1980)  
RIVERSIDE IRRIGATION STUDY TREES

Species	Accession Number	Origin	0.6 Bar			2.0 Bar			5.0 Bar			Total Per Accession
			Number Trees w/Pods	Range Pod Yield Tree (g)	Total Prod. (g)	Number Trees w/Pods	Range Pod Yield Tree (g)	Total Prod. (g)	Number Trees w/Pods	Range Pod Yield Tree (g)	Total Prod. (g)	
<i>P. velutina</i>	0020	Arizona	12	27- 1064	4350	12	26- 1045	3822	12	53- 1498	5571	13,743
<i>P. sp.</i>	0080	Arizona	11	24- 639	2241	11	45- 1013	4631	11	8- 1438	4969	11,841
<i>P. velutina</i>	0032	Arizona	11	38- 1120	3160	11	16- 705	2242	6	75- 485	1557	6,959
<i>P. sp.</i>	0028	Texas	10	16- 206	665	7	25- 611	1293	8	8- 920	1668	3,626
<i>P. sp.</i>	0074	New Mexico	2	12- 44	56	9	9- 345	735	10	7- 992	1871	2,662
<i>P. velutina</i>	0025	Mexico	8	3- 221	724	9	2- 184	450	7	45- 475	1363	2,537
<i>P. glandulosa</i> var <i>torreyana</i>	0001	California	5	11- 106	284	5	5- 87	213	5	57- 818	1613	2,110
<i>P. alba</i>	0137	Argentina	2	8- 24	31				9	10- 867	1418	1,449
<i>P. alba</i>	0138	Argentina	1		27				5	4- 917	969	996
<i>P. alba</i>	0039	Argentina	7	7- 177	380				8	10- 161	580	960
<i>P. nigra</i>	0133	Argentina	5	2- 36	59	2	9- 307	316	5	25- 210	410	785
<i>P. articulata</i>	0016	Baja, Mexico	5	1- 15	28	3	14- 24	54	5	22- 216	490	572
<i>P. alba</i>	0134	Argentina				4	1- 181	264	2	26- 33	59	323
<i>P. laevigata</i>	0114	Mexico	4	3- 64	141							141
<i>P. sp.</i>	0116	Mexico	1		9	9			1		1	9
<i>P. alba</i>	0037	Argentina										1
TOTAL					12,155			14,020		22,539	48,714	

Pods were dried to a moisture of 6%.

Individual trees with 50% dry matter partitioning into pod production are probably far from normal but highly desirable in pod production, breeding, and selection programs. Unfortunately trees in this accession (0080) are exceedingly bushy and prostrate and hold little potential for pod production in managed orchard settings. Hopefully the high dry matter partitioning into pod production can be bred into upright single stemmed selections. Perhaps the reason *P. chilensis* (0009) had the highest woody biomass production all three years in the irrigation study was due to its complete lack of flower and pod production.

The maximum possible pod production per hectare can be estimated from *P. velutina* (0020) which had the greatest pod production in the dry plot. *P. velutina* (0020) had a total pod production of 5,571 g in the Riverside irrigation study dry plot. This particular plot was bordered on the North and West sides by *P. chilensis* (0009) which were nearly twice as tall as the *P. velutina*. The plot was bordered on the South side by a *P. glandulosa torreyana* of the same size, while it was bordered on the East side by a *P. africana* plot which died 1½ years before the pod harvest. Accordingly we believe competition from neighboring plots was sufficiently high to minimize border effects from the plot of 12 trees in a 4 x 3 array. The total pod production of 5,571 g is an average of 464 g/tree in the dry plot. Since the trees were on a 1.22 m spacing, 6,724 trees were

present per hectare for a yield of 3,120 kg/ha. In a directly adjacent *P. chilensis* (0009) plot 1,592 g of pods were located that had identical external morphological features to the *P. velutina* (0020) pods but were strikingly different from *P. chilensis* pods. If these pods were included with the pods mentioned above the yield estimate would be 4,010 kg/ha for the *P. velutina* (0020) plot. This plot received 370 mm (14.6") rainfall the previous winter but no rain or irrigation from May 1980 till harvest in later summer. A pod production of 3,000-4,000 kg/ha is an appreciable yield for the level of water received.

As the trees on this narrow spacing probably achieved complete utilization of water and sunlight a 3,000-4,000 kg/ha pod production is probably the maximum that could be achieved at wider (5-6 m) spacings amenable to mechanical harvesting. Longer time periods would be required to achieve comparable pod production levels at wider spacings. The 5.6 kg pod yield actually measured in this  $1.8 \times 10^{-3}$  ha is considerably greater than the 15 kg/ha pod yield reported by Parker and Martin (1952).

In the Imperial Valley study some of the higher pod producing accessions (Table 33) such as *P. velutina* (0020) and *P. velutina* (0032) were also high pod producers in the Riverside studies. The greatest pod producer in the Imperial Valley was a screwbean (*P. pubescens* 0245) which was not included in the Riverside studies. Generally *P. pubescens*, *P. velutina*, *P.*

*alba*, and *P. articulata* had greater pod productivity than native *P. glandulosa* var. *torreyana* selections.

Seed yields from *Leucaena* and *Parkinsonia* were not measured (with the exception of one *Leucaena*) but were both probably greater than *Prosopis*. One *Leucaena*, completely stripped for seed, was found to have 1800 g of seeds which is more than for any *Prosopis*.

Of especial interest in the Imperial Valley trials was pod production by *P. pallida* (0041) from Hawaii and *P. juliflora* (0044) from West Africa. Both of these selections were eliminated from Riverside plots by an abnormally low freeze in December 1978. *P. pallida* (0041) had good biomass production the first year in the UCR irrigation study, had the greatest nitrogen fixation rate in the greenhouse study described elsewhere in this report, had excellent growth at high salinity levels and had large sweet pods making its only detracting character low frost tolerance. Since interspecific hybrids naturally occur in *Prosopis* and since *Prosopis* obligately out-crosses (Simpson, 1977) we hope seed from *P. pallida* has hybridized with surrounding native or South American *Prosopis* to increase frost tolerance in the progeny.

#### Summary of experimental plot mesquite pod yield data

In the UCR field trials mesquite pod yields were nearly twice as great in drought stressed mesquite selections as in well watered selections. Perhaps this is the reason the River-

Table 32  
MESQUITE FLOWERING AND POD SET SIX MONTHS AFTER  
TRANSPLANT IN IMPERIAL VALLEY (1979)

Species	BIOMASS SECTION			No. flower- ing trees	Flowers/ Tree Avg.	Flowers/ Tree Range	Pods/ Tree Range
	Accession Number	Origin					
<u>Prosopis velutina</u>	0020	Arizona		5	8.6	1-20	0-6
<u>Prosopis</u> spp.	0032	Arizona		8	7.5	1-12	1-7
<u>Prosopis glandulosa</u> var. <u>torreyana</u>	0246	California		1	1	-	2
<u>Prosopis velutina</u>	0247	California		1	1	-	-
POD CHARACTER SECTION							
<u>Prosopis glandulosa</u> var. <u>torreyana</u>	0295	California		1	30	-	3
<u>Prosopis glandulosa</u> var. <u>torreyana</u>	0224	California		1	4	-	

These measurements were made 23 August 1979 when most of the pods were quite immature. As these trees are 6 hr round trip drive from Riverside, it was not possible to collect mature pods because they fall off at maturity and the rabbits then eat them. There were 16 possible trees/accession that could have produced pods in the biomass section and 8

Table 33  
IMPERIAL VALLEY SECOND SEASON (1980)  
POD YIELD PER TREE (g)

Species	Accession Number	Origin	Number of Trees with Pods <sup>1</sup>	Range pod yield per Tree <sup>2</sup>	Total pod production
<u>P. pubescens</u>	0245	Julian, CA	5	14- 583	1037
<u>P. velutina</u>	0032	Cochise, AZ	12	3- 287	955
<u>P. articulata</u>	0016	Baja, Mexico	6	5- 593	820
<u>P. alba</u>	0039	Argentina	3	50- 493	629
<u>P. velutina</u>	0020	Arizona	8	9- 107	422
<u>P. alba</u> (?)	0166	Thermal, CA	3	18- 309	403
<u>P. alba</u>	0137	Argentina	5	6- 122	229
<u>P. velutina</u>	0247	Westmoreland, CA	7	9- 93	216
<u>P. alba</u> (?)	0168	Desert Shores, CA	3	5- 76	149
<u>P. glandulosa</u> var. torreyana	0182	Blythe, CA	5	6- 53	123
<u>P. alba</u> ?	0285	Barstow, CA	2	40- 60	101
<u>P. glandulosa</u> var. torreyana	0246	Julian, CA	3	8- 37	76
<u>P. nigra</u>	0133	Argentina	1	47	47
<u>P. alba</u> (?)	0163	Indio, CA	1	44	44
<u>P. pubescens</u>	0263	Ash Meadows, NV	3	2- 14	22
<u>P. glandulosa</u> var. torreyana	0216	Death Valley, CA	2	2- 10	12
<u>P. glandulosa</u> var. torreyana	0276	Panamint Valley, CA	1	10	10
<u>P. glandulosa</u> var. torreyana	0184	Blythe, CA	2	2- 8	10
<u>P. glandulosa</u> var. torreyana	0154	Palm Springs, CA	2	4- 5	9
<u>P. glandulosa</u> var. torreyana	0293	Temecula, CA	1	8	8
<u>P. juliflora</u>	0044	Senegal, W. Africa	1	7	7
<u>P. glandulosa</u> var. torreyana	0001	Thermal, CA	2	4	8

continued

Table 33  
IMPERIAL VALLEY SECOND SEASON (1980)  
POD YIELD PER TREE (g)

Species	Accession Number	Origin	Number of Trees with Pods	Range pod yield per Tree	Total pod production
P. <u>glandulosa</u> var. - <u>torreyana</u>	0171	Kane Springs, CA	1	5	5
P. <u>glandulosa</u> var. - <u>torreyana</u>	0250	Mecca, CA	1	5	5
P. <u>glandulosa</u> var. - <u>torreyana</u>	0170	Kane Springs, CA	1	3	3
P. <u>glandulosa</u> var. - <u>torreyana</u>	0239	Thermal, CA	1	3	3
P. <u>pallida</u>	0041	Hawaii	1	3	3
P. <u>glandulosa</u> var. - <u>torreyana</u>	0210	Death Valley, CA	1	2	2
P. spp.	0186	Ehrenberg, AZ	1	1	1
				Total	5249

100

1. Out of a possible 12 trees
2. Range for trees that produced pods
3. The accession was inadjaacent planting for pod characters

side orchard trees, which had the widest spacing and received the most frequent irrigation, took the longest time to produce pods and consistently produced less pods than other trees. In one of the highest pod producing accessions (0080) 50% of the previous year's dry matter production was partitioned into pod production. Pod production in one tree of accession 0080 was 60% of above ground biomass.

In apparent contradiction to the stimulation of pod production by drought stress is the reinitiation of flowering and pod set in native mesquite stands by summer rainfall. We offer no explanation for these contradictory phenomenon. Generally flowering in the spring is initiated by 80-85°F weather. Sustained high temperatures appear necessary to attract pollinating bees. We believe mesquite pod production in Imperial Valley is consistently earlier and greater than in Riverside because of more sustained hot weather in the Imperial Valley. Depending on the air temperature and rainfall mesquite pod maturity may range from early July to early September. Tree crops often have a tendency to alternate bearing, but these plantings have not been established long enough to study this problem. A multi-disciplinary approach will be required to manage pod production in a synchronous fashion amenable to mechanical harvesting.

Arizona derived *P. velutina* accessions 0020, 0025, 0032, and *P. sp* 0080 from Arizona appear promising for pod production. Despite high pod production accession 0080 shows little potential

for mechanized biomass production because of an extreme prostrate-bushy character.

The Arizona accessions have had the highest pod production for several seasons but the *P. alba* and *P. chilensis* may become more productive than the Arizona selections as they reach maturity.

The maximum pod production for *P. velutina* (0020) in the dry plot which received 370 mm rainfall the previous winter is estimated to be 3,000-4,000 kg/ha (6% moisture).

#### B. Mesquite pod production from mature trees

Pod production has been measured on three mature mesquite trees. One of these trees, a southern California native *P. glandulosa* var. *torreyana* (0001), is located at the home of the late Mrs. Ruby Modesto in Thermal, California. This tree is 7.5 m tall with two main trunks 25 cm in diameter at breast height. The tree is located in an area with less than 100 mm annual rainfall, with July daily maximum temperatures of 41°C and over a water table approximately 4 m from the surface. The tree in Mrs. Modesto's yard is not an unusually large or prolific bearing tree. It was chosen because it had been pruned to allow passage beneath its canopy which greatly facilitated pod harvest.

Psyllid insects caused considerable leaf damage to this tree every year. Mistletoe had also severely infested this tree until the mistletoe was killed with chemicals in January of 1979. All the pods were picked from the tree in 1977 and 1978 while in 1979 and 1980 they were picked from the ground

at weekly intervals after they had fallen. Pod yields at a moisture content of approximately 6% were 41 kg in 1977, 51 kg in 1978, 9 kg in 1979, and 41 kg in 1980. We attribute the low pod yield in 1979 to an extraordinary early and severe frost (-9°C or 16°F) which damaged citrus, avocado, jojoba, palo verde, oak and guayule throughout the southwestern United States and northwestern Mexico.

A *Prosopis alba* (0166) tree planted as an ornamental and windbreak in the vicinity of the *P. glandulosa* var. *torreyana* (0001) was harvested because its progeny were the best biomass producers in Imperial Valley biomass test plots. This thornless evergreen tree had a canopy diameter of nearly 50 meters and provided 38 kg (6% moisture) of 14 cm long flat curved pods. Only a small portion of the branches and nodes of this tree produced pods. For its size this was a light yield.

Chemical analyses from Bob Becker at the Western Regional Research Center indicated that the pod pericarp of a tree (0388) along the Colorado River 30 km north of Yuma, Arizona, had an exceptionally high (39%) sugar content. In August 1980, 73 kg (6% moisture) of these 30 cm long, 2.0 cm wide pods were picked up beneath this tree in five man-hours. This 17-year-old tree was located approximately 1.5 m above Colorado River groundwater table in a row of five South American origin ornamental trees presumably from the same seed source. One of these trees was a South American *P. alba* specimen in having tripinnate leaves,

finely divided leaflets, no pubescence, absence of thorns, and short (12 cm long) flat curved pods. The tree we harvested (0388) had thorns of native mesquite, pod pubescence of *P. velutina*, leaf characters intermediate between *P. velutina* and *P. alba*, pods much larger than *P. alba* or *P. velutina*, straight and red-tinged pods like *P. velutina*, and the growth rate and tree shape of *P. alba*. We conclude *P. spp* (0388) is a naturally occurring *P. alba* x *P. velutina* hybrid. Numerous examples of interspecific *Prosopis* hybrids occur in the literature (Burkart, 1976).

All these pod collections were made near a highway or dwelling where wild animals infrequently occur which would carry the fallen pods away. It is impossible to measure pod yields more than several hundred meters from roads or dwellings because of animal use. One tree, located 100 meters from a paved road, was estimated to contain 30 to 40 kg of near ripe pods. Two weeks later a single pod could not be observed on the tree, on the ground, or in the vicinity of the tree. Small mammals had removed every pod.

In summary, in areas with shallow groundwater mature tree yields around 40 kg are common and 72 kg yields are possible if located in very favorable circumstances. A reasonable yield goal for large managed mesquite tree orchards in areas with groundwater should be 50 kg (6% moisture) per year. On areas with groundwater present, the spacing would not be contingent

on reducing water competition and standard orchard spacings of 7 x 7 m would be adequate for 200 trees per hectare and a 10,000 kg pod yield per hectare.

### C. Mesquite Pod Chemical Composition

Protein, fiber, and sugar contents are given for selected mesquite pod samples in Table 34. Pod samples from accession 0020, 0025, 0032, and 0001 were taken from UCR field trees whose yields are listed in Table 28. The three *P. velutina* accessions originally from southern Arizona and adjacent Mexico had similar early pod producing characteristics, but nevertheless had quite distinct pod chemical characteristics. The highest pod producer 0020 unfortunately had the lowest protein and sugar content. The highest sugar content (34%) was obtained from a southern native *P. glandulosa* var. *torreyana*. These sugar contents are reflected in common names of velvet mesquite and western honey mesquite for *P. velutina* and *P. glandulosa* var. *torreyana* respectively.

The second portion of Table 34 lists proximate values only for pericarp tissue because the seeds were saved for propagation. Accession 0377 and 0372 were collected within 100 meters of each other in the desert where little differences in soil or environmental conditions were noted. Accession 0377 had a very sour-bitter taste while accession 0372 had a very sweet taste with no bitter after-taste. Chemical analyses, courtesy of B. Becker at the USDA/Western Regional Research Center, Albany, CA con-

Table 34  
PROXIMATE ANALYSES OF MESQUITE POD SAMPLES

Trees grown on UCR experimental plots (whole pods)					
Accession Number	Species	H <sub>2</sub> O (%)	Protein (%) N x 6.25	Fiber %	Sugar %
0020	<i>P. velutina</i>	1.6	11	30	13
0025	<i>P. velutina</i>	2.1	14	19	28
0032	<i>P. velutina</i>	2.6	17	24	19
0001	<i>P. glandulosa</i> var. <i>torreyana</i>	2.2	14	20	34
Mature wild or ornamental southern California trees (Pericarp only - minus seeds) <sup>a</sup>					
0377	<i>P. glandulosa</i> var. <i>torreyana</i>	8.1	8	30	13
0372	<i>P. glandulosa</i> var. <i>torreyana</i>	8.3	5	23	41
0388	<i>P. alba</i> x <i>P. velutina</i> hybrid	4	10	19	40

<sup>a</sup> Seeds from these pods were saved for propagation use.

These chemical determinations performed courtesy of B. Becker,  
USDA-Western Regional Research Center, Albany, California.

firmed the taste differences but were unable to identify the sour principle in 0377. The difference in pod chemical characters between 0372 and 0377 located only 100 yards apart illustrates the genetic diversity found in *Prosopis* and suggests that even higher sugar content pods might be located with a more thorough search. Accession 0388 had a more favorable pod composition than either 0372 or 0377 because of higher protein, lower fiber, and nearly equivalent sugar contents. Unlike 0372 accession 0388 had a slightly bitter-astringent taste which would not make it as acceptable as 0372 for human food. Pods of 0388 are nearly twice as long and wide as 0372, 0377, and 0001. The larger sized pods would facilitate harvesting of fallen pods from mesquite trees.

The resistance of mesquite to leaf psyllid attack increases in the order *P. glandulosa* var. *torreyana*, *P. velutina*, *P. alba* suggesting that the 0388 hybrid will possess at least moderate resistance to psyllids. We have obtained several rooted cuttings of 0388 from several hundred attempted cuttings. Much higher rooting success rates can be achieved with "clean" greenhouse stock grown under optimal conditions for rooting of cuttings.

#### D. Ethanol production from mesquite pods

Fermentation of high sugar content *Prosopis* pods to alcohol for use in the transportation sector is attractive because unlike high moisture content sorghum and sugar cane, the pod sugar is dry, non-perishable and at 44 percent sucrose is considerably

higher than most plant sources. Perhaps even more important, unselected mesquite strains presently occur on 30 million hectares of semi-arid marginal land in southwestern United States. This large land resource base is crucial to development of energy or chemical feedstock crops because of the enormous quantities of fuel or chemical feedstocks (10-100 tons/hr) consumed by commercial scale chemical manufacturing or power plants.

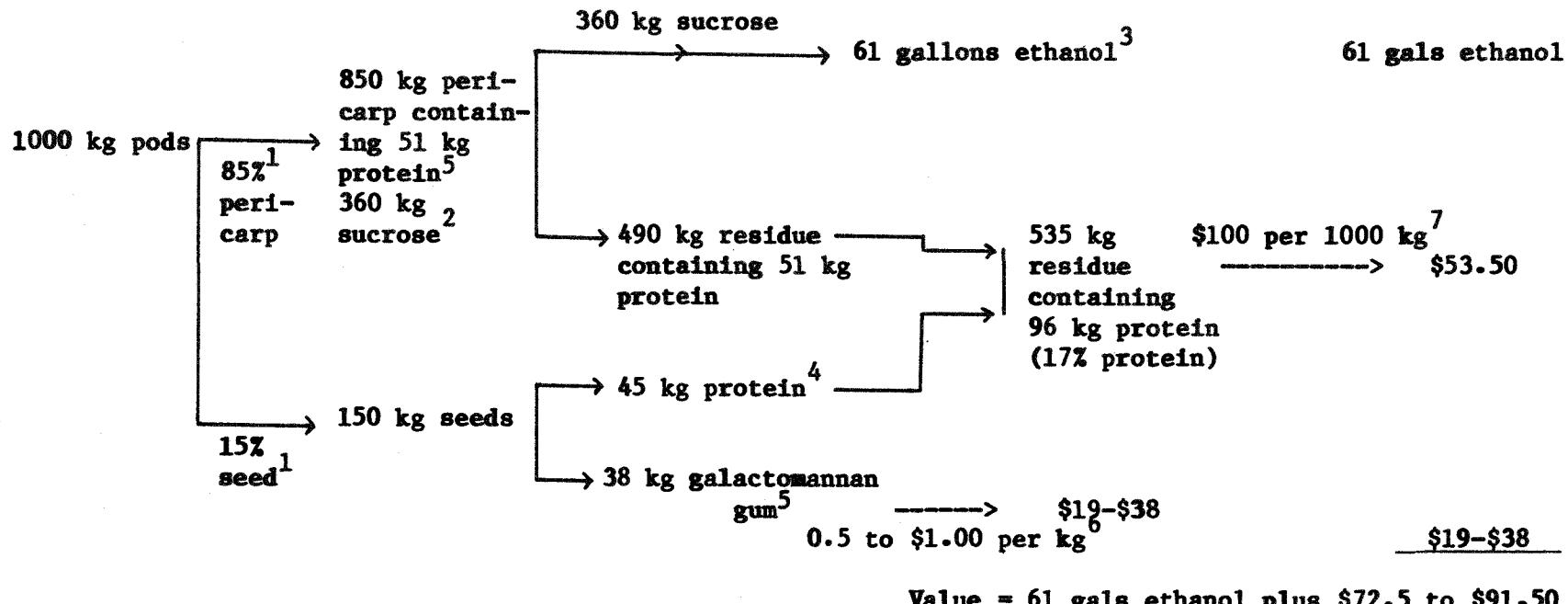
A recent workshop sponsored by the Solar Energy Research Institute (SERI) on energy from tree crops contracted with MIT for fermentation of 2 mesquite pod varieties and one honey locust (*Gleditsia triacanthos*) pod selection. A *P. alba* x *P. velutina* hybrid mesquite tree which produced 73 kg of 40 percent sugar pods (described above) was included in these fermentation trials. According to the MIT analyses the second season hybrid mesquite pods were 43.5 percent sugar. The hybrid mesquite pods had the highest yield and rate of ethanol production of the 3 substrates examined with an ethanol yield of 0.23 g ethanol/g substrate fed, at a rate of 0.44 g ethanol/L - hr (Avgerinos and Wang, 1980). The land area required for small commercial sized ethanol production plants (1,000 barrels/day) could be contained in a circle of radius (maximum haul) of 6.8 miles, assuming a conversion of 2.6 gallons of ethanol per 55 lb of pods and a 4,000 lb/acre pod production. Twelve percent of the land area in this 6.8 mile radius would be devoted to high woody biomass producing mesquite varieties to provide energy for the

distillation process. The calculated area (12% of total) required for distillation energy assumes production of 4,000 lbs of oven dry wood per acre per year, 8,000 Btus per pound of wood, and an energy requirement of 25,000 Btus/gallon to distill the alcohol.

E. Fractionation and use of mesquite pod sugar, protein, and gum

Mesquite pods should be fractionated into sugar, protein, and gum fractions to realize their full economic potential (Figure 4). After the pods have been dried at 52°C for several hours they can be ground in burr type mills which release the seeds from the sugar containing pericarp. Seed cleaners are available, such as Clipper cleaners from Burrows Equip., Chicago, Illinois, which perform good separation of the seeds and floury pericarp. The floury pericarp of a selected *Prosopis* strain contains 41% sucrose (Becker and Felker, unpublished observations) and it is this fraction that would be subjected to fermentation. The seeds contain approximately 30% protein and 25% galactomannan gum (Becker and Grosjean, 1980). Becker at USDA Western Regional Center believes it will be possible to separate the protein from the gum with a dry milling process. The seed protein fraction could be mixed with the pericarp residue after fermentation to be sold as livestock feed (similar to dry distillers grains) as neither seeds nor pods contain cyanogenic glucosides. Galactomannan gums are found in a variety of

Figure 4  
Returns from mesquite pod fractionation



<sup>1</sup> Becker and Grosjean (1980)

<sup>2</sup> Felker and Becker

Unpublished analysis for selected mesquite variety

<sup>3</sup> Assumes theoretical conversion of 2 moles alcohol per mole of glucose

<sup>4</sup> Assumes Becker and Grosjeans (1980) value 30% protein in seed

<sup>5</sup> Assumes Becker and Grosjean (1980) value of 25% galactomannan gum in seed.

<sup>6</sup> Values from Whistler (1973) page 326 for botanically related carob seed gum

<sup>7</sup> Substitute value equivalent to Dry Distillers grains

Table 35  
PROJECTED COSTS FOR MESQUITE POD PRODUCTION

	Cost per 60 yr rotation per acre
Land lease ( $\$10 \text{ acre}^{-1} \text{year}^{-1}$ )	\\$ 600.00
Site preparation (herbicides, bulldozing & discing)	178.50
Seedling costs @ \$0.15 each 265/acre pods	39.75
Planting costs (1,000 trees/hr with mechanical transplanter + 3 man crew) @ \$0.031 each	8.21
Insecticide application: 6 Sevin applications/yr @ \$6 each/yr.	2,160.00
Fertilizer costs: 100 lbs. P, 300 lbs. K, 50 lbs. S per 10 year	402.00
Pruning costs	unknown
Total per rotation	4,602.46
Product	100 tons pods
Production cost per ton	\$ 46/ton and \$25/ton if insect resistant varieties could be used
Harvesting costs	\$ 12-39 per ton
TOTAL	\$ 58-85 per ton

This analysis assumes a south Texas location receiving 20" annual rainfall where brush must be cleared from site prior to planting. Pod production can start as early as the second or third year. No pod production was assumed till year 10 when a yield of 4,000 lbs. pods/acre/year was assumed for 50 years. A pod production of 10,000 lbs/acre/year might be possible on a river bottom site with unlimited groundwater.

industrial, cosmetic, and food uses (Whistler, 1973). A 1% aqueous mesquite gum solution has a viscosity of 3,000 centipoise (Figueirido, 1975) and compares favorably with viscosities for equivalent carob and guar solutions of 100 and 4,200 centipoise respectively (Whistler, 1973). Prices for mesquite seed gums could be expected to be similar to carob seed gum prices which ranged from \$0.62 to \$1.11 per kg in 1970 (Whistler, 1973). As can be seen in Figure 4, mesquite seed gum could be a valuable byproduct of alcohol production. The world production of carob seed gums was 15,000 tons in 1970. Pedigree Petfoods, one of the largest European pet food manufacturers is currently evaluating the quality of mesquite seed gums.

#### F. Economics of mesquite pod production

Updated cost estimates for mesquite pod production from our 1979-1980 annual report are given in Table 35. These projected costs are for a hypothetical large scale southwestern United States mesquite biomass farming operation receiving 20 inches annual rainfall. Seedling costs, herbicide applications, and insecticide application are based on our current empirically developed procedures. It is assumed the site is occupied with brush requiring herbicide applications, bulldozing, and discing prior to transplanting. (Credits from harvesting mesquite lumber, cordwood, or chips could be substantial but are ignored in this analyses.) The land lease of \$10 per acre is that reported by Scifre (1973) as return to cattle ranchers. Herbel (1979)

has reported a lower figure of \$1.60 per acre as net return for cattle grazing. Fertilizer costs are computed to replace the nutrients removed in the biomass.

Mesquite pod harvesting costs may be similar to harvesting costs encountered for almond production in the California San Joaquin Valley. Mr. Yeary, an economist with the University of California Kearney field station indicates the following three pieces of equipment and harvesting costs (operating plus ownership) are necessary for almond harvesting; tractor mounted boom shaker (\$54.20/acre), self-propelled sweeper (\$27.80/acre), self-propelled pick up machine (\$50.00/acre). Since mesquite pods fall to the ground at maturity, the boom shaker would not be required and the harvesting cost would be \$77.80 per acre or \$39.00 per ton for a 2 ton/acre crop. Thus the total harvested cost would be \$85.00 per ton. Almond harvesting equipment is highly capital intensive and geared to harvest of high value nut crops. The cost for farm tractor pulled light equipment such as disc, seeder, cultivator or rake to cover an acre one time is in the \$3.00-\$5.00 acre range (Doane, 1980). If side rakes, and/or hay baler pickups could be modified to harvest fallen pods in 5 passes through the field, the harvesting cost would be \$25 per acre. Mechanical mesquite pod harvesting costs probably would be in the \$12.00-\$40.00 per ton range and projected harvested mesquite pod costs in the \$58-\$85 per ton range.

## IX. Vegetative Propagation\*

Self-incompatibility in mesquite (*Prosopis spp*) (Simpson, 1977) causes outcrossing so that trees propagated from seed are extremely variable. We have observed coefficients of variation as high as 70% for mesquite biomass production among trees from the same parent in the UCR irrigation study. Vegetative propagation techniques are necessary to propagate single tree selections possessing high woody biomass production, high pod production, thornlessness, other desirable characters and to reduce genetic variability in controlled greenhouse and field experiments. Several reports of vegetative propagation of rangeland and desert shrubs have appeared (Chase and Strain 1966; Everett et al. 1979; Nord and Goodin 1970; and Wieland et al. 1971) but the only report of mesquite vegetative propagation is negative (Chase and Strain 1966). We report the first successful rooting of mesquite cuttings.

The origins of these plants, with two exceptions, are described in the section on UC-Riverside field trials. Accession 0351 originated from a cutting of a 25 year old, 17.5 m tall ornamental tree of South American origin growing near Indio, California, and accession 0352 originated from a cutting of a 4 m tall, 1.75 year old *P. alba* (?) growing in the UCR orchard study.

Plants used for cuttings in Table 36 were grown in the greenhouse and were approximately a year old with a maximum

\*This section is condensed from an article in Journal of Range Management (1981).

height of about 2 meters. Each cutting contained two nodes with the leaves removed from the lower node. All cuttings for each species came from the same plant and were taken from the tip back until brown wood was encountered. Cuttings were given a 3 sec dip to a depth of 1 to 2 mm in the hormone solution before they were stuck in vermiculite filled pots. Plastic pots approximately 13 x 13 x 13 cm were used. Each pot ( $160 \text{ cm}^2$  surface area) received 80 ml of a 500 mg/L Banrot <sup>TM</sup> suspension. The average diameter and length of cuttings were 3 and 60 mm respectively. The *P. alba* cuttings were longer (10 cm) and thicker and did not callus to the extent of the other cuttings. Use of larger cuttings for *P. alba* was unavoidable because the distance between nodes was longer than for other species. The cuttings were evaluated after three weeks.

The plastic pots were placed in a translucent high humidity tent chamber with a thermostatically controlled evaporative cooler. The tent chamber was located in the greenhouse. A 10 g/L Dithane suspension was sprayed on all cuttings in Tables 37 and 38 and markedly reduced problems with the fungus *alternaria*. For mature trees terminal branches were cut to 50 cm lengths, misted with a Dithane suspension, the ends placed in water and transported in a portable ice filled cooler. Within 2 hrs. after collection 2 node cuttings were made and the hormone treatment applied. The indole amino acid conjugates were graciously provided by R. Hangarter, Dept. Botany and Plant Pathology, Michi-

Table 36. Rooting ability among widely divergent Prosopis species

Species (accession number) (Origin)		Percent rooted	Number roots per number attempted	Length longest root per number attempted/(cm)
<i>P. alba</i> (0352) (Argentina)	covered	80	4.4 a <sup>Z</sup>	3.4 a
	uncovered	30	1.6 a	1.1 a
<i>P. articulata</i> (0016) (Mexico)	covered	100	6.5 a	12.6 a
	uncovered	90	7.0 a	10.6 a
<i>P. chilensis</i> (0009) (Argentina)	covered	90	9.0 a	6.4 a
	uncovered	100	12.2 a	12.2 b
<i>P. glandulosa</i> var <i>torreyana</i> (0001) (California)	covered	90	14.1 a	10.4 a
	uncovered	70	11.4 a	7.2 a
<i>P. pallida</i> (0041) (Hawaii)	covered	90	10.0 a	7.9 a
	uncovered	80	6.0 a	6.6 a
<i>P. velutina</i> (0020) (Arizona)	covered	70	6.8 a	7.4 a
	uncovered	50	3.2 a	3.5 a
<i>P. spp</i> (0351)	covered	100	6.6 A	8.2 A
	uncovered	30	0.9 B	0.7 B
All varieties	covered	88	8.20a	8.04a
	uncovered	64	6.04b	5.98b

<sup>Z</sup> Mean separation by Duncans multiple range test was only performed within a species for covered and uncovered. Means followed by same small (or capital) letter are not different at 5% (or 1%) level.

gan State University, East Lansing, Michigan 48824.

The results of initial screening trials using 2 N  $H_2SO_4$  predips (Lee et al. 1976), osmocote (Gouin 1974), ethrel (Swanson 1974) wounding (Howard 1973) and various auxins led to a hormonal dip consisting of in (mg/L): indolebutyric acid - 6,000; naphthaleneacetic acid - 9,000; boric acid - 100,  $CaCl_2 \cdot 2H_2O$  - 200, thiamine - 100; Banrot<sup>TM</sup> - 100. The solvent was 70% ethanol since lower ethanol concentrations would not dissolve the naphthalene acetic acid. The cutting solution was stored in the freezer and discarded if it became yellow.

Daytime relative humidities of only 60% were achieved in this chamber and thus 2 pots were covered with a polyethylene bag and 2 pots were left uncovered. As shown in Table 36, six species of widely divergent origins gave at least 70% successful rooting when using a polyethylene cover and the hormone mix described above. The polyethylene cover over individual pots did not seem to be very helpful except for the clone of the ornamental *Prosopis* (0351). When all the species were considered together the number of roots/cutting and the length of the longest root/cutting were significantly greater (5% level) in the covered treatment. Successful use of this technique is not restricted to a few special species or accessions since on the average 8 roots of maximum length of 8 cm were obtained in 3 weeks from widely divergent *Prosopis* species.

Dimethylsulfoxide (DMSO) was substituted for 70% ethanol

because DMSO is less volatile and because DMSO can tolerate more water from wet plant stems without causing precipitation of NAA and IBA.

A comparison of the root inducing properties of three strengths of a commercially available rooting formulation (cut-start xx, xxx, and xxxx) that is very effective in rooting jojoba (*Simmondsia chinensis*) cuttings (Yermanos, pers. comm.) with the formulation described here is presented in Table 37. The length of the longest root did not appear to be significantly different among treatments but the formulation we developed gave a greater percentage rooting and a greater number of roots per cutting.

This technique has its shortcomings since even in the greenhouse it works better in the spring than in the summer or fall. In the spring 100% of cuttings from clone 0351 rooted as reported in Table 36 but only 15% rooted in November. Some environmental-plant hormone interactions appears to be regulating cutting success for greenhouse grown seedlings since, at a particular time, all species root well or not at all.

Indoleacetic acid (IAA) predominantly exists in legume seeds in the form of amide linked IAA - amino acid conjugates which unlike free IAA are immune to attack by peroxidases (Cohen and Bandurski 1978). Several of these IAA and IBA conjugates were examined for their capability to overcome the recalcitrant nature of out-of-doors grown trees to initiate roots from cuttings

Table 37. Comparison of rooting formulation described here with a commercially available rooting formulation.

Hormone Treatment	Replicate	% rooted	Length longest root (cm)	Number of roots
Formulation described here	1	60	12.6 $\pm$ 7.9	8 $\pm$ 4.9
	2	80	9.6 $\pm$ 6.0	6.6 $\pm$ 4.6
	3	73	10.5 $\pm$ 3.2	11 $\pm$ 9.9
Cutstart xx	1	20	7.5 $\pm$ 3.5	1 $\pm$ 0
	2	30	9.1 $\pm$ 6.9	2.7 $\pm$ 2.0
	3	30	17 $\pm$ 3.0	2.3 $\pm$ 1.1
Cutstart xxx	1	30	5.7 $\pm$ 8.9	1.3 $\pm$ 0.6
	2	61	14 $\pm$ 3.9	2.1 $\pm$ 1.1
	3	33	15 $\pm$ 5.2	2.5 $\pm$ 1.7
Cutstart xxxx	1	31	12.1 $\pm$ 5.6	1.0 $\pm$ 0
	2	64	10.7 $\pm$ 3.3	2.4 $\pm$ 1.3
	3	50	10.7 $\pm$ 6.3	1.8 $\pm$ 1.3

Cuttings were taken from greenhouse grown ornamental mesquite of accession 0351. Ten cuttings per replicate were used.

Table 38. Effect on indoleamino acid conjugates on rooting of mesquite cuttings.

A. Using stock material from 7 ft. tall clonal plants (accession 0351) in greenhouse.

Hormone Used	% rooted	Average number of roots per cutting	Length longest root per cutting
indolebutyric acid	40.6	7.1 $\pm$ 3.0	15.9 $\pm$ 3.6
indolebutyryl-phenylalanine	53.1	5.4 $\pm$ 4.0	10.7 $\pm$ 6.1
indolebutyryl-alanine	53.1	7.3 $\pm$ 3.9	15.3 $\pm$ 5.3
indoleacetyl-alanine	50.0	2.2 $\pm$ 1.6	14.4 $\pm$ 4.9
indoleacetyl-leucine	37.5	2.0 $\pm$ 1.3	12.7 $\pm$ 4.4

B. Using stock material from 3 year old tree (*P. velutina*) out-of-doors.

Zero percent rooting for all treatments (no rooted cuttings from 160 cuttings).

For each treatment 4 pots with 8 cuttings were used (4 replicates). Computation of average number of roots and length longest root is for those cuttings which rooted (not divided by 32).

Mixture was composed of naphthalene acetic acid 9,000 mg/L; boric acid, 200 mg/L; thiamine, 200 mg/L; Banrot, 200 mg/L;  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ , 200 mg/L, and the hormone indicated. IBA was used at 6,000 mg/L and other hormones were used at equivalent molarities. Mixture was dissolved in 100% DMSO and used as a 3 sec. dip.

(Table 38). When using greenhouse grown stock material little differences in the rooting of cuttings made with indolebutyric compounds were noted although a lower number of roots per cutting were observed with the indoleacetic compounds. The IBA - alanine treated cuttings had greener looking leaves and appeared to have a more fibrous root system than other treatments. None of these compounds were effective in rooting cuttings of an out-of-doors grown 3 year old *P. velutina* that was similar to the *P. velutina* successfully rooted in Table 36. Repeated attempts throughout the growing season to obtain cuttings from a specific mature out-of-doors grown *Prosopis* generally will be successful in obtaining one or two rooted cuttings if liberal use of dithane spray and thorough disinfection of cutting tools with ethanol is practiced. The rooted cuttings obtained can be grown under optimal greenhouse conditions where rooting percentages of 50% or more can often be obtained.

The first report of rooting of mesquite cuttings can be very successful if carried out in the spring of the year using young trees with actively growing foliage. More research will be required to allow successful propagation of mesquite all year round from young and old trees.

## X. Development of Cultural Practices

## A. Weed Control Measures

On the UCR field studies, cool season winter weeds such as *Malva parviflora* were effectively controlled three months after the seedlings had been transplanted, with either of the pre-emergence herbicides Karmex 3-(3,4 dichlorophenyl)-1, 1-dimethyl urea or simazine (2-chloro-4,6 bis (ethylamino)-s- triazine) at 2 kg/ha, which did not visibly damage the seedlings. Post-emergence weeds were controlled with the contact herbicide phytar (hydroxydimethylarsine oxide) applied at 2½ kg/ha with a shielded applicator. In the Imperial Valley plantings, one month after transplant Treflan was incorporated into the soil at 0.5 kg/ha and followed by an irrigation. Except for weeds between the trees in the rows and some bindweed, Treflan (Trifluralin) provided adequate weed control. Roundup (glyphosate) was used with a shielded applicator to control the latter weeds.

In a Tucson, Arizona planting simazine was used at 2 kg/ha at transplant with an irrigation and caused greater than 50% mortality to mesquite seedlings planted in 15" long waxed cardboard plant containers. Simazine has never caused a problem on seedlings transplanted longer than 3 months at Riverside but it is clear that it cannot be used at transplant.

In the mountain cold screening site, bracken fern was a problem that could not be controlled by spraying 1.2 m wide strips with roundup since rhizomes originated from outside the

controlled area. Bracken fern is not likely to be a problem in typical arid sites and bracken fern control measures are no longer under investigation.

Recently completed plantings at Texas A&I University used Treflan incorporated at 2.3 L/ha (1 qt/acre) prior to transplant. Except for johnson grass, bermuda grass, and nutsedge good weed control was achieved. No phytotoxic effects were observed on the mesquite seedlings despite a 3" rainfall one week after transplant. A one row sweep cultivator will be used for weed control until the trees have been transplanted 3 months when a simazine/eptam application will be made.

Future plantings will incorporate Treflan at 2.3 L/ha prior to transplant and use simazine at 2 kg/ha 3 months after the seedlings have been transplanted.

#### B. Insect Problems and Control Measures

Psyllid insects (Homoptera: Psyllidae *Aphalaroida* (spp) have been observed to seriously damage growing shoots and immature leaves on mesquite (*Prosopis* spp) in native desert stands and in managed biomass production field trials in southern California and constitute the major economically important insect problem. Psyllid predation of *Prosopis* leaves was not mentioned in a recent review on *Prosopis* leaves as a resource for insects (Cates and Rhoades, 1977) but a checklist of insects on *Prosopis* contains citations for occurrence of psyllids on *Prosopis* (Ward

et al., 1977).

Psyllids are aphid-like sucking insects that are approximately 2 mm long. They destroy new shoots and leaves and lay their eggs in young leaves in such a fashion to cause them to fold inwards. Young shoots may exude white gummy pustules in response to psyllid predation. Psyllid damage was evaluated on the fifty-five accessions of *Prosopis* and other tree legumes grown in the biomass screening trial in the California Imperial Valley. Seedlings planted in April 1979 first sustained light psyllid damage in late May and early June 1979. Psyllid damage through late June and July and August was almost non-existent presumably because of high summer temperatures (July mean daily maximum temperature of 41.7°C). In late September psyllid damage again became severe. At this time the trees ranged in height from 50 to 250 cm with the *P. tamarugo* being an exception in rarely exceeding 25 cm. A visual estimate of the damage to all trees was made at this time on a scale of 0 to 3. A 0 estimate indicated complete absence of psyllids and no visible damage to any part of the tree. A "slight" estimate indicated that several of the most immature shoot tips could be observed to be damaged but few if any psyllids were present. A 2 or "moderate" estimate indicated that numerous psyllids were observed along 3 to 4 cm long immature shoots and that the youngest immature leaves were no longer present. A 3 or "severe" estimate indicated that 10 to 15 cm long portions of the shoots and leaves

had nearly continuous cover of psyllids. Several of the "severe" trees eventually succumbed.

The ranked order of psyllid resistance for the 55 accessions planted in the California Imperial Valley is presented in Table 39. None of the genera *Leucaena*, *Parkinsonia*, *Cercidium*, or *Olneya* had any psyllid insect damage. *Prosopis tamarugo* was the only *Prosopis* to be completely without damage although two closely related *Prosopis pubescens* (screwbean) selections had very little damage. The South American *Prosopis alba* accessions fell in a group with insect damage ranging from 0.38 to 1.53. Two closely related tropical species *P. pallida* and *P. juliflora* had identical insect damage of 1.63. The 3 *P. velutina*s fell together with insect damages ranging from 1.75 to 1.88. The California native species *P. glandulosa* var. *torreyana* had the most severe insect damage and fell together as a group.

The resistance of *Prosopis* selections to psyllids closely follows taxonomic lines. Highly psyllid resistant *P. tamarugo* and *P. pubescens* are the only species in section *strombocarpa*. The psyllid resistance of *Prosopis alba*, *P. velutina*, and *P. glandulosa* var. *torreyana* fall into individual separate groups. Generally *P. alba*, *P. nigra*, and *P. chilensis* species are more psyllid resistant than the North American *P. glandulosa* and *P. velutina* taxa. *Prosopis* leaf flavonoids fall into 2 major categories with *P. glandulosa*, *P. velutina*, and *P. juliflora* lacking the quercetin derivatives found in *P. alba*, *P. chilensis* and

Table 39

RANKED ORDER OF INSECT DAMAGE ON PROSOPIS AND OTHER TREE LEGUMES

<u>Species</u>	<u>Accession Number</u>	<u>Origin</u>	<u>Insect Damage</u>
<u>Leucaena leucocephala</u>	0147	Hawaii	0.0
<u>Parkinsonia aculeata</u>	0322	California	0.0
<u>Cercidium floridium</u>	0324	California	0.0
<u>Prosopis tamarugo</u>	0317	Chile	0.0
<u>Olneya tesota</u>	0343	California	0.0
<u>Prosopis pubescens</u>	0245	California	0.08
<u>Prosopis pubescens</u>	0263	Ash Meadows, Nev.	0.09
<u>P. alba</u> (?)	0137	Argentina	0.38
<u>P. alba</u>	0039	Argentina	0.56
<u>P. chilensis</u>	0009	Argentina	0.63
<u>P. alba</u> (?)	0168	S. America	0.71
<u>P. alba</u> (?)	0194	S. America	0.75
<u>P. nigra</u>	0133	Argentina	0.79
<u>P. alba</u> (?)	0285	S. America	0.80
<u>P. alba</u> (?)	0013	S. America	0.92
<u>P. alba</u>	0098	Argentina	0.94
<u>P. alba</u>	0163	S. America	0.94
<u>P. spp</u>	0280	Mexico	1.08
<u>P. alba</u>	0166	S. America	1.13
<u>P. nigra</u>	0038	Argentina	1.25
<u>P. articulata</u>	0016	Mexico	1.33
<u>P. alba</u>	0037	Argentina	1.38
<u>P. glandulosa</u> var. <u>torreyana</u>	0216	Death Valley, CA.	1.44
<u>P. alba</u> (?)	0286	S. America	1.53
<u>P. pallida</u>	0041	Hawaii	1.63
<u>P. julflora</u>	0044	West Africa	1.63
<u>P. glandulosa</u> var. <u>torreyana</u>	0165	Thermal, CA.	1.63
<u>P. alba</u>	0132	Argentina	1.69
<u>P. glandulosa</u> var. <u>torreyana</u>	0255	29 Palms, CA.	1.71

continued

Table 39

<u>Species</u>	<u>Accession Number</u>	<u>Origin</u>	<u>Insect Damage</u>
<u>P. velutina</u>	0020	Arizona	1.75
<u>P. glandulosa</u> var. <u>torreyana</u>	0289	Harper Drylake, CA.	1.77
<u>P. velutina</u>	0032	Arizona	1.81
<u>P. spp.</u>	0234	Bakersfield, CA.	1.81
<u>P. velutina</u>	0247	Westmoreland, CA.	1.88
<u>P. glandulosa</u> var. <u>torreyana</u>	0154	Palm Springs, CA.	1.88
<u>P. glandulosa</u> var. <u>torreyana</u>	0250	Mecca, CA.	1.88
<u>P. glandulosa</u> var. <u>torreyana</u>	0258	Mesquite Drylake, CA	1.88
<u>P. glandulosa</u> var. <u>torreyana</u>	0261	Pahrump, Nev.	1.88
<u>P. spp.</u>	0296	Temecula, CA.	1.93
<u>P. glandulosa</u> var. <u>torreyana</u>	0157	Whitewater, CA.	1.94
<u>P. glandulosa</u> var. <u>torreyana</u>	0199	Needles, CA.	1.94
<u>P. glandulosa</u> var. <u>torreyana</u>	0171	Kane Springs, CA.	2.00
<u>P. glandulosa</u> var. <u>torreyana</u>	0170	Kane Springs, CA.	2.00
<u>P. glandulosa</u> var. <u>torreyana</u>	0205	Shoshone, CA.	2.00
<u>P. glandulosa</u> var. <u>torreyana</u>	0271	Saline Valley, CA.	2.00
<u>P. spp.</u>	0186	Ehrenberg, Arizona	2.00
<u>P. glandulosa</u> var. <u>torreyana</u>	0291	Newberry, CA.	2.00
<u>P. glandulosa</u> var. <u>torreyana</u>	0182	Blythe, CA.	2.00
<u>P. glandulosa</u> var. <u>torreyana</u>	0184	Blythe, CA.	2.06
<u>P. glandulosa</u> var. <u>torreyana</u>	0001	Thermal, CA.	2.06
<u>P. glandulosa</u> var. <u>torreyana</u>	0276	Panamint Valley, CA	2.06
<u>P. glandulosa</u> var. <u>torreyana</u>	0246	Julian, CA.	2.25
<u>P. glandulosa</u> var. <u>torreyana</u>	0190	Twin Palms, CA.	2.27
<u>P. glandulosa</u> var. <u>torreyana</u>	0239	Thermal, CA.	2.38
<u>P. glandulosa</u> var. <u>torreyana</u>	0210	Death Valley, CA.	2.47

Insect damage is average for 16 single tree replicates.

0= no damage; 1= slight damage; 2= moderate damage; 3=severe damage.

members of the strombocarpa section *P. reptans* and *P. strombulifera* which are closely related to *P. pubescens* and *P. tamarugo* (Carmen, 1977). Perhaps these quercetin derivatives are responsible for the psyllid resistance in the latter taxa.

The same pattern of psyllid resistance among *Prosopis* taxa was observed in the Salar de Pintados of northern Chile by Feller in October 1980. The algarrobo population (closely related to *P. alba*) was exceedingly variable in leaf and pod morphology and had nearly dead trees without leaves and healthy trees with lush green foliage. Upon closer examination insects similar to southern California psyllids had heavily damaged the terminal shoots of nearly dead trees while few psyllids and little damage was observed on resistant trees. In contrast to the algarrobo population, psyllids or psyllid damage were not observed on tamarugo trees.

Greenhouse salinity screening trials found *P. tamarugo* had the greatest salt tolerance of any *Prosopis* and that *P. tamarugo* grew on a nitrogen-free nutrient solution with salinities greater than seawater. Since *P. tamarugo* had the lowest biomass productivity of all Imperial Valley accessions, we assumed it had established itself as climax vegetation in northern Chilean salars because of its salt tolerance. It was therefore surprising to observe some mature healthy green algarrobos in the Salar de Pintados on the 0.5 m thick salt cursts. Well monitoring data taken by CORFO in this region indicates the depth to groundwater

is 10 m and the groundwater salinity is in the 3,000 mg/L range (Zelada per. comm.). These salinities are much below toxicity levels observed for *Prosopis* species in the salinity study. It appears that the successful adaptation of tamarugo to the salars of northern Chile is more a result of psyllid insect resistance than tolerance to high salinity. The northern Chilean salt deserts is a good source of highly psyllid resistant *P. alba*-like clonal propagules.

Chemical control of psyllids on non-resistant *Prosopis* strains in the field has been effective with orthene (O,S-di-methyl-acetylphosphoramidothioate) sprayed at 3 week intervals at the rate of 5 ml/L. Preliminary trials with Sevin which has one-third the material cost of orthene has proven effective and will be evaluated further. A contact insecticide with little residual activity consisting mainly of a coconut oil detergent greatly reduced the psyllid population for approximately 10 days and appeared to stimulate the psyllid predator ladybug (*Coccinella transversoguttata*) population. The soap based insecticide might prove useful in conjunction with biological control of psyllids, but does not last long enough and requires too much water with application to be cost effective. Caution must be exercised when insecticides are used to avoid killing pollinating bees.

Researchers at UC-Davis have found the synthetic pyrethroid, pydrin to be more effective against pear psylla than any other insecticide. Since synthetic pyrethroids are very expensive

they will be used only as a last resort.

The greatest potential for solving the psyllid problem is through the use of a psyllid-resistant South American derived *Prosopis* selections shown in Table 39. The South American accessions possess the greatest biomass production and there should be no problem which would prevent commercial production of woody biomass from *Prosopis*.

However, the California native varieties with the sweetest pods and the greatest pod production are less resistant to psyllid attack. As shown in Table 39, there is considerable variation for psyllid resistance in the native varieties, but we have not yet identified any completely psyllid resistant natives (except for the screwbean (*P. pubescens*)). There are numerous reports of South American species of *P. alba* and *P. nigra* with high sugar content pods and we would expect these to have good psyllid resistance. The putative *P. alba* x *P. velutina* (0388) hybrid has 40-44% sugar pods and hopefully will exhibit good psyllid resistance.

The bruchid *Algarobius prosopis* burrows into mesquite pods and destroys the seeds. Bruchid insects lower the protein content of the pods and decrease the number of seeds available for propagation but they do not affect woody biomass production or quantity of beans produced. Freezing the pods is nearly as effective as fumigation for bruchid control and does not affect seed germination. Kingsolver et al. (1977) have amply reviewed

the biology of this insect. Orthene, first sprayed at 5 ml/L three weeks after flowering (so that pollinating bees were not killed) and at 3-week intervals thereafter, decreased the number of bruchid emergence holes from 23 to 1 per 100 pods, but it was not effective when injected into the stem. Malathion seems as effective as Orthene.

Spider mites (*Tetranychus pacificus*) occur only in the greenhouse and may completely defoliate *Prosopis* seedlings. Because the mites are less than 1 mm long, their appearance is first noted by white speckled leaves and webs along the main stem and between the leaf axils. The miticide chlorbenzilate completely defoliated the seedlings but the systemic insecticide Orthene used every 3 weeks provided effective control without phytotoxic effects.

Greenhouse trials with the soil systemic insecticide disyston (disulfoton) gave good control of spider mites and psyllids accidentally brought in from the field but caused severe phytotoxic effects to potted greenhouse plants. The soil systemic Temik (aldicarb) provided excellent control of spider mites and psyllids with no phytotoxic effects to mesquite.

## XII. Plant Physiological Traits

A. Screening *Prosopis* Germplasm for Cold Tolerance\*

*Prosopis* exhibits good heat and drought tolerance but it seldom occurs farther north than 37°N latitude because of a lack of cold tolerance. The average annual minimum temperature isotherm of minus 20.5°C has been suggested to define the northern limit for natural *Prosopis* distribution (Fisher *et al.*, 1959). As previous studies indicated considerable variability in frost tolerance (Peacock and McMillan, 1968) we examined representative species from a biomass screening trial for their capability to withstand freezing temperatures.

A site was chosen 30 km north of Idyllwild, California, in the San Jacinto Mountains at 1,520 m (5,000 ft) elevation where seedlings would experience temperatures much colder than typical mesquite habitats.

Thirty *Prosopis* accessions were randomly replicated as single tree replicates in 21 blocks. The 21 blocks were evenly divided into 3 plots located several hundred meters apart on gently sloping terrain. The tree spacing was 3 m in all directions. The site was dominated by grasses, forbs, and bracken fern. Forty-five days prior to transplant, 60 cm wide swaths were sprayed with roundup (glyphosate) at a rate of 120 ml/8 liters using backpack sprayers. Five cm diameter, 40 cm deep holes were drilled with a truck mounted soil sampling rig. In June 1979 the seedlings were planted in these holes after removing

\*This work abstracted from an article submitted to Forest Science.

the waxed cardboard plant band. Approximately one liter of water was applied to each transplanted seedling but the mountain soil possessed considerable water repellency which prevented good water penetration. A circular 60-cm diameter hard-wire cloth fence was placed around each seeding to prevent browse from small mammals. Pocket gophers destroyed trees in portions of the field and bracken ferns constituted a weed problem on other areas of the field. U.S. Forest Service regulations prevented timely control of weed and gopher problems. A minimum thermometer was placed on a 1.2 m tall post at the high and low elevation point of each of the three plots. A 30-day recording thermograph from Sciences Associates was placed in a meteorological shelter approximately 700 m from the site. Not until mid-January was it discovered that the chart drive was supplied with warm weather lubricant that caused it to cease operations at extended freezing temperatures. The temperature at the thermograph site was often 1-2°C warmer than the minimum thermometer sites. On 25 September tree losses were noted and all dead, damaged, or missing trees were excluded from the study so that the resulting trees had 100% survival for that date. A Newman-Keuls test was used to evaluate stem survival among accessions because of unbalanced population sizes.

Percentage stem kill can be visually assessed since the stem of the native mesquites possess a prominent red anthocyanin pigmentation which turns to a straw yellow color if the tissue dies.

The first year's growth of the stem of the South American varieties possess a green pigmentation which also discolors if the tissue becomes dead. All the trees were visually graded into 0, 25, 50, 75 and 100% stem survival at monthly or 3 week intervals. At this time minimum temperature measurements were recorded and the 30 day temperature recording was retrieved. The stem survival estimates continued until mid-summer (10 July) when axillary bud emergence occurred and firmly established the position of stem kill. Many of the trees which suffered 100% stem kill (to the ground) resprouted from the base in the summer.

A brief description of the origin of the germplasm included in this study is presented in Table 40. South American derived *Prosopis* ornamentals (accessions 13, 163, and 285) contributed three accessions. Accession 0163 was the tallest tree (18 m) in a one Km long planting of 25 year old ornamental trees and appears promising for biomass production. Accessions 13 and 0163 from coastal and low desert regions respectively experience less severe winters than the Mojave "high desert" near Barstow which was the origin of 285.

Several collections (accessions 25, 26, 28, 74 and 79) were made by Simpson in Texas, New Mexico and Arizona in regions that generally experience colder continental climates than southern California. *P. tamarugo* (317) was included because of its importance as a fodder plant in the cooler Chilean salt deserts (Anon., 1975). Accession 0349 was from the Texas Panhandle at

TABLE 40

## DESCRIPTION OF GERMPLASM

Ion	Species	Origin	Elevation (m)	Other Comments
	<u>P. glandulosa</u> v. <u>torreyana</u>	Thermal Calif.	-30m	Typical low Colorado desert <u>Prosopis</u>
	<u>P. chilensis</u>	Argentina	----	High biomass producer (1)
	<u>P. alba</u> (?)	S. America	----	Is commercial ornamental
	<u>P. articulata</u>	Baja, Mexico	----	High biomass producer (1)
	<u>P. velutina</u>	Sonora, Mexico	----	High biomass producer (1)
	<u>P. glandulosa</u> v. <u>glandulosa</u>	Lordsburg, New Mexico	----	8 yr record low -17°C (2)
	<u>P. glandulosa</u> v. <u>glandulosa</u>	Hudspeth, Texas	----	Texas range species
	<u>P. alba</u>	Argentina	----	High biomass producer (1)
	<u>P. nigra</u>	Argentina	----	----
	<u>P. alba</u>	Argentina	----	High biomass producer (1)
	<u>P. glandulosa</u> v. <u>glandulosa</u>	Mesquite, New Mexico	----	10 yr record low -17°C (2) & low biomass producer
	<u>P. velutina</u>	York, Arizona	----	12 yr record low -19°C (2)
	<u>P. alba</u> X <u>glandulosa</u> v. <u>torreyana</u>	S. America	----	18m tall - 25 yr old ornamental
	<u>P. glandulosa</u> v. <u>torreyana</u>	Needles, Calif.	180m	Northern part of natural range
	<u>P. glandulosa</u> v. <u>torreyana</u>	Mesquite Dry Lake, Calif.	850m	Northern and upper elevation range limit
	<u>P. glandulosa</u> v. <u>torreyana</u>	Mesquite Dry Lake, Calif.	850m	Northern and upper elevation range limit
	<u>P. velutina</u>	Bakersfield, Calif.	90m	----
	<u>P. glandulosa</u> v. <u>torreyana</u>	Mesquite Dry Lake, Calif.	850m	Northern and upper elevation range limit
	<u>P. glandulosa</u> v. <u>torreyana</u>	Mesquite Dry Lake, Calif.	850m	Northern and upper elevation range limit

continued.

Ion	Species	Origin	Elevation (m)	Other Comments
	<u>P. glandulosa</u> v. <u>torreyana</u>	Pahrump, Nevada	850m	Northern and upper elevation range limit
	<u>P. glandulosa</u> v. <u>torreyana</u>	Scottys Castle, Calif.	915m	Northern and upper elevation range limit
	<u>P. glandulosa</u> v. <u>torreyana</u>	Big Sands Spring, Calif.	915m	Northern and upper elevation range limit
	<u>P. glandulosa</u> v. <u>torreyana</u>	Saline Valley, Calif.	305m	Northern part natural range
	<u>P. alba</u> (?)	Barstow, Calif.	550m	Ornamental from "High Desert"
	<u>P. glandulosa</u> v. <u>torreyana</u>	near Julian, Calif.	915m	Upper elevation range limit
	<u>P. glandulosa</u> v. <u>torreyana</u>	near Julian, Calif.	915m	Upper elevation range limit
	<u>P. glandulosa</u> v. <u>torreyana</u>	near Julian, Calif.	915m	Upper elevation range limit
	<u>P. tamarugo</u>	Chile	----	Supposedly cold tolerant (3)
	<u>P. glandulosa</u> X	Lubbock, Texas	----	9 yr record low -24°C (2)
	<u>P. velutina</u> (?)			

ons 25, 26, 28, 37, 38, 39, 74, and 79 were kindly supplied by Prof. Solbrig at Harvard. Accession 9 was provided by USDA Beltsville, MD, 16 was from UCR Botanic Garden, 317 was USDA Northern Regional Research Center and 349 was provided by Dr. Traylor of Texas Tech University. Remaining accessions were collected by authors. (1) = Riverside Irrigation Study, (2) = Anon, 1965, (3) Anon, (1975).

Lubbock where a 9 year record low of minus 24°C has been recorded (Anon, 1965). The Texas Panhandle/Oklahoma region is one of the coldest regions in the world where *Prosopis* naturally occurs. This accession (0349) had leaf characters of *P. glandulosa* var. *glandulosa* but because of its extreme leaf pubescence we hypothesize it has hybridized with *P. velutina*.

Accessions 9, 37, 38, and 39 from Argentina were the best biomass producers in the Riverside irrigation study. *P. articulata* is fast growing, salt tolerant and was included to represent Baja Mexico germplasm. The remainder of the accessions were from the highest elevation and most northerly parts of *Prosopis* natural range in California and were obtained from our *Prosopis* germplasm collection of southern California deserts.

The ranked mean stem survival per tree evaluated in the middle of the summer is listed in Table 41. The most striking feature of this table is the 0 to 91% range in tree stem survival. None of the four South American accessions (13, 37, 38, 317) had above ground portions which survived. Low survival was observed for closely related *P. alba* (39), *P. chilensis* (9), and the Baja Mexico native *P. articulata* (16). The progeny of *P. alba* (285) from the high desert survived better than other *P. alba* accessions possibly because only 285 was close enough to native *Prosopis* to allow cross-pollination with more cold tolerant native species. A broad continuum in stem survival per tree is observed from *P. glandulosa* v. *torreyana* (303) with 43% survival to *P. glandulosa* v. *torreyana* (0301) with

TABLE 41

## RANKED % STEM SURVIVAL PER TREE AT END OF WINTER

Species	Origin	Mean Stem Survival per Tree (%)
<u>P. alba</u>	S. America	0 Z
<u>P. alba</u>	Argentina	0 Z
<u>P. nigra</u>	Argentina	0 Z
<u>P. tamarugo</u>	Chile	0 Z
<u>P. chilensis</u>	Argentina	6 ZY
<u>P. alba</u>	Argentina	7 ZY
<u>P. articulata</u>	Baja, Mexico	15 ZYX
<u>P. alba</u>	Barstow, Calif.	28 ZYXW
<u>P. glandulosa</u> v. <u>torreyana</u>	Julian, Calif.	43 ZYXWV
<u>P. glandulosa</u> v. <u>glandulosa</u>	Hudspeth, Texas	48 ZYXWV
<u>P. glandulosa</u> v. <u>glandulosa</u>	Lordsburg, New Mexico	50 ZYXWV
<u>P. alba</u> x <u>P. glandulosa</u> v. <u>torreyana</u> (?)	S. America	50 ZYXWV
<u>P. glandulosa</u> v. <u>torreyana</u>	Big Sands Spring, Calif.	50 ZYXWV
<u>P. glandulosa</u> v. <u>torreyana</u>	Needles, Calif.	54 ZYXWV
<u>P. glandulosa</u> v. <u>torreyana</u>	Julian, Calif.	55 ZYXWV
<u>P. glandulosa</u> v. <u>glandulosa</u>	Mesquite, New Mexico	58 YXWV
<u>P. glandulosa</u> v. <u>torreyana</u>	Julian, Calif.	58 YXWV
<u>P. glandulosa</u> v. <u>torreyana</u>	Mesquite Dry Lake, Calif.	59 YXWV
<u>P. velutina</u>	Bakersfield, Calif.	60 YXWV
<u>P. glandulosa</u> v. <u>torreyana</u>	Scottys Castle Calif.	60 YXWV
<u>P. glandulosa</u> v. <u>torreyana</u>	Pahrump, Nevada	60 YXWV
<u>P. velutina</u>	York, Arizona	64 XWV
<u>P. glandulosa</u> v. <u>torreyana</u>	Thermal, Calif.	69 XWV

41 continued.

sion er	Species	Origin	Mean Stem Survival per Tree (%)
	<u>P. glandulosa</u> v. <u>torreyana</u>	Julian, Calif.	71 XWV
	<u>P. glandulosa</u> v. <u>torreyana</u>	Mesquite Dry Lake, Calif.	75 WV
	<u>P. velutina</u>	Sonora, Mexico	77 WV
	<u>P. glandulosa</u> x <u>P. velutina</u>	Lubbock, Texas	78 WV
	<u>P. glandulosa</u> v. <u>torreyana</u>	Mesquite Dry Lake, Calif.	79 WV
	<u>P. glandulosa</u> v. <u>torreyana</u>	Mesquite Dry Lake, Calif.	80 WV
	<u>P. glandulosa</u> v. <u>torreyana</u>	Saline Valley, Calif.	91 V

Mean stem survival followed by same letter are not significantly different at 5% as judged by Newman-Keuls test.

71% survival. The accessions with the greatest survival had origins in Lubbock, Texas; Sonora, Mexico; Mesquite Dry Lake, California; and Saline Valley, California with mean stem survivals clustered together and not significantly different. Accession 163 a presumptive *P. alba* x *P. glandulosa* v. *torreyana* hybrid had survivals intermediate between the native of its nearest geographical and elevation origin, i.e. accession 1, and the *P. alba* accessions with zero percent survival.

The stem survival per tree is presented as a function of time through the winter in Table 42. The mean minimum temperature of the six minimum thermometers for the period prior to the stem survival estimates is also presented in Table 42. A minus 5.4°C temperature occurred two nights prior to the date stem survival measurements were taken on 21 November and could not have resulted in visible effects by the time the estimates were made. Little loss in stem survival was noted one month later on 21 December. Large losses in stem survival were observed for accessions 9, 13, 16, 37, 38, 39, and 317 on the 21 January observation date, evidently due to a minus 6°C freeze on 23 December. The minus 6°C freeze was only 0.6°C colder than the minus 5.4°C freeze of 20 November and it seems unlikely that this temperature difference could have caused the greater stem mortality observed on 21 January. The recording thermograph indicated temperatures below freezing occurred for 12 hours on 23 December and only six hours on 20 November. The duration of

of the freeze seems critical to plant survival. Following the 21 January observation period, the stem survival for cold tender accessions 9, 13, 16, 37, 38, and 39 decreased in a gradual fashion which we believe is the result of the December freeze. The increase in survival for *P. tamarugo* (accession 317) from 21 January to 15 February was the result of a reinterpretation of stem survival in this different looking species. As judged by later data, this reinterpretation and upward adjustment of stem survival evidently was incorrect. Freezing temperatures occurred every period until the last freeze of minus 3.5°C on 25 May.

Biomass estimations were made on the trees with 100% stem survival at the end of the winter since woody biomass productivity is as important as cold tolerance. Fifteen of the largest trees were transplanted to pots for use as breeding stock, thus obviating direct harvest and biomass determination. The oven dry biomass was estimated from stem diameter measurements with the equation  $\log_{10}$  dry biomass (Kg) = 2.55  $\log_{10}$  basal diameter (cm) - 1.25 (n = 212,  $r^2$  = 0.95) derived from first season Imperial Valley trees. Generally the frost tender accessions had high biomass production and low survival with *P. chilensis* and *P. articulata* having the greatest biomass production but only being represented by one surviving tree out of a possible 21. In contrast accession 271 had the greatest percent stem survival in Table 41 and also ranked high in biomass production.

During an earlier experiment screening for biomass pro-

## PERCENT STEM SURVIVAL PER TREE THROUGH THE WINTER

Location	Date										
	21 Nov	21 Dec	21 Jan	13 Feb	5 March	27 March	17 April	12 May	11 June	10 July	
	100	100	100	100	100	100	89	79	73	69	
	83	88	59	59	47	38	34	17	13	6	
	96	88	50	69	50	40	35	13	6	0	
	98	98	61	64	50	42	35	27	15	15	
	98	98	95	95	91	84	86	80	77	77	
	100	100	100	100	88	88	88	75	63	50	
	98	93	82	86	82	82	82	66	66	48	
	98	97	53	40	35	23	13	7	2	0	
	100	89	36	34	14	3	0	0	0	0	
	93	84	66	70	46	34	29	14	7	7	
	97	100	86	97	81	89	83	81	75	58	
	100	100	100	100	100	95	98	95	95	64	
	96	96	94	92	92	81	75	60	56	50	
	98	100	94	88	79	75	75	67	62	54	
	100	100	94	97	94	97	97	94	94	75	
	100	97	94	78	88	88	72	75	66	59	
	98	95	93	93	93	82	75	73	58	60	
	100	95	100	95	80	80	85	80	80	80	
	100	100	100	98	92	94	92	88	83	79	
	100	100	98	100	96	100	92	77	75	60	
	100	100	100	100	100	97	93	77	78	60	
	100	96	93	96	89	82	68	71	50	50	
	100	100	100	100	100	100	100	91	97	91	
	100	100	100	98	70	65	60	45	30	28	

2 continued.

on

Date

21 Nov	21 Dec	21 Jan	13 Feb	5 March	27 March	17 April	12 May	11 June	10 July
100	100	100	100	100	95	93	82	79	71
100	100	88	77	53	52	48	48	43	43
100	100	98	98	91	80	75	68	59	55
100	100	88	100	92	83	88	79	63	58
91	91	18	50	45	20	0	0	0	0
100	100	100	94	94	94	94	88	88	78
Temperature									
mean	-5.4	-4.7	-6.0	-4.4	-2.4	-3.9	-3.3	-3.0	-3.5
range	.8	1.4	.6	1.7	.5	.6	.7	1.2	1.1
on									2.2

Sept all trees were 100%. The lowest temperature is for period prior to observation date.

duction on the UC-Riverside campus all six month old seedlings of *Prosopis tamarugo*, *P. alba*, *P. nigra*, *P. articulata*, *P. chilensis*, *P. kuntzei*, *P. ruscifolia*, *P. laevigata* and numerous North American native species survived an unusually low several hour minus 5°C freeze without damage. The above species can be grown in climatic regions similar to southern California. Selections of *P. alba* (?) are now one of the most widely used ornamental trees in Tucson and Phoenix, Arizona. In contrast all seedlings (36 seedlings/accession) of one accession of *P. juliflora* from West Africa, of two accessions of *P. pallida* from Hawaii, and of 2 accessions of *P. africana* from West Africa were killed to the ground by the same freeze. These latter accessions successfully survived several minus 1.5°C freezes but nevertheless they probably are too cold sensitive to be grown even in subtropical regions of continental United States.

The more severe cold tolerance screening trial reported here indicates that *P. alba*, *P. articulata*, *P. chilensis*, *P. nigra*, and *P. tamarugo* are more frost sensitive than the North American native species. Some individual *P. alba* and *P. chilensis* survived and show promise for biomass production outside of subtropical areas. Evidently naturally occurring hybrids have been formed with the native species that confer additional cold tolerance to the *P. alba* progeny. It appears that deliberate hybridization to transfer frost tolerance or high rates of biomass production will be successful.

TABLE 43

RANKED BIOMASS PER ACCESSION FOR TREES WITH 100%  
STEM SURVIVAL PER TREE AT END OF WINTER

Accession Number	Species	Biomass (g)	Number with 100% Stem Survival
13	<u>P. alba</u> (?)	0	0
37	<u>P. alba</u>	0	0
38	<u>P. nigra</u>	0	0
317	<u>P. tamarugo</u>	0	0
26	<u>P. glandulosa</u> v. <u>glandulosa</u>	1.8	1
79	<u>P. velutina</u>	2.3	5
266	<u>P. glandulosa</u> v. <u>torreyana</u>	2.9	3
74	<u>P. glandulosa</u> v. <u>glandulosa</u>	3.0	4
257	<u>P. glandulosa</u> v. <u>torreyana</u>	4.5	4
201	<u>P. glandulosa</u> v. <u>torreyana</u>	5.2	4
258	<u>P. glandulosa</u> v. <u>torreyana</u>	5.6	9
261	<u>P. glandulosa</u> v. <u>torreyana</u>	5.6	6
28	<u>P. glandulosa</u> v. <u>glandulosa</u>	5.8	3
285	<u>P. alba</u>	6.2	1
349	<u>P. glandulosa</u> x <u>P. velutina</u> (?)	6.3	11
308	<u>P. glandulosa</u> v. <u>torreyana</u>	6.3	2
200	<u>P. glandulosa</u> v. <u>torreyana</u>	7.0	4
231	<u>P. velutina</u>	8.7	5
304	<u>P. glandulosa</u> v. <u>torreyana</u>	8.8	3
265	<u>P. glandulosa</u> v. <u>torreyana</u>	10.0	8
39	<u>P. alba</u>	10.6	1
303	<u>P. glandulosa</u> v. <u>torreyana</u>	10.8	4
25	<u>P. velutina</u>	11.1	8
271	<u>P. glandulosa</u> v. <u>torreyana</u>	13.3	6
1	<u>P. glandulosa</u> v. <u>torreyana</u>	15.2	7

Table 43 continued.

Accession Number	Species	Biomass (g)	Number with 100% Stem Survival
301	<u>P. glandulosa</u> v. <u>torreyana</u>	15.3	10
199	<u>P. glandulosa</u> v. <u>torreyana</u>	15.6	5
163	<u>P. alba</u> X <u>P. glandulosa</u> v. <u>torreyana</u> (?)	17.0	5
16	<u>P. articulata</u>	27.0	1
9	<u>P. chilensis</u>	52.0	1

Ovendry biomass predicted from stem diameter measurements using equation log<sub>10</sub> dry biomass (kg) = 2.55 log<sub>10</sub> basal diameter (cm) -1.25.

The cool ( $20^{\circ}\text{C}$ ) mountain climate was not warm enough to provide optimum growth conditions with the result that the trees were not large at the onset of cold weather. Larger, longer established trees could be expected to have a greater survival and therefore this trial represents a more severe than normal situation.

The minimum temperatures experienced during these trials were not extreme but nevertheless they caused considerable stem mortality. All these accessions survived a minus  $5^{\circ}\text{C}$  freeze a year earlier on the University of California, Riverside campus without damage and a minus  $5.6^{\circ}\text{C}$  freeze in the mountain trials with little damage. A longer lasting  $6^{\circ}\text{C}$  freeze with 12 hours of below freezing weather evidently was the cause of most of the mortality observed here. A colder screening trial will be necessary to accurately rank the most cold tolerant accessions observed here i.e. 25, 258, 257, 271, and 349.

In these trials and other ungrazed trials on the University of California, Riverside campus accessions 28, 26, and 349 from New Mexico and West Texas have been observed to be multistemmed shrubs with prostrate tendencies unlike erect single stemmed accessions such as 199, 301, 9, and 1. As accessions 28 and 26 possess neither frost tolerance, or high biomass production (see section on Riverside biomass estimation) and as they are managed with much more difficulty than erect single stemmed varieties they offer little promise for germplasm breeding stock.

Prostrate shrubby mesquites typical of 26 and 28 dominate large areas of New Mexico and West Texas and probably could be replaced with erect type trees with greater cold tolerance and biomass productivities if deemed appropriate to do so.

A general tendency exists towards accessions possessing either high biomass productivity - low cold tolerance or low biomass productivity - high cold tolerance, but accessions and individual trees with high biomass productivity - high cold tolerance are exceptions to this tendency and offer opportunities for improved biomass production on the coldest areas where *Prosopis* now occurs.

### B. Screening *Prosopis* for Salinity Tolerance\*

*Prosopis* naturally occurs in saline environments near salt water bodies, such as the California Salton Sea, and in the Chilean Atacama salt desert but quantitative data does not exist on its salinity tolerance. We examined the salinity tolerance of several *Prosopis* species to better understand their ecology, and to delineate their possible role in managed saline food and fuel production systems.

Six species of divergent backgrounds were included in this study. *Prosopis articulata* (0016) is native to Baja, Mexico; *P. pallida* (0041), introduced into Hawaii in the 1850's grows along the seacoast; *P. chilensis* (0009) of Argentina was the best biomass producer in the UCR field trials; *P. velutina* (0020) was the best pod producer in UCR field trials and is the predominant Arizona rangeland species; *P. glandulosa* var. *torreyana* (0001) is native to southern California deserts, and *P. tamarugo* (0317) of Chilean origin is presently part of a large development project in the Chilean Atacama salt desert where it has been planted for sheep forage.

Except for *P. tamarugo* which we have not successfully rooted from cuttings, clonal material was prepared for all species as described in the section on vegetative propagation. One tree was used per pot and three pots per treatment for the clonal material, while six seedlings per treatment were used for *P. tamarugo*. Varieties and treatments were randomly distributed in

\*This work abstracted from an article in press in "Plant and Soil". Dr. P.F. Pratt, and Mr. A.E. Laag of the Department of Soil and Environmental Sciences, University of California, Riverside were collaborators on this work.

in the greenhouse. The plant species, rhizobial strain and inoculation techniques, and nitrogen-free nutrient solution used here were identical to that of a previous experiment (see section on nitrogen fixation) in which all these species exhibited nodulation, nitrogen fixation (acetylene reduction) and growth on a nitrogen-free media.

Three treatments, all based on the same nitrogen-free nutrient solution consisted of; (1) a control with no added NaCl, (2) a medium salinity treatment which varied from 6,000 to 12,000 mg/L NaCl, and (3) a high salinity treatment which varied from 6,000 to 36,000 mg/L NaCl. Twenty liters of the control nutrient solution contained;  $K_2SO_4$ , 8.7 g;  $MgSO_4 \cdot 7H_2O$ , 9.8 g;  $Ca(H_2PO_4)_2 \cdot H_2O$ , 2.5 g;  $CaSO_4 \cdot 2H_2O$ , 6.9 g; Sequestrene 138 (6% Iron) (Ciba Geigy), 2.1 g; and micronutrient stock solution, 4 ml. Two liters of the micronutrient stock (Summerfield *et al.*, 1977) contained;  $KCl$ , 2.7 g;  $H_3BO_3$ , 30 g;  $MnSO_4 \cdot H_2O$ , 17 g;  $ZnSO_4 \cdot 7H_2O$ , 2.7 g;  $(NH_4)_6Mo_7O_24 \cdot 4H_2O$ , 2.7 g;  $CuSO_4 \cdot 5H_2O$ , 2.4 g; and 10.8 ml,  $H_2SO_4$  (specific gravity 1.83). The pH of the resulting macro-nutrient plus micronutrient solution was 4.8, and was adjusted with 30% NaOH to pH 6.5-7.0.

Twenty-liter pots filled with coarse washed sand were flushed twice daily with the appropriate nutrient solution essentially as previously described (Eaton and Bernardin, 1962). Mixtures of calcium and sodium salts are often used in salinity studies but the legume's need for phosphate and the problems with pre-

cipitation of phosphates at high calcium concentrations led us to use only sodium chloride. Rooted cuttings were allowed to overcome transplant shock for 30 days before the treatment was applied. Tree heights were measured 30 days after imposition of a salinity treatment. If significant differences between treatments were not noted, the salinity level was increased. Stem elongation was used as an indicator of salinity stress since it is a non-destructive measurement and since inhibition of cellular growth is the most sensitive response to a similar stress, e.g., water stress (Hsaio, 1973). A computer was used to calculate delta height, and to carry out an analysis of variance and Duncan's multiple range test, if appropriate.

The height increase during the salinity treatments are presented in Table 44. Significant differences between treatments were first observed in the species *P. chilensis*, *P. glandulosa* var. *torreyana*, and *P. velutina* at the 12,000 and 18,000 mg/L salinity levels although non-significant but substantially lower values were observed for *P. glandulosa* var. *torreyana* and *P. velutina* during the previous 12,000 mg/L salinity treatment. Significant differences were not noted in the 36,000 mg/L salinity treatment for the 16 July - 3 June period despite large differences in the means, which suggests that sufficient number of replicates were not included in the study. At this point some of the 2.5 m tall control trees became rootbound and plugged drainage holes in the pots, which reduced growth in the control

TABLE 44. Effect of Salinity on *Prosopis*  
Stem Elongation

NaCl concen- tration (mg/L)	Height Increase (cm)					
	SPECIES					
	<u>P.</u> <u>articulata</u>	<u>P.</u> <u>chilensis</u>	<u>P.</u> <u>glandulosa</u> var. <u>torreyana</u>	<u>P.</u> <u>pallida</u>	<u>P.</u> <u>tamarugo</u>	<u>P.</u> <u>velutina</u>
2 April - 25 February						
0	73 y	31 z	44 z	44 z	4.1 z	2.8 z
6,000	28 z	16 z	47 z	31 z	4.7 z	16.3 z
6,000	72 y	16 z	31 z	29 z	5.6 z	9.7 z
28 April - 2 April						
0	50 z	49 z	22 z	35 z	4.1 z	22 z
6,000	49 z	48 z	8.3 z	54 z	4.7 z	35 z
12,000	62 z	45 z	3.0 z	24 z	4.4 z	5.6 z
3 June - 28 April						
0	20 z	56 y	61 y	12 z	11.4 z	42 y
12,000	61 z	55 y	21 z	58 y	7.9 z	1 z
18,000	46 z	9 z	9.3 z	34 yz	6.7 z	8 yz
16 July - 3 June						
0	24 z	39 yz	49 y	37 z	18.1 y	65 z
12,000	35 z	55 y	50 y	44 z	9.1 z	34 z
36,000	2.7 z	-0.3 z	0.7 z	15 z	3.4 z	0.3 z
16 July - 24 June						
0	8.7 z	14 z	11 z	25 z	8.9 z	35 z
12,000	3.7 z	27 z	18 z	24 z	4.6 z	2 z
36,000	4.0 z	0.7 z	1 z	5 z	2.0 z	0 z

Values followed by same letter for one growth period and for one species are not significantly different at the 5% level as judged by Duncan Multiple Range test.

treatment and prevented more detailed examination of higher salinity levels. The trees were measured three weeks and six weeks after imposition of the 36,000 mg NaCl/L treatment to avoid possible carryover effects from growth in the previous 18,000 mg/L treatment. Height increases were observed for *Prosopis articulata*, *P. pallida* and *P. tamarugo* in the 36,000 mg/L salinity treatment. *P. glandulosa* var. *torreyana* had nearly ten times the height of *P. tamarugo* and thus we consider the 2-cm growth for *P. tamarugo* to be real, while the 1-cm growth for *P. glandulosa* var. *torreyana* we consider to be measurement error. *P. articulata*, *P. pallida*, and *P. tamarugo* maintained nearly full leaf cover in the high salinity treatment, whereas the other species lost most of their leaves. The dry biomass harvested for each treatment at the end of the experiments are presented in Table 45. The dry biomass of *P. articulata*, *P. pallida*, and *P. tamarugo* in the high salinity treatment is 1/4 to 1/2 of the control, whereas the dry biomass in the high salinity treatment was 1/6 to 1/10 of the control for the other species. The growth of two contrasting *Prosopis* accessions are presented in Figure 5. At the end of the second salinity treatment (0, 6,000, and 12,000 mg/L) the growth of *P. glandulosa* var. *torreyana* was reduced but the growth of *P. tamarugo* was not. The growth of the *P. tamarugo* was not reduced until the end of the 0, 12,000, 18,000 mg/L salinity treatment. Although *P. tamarugo* possesses high tolerance to salinity its growth is slow when compared to *P. glandulosa* var. *torreyana* as can be noted by the difference in the size of the units on the figure.

The statistics are not very helpful with the high variability and the number of replicates used here. Nevertheless, it appears as if all species will tolerate a salinity of 6,000 mg/L with no reduction in growth. *P. velutina* appears to tolerate 12,000 mg/L poorly while the remaining species tolerate these salinity levels with little difficulty. Only the *P. articulata*, *P. pallida*, and *P. tamarugo* tolerate the 18,000 mg/L salinity level with little reduction in growth and these are the only species that grew in the 36,000 mg/L salinity level.

The salinity tolerance of *Prosopis tamarugo*, *P. articulata*, and *P. pallida* are on a par with some of the most salt-tolerant terrestrial plants, such as *Chenopodium*, *Atriplex*, *Salicornia*, *Suaeda* (Somers, 1979), and are much more salt-tolerant than annual legumes such as peas (*Pisum sativum*) and green beans (*Phaseolus vulgaris*) that poorly tolerate salinities with electrical conductivities (EC) greater than 5 mmhos/cm or 3,000 mg NaCl/L (Richards, 1954).

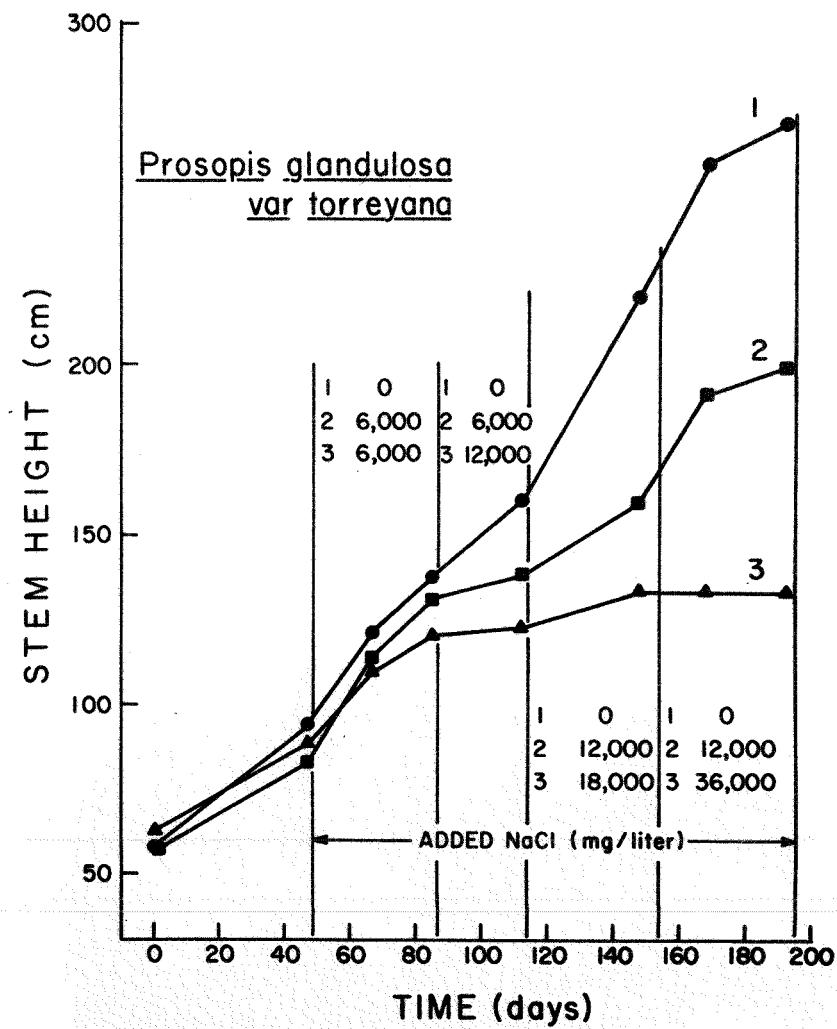
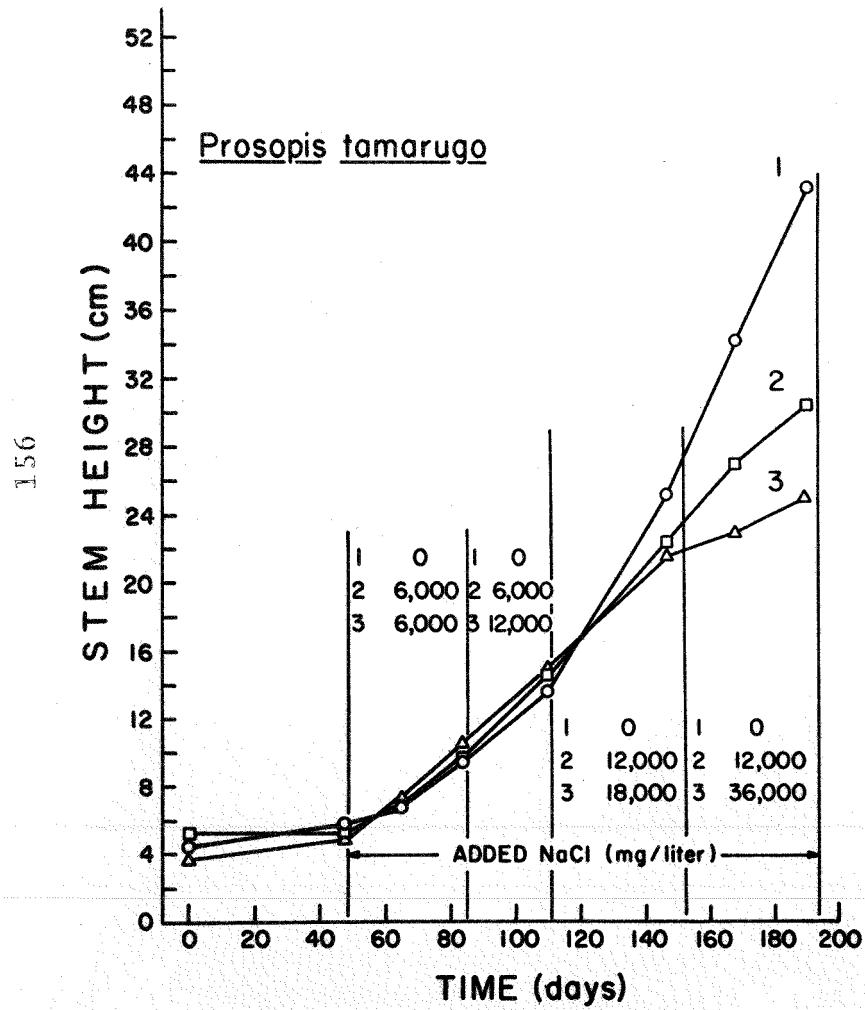
The *Prosopis* in these experiments were grown on a nitrogen-free medium so that their growth was possible only if they were fixing nitrogen. Nodulation and nitrogen fixation (acetylene reduction) was unequivocally demonstrated for these same selections on the same nitrogen-free nutrient solution in the section on nitrogen fixation. To our knowledge, this is the first report of growth and nitrogen fixation in salinities nearly equivalent to seawater. The geographical origin of these plants may help

TABLE 45. Effect of Salinity on Dry Biomass of *Prosopis* Seedlings

Salinity level	TOTAL DRY BIOMASS					
	<i>P. articulata</i>	<i>P. chilensis</i>	<i>P. glandulosa</i> var. <i>torreyana</i>	<i>P. pallida</i>	<i>P. tamarugo</i>	<i>P. velutina</i>
Control	380y	132x	332x	416y	1.9z	61y
155 Medium	141z	87y	147y	327yz	1.2z	33yz
High	169z	24z	54z	114z	.9z	7z

Values followed by the same letter within a species are not significantly different at the 5% level as judged by the Duncan multiple range test.

FIGURE 5



to explain their salinity tolerance. *P. tamarugo* has evolved in the 0.5 m thick salt crusts in the northern Chilean salt deserts. *P. pallida* and *P. articulata* occur along arid coastal regions of Hawaii and Baja Mexico respectively where the groundwater probably mixes with seawater. *P. glandulosa* var. *torreyana* has evolved in low lying portions of water catchment basins in southern California deserts where both water and salt accumulates. *P. velutina* primarily occurs in the United States on upland rainfed regions where salinity is not usually a problem. The ecology of the *P. chilensis* obtained from Buenos Aires is unknown. Another promising tree legume *Leucaena leucocephala* occurs near the Hawaiian coast and may possess similar salt tolerance.

Presumably because *Prosopis* self-infertile flowers result in heterozygous seeds we have observed striking differences in pod, leaf, and thorn morphology, and a 5 to 10 fold difference in biomass production among *Prosopis* progeny from the same tree. Mass screening of seedlings resulting from obligate outcrossed seeds of the promising salt-tolerant species, *P. articulata*, *P. pallida*, and *P. tamarugo*, might find selections that could be used to provide livestock food or biofuels along desert coastal regions with seawater irrigation. *P. articulata*, *P. pallida*, and *P. tamarugo* are not as frost-hardy as *P. glandulosa* var. *torreyana* with which they form interspecific hybrids (see section on frost tolerance).

Brackish wastewater that requires pumping or tile drainage

systems for disposal could be concentrated by irrigating salt tolerant *Prosopis* species with a low-leaching fraction. Such problems exist in California's San Joaquin Valley, where irrigation drainage water with EC's in the 3,000 to 6,000 range are too saline for reuse on most agricultural crops and are too close to the soil surface to permit leaching with fresh water.

This experiment established that more than three clonal replicates are required to overcome the biological variability in the system, that all *Prosopis* species tested can withstand salinities generally considered too brackish (6,000 mg/L) for agricultural production without reduction in growth, that trials to develop halophilic nitrogen-fixing *Prosopis* should concentrate on *P. articulata*, *P. pallida* and *P. tamarugo*, and that 18,000 mg/L and higher salinity levels should be tested immediately after overcoming transplant shock. High salinity levels may adversely affect processes such as flowering and fruit set, and it will be necessary to repeat these trials in the field, where mature plants can be observed for a complete life cycle.

### C. Screening *Prosopis* for Nitrogen Fixation\*

Leguminous trees such as *Prosopis* are often very prominent in semi-arid ecosystems yet their nitrogen fixing capabilities have been very poorly studied. Although mesquite (*Prosopis spp*) occurs on 30 million hectares in the U.S.A. (Parker and Martin, 1952) and large areas in semi-arid South American and Asia, it was not reported to be nodulated until 1972 (Gupta and Balera, 1972). The first indication that mesquites nodules were effectively fixing nitrogen was reported by Bailey (1976) who demonstrated a correlation between nodule abundance and above ground dry matter and nitrogen for plants grown in pots. Only recently has a report of acetylene reduction by detached nodules appeared (Eskew and Ting, 1978). Cross inoculation between (*Prosopis cineraria* and *Acacia senegal* has been reported (Basak and Goyal, 1975) but as yet there is no indication of cross inoculation between North and South American and African *Prosopis* species. Using a North American mesquite rhizobia strain as inoculum we examined the cross inoculation characteristics of twelve species of *Prosopis* and the effectiveness of this nodulation as judged by growth on a nitrogen free nutrient solution and acetylene reduction by the intact plant.

The taxonomic description of accessions used can be found in the section on UCR field studies. An unidentified Texas

\*This section has been condensed from wholly DOE supported work published in Plant and Soil 57, 177-186 (1980) by Felker and Clark.

*Prosopis* (0028) was included which presumably is *P. glandulosa* var. *glandulosa*. Five replicates of 12 species were grown in 4-liter pots filled with coarse vermiculite and irrigated daily with 280 ml of a full strength nitrogen-free solution described in the accompanying article on salinity tolerance. The plants were inoculated with a rhizobia strain isolated by Eskew from nodules of a mesquite grown in the greenhouse in soil from beneath a desert mesquite tree. This rhizobia isolate is available from J. Burton, Nitragin Co., Milwaukee, Wisconsin.

Acetylene reduction of detached nodules may underestimate acetylene reduction (Eskew and Ting, 1978), (Huss-Daniel, 1978) so that acetylene reduction was determined on the intact plants using mylar bags (Eskew and Ting, 1978). The internal standard, propane, was adopted from Balandreau and Dommergues' (Balandreau and Dommergue, 1973) technique, after verifying that the ethylene/propane peak height ratio was constant from 2 to 400 ppm, to correct for the irregularly shaped bags and differences in injection volume. The acetylene reduction assays were conducted on 5 partially cloudy February days in the greenhouse when the photosynthetically active radiation ranged from 200 to 1400  $\mu\text{E}$   $\text{m}^{-2}\text{sec}^{-1}$ . After the acetylene reduction assays, the plants were harvested, dried, weighed and nitrogen determinations done by the micro-Kjeldahl method.

Representatives of twelve *Prosopis* species grew on an inert vermiculite medium supplied with a nitrogen-free nutrient solu-

TABLE 46 . Acetylene reduction versus dry matter and total nitrogen

Species	Acetylene reduction (mg/plant/h)		Total N plant (mg)		Dry matter (g)	
	X	S	X	S	X	S
<i>P. africana</i> (0045)	0.008	0.002	7	4	0.6	0.4
<i>P. alba</i> (0098)	0.13	0.06	123	113	4.9	3.2
<i>P. alba</i> (0132)	0.18	0.14	96	40	2.7	1.2
<i>P. articulata</i> (0016)	0.63	0.25	336	75	16.5	3.3
<i>P. chilensis</i> (0009)	0.71	0.10	326	28	18.7	2.4
<i>P. glandulosa</i> var. <i>glandulosa</i> (0028)	0.12	0.15	63	23	3.4	1.5
<i>P. glandulosa</i> var. <i>torreyana</i> (0001)	0.60	0.27	364	45	19.0	2.6
<i>P. kuntzei</i> (0135)	0.23	0.10				
<i>P. nigra</i> (0034)	0.41	0.30	245	141	11.0	6.1
<i>P. nigra</i> (0038)	0.60	0.23	339	103	17.6	5.3
<i>P. pallida</i> (0041)	1.05	0.45	705	172	28.1	6.4
<i>P. ruscifolia</i> (0131)	0.18	0.13	107	58	4.9	2.7
<i>P. tamarugo</i> (0042)	0.13	0.08	210	42	12.5	2.6
<i>P. velutina</i> (0046)	0.45	0.21	234	116	10.1	4.8

Correlation coefficient for acetylene reduction versus total N/plant = 0.814\*\*\*.

Correlation coefficient for acetylene reduction versus dry matter/plant = 0.77\*\*\*.

*P. kuntzei* were not sacrificed due to small germplasm supplies.

X = Mean

S = Standard Deviation

tion and reduced acetylene to ethylene (Table 47). The correlations between acetylene reduction/plant and total N/plant and the correlation between acetylene reduction and dry matter/plant were significant at the 0.1% level and indicates the acetylene assay is a useful indicator of nitrogen fixation. All plant species tested possess nodules required for nitrogen fixation. Having established that mesquite can (1) nodulate, (2) grow on a nitrogen free nutrient media, and (3) reduce acetylene there can be little doubt that mesquite is capable of forming effective symbioses with nitrogen fixing bacteria. Excluding the anomalously low values for *P. africana*, there is almost a 10-fold range in acetylene reduction/accession.

We have no reason to believe that our assay conditions, our watering schedule, or the composition of our nutrient solution are optimal for mesquite nitrogen fixation. Nevertheless the values for acetylene reduction/plant for our best accession, *P. pallida* were 1.0 mg or 35 umole of ethylene/h and compare favorably with the maximum reported by various workers expressed in umoles/plant/h for desert shrubs - 16 (Eskew and Ting, 1978), peas - 25 (Mahon, 1977), soybeans - 40 (Thibodeau and Jaworski, 1975) and for alder seedlings - 60 (Huss-Daniel, 1978). If the positive correlation between above ground dry matter and acetylene reduction can be extended to desert ecosystems where mesquite trees may have multiple 25 cm diameter trunks, it follows that mesquite may contribute large quantities of nitrogen to

TABLE 47. Comparison of dry matter and acetylene reduction of greenhouse plants with growth in field for twelve *Prosopis* accessions

Greenhouse plants	Field plants	m	b	r	df
Mean acetylene reduction per accession	Mean stem volume of wet, medium and dry treatments	63.6	6.28	0.88***	10
Mean acetylene reduction per accession	Mean stem volume of wet treatment	59.9	2.65	0.94***	10
Mean dry matter per accession	Mean stem volume of wet, medium and dry treatments	2.13	6.47	0.84***	10
Mean dry matter per accession	Mean stem volume of wet treatment	2.00	2.94	0.88***	10

Values of m and b are for line  $y = mx + b$ .  
 Field data is from another study (Felker *et al.*, 1981).

natural ecosystems. Probably, mesquite orchard in semi-arid ecosystems could be managed to fix large quantities of nitrogen in agricultural settings.

Our greenhouse studies show a high correlation between acetylene reduction and above ground dry matter. This correlation does not imply a cause and effect relationship. Two equally plausible but opposing reasons for this correlation could be (1) that genetically predetermined fast growth created a large sink for nitrogen which stimulated nitrogen fixation, or (2) that those accessions with high nitrogen fixation capabilities created a source of nitrogen to enable the plant to grow more rapidly. These plants could be grown with high levels of exogenously supplied nitrate to resolve this question.

Comparisons of stem volume biomass estimates from first year UCR field study with greenhouse data for 12 of the accessions used in this greenhouse nitrogen fixation study are presented in Table 47. Both dry matter accumulation and acetylene reduction rates of greenhouse grown plants correlates well with growth data collected for field plants. The field plants in the previous study were watered when the soil water potential at 30 cm depth reached - 60 kPa (-0.6 Bar), - 200kPa (-2 Bars) or -500 kPa (-5 Bars). The greenhouse grown plants were watered every other day until drainage occurred. Accordingly the growth of the greenhouse grown plants might be expected to correlate more closely with the growth of the plants in the wet field treatment than growth for

the mean of the wet, medium, and dry treatment. This is in fact the case as is shown in Table 47. Perhaps *P. chilensis* was over-watered in the greenhouse and in the wet field treatment, causing it to drop from the highest volume producing accession in the dry field treatment to be second and third highest in acetylene reduction and dry matter in the greenhouse, and fourth highest in volume production in the wet field treatment.

In general we are skeptical of correlations between a single 2 h measurement and field data from 200 day old plants and therefore high correlations presented in Table 47 were unexpected. It appears that instantaneous acetylene reduction measurements reflect something of importance to plant growth. It would be naive to suggest that the reason for this correlation is nitrogen fixation *per se* and not the genetically predetermined complex metabolic regulations and source-sink relationships which govern plant growth.

This is the first report of whole plant acetylene reduction by any species of *Prosopis* and it is the first report of cross inoculation between African and North and South American *Prosopis* species. Evidence presented here establishes the fact that at least 12 of the 44 species of *Prosopis* can nodulate and fix nitrogen. With the report of nodulation in the near Eastern species *P. cineraria* (Basak and Goyal, 1975), there is a report of nodulation in all the major taxonomic and geographic sections of the genus *Prosopis*. Therefore we presume that most *Prosopis*

species are capable of nodulating and fixing nitrogen. Other workers (Bailey, 1976), (Gupta and Balera, 1972) have observed nodulations in one species and Bailey (1976) has demonstrated a significant and positive correlation between nodule abundance and plant size and plant total nitrogen.

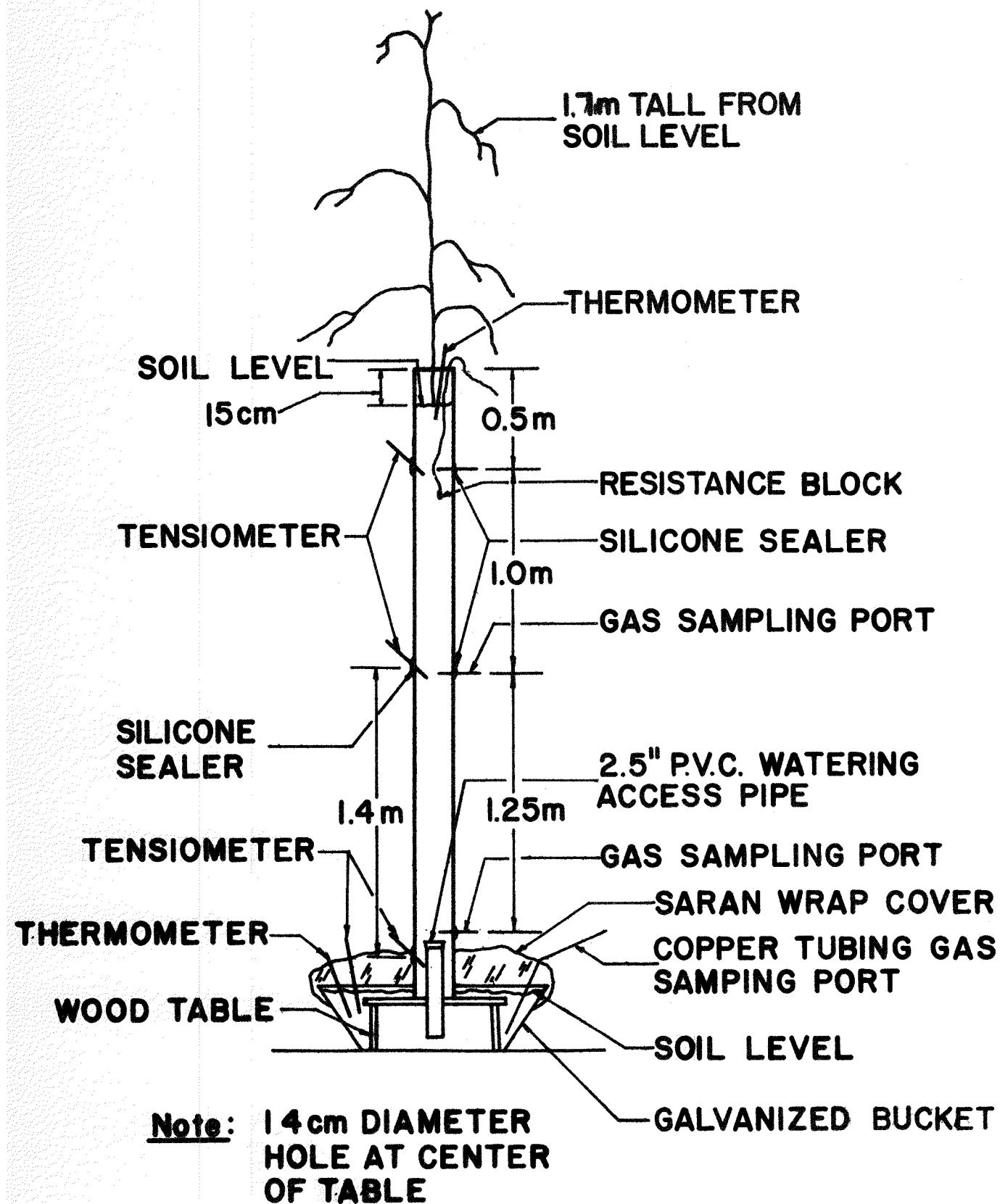
While soil beneath mesquite trees have been shown to have almost three times as much organic carbon and nitrogen as that outside of mesquite's foliage cover (Tiedemann and Klemmedson, 1973), there is no report of nodulation by *Prosopis* in a natural ecosystem and this has caused speculation that mesquite may not fix nitrogen in field settings (Allred, 1949). Attempts to locate nodules in the field have been confined to the top meter of soil (Bailey, 1976) despite the fact that mesquite root systems commonly reach depths of 10 meters (Meinzer, 1927) and have been tentatively identified in an open pit mine in Arizona at a depth of 53 m (Philips, 1963). Such a deep root system should allow mesquite nodules to be less affected by drought stress than annual legumes. For example, a soil water potential of -1500 kPa (-15 Bars) extended to a depth of 1.4 meters at the end of the dry season in West Africa where the annual rainfall was 600 mm. In contrast the soil water potential under the same conditions was -100 kPa (1 Bar) at a 4 meter depth. In these regions the leguminous tree *Acacia albida* increases the yield of peanuts grown beneath its canopy cover (Dancette and Poulain, 1969) and illustrates the comparative advantage of deep rooted legumes. A comparison of soil

profile oxygen, temperature, and water gradients with mesquite nitrogen fixation to 10 meter depths in a field setting would indeed be a challenging undertaking.

A phraetophytically simulated greenhouse experiment was conducted with mesquite in a 3 m deep soil column to determine if nodules could be observed at deeper depths where moisture is more abundant. Mesquite seedlings were grown in two soil filled 15 cm (6") diameter 3.05 m (10 ft) long plastic drain tubes which were supported in a bucket of soil so that water could be directly added to the bottom of the root zone as shown in Figure 6. To facilitate inspection of the root system after the experiment, the tubes were cut lengthwise into two equal pieces, resealed with duct tape, and reinforced with wire. The tubes were stood on 15 cm tall "tables" with the center portions removed, in a galvanized 20 liter bucket. The columns were placed in a greenhouse where the night air temperature was 27°C and the daytime temperature was 35°C at the 2 m height. Air temperatures often reached 45°C, 4.5 m from the greenhouse floor where mesquite leaves occurred.

The tube was filled to within 10 cm of the top with a horticultural soil mix that contained micronutrients. A "Bouyoucos" type resistance block of special design (Cannell and Asbell, 1964) calibrated to 2200 kPa was placed 0.5 m from the top of the soil level. Holes were drilled into the tube to place tensiometers, and gas sampling ports used to measure acetylene reduc-

FIGURE 6



tion, at a distance of 0.5 m, 1.5 m, and 2.75 m from the top of the tube. The soil in the column and bucket were saturated with a nitrogen free nutrient solution described in the salinity experiment. On May 31, 1979 four scarified *Prosopis glandulosa* var. *torreyana* seeds were germinated in the top of the tube and later thinned to the tallest seedling. A liquid culture media (0.5 ml) containing at least one million mesquite rhizobia and 50 ml of water were added to the top of the soil columns at the time the seeds were germinating. No further liquid additions were made to the top of the soil column. Deionized water (1.5 L) and occasionally nitrogen free nutrient solution (1.5 L) were added to the bucket beneath the soil column when the tensiometers reached 60 kPa. In the summer this occurred twice weekly. Tensiometer and resistance block readings were taken weekly to determine when and where moisture was being extracted by the root system.

Acetylene assays were conducted using the internal standard propane. Acetylene (300 ml) was injected into each port after injection of one ml of the internal standard propane. The incubation was carried out for 2½ hours from mid morning until noon. Gas samples were withdrawn for glc analyses at the conclusion of the incubation. A vacuum line was connected to the gas sampling ports to assist in removal of incubation gases. Saran has a low permeability to ethylene and was used to enclose the bucket-tube interface for the acetylene reduction assays.

A scholander pressure bomb was used to measure xylem leaf water potentials before and after the acetylene reduction assays. After the conclusion of the acetylene assays, the tubes were dismantled, split open and meticulously hand examined for presence of nodules.

From May 31, 1979 when the seedlings were planted till September the water potential at all positions was less negative than 10 kPa. In mid September the soil moisture content at the 0.5 m depth was depleted to 50 kPa when the soil at all lower depths was less negative than 10 kPa. Three weeks later the soil moisture was depleted to 50 kPa at the 1.5 and 2.75 m depths. Presumably because of a larger soil volume, two additional weeks were required to deplete the soil moisture to 50 kPa in the bucket.

On 16 May 1980 the resistance readings at the 0.5 m depth exceeded the 2200 kPa calibration limit of the resistance blocks. At this point the plants had been using water from the bucket beneath the tube for 6 months and it was concluded the plants were growing in a phreatophytic soil water environment. On September 17, 1980, one year and 4 months after the seeds were planted, acetylene reduction assays were conducted on both tubes as shown in Table 48. At this point the 0.5 m deep resistance block readings exceeded the calibration curve limit (2200 kPa) by a factor of six. The tubes were then evacuated as described in the methods and assayed two days later when a nearly four

TABLE 48 . Mesquite nitrogen fixation and associated environmental parameters in a 3 m deep soil columns.

	Incubation Dates							
	17 Sept		19 Sept		22 Sept		4 Dec	
	tube	tube	tube	tube	tube	tube	tube	tube
	1	2	1	2	1	2	1	2
Ethylene production (mg/hr)								
tube depth								
0.5 m	0.00	0.00	0.01	0.06	0.01	0.01	0.00	0.00
1.5 m	0.00	0.00	0.00	0.03	0.02	0.01	0.00	0.00
2.75 m	.42	1.57	0.13	0.22	0.04	0.07	0.22	0.71
bucket	1.90	0.39	0.45	0.17	.25	0.01	1.50	0.38
Air temperature (°C)								
initial	43	43	34	34	38	38	29	29
final	47	47	39	39	39	39	37	37
Surface soil temperature (°C)								
initial	37	37	34	38	33	37	30	33
final	42	42	37	41	38	37	34	33
Bucket soil temperature (°C)								
initial	28	32	28	31	--	--	27	28
final	30	34	29	34	--	32	30	30
Leaf xylem water potential (kPa)								
initial	2900	3000	--	--	--	--	3200	2500
final	3400	3800	3300	3500	3250	3500	3500	3000

fold decrease in activity was observed despite a cooler air temperature. The tubes were again evacuated and assayed 3 days later when another several fold decrease in activity was observed. Despite the evacuation procedures, background samples taken prior to incubation on the second and third attempts found significant quantities of acetylene and ethylene in the columns. (Values reported in Table 47 are corrected for background ethylene concentration). It was felt that either the acetylene or the ethylene produced from acetylene by the plant was causing an inhibition of nodule activity. The ports were again evacuated and the septa removed to allow the soil environment to come into equilibrium with the air. One month later gas samples taken from the column were found to be free of acetylene and ethylene. Eight weeks later in December when the plants had ample opportunity to recover, the tubes were assayed for acetylene reduction when values comparable to the first date were observed.

As shown in Table 48 on 17 September, no acetylene reduction was observed in tube 1 and a rate of 1.9 mg/plant/hr was observed in the bucket. In tube 2 more ethylene production occurred in the bottom port of the tube than in the bucket. The nodule distribution exactly followed the pattern of acetylene activity. In tube 1 only 2 nodules with a total fresh weight of .03 g were found in the soil column and that at the soil column - soil bucket interface while 149 nodules with a fresh biomass of 7.2 g were observed in the bucket beneath tube 1. In the second tube

30 nodules, 27 nodules, 14 nodules, and 6 nodules with a fresh biomass of 1.65 g, 0.78 g, 0.87 g, and 0.38 g were located in regions 2.5 to 2.65 m, 2.65 m to 2.75 m, 2.75 m to 2.8 m, and 2.9 to 3.05 m from the top of the tube respectively. Nodules in the 2.65 m region were almost exclusively located in a 15 cm thick layer of coarse vermiculite which was inadvertently placed in the tube. Twenty-eight nodules with a mass of 4.9 g were located in the bucket beneath tube 2.

At the conclusion of the experiment on 4 December, the oven dry weights and basal stem diameters were 100 g-0.84 cm and 65 g-0.82 cm for the mesquite trees in tube 1 and tube 2 respectively.

The environmental parameters measured at the beginning and end of the acetylene reduction incubation period are also presented in Table 48. Leaf xylem water potentials did not vary greatly between assay dates and generally ranged from 2900 to 3500 kPa. These values are more negative than found in temperate plants such as soybeans (Huang *et al.*, 1975). Leaf xylem water potentials taken from daily-watered *Prosopis* used for vegetative propagation stock were minus 1700 kPa.

The first incubation date has both the highest acetylene reduction rates and the most severe environmental conditions with air temperatures of 46°C. It was surprising to observe leaf water potentials of minus 3000 kPa when the root zone only experienced 60 kPa. Acetylene reduction rates of 1.9 mg/plant/hr compare favorably with annual legumes and indicate that 40°C

air temperatures and leaf xylem water potentials of minus 3000 kPa are not particularly stressful for *Prosopis*. In contrast, the acetylene reduction in soybeans was 100% inhibited at a leaf water potential of 2800 kPa (Huang *et al.*, 1975). Perhaps an osmotic regulation mechanism occurs in *Prosopis* to allow it to maintain low water potentials without damage. Even though the plant was fixing nitrogen and apparently not stressed, nodules and nodule activity were located no closer than 2.7 m from the soil surface. Arguments that mesquite does not fix nitrogen on the 30 million hectares where it now occurs in southwestern United States (Parker and Martin, 1952) because nodules cannot be located in the top meter of soil (Bailey, 1976) deserve re-evaluation.

We believe the importance of soil nitrogen to plant productivity in semi-arid climates has been underestimated. Typical values for total soil nitrogen are 0.02% to 0.05% N (Charreau and Vidal, 1965), (Tiedemann and Klemmedson, 1973) and are equivalent to 200-500 kg N/ha for a 10 cm depth. The importance of nitrogen to semi-arid ecosystems can be illustrated with a calculation of what typical water and nitrogen influxes could produce using empirically derived production coefficients. Assuming that one half a 300 mm annual rainfall (such as might occur in southern Arizona) is lost by surface evaporation and runoff, 150 mm of annual rainfall would be available for plant use. Assuming dry matter production values of 1 kg dry matter (DM)/ 1000

kg H<sub>2</sub>O for C<sub>3</sub> plants and 1 kg DM/300 KG H<sub>2</sub>O for C<sub>4</sub> plants (Fischer and Turner, 1978), 150 mm of available water/ha (1 ha = 10,000 m<sup>2</sup>) could produce from 1500 to 4500 kg DM/HA. If this rainfall occurred in an agricultural setting where the entire crop was harvested for grain or cattle fodder then the total N influx would be solely derived from rainfall, non-symbiotic nitrogen fixation, blue-green algallichen crusts *etc.* Nitrogen generally cannot be generated from mineral weathering and is ignored here. These nitrogen influxes have reported to be approximately 1-5 kg N/ha/yr (Eskew and Ting, 1978), (Paul *et al.*, 1971). If nitrogen losses by denitrification are ignored (which would only emphasize the importance of N for ecosystem productivity) and a plant protein content of 15% and a protein/nitrogen factor of 6.25 is assumed, dry matter production of 40-200 kg/ha/yr is all that could result. In contrast the water use efficiency calculations show that dry matter production of 1500 to 4500 kg/ha/yr is possible. Even higher levels of dry matter production, *i.e.* 8,930 kg/ha/yr have been demonstrated at 228 mm annual rainfall with applications of almost 300 kg N over a three year period (Alessi and Power, 1976). These latter nitrogen applications are equivalent to the total N content of a hectare of West African farmland or southwestern U.S. desert. Millet grain yields in regions of West Africa receiving 500-600 mm rainfall that have not been followed or received manure typically are in the range of 300-500 kg/ha/yr (Gillier, 1960) and lends support to

the hypothesis that nitrogen may limit plant productivity in some semi-arid ecosystems even more than water.

Mesquite and the closely related tree legumes of the genus *Acacia* constitute a major part of semi-arid ecosystems of the world which occupy 31 million square km (Griffith, 1961), yet there has been almost no effort directed to identifying and using their nitrogen fixing capabilities. If rainfall in semi-arid regions is to be effectively used by the plant, vast improvements in the soil fertility will be required. We suggest that use of nitrogen fixing leguminous trees such as mesquite or *Acacia albida* would be an effective and low cost method to improve water use efficiency of plants in semi-arid regions. Indeed *Acacia albida* has been used by West Africans to increase their millet, sorghum, and peanut yields (Charreau and Vidal, 1965), (Dancette and Poulain, 1969).

XII. Evaluation of *Prosopis* as an energy cropA. Projected Economics of Mesquite Wood Production  
for Commercial Sized Stands

The average cost of mesquite wood chips produced in biomass plantations over a 9 year period was projected to be \$25.24 per oven dry ton or \$1.49 per million Btus as summarized in Table 49. These costs must be considered tentative as mesquite biomass farming has never been done. The following discussion will point out the strengths and limitations of the data and those areas where cost reductions could have the greatest impact on lowering the price of the wood produced.

Mesquite biomass farming operations are thought to be most appropriately carried out on marginal land not suitable for farming because of low rainfall. The principal land use competition in such areas is cattle grazing. The land lease of \$10 per acre per year reported in Table 49 is over 5 times greater than the net annual return reported by Herbel (1979) for cattle grazing in South Texas. Scifres et al (1973) computed a \$10 per acre per year return on land for cattle ranching but it is felt by professional range managers in South Texas that \$5 per acre per year return on the land would be quite optimistic (McLendon pers. commun.). Hunting leases in South Texas range from \$3-5 per acre per year and may return nearly as much to the rancher as grazing cattle. The first growing season after planting, mesquite should be large enough to avoid damage from common domestic game animals so that hunting leases should be possible on biomass farms.

Site preparation costs of \$178 assume the site has moderate brush which must be bulldozed, stacked, burned and the resulting field disced into a normal seedbed. No credits are assumed for harvesting existing brush for boiler fuel, cordwood, fence posts, or mesquite lumber despite the fact that boiler fuelwood is worth at least \$12 per green ton (\$25 per dry ton), that cordwood sells from \$100-200 per cord, that 4" mesquite fenceposts are \$1 each, and that cut, planed, and cured mesquite wood (from 14" diameter 6 ft long pieces) is worth \$4-5 per board foot. Sites with brush dense enough to require the intensive site preparation outlined in Table 49 probably have 10-20 dry ton equivalents of brush which could nearly pay for site preparation costs.

We have chosen to err on the conservative economic side and to avoid substantial credits in site preparation from existing brush.

#### 1. Seedling and Tissue Culture Propagule Cost Estimates

The production of 7 dry tons acre<sup>-1</sup> year<sup>-1</sup> or 21 tons per 3 year rotation assumes use of either rooted cuttings or tissue culture propagules. While Dr. Murashige at UC-Riverside has initiated research on tissue culture propagation of *Prosopis*, it has not been successfully tissue cultured to date. Projected costs for tissue culture propagated *Prosopis* were estimated from mass propagated plants now in commercial production by assuming tissue culture methods could be developed that are comparable to other commercial tissue cultured plants. Personal communication

TABLE 49  
MESQUITE WOOD CHIP PRODUCTION COST ESTIMATES

Item	Cost per rotation per acre		
	Initial Planting	1st coppice Rotation	2nd coppice Rotation
Land Lease-3 yrs. @ \$10/yr.	\$30.	\$30.	\$30.
Irrigation costs-none used	--	--	--
Equipment costs-computed as rentals	--	--	--
Seedlings via tissue culture 450 x \$0.35	\$160.	--	--
Site preparation:			
Application of 2-4-D to kill all perennial root sprouting vegeta- tion.			
2-4-D ester @ 4 pts./acre @ \$1.37/pt = 5.50 acre application = 3.25 acre	8.75	8.75	
Double chaining with two cater- pillar D-8's at \$60/hr for brush removal	100.00		
Root-dozing, brush stacking, burn- ing, misc.	50.00		
Disc to smooth land	20.00		
TOTAL site preparation	179.00	\$179.	--
Planting costs	\$21.	--	--
Herbicide application			
Treflan application prior to transplant @ 1 qt/acre =	7.13		
materials and application	5.00		
	12.13		

TABLE 49

## Con't MESQUITE WOOD CHIP PRODUCTION COST ESTIMATES

Item	<u>Cost per rotation per acre</u>		
	Initial Planting	1st coppice Rotation	2nd coppice Rotation
Simazine application 3 months after transplant Simazine 80 w p @ \$2.65/lb 2.5 lbs/acre = 6.62 Application = 3.50 10.12			
TOTAL Herbicides	\$22.	--	--
Insecticide applications none required	--	--	--
Fertilizer costs	\$79.	\$79.	\$79.
TOTAL Production Cost	\$491.	\$109.	\$109.
Product (7 dry tons acre-1 year-1 x 3 years)	21 tons	21 tons	21 tons
Production cost per dry ton	\$23.38	\$5.19	\$5.19
Harvesting cost per dry ton	\$14.00	\$14.00	\$14.00
TOTAL harvested cost per ton	\$37.38	\$19.20	\$19.20

Average cost per dry ton over 9 years (3 rotations) = \$25.26  
(1.49 per million Btu's.)

from Dr. Hugh Bollinger, Vice President of Native Plants, Inc. which engages in commercial tissue culture indicates that wholesale prices for most tissue culture propagated stock in  $2\frac{1}{4}''$  x  $2\frac{1}{4}''$  liners range from \$0.25 to \$0.35 each. Some horticultural tissue cultured plants sell for as little as \$0.10 to \$0.15, while jojoba which is very difficult to successfully harden off sells for \$0.75 each. If an additional \$0.05 were added to the above average price to plant the propagules in longer  $1\frac{1}{2}''$  x  $1\frac{1}{2}''$  x 15" plant bands, the resulting tissue cultured plant would range from \$0.30 to \$0.40 each. Thus planting stock would range from \$135 to \$180 per acre. (A \$160 estimate is used in Table 49.

While we feel dry matter production of 7 tons acre $^{-1}$  year $^{-1}$  from tissue cultured plants should easily be possible, propagules are not available to date and seed propagated plantlets will have to be used in the immediate future. Average dry matter production for the inner block of *P. chilensis* (0009) trees in Imperial Valley water use efficiency study had a dry matter production of 6.5 tons/acre/year for the first two years. Since biomass productivity in tree stands increase exponentially the first several years and since *P. alba* (0166) had higher biomass production than *P. chilensis* (0009) in the screening trial, a dry matter production of 7 tons acre $^{-1}$  year $^{-1}$  may even be possible with seedlings.

Propagation costs of \$0.11 per seedling are outlined in Table 50. The major cost is for the cardboard plant band, followed by the soil mix and then the placement of plant bands into

TABLE 50  
SEEDLING PROPAGATION COSTS

<u>Item No:</u>	<u>Item Description or Operation</u>	<u>Cost/Seedling</u>
1.	Purchase open-ended waxed cardboard plant bands with holes punched on sides $1\frac{1}{2}''$ x $1\frac{1}{2}''$ x 15".	\$ .050
2.	Unfold plant bands and insert into milk cases (370 hr. $^{-1}$ x \$4.00 hr. $^{-1}$ ).	.011
3.	Ingredients for soil mix.	.031
4.	Mixing soil and filling plant bands (480 hr. $^{-1}$ x \$4.00 hr. $^{-1}$ ).	.008
5.	Seeds-extraction and seed cleaning at 2,000 per hour @ \$4.00/hr.	.002
6.	Watering-use of automatic watering system.	<.001
7.	Greenhouse space rental @ $65 \text{ ft}^2/2000$ seedlings/\$0.13/ $\text{ft}^2/\text{month}$ .	<u>0.012</u>
	TOTAL	\$0.114

the milk cases. Seedling costs are a small fraction of overall biomass farm costs, suggesting that efforts in cost reduction be directed towards other biomass farm aspects.

Seeds of South American ornamental origin produce many stunted, disfigured seedlings-evidently of genetic origin which should be pulled up at the first or second true leaf stage and the container reseeded.

## 2. Soil Mix Costs

Long, narrow (1½" x 1½" x 15") open ended waxed cardboard containers were used for mesquite to stimulate development of a taproot and to enhance the seedlings ability to reach moisture immediately after transplant in semi-arid soils. A single milk case (12" x 12") containing 64 of these plant bands weighed almost 41 kg (90 lbs) when a standard University of California horticultural mix was used. Thus only 11 cases (11 ft<sup>2</sup>) could be carried in a ½ ton pick-up despite space for many more. The following soil mix was improvised from the UC-mix to lower the density and to stimulate nodulation by providing low nitrogen and high phosphate levels. One milk case now weighs 26 kg (57 lbs)- a 35% reduction.

Hand mixing of ½ yard "synthetic" soil mixes consisting of the eleven items in Table 51, occasionally results in stunted chlorotic growth of small batches of seedlings from inadequate mixing. We suggest a soil mixer be used in such operations.

TABLE 51  
SOIL MIX PRICE AND COMPOSITION

<u>Item</u>	<u>Quantity</u>	<u>Unit Price</u>	<u>Total Price</u>
Peat	6 ft <sup>3</sup> bale	10.25/bale	\$10.25
Perlite	6 ft <sup>3</sup> bale	8.50/bale	8.50
Vermiculite	6 ft <sup>3</sup> bale	8.50/bale	8.50
Triple Super Phosphate (0-46-0)	1.7 lb.	\$0.30/lb.	0.51
Nitrogen fertilizer (34-0-0)	2.5 oz.	\$0.076/lb.	.01
Potassium fertilizer (0-0-60)	1 lb.	\$0.12/lb.	.12
Lime (99%)	2 lb.	\$0.06/lb.	.12
Micronutrients (emisgran)	2.5 lb.	\$0.60/lb.	1.50
Fungicide (Banrot)	0.3 oz.	\$21.00/lb.	0.40
Rhizobia	?	?	--
		TOTAL	\$29.91

This quantity is sufficient for 864 plant bands which results in a seedling cost of \$0.031. This mix contains little nitrogen to avoid repression of nodulation. Occasional batches of the mix result in chlorotic seedlings that can be reversed by addition of more micronutrients. A lime-micronutrient imbalance is suspected.

### 3. Planting Cost Estimates

A mechanical tree planter capable of planting the 15" tall seedling containers even with ground level is assumed for this analysis. It is assumed the single row planter will be pulled by an 85 hp, 4-wheel drive tractor at a ground speed of 1.5 mph (2.4 kph) planting a tree every 3 m and consuming 5.5 gallons of diesel per hour. The maximum tree planting rate at this speed and spacing is 800 trees per hour. Assuming long rows with little turning, 750 trees per hour (1 tree every 4.8 sec) should be possible. The three man crew consists of a tractor driver, a laborer on the tree planter and a laborer keeping the planter supplied with trees. Costs for these items are summarized in Table 52. Equipment items have been computed as rentals to avoid depreciation, upkeep, etc. Tractor and planter rental costs and fuel consumption rates were obtained from D. Baucum, manager of a John Deere dealership.

These planting costs are quite arbitrary and large deviations from rates specified are possible. For example, higher planting rates of 1,000 trees per hour have been achieved with the same planter at Michigan State. The planter specified above does not have a mechanism to position the seedling at the correct depth in the furrow and to set the trees at the correct spacing in the row. At 750 trees per hour, the operator must plant one tree every 4.8 sec. Faster ground speeds and higher planting rates could be achieved if the planter operator could load seedlings on a device that would lower the seedling into the furrow and

TABLE 52  
PLANTING COST ESTIMATE

<u>Equipment or Manpower</u>	<u>Charge per Hour</u>
Tractor driver	\$ 4.50
2 laborers	\$ 4.00 ea.
85 hp 4-wheel drive tractor rental	\$15.00
Fuel cost-5.5 gal. hr. <sup>-1</sup> @ \$1.14 gal. <sup>-1</sup>	\$ 6.27
Planter rental	\$ <u>1.00</u>
TOTAL	\$34.77

$$2.4 \text{ kph ground speed} \times 333 \text{ trees km}^{-1} = 800 \text{ trees hr.}^{-1} \\ \text{deduct 50 for turning} \quad = 750 \text{ trees hr.}^{-1}$$

$$\text{Planting Cost per Seedling} = \$34.77 \text{ hr/750 trees hr.} = \underline{\$0.046/seedling}$$

$$\text{Planting Cost per Acre (450 trees)} = \$20.70$$

plant it at the correct depth and spacing in the row.

Not included in the planting cost estimates is the time required for field layout which can be substantial if the position of the row ends must be marked. Row markers common to agricultural implements but not currently available on tree planters could greatly speed field layout.

Techniques are available that could greatly hasten the planting rate and lower planting costs such as shallow multiple row planters and direct seeders. However, on semi-arid soils these techniques probably would require supplemental irrigation to consistently achieve good stand establishment. Drip irrigation systems at approximately \$1,000 per acre are approximately 50 times more expensive than planting costs described here.

#### 4. Herbicide Costs

The primary concern for use of a herbicide at transplant when tender seedlings have shallow root systems is that the herbicide have no phytotoxic effects on the transplanted seedlings. Of secondary concern is that the herbicide allow the seedlings to get ahead of the weeds by suppressing or killing them. Thus we have chosen to use Treflan prior to transplant at 1 quart per acre because it does not readily leach and because it is not effective against plants with vigorous tap roots such as mesquite. Three months after the seedlings are established when they have deeper root systems, the broader spectrum and riskier herbicide Simazine is used at 2.5 lbs/acre. By the time the residual

activity from these herbicides is gone (perhaps 12 months) the trees should have high canopy covers and be sufficiently well established to effectively compete with the weed species. The Simazine application at \$10.12 per acre is cheaper than Treflan because Treflan must be disced twice at right angles for effective incorporation.

#### 5. Fertilizer Costs

No fertilizer trials have been concluded with mesquite and therefore costs have been calculated to replace nutrients removed in biomass to achieve sustainable production levels. These calculations and costs are outlined below assuming a yearly oven-dry wood production of 14,000 lbs/acre, a 3 year rotation, and a resultant 42,000 lb/harvest yield. Fertilizer costs are for ton lots and wholesale prices in 1979 dollars.

**Nitrogen:** Mesquite is a nitrogen fixer and no applied nitrogen is deemed necessary.

**Phosphorus:** Phosphorus is assumed to occur in the plant at a 10-fold lower level than nitrogen or at a level of 0.15%. Thus 42,000 lbs would require 63 lbs of P. Triple superphosphate costs \$260.00/ton is 45%  $P_2O_5$  or 20% P. Thus 315 lbs of super phosphate costing \$41.00 would be required.

**Potassium:** A recent study (Zavitkovski, J. 1979, For. Sci. 25: 383-392) indicates a potassium level of 0.6% is typical of woody biomass. Thus 250 lbs of K would be required for 42,000 lbs of biomass. Muriate of potash is 60%  $K_2O$  and 50% K and costs \$130.00/ton. Thus 250 lbs of K would require 500 lbs of muriate of potash costing \$32.50.

**Sulfur:** Legume dry matter production has long been known to respond to sulfur applications and Australian

field trials with legume pastures have shown that soil sulfur levels of at least 4 ppm are required for optimal growth (Probert, M.E. and R. K. Jones, 1977, Aust. J. Soil. Res. 15: 137 -146. In order to achieve a 5 ppm sulfur concentration to a 39 inch depth, 50 lbs/acre would be required. Granulated sulfur consisting of 98% S costs \$90/ton or \$2.30 for 50 lbs.

All of the above fertilizers could be applied in one application costing \$3.50/acre at the beginning of each rotation. Thus, total fertilizer costs per acre for the 3 year rotation would be:

Phosphate	\$ 41.00
Potassium	\$ 32.50
Sulfur	\$ 2.30
Application	\$ <u>3.50</u>
Total	\$ 79.30/acre

If *Prosopis* were grown in dedicated biofuel plantations it should be possible to return nearly stoichiometric amounts of minerals present in harvested biomass to the biomass farm. The ash from the conversion technology should contain nearly all the  $K_2O$ ,  $P_2O_5$ , and micronutrients present in the original biomass. It is possible that fertilizer mineral nutrients, other than nitrogen and sulphur which are volatized, could be obtained free by charging ash distribution against waste disposal costs. Ash disposal problems from energy or chemical feedstock conversion technologies that are supported by biofuel plantations will be much easier to deal with than from residues from municipal solid waste methane generating plants or nuclear power plants. Elimination of fertilizer costs by recycling ash would reduce the first

rotation harvested cost to \$33.61 dry ton and the cost averaged over 9 years to \$21.48 per dry ton (\$1.26 per million Btu's).

#### 6. Harvesting Costs

The harvesting costs assume use of the mesquite combine developed by Dr. Ulich at Texas Tech University. This combine is modified from a rubber tired 130 hp diesel Massey Ferguson tractor and can fell, collect, and retain natural stands of mesquite up to 8" in diameter at a cost of \$14.00 per dry ton (Ulich, 1980). In light stands it can harvest 4 tons per hour. This machine seems quite capable of harvesting regularly spaced, even diameter mesquites less than 8" in diameter that will occur in 3 year old mesquite plantations and would be much less capital intensive than other track mounted designs. Spare parts could be readily obtained for the tractor which constitutes a major portion of the harvester.

#### 7. "Discussion of Wood Production Costs"

The most costly item in mesquite wood chip production is biomass harvesting. When averaged over 3 rotations, harvesting accounts for 55% of all costs. Harvesting costs account for 73% of all costs for coppice rotations after site preparation costs, seedling costs, and planting costs have been "paid for". By fine tuning harvesting equipment to handle narrow ranges in stem diameter and regular plant densities and spacings we hope less capital intensive swath harvesters can be developed to lower harvesting and total production costs.

After harvesting costs, site preparation costs are the next most costly item. Substantial opportunities are available to defray these costs by harvesting large mesquite pieces (14" in diameter 6' long) for furniture wood which sells for \$0.50 per board foot in rough and \$4.00-\$6.00 per board foot in planed and cured form; by harvesting 14" to 6" diameter material for cordwood which sells for \$100-\$200 per cord; and for chipping the remaining material for boiler fuel at \$25 per dry ton. If judiciously carried out it is possible that harvesting of existing brush might cover all site preparation costs and perhaps show a profit. Elimination of site preparation costs would reduce 3 rotation average production costs from \$25.26 to \$22.40 per dry ton.

Seedling costs from tissue culture are a substantial portion of the initial investment (\$160 per acre) but little information is available to assess possibilities for decreasing these costs.

As mentioned in the section on fertilizer costs, a substantial opportunity is present to obtain the plants fertilizer mineral requirements free as a by-product of ash disposal from the conversion technology. This would reduce 3 rotation costs from \$25.26 to \$21.48 per dry ton.

It has been difficult to arrive at an equitable land lease and it is more difficult to project equitable land leases for the future. Nevertheless, it seems as if a \$10 per acre per year land lease should double or triple returns to cattle ranchers.

Under this scenario, planting costs, seedling costs, and herbicide costs do not significantly contribute to production costs. Low priority should be assigned to reducing costs in these categories. However continuing research on planting techniques, seedlings, and herbicides is essential to insure high production levels and possible impacts on ease and costs of harvesting.

A drop in production level to 6 tons/acre/year or an increase to 8 tons/acre/year would change 3 rotation average costs from \$25.26 to \$27.13 and \$23.84 per dry ton respectively. As discussed in the section on land resource base, yields in the 7 dry ton acre<sup>-1</sup> year<sup>-1</sup> range are not deemed possible in short growing seasons in the Texas Panhandle, or in the lower rainfall regions (less than 19 inches) in West Texas, New Mexico and Arizona unless plantations are present in river bottoms.

Under the most carefully managed biomass plantation where brush were harvested to write off site preparation costs and where fertilizer costs were eliminated by use of ash from conversion technology, the average cost per dry ton over 3 rotations would be \$18.65 or \$1.10 per million Btu's.

In summary, harvesting costs dominate the economics of plantation produced biomass with site preparation costs, tissue cultured seedling costs, and fertilizer costs following in that order. Planting costs, herbicide costs, and the land lease do not significantly contribute to overall harvested costs. Har-

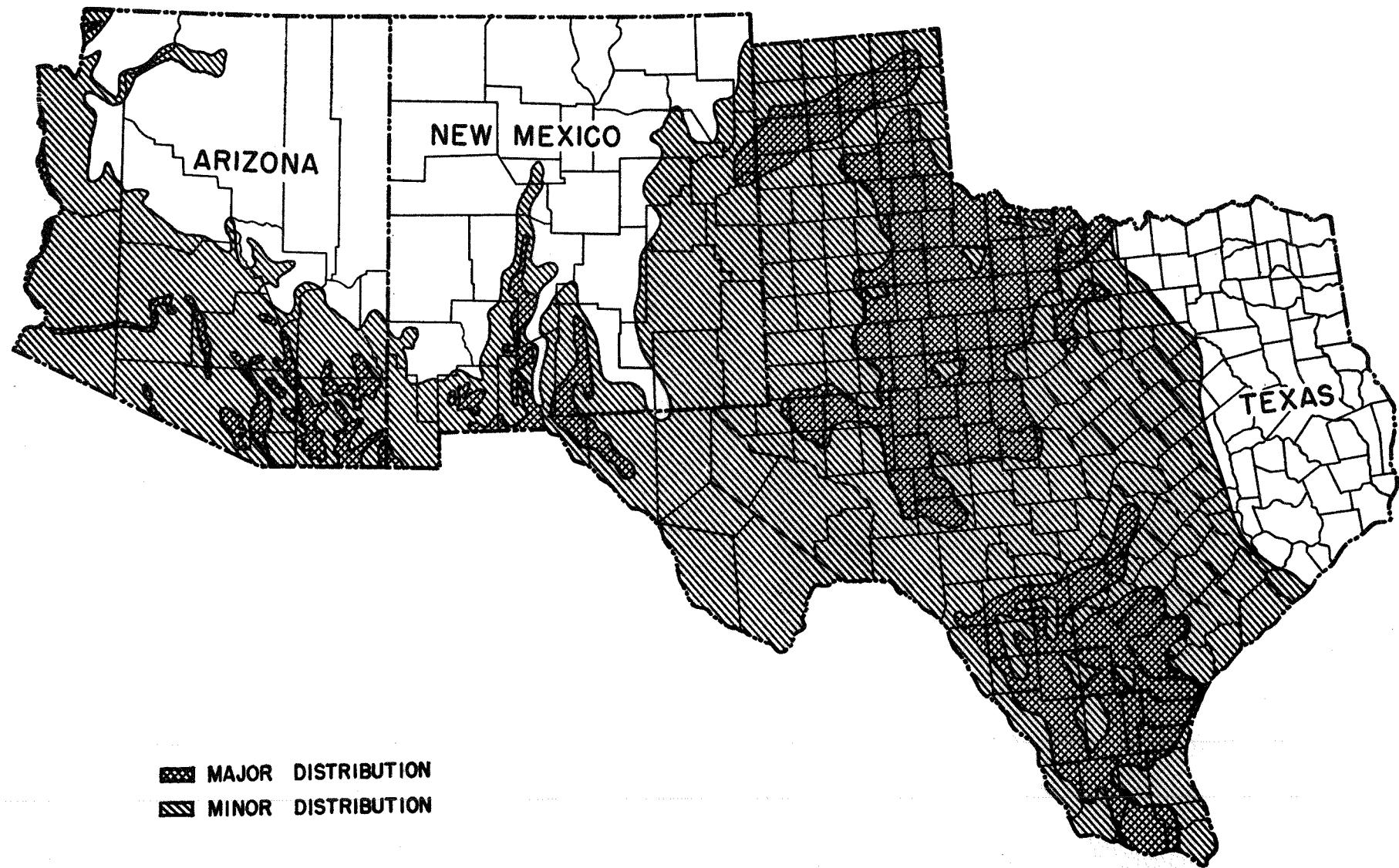


FIGURE 7.—Distribution of mesquites in the Southwest.

Source: Parker and Martin, 1952.

vested mesquite wood chips delivered to the edge of the field are projected to cost \$25.00 per dry ton or \$1.50 per million Btu's.

#### B. "Land and Water Resource Base"

The 72 million acres of mesquite in the United States are distributed as presented in Figure 7 (Parker and Martin, 1952). Large areas of mesquite grow on upland sites (away from river-bottoms) in rainfalls ranging from 28" near Corpus Christi, Texas to approximately 8" annual rainfall midway between Phoenix, Arizona and the Colorado River. In areas where groundwater accumulates as in riverbottoms and valley bottoms surrounded by mountainous watersheds with little vegetation cover, mesquite growth is abundant at 3" annual rainfall along the Colorado and Gila Rivers and in the California Coachella Valley and Mojave Desert. Where groundwater is near the surface, mesquite stands are even abundant in Death Valley with 1.8" annual rainfall.

Water supplies of sufficient quality to be used in commercial agriculture are overcommitted in southwestern United States as exemplified by Supreme Court battles between the States of Arizona and California over Colorado River water entitlements and as exemplified by depleting fossil fuel groundwater resources in southern Arizona and the Texas Panhandle. It is inappropriate to consider use of high quality irrigation water on biomass farms of the scale required for commercial chemical feedstock production or power generation. Since some *Prosopis* grow well in  $\frac{1}{2}$

seawater, irrigated biomass farming with *Prosopis* would be attractive if water is available that is too saline for use on agricultural crops. Several hundred thousand acre-feet of water from irrigation tile drains in the California Imperial Valley is too saline for reuse on agricultural crops and currently is drained into the Salton Sea (pers. commun. Dr. B. Meeks, Research Leader USDA-Imperial Valley). Large areas in northwestern parts of California's San Joaquin Valley as well as significant portions of South Texas coastal sorghum and cotton growing regions have saline groundwater too close to the surface for tiling or farming but might be suitable for mesquite biomass farming.

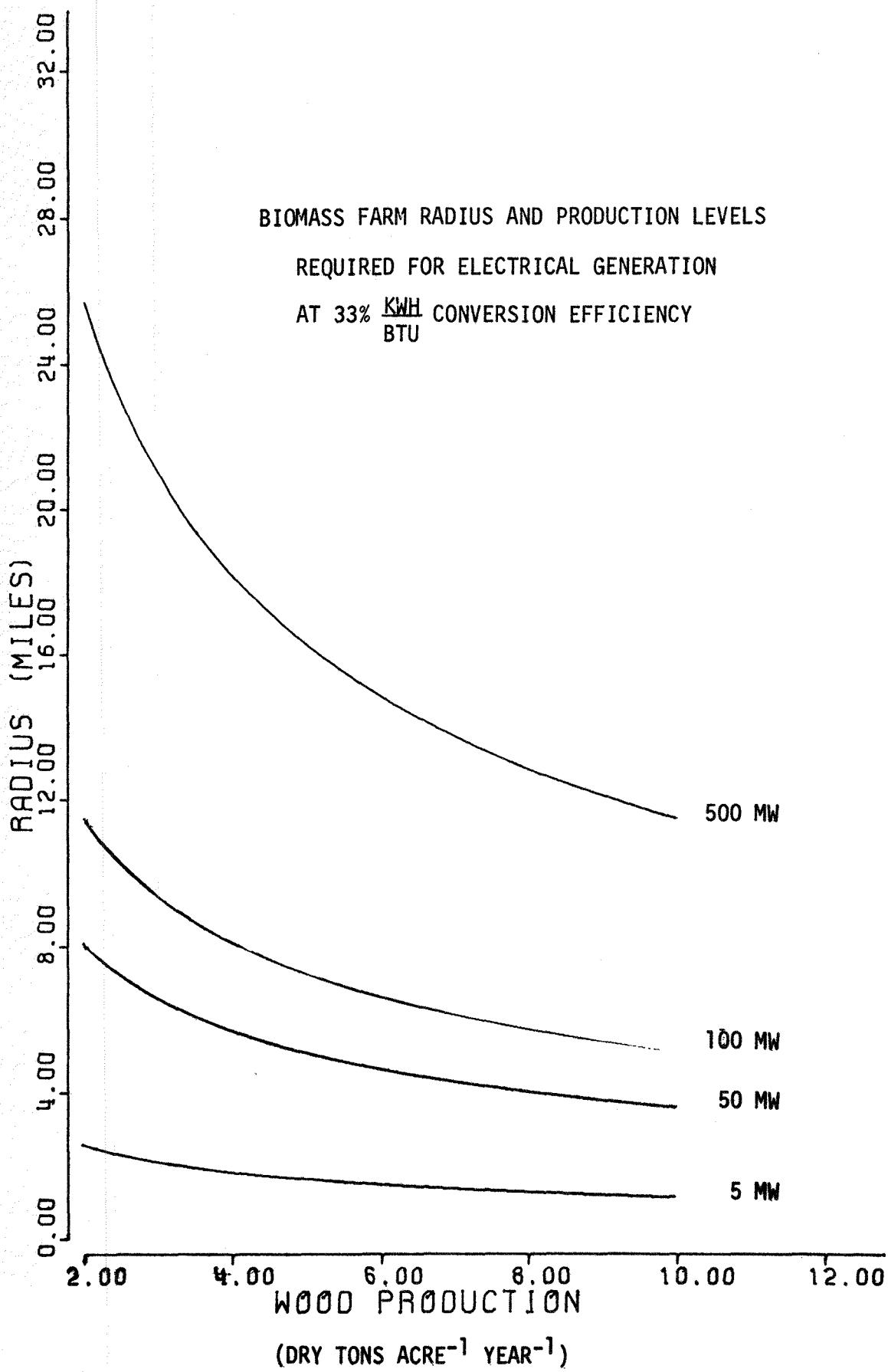
Mesquite relies solely on rainfall in largest areas where it now occurs. Southern Arizona sites with 8" annual rainfall would be expected to be considerably less productive and have longer harvest rotations than mesquite dominated areas in South Texas. Stand establishment with no irrigation in 8" annual rainfall regions will also be more difficult than in South Texas. However grazing productivity is so low in southern Arizona that state grazing leases of \$2 per animal unit month are for 100 to 150 acres. Thus the State of Arizona receives approximately \$0.20 per acre per year from grazing leases. The 7 million acres of state lands held in Arizona sharply contrast to almost no state held lands in Texas.

Temperature strongly affects mesquite distribution and productivity. Shoot elongation in mesquite is very slow at tem-

peratures less than 27°C (80°F) (Felker *et al.*, 1981). Two year old Imperial Valley *P. chilensis* (0009) trees had the same biomass as three year old *P. chilensis* (0009) trees grown in Riverside under the same irrigation treatment. We believe the longer hotter Imperial Valley growing season was responsible for this difference. The 7 dry ton/acre/yr productivity levels discussed in this report are for areas with 5 to 6 months over 80°F such as South Texas, and low elevations in Arizona and California. More northerly and high elevation regions such as the Texas Panhandle and southern New Mexico are expected to have lower production levels even with adequate moisture because of fewer days over 80°F. Additionally, the average annual minimum temperature isotherm of minus 20.5°C (Fisher, 1959) which roughly goes from NW Arizona to SE Arizona to SE New Mexico, through the northern portion of the Texas Panhandle to Oklahoma has been postulated to be the northern distribution limit for mesquite. Even if mesquite could tolerate winter temperatures of minus 20.5°C, summer daily temperatures probably would have so few 80°F plus days that other nitrogen fixing genera such as *Alnus* or *Robinia* would be more productive.

Some inexpensive energy sources do not readily lend themselves to deliver the huge quantities of energy currently used in the United States. Figure 8 graphically expresses the size biomass farm required to power commercial sized power plants assuming a 33% Btu to Kwh conversion efficiency. This figure

FIGURE 8



assumes an unrealistic 100% use of land area encompassing the electrical generation facility and avoids areas required for access roads, municipalities, etc. Nevertheless it provides a concept of the biomass farm size required for electrical generation. At our projected yield of 7 dry tons acre<sup>-1</sup> year<sup>-1</sup> a circle of radius 1.38, 4.35, 6.15 and 13.75 miles would be required for 5, 50, 100, and 500 MW power plants respectively. Approximately a dozen 10-20 MW wood fired power generating plants currently operate in the United States but no wood fired power plants larger than 50 MW currently exist (Garrett, 1981). Constraints to wood fired power plants over 25 MW probably stem from inability to obtain forest residues on a sustained basis within a 50 mile haul. From the model presented here it is clear that even 500 MW plants would be within a 15-20 mile haul if a dedicated biomass plantation were used to provide the fuel source. The 13.75 mile radius for the 500 MW plant would occupy 380,000 acres or less than one-half of a well known ranch in South Texas that has in one time or another been nearly covered by mesquite. Capital costs of 500 MW power plants are in the billion dollar range so that acquisition of 380,000 acres at \$1,000 per acre or \$0.4 billion dollars might not be unreasonable.

Power generating facilities supported by biofuel plantations could have a sufficiently short hauling distance to support 10 times larger facilities than possible when the feedstock is derived from forest by-products and residues.

### C. Environmental Assessments for Use of Mesquite as an Energy Crop

The most often expressed concern about use of fast growing mesquite (*Prosopis*) for energy purposes is that they will escape from biomass plantations to rapidly cover most of the rangelands of southwestern United States. We believe the chances of this are quite low for several reasons. The primary mechanism for spread of mesquite is seedling emergence from scarified seeds in cattle feces, but since *Prosopis* strains selected for rapid production of woody biomass partition less dry matter into pod production than many North American native strains there is little danger of spread of high biomass producing accessions. One of the most promising biomass producers, *P. chilensis* (0009) has not yet produced a pod in 4 years. In contrast some native mesquite have produced pods in six months after transplant and 3.8 kg of dry pods in their second growing season. Higher biomass producing South American *Prosopis* strains would poorly compete with seed production of many native mesquites for the first several years. As 3 year rotations are envisioned for biomass production very few pods would be produced in woody biofuel plantations. Fast growing South American *Prosopis* have been planted for ornamentals in the Tucson and Phoenix areas for several decades along highways and around buildings but no visible spread of these morphologically distinct species onto rangelands has been observed.

The spread of highly selected native mesquite strains for early and high pod producing characters constitute more of a

problem. Since these pods would be harvested soon after they have fallen and since cattle would be excluded from the high pod producing areas, a sufficiently low risk could be maintained.

The spread of mesquite onto rangelands has subtle but important benefits. We postulate that as cattle were continuously grazed on non-fertilized grasslands, the nitrogen nutrient cycling was interrupted. As the soils became lower and lower in nitrogen, grasses became unable to compete with nitrogen fixing mesquite so that mesquite became the dominant vegetation type. When ranchers removed the mesquite by mechanical or herbicide means, the luxuriant grass production which followed was interpreted as being solely due to release in water competition from mesquite. Only recently has nitrogen fixation in mesquite and several fold higher soil N and organic matter levels under mesquite (Tiedeman and Klemmedson, 1973) been demonstrated.

Environmental assessments of mesquite biomass farming should be compared to environmental assessments of alternative fuels likely to be used in the latter part of this century i. e. coal and nuclear. Dense stands of established mesquite biomass farms could easily provide wildlife habitat for birds and small mammals and would be considerably less objectionable than strip mines. The ash produced from biomass is generally less (1-2%) than ash produced from coal (6-8%). Positive benefits from biomass derived ash would be possible from ash distribution on the biomass farm to recycle phosphate, potassium, and micro-nutrients. Waste

disposal from nuclear plants is clearly a more difficult issue to resolve. The sulfur content of woody biomass fuels is negligible compared to coal and would obviate the need for complex  $\text{SO}_2$  removal devices. Particulate matter problems from wood probably would be similar to coal.

If the biomass plantation were to be abandoned after 20 or 30 years, considerable root plowing and raking would be necessary to return the land to a form suitable for agriculture. *Prosopis* leaf litter probably has substantially less protein than the 23% crude protein (D. Kohl-pers. comm.) found in healthy *Prosopis* but the nearly 1 cm thick leaf litter layer observed under 3 year old *P. chilensis* trees undoubtedly contains substantial quantities of nitrogen and organic matter. After 20 to 30 years of biomass farming we would expect soil nitrogen, organic matter and associated fertility parameters to be considerably greater than before the biomass farm was established.

In summary, in South Texas we believe electrical generating facilities supported by *Prosopis* biomass farming operations will prove to be more attractive environmentally than either nuclear or coal supported systems.

## XIII. General Summary

## A. Evaluation of Plant Characteristics Affecting Biomass Production

It is unlikely that one plant selection will serve all geographical areas, uses, and ecological conditions equally well. A synthesis of positive and detracting attributes of at least one accession of each *Prosopis* species is presented in Table 53 to gauge the success a particular accession may have in meeting site specific requirements. Some of the traits have been examined in a cursory fashion so that minor management practice changes might substantially alter these results. For example greater coppicing percentages might have been observed if chain saw cuts were made higher than ground level to include more stem primordia.

The three *Prosopis* accessions which have the greatest potential for woody biomass production in semi-arid southwestern United States are *P. alba* (0166), *P. chilensis* (0009), and *P. articulata* (0016). *P. alba* (0166) had the highest biomass production of the three selections, it has good coppicing characteristics, and low psyllid insect damage. *P. alba* (0166) has been successfully rooted from cuttings and selections without thorns have been observed. The frost and salinity tolerances of *P. alba* (0166) have not been measured but this tree occurs where a 5 mm salt layer covers the ground and a mature tree survived a -9°C (16°F) frost in Dec., 1978 without apparent damage. We believe it will prove to be more frost hardy than either *P. articulata* (0016) or *P. chilensis* (0009).

*P. chilensis* (0009) has high biomass productivity, good copicing characteristics, lower psyllid damage than either *P. alba* (0166) or *P. articulata* but is more difficult to root than either *P. alba* (0166) or *P. articulata* (0016). The frost tolerance of *P. chilensis* and *P. articulata* are approximately equal and probably significantly less than *P. alba* (0166). Thornless trees of *P. chilensis* (0009) have been cloned. No pod production has occurred on 4 year old trees. As noted in Riverside plots *P. chilensis* will probably produce more biomass in drier regimes than will *P. articulata*.

*P. articulata* is a good biomass producer that seems more responsive to water applications (such as in the greenhouse salinity experiment) than *P. chilensis*. All trees in this accession have numerous large thorns, that would detract from its potential for biomass farming but would prove advantageous for privacy hedges, barriers or areas subject to severe browse pressure. *P. articulata* has low frost tolerance but grows well in salinities  $\frac{1}{2}$  that of seawater.

Promising pod producing accessions are *P. velutina* (0020), *P. pubescens* (0245), *P. velutina* (0032), and the putative hybrid (0388) with 40-44% sugar pods (not reported in Table 53). In spite of high pod production *P. sp.* (0080) is too multistemmed at ground level to be promising. It is too early to speculate which accessions will be most productive at maturity.

*P. juliflora* (0044) from West Africa, *P. pallida* (0041) from

Table 53

SUMMARY OF PLANT CHARACTERISTICS AFFECTING BIOMASS PRODUCTION

Species	Biomass <sup>1</sup>	Biomass <sup>2</sup>	Pod <sup>3</sup>	Pod <sup>4</sup>	Coppice <sup>5</sup>	Frost <sup>6</sup>	Insect <sup>7</sup>	Thorns <sup>8</sup>	N <sub>2</sub> Fixation <sup>9</sup>	Salinity <sup>10</sup>	Rooted <sup>11</sup>
	Tree	Tree	Tree	Tree							Cuttings
	Tree	Imp.	Tree	Tree	Imp.						
	UCR	Val.	UCR	Val.							
<i>P. africana</i> (0045)	0.0		0.0			Short -1.5 C ok NO-5 C		None	0.008		
<i>P. alba</i> (0039)	6.8	10.6	48	52	100%	Short -5 C ok	0.56	Some			
<i>P. alba</i> (0132)	4.3	15.9			100%		1.69		0.18		
<i>P. alba</i> ? (0166)		29.0		34	75%		1.13	Some			YES
<i>P. articulata</i> (0016)	7.8	18.5	41	68	25%	Short -5 C ok	1.33	All	0.63	1.8%	YES
<i>P. chilensis</i> (0009)	9.2	18.3	0.0	0.0	75%	Short -5 C ok	0.63	Some	0.71	1.2%	YES
<i>P. glandulosa</i> var <u><i>glandulosa</i></u> (0028)	1.7		139			Long -5 C ok		All	0.12		
<i>P. glandulosa</i> var <u><i>torreyana</i></u> (0001)	4.9	8.1	134	0.7	50%	Long -5 C ok	2.06	All	0.60	1.2%	YES
<i>P. juliflora</i> (0044)	0.0	10.4	0.0	0.7	25%	Short -1.5 C ok NO-5 C	1.63				

con't (2)

Table 53

Species	Biomass <sup>1</sup>	Biomass <sup>2</sup>	Pod <sup>3</sup>	Pod <sup>4</sup>	Coppice <sup>5</sup>	Frost <sup>6</sup>	Insect <sup>7</sup>	Thorns <sup>8</sup>	N <sub>2</sub> Fixation <sup>9</sup>	Salinity <sup>10</sup>	Rooted <sup>11</sup>
	Tree	Tree	Tree	Tree			Damage				Cuttings
	UCR	Imp.	UCR	Imp.							Val.
<u>P. kuntzei</u> (0130)	0.4		0.0			Short -5 C ok		All	0.23		NO
<u>P. laevigata</u> (0114)	3.2		0.0			Short -5 C ok		All			
<u>P. nigra</u> (0038)	4.8	2.5			75%	Short -5 C ok NO Long -5 C	1.25	All	0.60		
<u>P. pallida</u> (0041)	0.0	5.0	0.0	0.25	0%	Short -1.5 C ok NO-5 C	1.63	All	1.05	1.8%	YES
<u>P. pubescens</u> (0245)		2.6		86	25%		0.08	All			
<u>P. ruscifolia</u> (0131)	1.0		0.0			Short -5 C ok		All	0.18		
<u>P. tamarugo</u> (0042)	1.7		0.0						0.13		
<u>P. tamarugo</u> (0317)		0.2			100%	Short -5 C ok NO Long -5 C	0.0	All		1.8%	NO
<u>P. velutina</u> (0020)	3.0	3.7	464	35	75%	Short -5 C ok	1.75	All		0.6%	YES
<u>P. spp.</u> (0080)	1.4		414			Short		All			

con't (3)

Table 53

Species	Biomass <sup>1</sup>	Biomass <sup>2</sup>	Pod <sup>3</sup>	Pod <sup>4</sup>	Coppice <sup>5</sup>	Frost <sup>6</sup>	Insect <sup>7</sup>	Thorns <sup>8</sup>	N <sub>2</sub> Fixation <sup>9</sup>	Salinity <sup>10</sup>	Rooted <sup>11</sup>
	Tree UCR	Tree Imp. Val.	Tree UCR	Tree Imp. Val.			Damage				Cuttings
<u>Cercidium floridum</u> (0324)	2.4				0%		0.0		0.0		
<u>Leucaena leucocephala</u> K-8 (0147)	15.5				75%		0.0	None	YES		
<u>Olneya tesota</u> (0343)	0.3				75%		0.0	All	.33		
<u>Parkinsonia aculeata</u> (0322)	13.0				100%		0.0	All	NO		NO

1. Values are for UCR third season average of 3 treatments measured oven dry biomass/tree (kg).
2. Values (kg) are for coefficient calculated oven dry weight at end of second season.
3. Pods per tree UCR 3rd season dry irrigation plot (grams).
4. Pods per tree Imperial Valley screening trial (grams).
5. Coppice is the percent of stumps cut in 1979 that sprouted in 1980. Only four stumps were measured per accession.
6. Short-1.5°C indicates survived several-1.5°C frosts on UCR campus. Short-5°C indicates exposure to an absolute minimum of -5°C suspected to be less than several hours duration. Long -5°C indicates exposure to 12 hours of below freezing weather which contained a -5 C°freeze.
7. Insect damage ranges from 0.0 to 3.0 with 0.0 being no damage and 3.0 being severe damage.
8. *P. africana* is the only species in which all trees possess no thorns. Accessions listed as some have individual trees without thorns.
9. These are values listed in mg acetylene reduced per hour per plant. All selections listed with nitrogen fixation rates possessed nodules. Yes and no indicates positive or negative literature confirmation of nitrogen fixation.
10. Indicates maximum salinity level in watering media that does not significantly inhibit stem growth.
11. Yes-indicates cuttings have been successfully rooted. No-indicates an unsuccessful attempt to root cuttings.

Hawaii, and *P. africana* (0045) from West Africa cannot tolerate cold temperatures of even sub-tropical climates such as southern California. *P. juliflora* (0044) and *P. pallida* (0041) may show promise for truly tropical regions.

The *P. alba* accessions (0039) and (0132) collected by Solbrig in Argentina appear sufficiently promising that additional collections should be made in Argentina for biomass production, frost tolerance, and psyllid resistance.

Selections such as *P. laevigata* (0114) from Mexico, *P. glandulosa* var. *glandulosa* (0028) from west Texas, *P. nigra* (0038), and *P. ruscifolia* (0131) do not possess any outstanding character that warrants their inclusion in future selection efforts. In spite of its slow growth, the very dense wood (S.G. = 1.25) of *P. kuntzei* warrants its being carried along in a screening nursery.

The extremely high salt tolerance of *P. tamarugo* (0042) and its complete psyllid resistance suggests it should be carried forward in spite of its slow growth. Perhaps additional Chilean collections should be made for faster growth.

*Leucaena leucocephala*'s complete resistance to psyllids, its capability to grow in cooler weather than *Prosopis*, and its high nitrogen fixing characteristics makes it especially useful in some circumstances.

#### B. Estimation of Biomass in Kg/Ha

No plots were established that were large enough to evaluate the edge effect through multiple rows of trees and unequivocally

determine oven dry biomass in kg/ha. Nevertheless estimates have been made from irrigation plots at UCR and the Imperial Valley screening trial and water use efficiency plots.

The Riverside plots were in a 4 x 3 array that only had 2 inner trees. In the *P. chilensis* (0009) medium and dry plots the two inner trees were 68% of the average tree biomass per plot illustrating a more severe edge effect than in Imperial Valley trees where the inner trees were 81% of the average biomass per plot. The *P. chilensis* (0009) average measured (not projected from regression equations) oven dry biomass for the inner trees in the medium and dry irrigation treatment were 6.0 and 6.2 kg that corresponds to a 41 T/ha 3 season yield (2.5 years) or a 13.7 T ha<sup>-1</sup> annual increment. This yield was obtained with a total irrigation plus rainfall of 1390 mm or a season average of 460 mm (18.2").

The replicate plots in the Imperial Valley water use study consisted of 25 trees in a 5 x 5 array that contained 9 inner trees. The first and second season dry matter production for these inner trees were 9.8 and 19.2 T/ha for *P. alba* (0039) and 11.7 and 16.9 T/ha for *P. chilensis* (0009). The two season average annual production was 14.5 T/ha.

The total dry matter production for all 55 selections harvested in the Imperial Valley screening trial was 16.5 T/ha at the end of the second season which is an average annual increment of 8.2 T/ha. The average tree for all accessions was 9.2 kg and the

largest tree was over 6 times greater with a dry biomass of 56.3 kg.

In climates with temperatures similar to Imperial Valley we believe a reasonable production goal would be  $48 \text{ T/ha}^{-1}$  at the end of 3 years. A three year growing cycle would be sufficiently short to provide a rapid return on the investment and a  $48 \text{ T/ha}$  wood density would be great enough to fully utilize harvesting equipment while minimizing transportation costs. This  $48 \text{ T/ha}$  production could be achieved if the second season productivity in the water use plots for *P. alba* (0039) and *P. chilensis* (0009) remained the same (and did not increase as expected) or if clones which produced 56.3 kg in two seasons at  $1.5 \times 3.6 \text{ m}$  spacing were planted at wider ( $3 \text{ m} \times 3 \text{ m}$ ) spacings and allowed an additional year to achieve 45 kg/tree. ( $50 \text{ T ha}^{-1}$ ).

### C. Commercialization of Mesquite Biomass Farming

We foresee no technically insurmountable barriers to commercialization. The major problem facing commercialization is the lack of sufficient quantities of either seed or clonal propagules. The current DOE grant at Texas A&I is devoting \$33,000/yr to develop clonal propagation methods. Development of equipment items such as multiple row planters and matching multiple row cultivators, row markers, and increased mechanization of greenhouse operations will be necessary to be efficient and cost effective. A quantitative evaluation of phytotoxicity from multiple levels of the major classes of insecticides and herbicides is required prior to

stablishment of commercial sized stands. An evaluation of coppice regrowth from cuts of different height and from different seasons of the year is also essential.

If 100-200 acre plots were established every year for four years with yearly improvements in greenhouse and field techniques incorporated into the planting operation, sufficient economic and technical information should be available at the end of the fourth year to establish 20,000-30,000 acre plantations capable of supporting small commercial size (20 megawatt) electrical generating facilities. A two to three year lead time would be required to develop 50,000-100,000 stock plants for cuttings in at least 50,000 ft<sup>2</sup> of greenhouses to propagate the 8-10 million seedlings required.

#### D. Current and Future Research Activities

In January, 1981 the mesquite research project was transferred to the Caesar Kleberg Wildlife Research Institute at Texas A&I University in Kingsville, Texas. Kingsville has 27" annual rainfall, low frost and is located in nearly contiguous dense stands of mesquite which occur on millions of acres of South Texas. The U.S. Department of Energy and the Caesar Kleberg Wildlife Research Institute have jointly funded 30 acres of replicated field trials, a 2800 ft<sup>2</sup> greenhouse, four growth chambers for evaluation of cutting experiments, a plant tissue culture facility, administrative support, 100% of Felker's time, a full time technician, a post-doc, and 2 graduate students.

The field experiments are designed to evaluate the effect of soil phosphate levels on flowering and pod production, to compare the 4 best pod producing accessions, to establish seed orchards, to develop selections for ornamental purposes, to screen new accessions, to further study the 44% sugar pod producer, to evaluate *Leucaena leucocephala* (K-8) for wood and forage production and to evaluate the biomass production and harvesting characteristics of the best biomass producer, *P. alba* (0166) every year for four years.

#### Conclusions

Our projected mesquite wood chip prices of \$25 per oven dry ton (\$1.50 per million Btu) harvested in the field are currently less than coal, oil, or natural gas prices in South Texas. The land resource base suitable to mesquite biomass farming is extensive with sufficiently low land leases ( $\$10 \text{ acre}^{-1} \text{year}^{-1}$ ) to be a minor component of proposed biomass farming operations. Woody biomass plantations producing 16 oven dry T/ha (7 T/acre) could supply a 500 megawatt plant within a 15 mile haul which is 10 times larger than the largest wood fired electrical generating facility in the United States that currently use forest by-products and residues. Preliminary environmental assessments for mesquite biomass farming supported electrical generation appears more attractive than coal or nuclear.

## XIV. REFERENCES

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## XV. SUPPORTING MATERIALS

## A. PUBLICATIONS AND MANUSCRIPTS PREPARED UNDER CURRENT DOE FUNDING

Peter Felker (1979) "Mesquite-An all purpose arid land tree" In New Agricultural Crops, G. A. Ritchie (Ed.), American Association for the Advancement of Science Symposium Volume 38.

Peter Felker and Philip Gardner (1979) Potential use of desert plants for food and energy production in California. J. Latting (Ed.), Proceedings of Desert Resources Symposium. California Native Plant Society Publishers. In Press.

Peter Felker, G.H. Cannell, Peter R. Clark and Joseph F. Osborn (1980) Screening Prosopis (mesquite) for biomass production and nitrogen fixation. Proc. International Congress for Study of Semi-Arid and Arid Zones, La Serena, Chile.

Peter Felker, Peter R. Clark, Joseph F. Osborn, and G.H. Cannell (1980) Nitrogen cycling-water use efficiency interactions in relation to management of tree legumes (Prosopis). "Browse in Africa" Symposium, Addis Abba, Ethiopia.

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Peter Felker (1980) Arid land plants: promising new tools for economic development and basic research. In "Symposium: the economic development of desert plants" Symposium proceedings sponsored by AIBS and Ecological Society of America, Tucson, AZ.

Peter Felker and Peter R. Clark (1981) Nodulation and nitrogen fixation (acetylene reduction) in desert ironwood (Olneya tesota) Oecologia 48: 292-293

Peter Felker (1980) Energy Farming of Desert Species. Presented at Energy Farms Workshop, California Energy Commission. 14 July 1980.

Peter Felker (1980) Development of low water and nitrogen requiring plant ecosystems to increase and stabilize agricultural production of arid land developing countries. Document prepared for Office of Technology Assessment of U.S. Congress. Presented Washington, D.C. 23 Nov 1980.

Peter Felker, Peter R. Clark, Joseph F. Osborn, and G.H. Cannell (1980) Utilization of mesquite (Prosopis spp.) pods for ethanol production. In Tree Crops for Energy Production on Farms. Proceedings of a workshop sponsored by Solar Energy Research Institute (SERI) at Estes Park, CO 14 Nov. 1980

Peter Felker and Peter R. Clark (1981) Rooting of mesquite (Prosopis) cuttings. J. Range Manage. In Press.

Peter Felker, Peter R. Clark, Joseph F. Osborn, and Glen H. Cannell (1981) Biomass estimation in a young stand of mesquite (Prosopis spp.), iron-wood (Olneya tesota) and Palo Verde (Cercidium floridum and Parkinsonia aculeata). J. Range Manage. In Press.

Peter Felker, Peter R. Clark, A.E. Laa, and P.F. Pratt (1980) Salinity tolerance of Prosopis articulata, P. chilensis, P. glandulosa var torreyana, P. pallida, P. tamarugo, and P. velutina grown in sand culture on nitrogen free media. Plant and Soil. In Press.

#### Manuscripts Submitted

Peter Felker, Peter R. Clark, Phyllis Nash, Joseph F. Osborn, and Glen H. Cannell (1981) Screening Prosopis (Mesquite) for cold tolerance. Forest Science.

Peter Felker (1981) Ecological implications of variation in psyllid (Alpha-laroida spp) insect resistance among Prosopis species in Californian and Chilean deserts. Oecologia.

Peter Felker and Peter R. Clark (1981) Position of mesquite (Prosopis spp) nodulation and nitrogen fixation (acetylene reduction) in 3 m long phraetophytically simulated soil columns. Plant and Soil.

## B. PRESENTATIONS

- Speaker: Peter Felker  
Title: Ethnobotanical and sylviculture aspects of mesquite (Prosopis spp.) in southern California.  
Date: 13 June 1978  
Occasion: Society for Economic Botany Annual meeting, St. Louis, MO
- Speaker: Peter Felker  
Title: Uses and potential of Prosopis as a food source in southern California.  
Date: 1 August 1978  
Occasion: International Group for Study of the Mimosoideae triannual meeting, London, England
- Speaker: Peter Felker  
Title: Mesquite-A leguminous tree for increasing food, fuel, and soil fertility in semi-arid climates.  
Date: 5 October 1978  
Occasion: Departmental Seminar of the Dept. of Soil & Environmental Sciences
- Speaker: Peter Felker  
Title: Possibilities for fuel and food from desert legumes.  
Date: 1 December 1978  
Occasion: Public forum sponsored by Desert Advisory Committee of Bureau of Land Management, U.S. Dept. of Interior
- Speaker: Peter Felker  
Title: Mesquite--A leguminous tree for increasing fuel, food, and soil fertility in semi-arid climates.  
Date: 5 February 1979  
Occasion: UCR Plant Sciences Department Seminar
- Speaker: Peter Felker  
Title: Food, fuel and feed from mesquite.  
Date: 25 May 1979  
Occasion: Invited seminar of USDA Western Regional Research Center, Albany, California
- Speaker: Peter Felker  
Title: Mesquite: A tree legume resource for semi-arid climates.  
Date: 15 September 1979  
Occasion: "Working Group on Scientific and Technical Cooperation between Mexico and the United States of America in the Field of Agriculture", Saltillo, Mexico
- Speaker: Peter Felker  
Title: Mesquite (Prosopis spp.): A nitrogen-fixing carbohydrate and protein producing tree for semi-arid climates.  
Date: 30 October 1979  
Occasion: Symposium speaker for American Association of Cereal Chemists, 64th Annual Meeting, Washington, D.C.

- Speaker: Peter Felker  
Title: Mesquite: A biomass energy source for arid lands.  
Date: 18 December 1979  
Occasion: Invited seminar for bio-energy group at Jet Propulsion Lab, Pasadena, CA
- Speaker: Peter Felker  
Title: Screening Prosopis mesquite for biomass and nitrogen fixation.  
Date: January, 1980  
Occasion: Supported presentation of International Congress for Study of Semi-Arid and Arid Zones, La Serena, Chile
- Speaker: Peter Felker  
Title: Nitrogen cycling-Water use efficiency interactions in relationship to management of tree legumes (Prosopis).  
Date: April, 1980  
Occasion: Invited seminar of "Browse in Africa Symposium" sponsored by International Livestock Center for Africa, Addis Ababa, Ethiopia
- Speaker: Peter Felker  
Title: Developing Prosopis for energy resources in arid lands.  
Date: May, 1980  
Occasion: Invited seminar of Office of Arid Land Studies and Dept. of Plant Science, University of Arizona, Tucson, AZ
- Speaker: Peter Felker  
Title: Methods for acquisition, storage, and evaluation of leguminous tree germplasm.  
Date: 3 June 1980  
Occasion: Invited presentation at "New and Underutilized Biological Resources" Symposium, Medellin, Colombia. AAAS, NSF and Interciencia, sponsors
- Speaker: Peter Felker  
Title: Uses of tree legumes in semi-arid regions.  
Date: 20 June 1980  
Occasion: Invited presentation at Symposium on Legumes, Society for Economic Botany, Bloomington, IN
- Speaker: Peter Felker  
Title: Development of Energy Resources of Prosopis for Arid Lands.  
Date: June, 1980  
Occasion: Invited seminar of Departments of Forestry and Botany and Plant Pathology, Michigan State University, E. Lansing, MI
- Speaker: Peter Felker  
Title: Energy farming of desert species.  
Date: 14 July 1980  
Occasion: Invited presentation at Energy Farms Workshop, California Energy Commission, Sacramento, CA

- Speaker: Peter Felker  
Title: Arid land plants: Promising new tools for economic development and basic research.  
Date: 4 August 1980  
Occasion: Invited presentation at Symposium for Economic Development of Desert Plants. Sponsored by American Institute of Biological Sciences and the Ecological Society of America, Tucson, AZ
- Speaker: Peter Felker  
Title: Development of low water and nitrogen requiring plant ecosystems to increase and stabilize agricultural production of arid land developing countries.  
Date: 23 November 1980  
Occasion: Invited presentation for Office of Technology Assessment of U.S. Congress. Presented Washington, D.C.
- Speaker: Peter Felker  
Title: Utilization of mesquite (Prosopis spp.) pods for ethanol production.  
Date: 14 November 1980  
Occasion: Invited presentation for Tree Crops for Energy Production on Farms workshop sponsored by Solar Energy Research Institute (SERI) at Estes Park, CO
- Speaker: Peter Felker  
Title: Developing economic potential of mesquite.  
Date: January, 1981  
Occasion: Invited seminar by Dean E. Cook, College of Geosciences, Texas A&M University, College Station, TX
- Speaker: Peter Felker  
Title: Overview of mesquite's potential for arid lands.  
Date: 23 April 1981  
Occasion: Invited presentation of Advisory Committee on Technology Innovation of U.S. National Academy of Sciences

### C. Relationship to other Programs

The major liaison with DOE supported mesquite research is the Caesar Kleberg Wildlife Research Institute that has provided 35 acres for field plots, a 2800 ft<sup>2</sup> greenhouse, and tissue culture facilities. Mesquite research is important in a wildlife institute because of the central role mesquite plays in South Texas vegetation.

Texas has a curious mixture of mesquite research and commercial activities. Texas Tech and Texas A&M continue with major mesquite eradication research programs to aid ranchers make \$2-\$5 per acre per year from cattle grazing. Crystal City, Texas, which was cut off from natural gas supplies two winters ago continues to rely heavily on mesquite for heating in the winter. Mesquite is highly regarded as a barbecue wood with numerous restaurants exclusively using mesquite wood for grilling. Native mesquite is widely employed as an ornamental in South Texas with an average retail price of \$35 for a 2 inch diameter balled tree. Mesquite parquet flooring, fireplace mantels, and gunstocks have been custom made by wealthy individuals and businesses but no commercial outlets supply mesquite lumber.

Concerns for arid-lands, anti-desertification, and production of firewood have created interest in *Prosopis* on the international scene. The Canadian International Development Research Center (IDRC) has supported a \$200,000 planting of *Prosopis* in the Sudan. The IDRC is also a major contributor to the Inter-

national Center for Research in Agroforestry (ICRAF) in Nairobi, Kenya. The U.S. Agency for International Development (AID) is currently supporting a major reforestation effort in Kenya that includes semi-arid regions. *Prosopis* is strongly being considered in Kenya's semi-arid regions and Felker will serve as consultant to AID's contractor Energy Development International (EDI) on this project. The United Nations Development Program (UNDP) provided funds for Felker to travel to the Sudan and establish a trial of 30 advanced selections of *Prosopis* for use for fuelwood, anti-desertification, and production of pods for livestock. Felker co-operated with A.E. Houri and H. Musnad of the Forestry Research Institute at Khartoum for this work. Mr. K. O. Khalifa has directed a project supported by the Sudan Council of Churches that established 160 acres of *Prosopis* along irrigation canals to prevent the sand from filling them. The Lutheran Church in America has expressed interest in *Prosopis* for reforestation of parts of Mauritania and Kenya. The Chilean government supported corporation CORFO has established 22,000 hectares of *P. tamarugo* in the rainless (less than 0.7 mm(0.03") rainfall/year) that supports sheep raising operations from production of *P. tamarugo* pod and leaf litter, Felker spent two weeks in Chile reviewing these plantations with CORFO. The Organization of American States (OAS) supported a Congress on the Study of Arid and Semi-Arid zones that paid Felker's transportation to Chile to learn of biomass research on *Prosopis*.

The Office of Technology Assessment (OTA) of the U.S. Congress conducted a workshop in "New and Innovative Biological Techniques" which included a presentation by Felker on *Prosopis*. The U.S. National Academy of Sciences has published an excellent book on "Firewood Crops" that has devoted several pages to use of *Prosopis* in arid countries. Several consulting firms in Washington, D.C. and Great Britain are currently submitting proposals to North African, East African, and Near Eastern countries to evaluate *Prosopis* for use in anti-desertification and ornamental programs.

Several major oil companies have expressed interest in the woody biomass and alcohol fuel potential (from pods) of mesquite, but thus far no significant activities have taken place.

Information developed from this research provided sufficient background for the National Science Foundation to award a \$650,000 3 year grant to a joint project of the University of California, Irvine; University of California, Riverside; and Washington University, St. Louis to study nitrogen cycling in a *Prosopis* dominated desert community. A productivity of 3,600 dry kg ha<sup>-1</sup> yr<sup>-1</sup> has been measured at a desert site receiving only 65 mm annual rainfall but located 6 m above groundwater. Even with a 30% canopy cover this productivity level is substantially higher than measured for any desert ecosystem at similar rainfall levels. Preliminary nitrogen budgets from this site indicate the trees are fixing somewhere between 10-40 kg N/ha/yr.