

## Initial Evaluation of *Prosopis alba* Griseb Clones Selected for Growth at Seawater Salinities

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*In a previous article, growth and survival of Argentine and Peruvian Prosopis were measured in a greenhouse hydroponic system in which the salinities were increased from 10 to 45 dSm<sup>-1</sup>. Twenty-one of the Prosopis alba seedlings that grew at the 45 dSm<sup>-1</sup> salinity were propagated by rooting cuttings and a seed orchard/long-term evaluation trial established. To develop predictors and/or correlations between seedling and performance in mature field trials, this study characterized the seedlings for growth, leaf, and thorn morphology and ease in asexual propagation by rooting of cuttings. The percentage rooting of all clones varied from 40 to 100%, the roots per cutting from 0.60 to 67, and the length of the longest root from 1.63 to 6.70 cm. The parent trees were selected from P. alba specimens in a highly saline area of Argentina where P. ruscifolia Griseb (which has larger leaves and 15 cm long spines) was the dominant species. Some progeny were intermediate in spine and morphological characters between P. alba and P. ruscifolia and were locally known as vinalillo (P. vinalillo Stuck). The thorn length varied from 7.7 mm to 53.3 mm for the vinalillo "species" and from 0 thorns to 28 mm for P. alba. There was no correlation between leaf/thorn characters and salinity tolerance. The overwhelmingly greater abundance of spiny P. ruscifolia over P. alba may be due to livestock palatability rather than salinity tolerance. The increasing demand for the high-quality Prosopis lumber for furniture may make recuperation of moderately saline soils (<30 dSm<sup>-1</sup>) economically attractive.*

**Keywords** agroforestry, arid, hardwood lumber, nitrogen fixation, sodic

### Introduction

Nitrogen fixing trees of the genus *Prosopis* show promise for the rehabilitation of saline soils in subtropical regions because of their high salt tolerance and because they have economically useful products that can provide the economic incentive to drive the recuperation of saline lands. The economic burden to reclaim the approximately 400 million ha of saline soils in the world (<http://www.fao.org/ag/agl/agll/spush/topic2.htm>) would be immense. Development of systems that would be sufficiently profitable to recover these saline soils are needed. We suggest that development of improved *Prosopis* clones will facilitate the rehabilitation of these

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degraded saline soils. The value of *Prosopis* is illustrated by the fact that in Argentina more than 100,000 tons of *Prosopis* logs are harvested annually for furniture, flooring, door, window, and shutter fabrication (Felker and Guevara, 2003), and flour from the ground pods are being developed for human food uses (Felker, Grados, Cruz, and Prokopiuk, 2003). In the U.S. there are numerous websites that offer mesquite (*Prosopis glandulosa* Torr. or *P. velutina* Woot.) lumber at prices greater than \$2000 per cubic meter (\$5 per board foot). Felker and Guevara (2003) have calculated that a sawn lumber price of \$800 will be required to achieve an internal rate of return of 11% for well-managed plantations of genetically unimproved stock. These workers suggested that moderately saline sites ( $<20 \text{ dS m}^{-1}$ ) with a high water table would be an ideal candidate for plantations as they should provide rates of internal return in the 20% range.

Various workers have reported high salinity tolerance for various *Prosopis* (Ahmad, Ismail, Moinuddin, and Shaheen, 1994; Baker, Sprent, and Wilson, 1995; Cony and Trione, 1998; Felker, Clark, Laag, and Pratt, 1981; Rhodes and Felker, 1988). Recently, we compared the survival and growth of *Prosopis pallida* (Humb. and Bonpl. ex Willd.) Kunth from Peru, and *P. alba* from Argentina and reported that 30 *P. alba* seedlings that grew in the highest salinity treatment ( $45 \text{ dS m}^{-1}$ ) were reotted for use in further trials and establishment of seed orchards (Velarde, Felker, and Degano, 2003). These 30 *P. alba* seedlings were selected from more than 2000 seedlings in a hydroponic selection system in the greenhouse and originated from nine mature *P. alba* specimens that we collected from a highly saline area (floodplain of the Rio Saladillo in the province of Santiago del Estero, Argentina  $28^{\circ}52'36.85''\text{S}$ ;  $63^{\circ}58'46.36''\text{W}$ ). We have also made clonal selections of *P. alba* for economically useful characters such as rapid growth rate, high pod production, and pods with improved flavor (sweeter pods without bitterness) characteristics (Felker, Lopez, Soulier, Ochoa, Abdala, and Ewens, 2001).

While these selections will probably have greater salinity tolerance than unselected *P. alba*, nothing is known about their growth rates, habits, or pod characters that will occur as they mature in the field. In a review of salt-tolerant woody species for reclamation of saline areas in Australia, Niknam, and McComb (2000) often found a correlation for *Eucalyptus* species among ranking of tolerance in greenhouse and field conditions, but such a correlation did not always occur. In this work we made an initial characterization of superior clones to serve as a baseline for predictions between long-term performance in field trials and characteristics measured in the greenhouse. Using asexual propagation by root cuttings, we have established a replicated field trial/clonal seed orchard with the same 21 elite salt-tolerant seedlings used in this study. When the trees have reached a harvestable size, we will measure form, growth rate, insect resistance, pod characters, etc. and correlate those traits with those measured in this article.

Due to frequent interspecific hybridization among *Prosopis* species, specimens with intermediate characters between several species often occur (Hunziker, Poggio, Naranjo, and Palacios, 1975). In spite of the fact that we selected specimens of *Prosopis alba* mother trees in accordance with Burkart (1976), great segregation in morphological characters was observed in the progeny. Some progeny possessed the leaflet morphology locally known as "vinalillo." Taxonomists have debated whether "vinalillo" is a hybrid between *P. alba* and *P. ruscifolia* (Hunziker et al., 1975). The weedy *P. ruscifolia* with its 15 cm long thorns is more common in the area where we collected seed than *P. alba*. Since *Prosopis* is self-incompatible and forms

interspecific hybrids, *P. alba* × *P. ruscifolia* hybrids are possible. Since both species are self-incompatible and thus highly heterozygous, one would expect considerable segregation of physiological and leaf morphological traits among the progeny. Thus we compared leaflet morphology among the progeny to determine whether any particular morphological character or “species classification” was related to salinity tolerance.

To capitalize on the high salt tolerance of these seedlings, it will be necessary to multiply them asexually. While rapid and reliable propagation by mini-grafting is possible (Ewens and Felker, 2003), this will not be useful since the rootstocks would come from genetic stock with unknown salt tolerance. Thus we characterized the potential of these clones for ability to root from stem cuttings.

## Materials and Methods

The original trees used to produce these seedlings were growing on Salorthid which was an alluvial, silty clay soil with low permeability. The electrical conductivity and exchangeable sodium percentage (ESP) in the area where these trees were, collected were 61 dS m<sup>-1</sup> and 47% for the 0–30 cm depth, 59 dS m<sup>-1</sup> and 46% for the 30–60 cm depth, and 56 dS m<sup>-1</sup> and 46% for the 60–90 cm depth (Velarde, Felker, and Gardiner, 2005).

The clones originated from 9 *P. alba* mother trees designated O1 to O9, respectively. These mother trees fell within Burkart's (1976) delineation of *Prosopis alba*. These individual plants were selected from a total of 64 plants per family evaluated (four blocks with 16 seedlings per replicate). No plants had sufficient growth to be selected from family O1 or O5 and only one plant was selected from family O2, O4, and O9. The 30 selected seedlings of *P. alba* with the maximum growth in the salinity treatments in the previous experiment of Velarde et al. (2003), were subjected to two additional months in the same 45 dS m<sup>-1</sup> experimental condition. Those plants showing a very healthy appearance and a new live apical meristem were chosen for further research. Overall plant growth was limited under this salinity level due to the small size of the root cell volume (50 cm tall plants in 5 cm deep cavity) that made them root-bound. Only 21 of the best plants from a total of 576 plants (3.6% of the total seedlings) were selected for further evaluation. Our goal was to find clones adaptable to Argentine conditions and therefore the Peruvian accessions were not evaluated due to lack of cold hardiness in Argentina.

The trees from the previous trial were repotted in normal greenhouse soil in 1-liter pots. Within the first year when they were about 1 m tall, cuttings were taken from the plants to evaluate their ease in asexual propagation by rooting cuttings. Due to the small size of these plants, the material for cuttings was limited and it was only possible to obtain five single plant replications (in separate blocks). The cuttings that resulted were used to establish a seed orchard/clonal evaluation trial with eight single tree replications in a randomized complete block design at the Universidad Catolica de Santiago del Estero Forestry Experiment Station in Fernandez, Argentina. Nine months after establishment in the field, one branch from three trees, of the same clone in different blocks were taken about 75% of maximum tree height on the sunny side (north in southern hemisphere) for leaf and thorn measurements using the criterion of Hilu, Boyd, and Felker (1982). Each sample was considered a replicate. The traits measured were length of longest leaf (mm), petiole length (mm), pairs of pinnae per leaf, length of largest pinnae, width

of largest pinnae, maximum number of leaflets per pinnae, length of leaflet, width of largest leaflet, average distance between the fourth and fifth leaflets, angle subtended by the pinnae, number of spines per node, and length of spines (mm).

The environmental conditions, hormones, and additional “rooting bacteria” used for these experiments have recently been reported (Felker et al., 2005). Basically, this system consisted of rooting; on a bench with bottom heat to provide root temperatures of about 33°C, light intensities of about 150  $\mu\text{moles m}^{-2} \text{s}^{-1}$  in the greenhouse, a mist system whose frequency was proportional to light intensity and air temperature, and a 3 second hormone dip in 100% water containing 6000  $\text{mg l}^{-1}$  potassium salt of indolebutyric acid, 9000  $\text{mg l}^{-1}$  of the potassium salt of naphthaleneacetic acid, 800  $\text{mg l}^{-1}$  thiamine HCl, and  $10^9$  bacteria  $\text{ml}^{-1}$  of both *Azospirillum* and *Agrobacterium rhizogenes* strain 232 “Tiger.” About 4 weeks after initiation of the experiment, the root system was gently removed from the pots and the root parameters measured. To avoid confounding effects related to variability in mist distribution, light intensity, etc., the cuttings were arranged in five blocks on the mist bench. We calculated the 95% confidence intervals of the number of roots per cutting, and the length of the longest root per cutting based on the five replicates.

## Results

The height growth for the 21 individual plants selected for asexual multiplication from the 45  $\text{dS m}^{-1}$  salinity treatment is provided in Table 1. Of these plants three, six, seven, and five plants had 3, 2, 1, and 0 cm growth, respectively, at seawater salinity. The seedlings with zero growth were very healthy with a green apical meristem and were among the tallest of the plants. We suspect they may have been “root bound.” The “vinalillo”-looking segregants (noted below) had no obvious differences in growth at the high salinities compared to the *P. alba* seedlings. This table also contains a brief description of the three most important economic traits, i.e., growth, size of spines, and rooting percentages that are discussed later. There appears to be little correlation among these traits. At this point in time, half-sib families, O7B3P11 and O9B4P14, appear to be among the overall most promising clones.

Quantitative measurements on the leaf characteristics in Table 2 show the segregation of what is commonly known as “vinalillo” in the progeny of the *P. alba* mother trees. The major distinguishing features between these two “groups” are: (1) that *P. alba* has many more leaflets per pinnae; (2) the leaflets of *P. alba* are smaller in width and length than vinalillo; and (3) the pinnae of vinalillo are more closely spaced within the pinnae. For example, within progeny of mother tree O7, plant O7B3P3 (a *P. alba*) and O7B4P6 (vinalillo) had 90 vs. 18 leaflets per pinnae, 9.3 vs. 26.7 mm in length for longest leaflet, 1.33 vs. 4.33 mm for width of the leaflet, and 2.0 vs. 11.0 mm distance between the fourth and fifth leaflet on the pinnae, respectively. These leaf characters for *P. vinalillo* are quite similar to that reported by Hunziker et al. (1975) (leaflet width 3–5 mm, 4–7 pairs of leaflets, and 5–12 mm between leaflets), which he suggested was a hybrid between *P. alba* and *P. ruscifolia*. Thus, in Tables 1 and 2 we have placed a V by those selections that unequivocally had the vinalillo morphology. As noted in Table 2, there was very great differences in spine characters among the vinalillo types with clone O4B1P6 having 53 mm long spines (13 mm 95% confidence interval) versus 7.7 mm long spines (4 mm confidence interval) for clone O7B4P6. The spine characters for the vinalillo clone O7B4P6 were of the same size as *P. alba* which is not deemed a problem by the local people. It is also

**Table 1.** Height growth of *Prosopis alba* clones in 45 dS m<sup>-1</sup> salinity and summary of most important economic traits

Summary of most important economic traits based on Tables 1 and 2 and Figure 1	<i>P. alba</i> clone (family, block, plant)	Height growth in 45 dS m <sup>-1</sup> salinity (cm)
Moderately productive, small spine, high rooting	O2B4P1	2
Moderately productive, small spine, high rooting	O3B1P13	2
Least productive, small spine, high rooting	O3B4P12	0*
Least productive, medium spine, low rooting	O3B4P7(V)	0*
Moderately productive, small spine, high rooting	O3B4P8	1*
Moderately productive, very large spine, medium rooting	O4B1P6(V)	2
Most productive, large spine, medium rooting	O6B1P11	3
Moderately productive, small spine, high rooting	O6B1P12	1
Moderately productive, small spine, high rooting	O6B1P13	1
Moderately productive, large spine, medium rooting	O6B4P4	1
Moderately productive, medium spine, high rooting	O7B3P10	1
Most productive, medium spine, high rooting	O7B3P11	3
Moderately productive, medium spine, high rooting	O7B3P3	1
Moderately productive, no spine, low rooting	O7B3P8	1
Least productive, medium spine, high rooting	O7B4P11	0*
Moderately productive, large spine, low rooting	O7B4P4(V)	2
Least productive, small spine, high rooting	O7B4P6(V)	0*
Moderately productive, medium spine, high rooting	O7B4P8	2
Moderately productive, medium spine, high rooting	O8B3P14	2
Least productive, no spine, high rooting	O8B3P15	0
Most productive, medium spine, medium rooting	O9B4P14	3

In spite of the zero growth of the clones noted with an asterisk, they were included for asexual propagation based on a visual inspection 2 months after the last measurement (with continued 45 dS m<sup>-1</sup> salinity) for vigor, size, and new meristem growth. The letter V after the seedling number indicates it had a leaf morphology of vinalillo rather than *P. alba*. These 21 clones originated from 9 *P. alba* mother trees designated O1 to O9, respectively. B1 through B4 is the block in the greenhouse salinity trial while P1–P16 is the code for the 16 plants in each block.

**Table 2.** Leaf and spine characteristics (mean  $\pm$  95% confidence interval (CI)) of *Prosopis alba* clones that grew in 45 dS m<sup>-2</sup> salinity level

Clone (Family, Block, Plant)	Leaf length (mm)		Petiole length (mm)		Pair pinnae		Length pinnae (mm)		Width pinnae (mm)		Maximum no. leaflets		Leaflet length (mm)		Leaflet width (mm)		Distance between leaflet (mm)		Pinnae angle degree		Number of spines/node		Spine length (mm)		
	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean
Control 20	128	23	19.3	5.8	2.33	0.65	92.0	13.8	16.7	3.3	77.3	12.5	9.3	1.3	1.33	0.65	1.00	0.00	73.3	26.1	2	0	10.0	8.0	
Control 23	135	15	25.7	5.8	2.00	0.00	93.0	14.2	17.3	2.8	75.3	16.4	8.7	1.3	1.67	0.65	1.00	0.00	65.0	15.0	2	0	10.3	9.9	
Control 24	142	12	34.3	10.5	2.00	0.00	90.0	15.0	15.7	4.6	81.3	19.0	7.7	1.3	1.67	0.65	1.00	0.00	58.3	16.3	2	0	6.5	5.6	
O2B4P1	167	23	25.0	9.8	3.00	0.00	110.0	11.3	16.7	3.3	94.0	7.8	8.3	1.7	1.67	0.65	1.00	0.00	68.3	61.0	2	0	5.0	0.0	
O3B1P13	105	11	11.7	3.3	3.00	0.00	81.7	6.5	11.7	3.3	82.7	18.2	6.7	3.3	1.00	0.00	1.00	0.00	53.3	19.9	2	0	4.3	1.3	
O3B4P12	130	0	16.7	3.3	2.67	0.65	95.0	5.7	15.3	2.8	82.0	7.8	8.0	2.0	1.00	0.00	2.00	0.00	51.7	8.6	2	0	5.0	0.0	
<b>O3B4P7 (V)</b>	<b>152</b>	<b>26</b>	<b>34.7</b>	<b>7.7</b>	<b>1.00</b>	<b>0.00</b>	<b>121.7</b>	<b>14.2</b>	<b>36.0</b>	<b>4.1</b>	<b>24.0</b>	<b>2.3</b>	<b>18.3</b>	<b>3.3</b>	<b>2.67</b>	<b>0.65</b>	<b>6.33</b>	<b>0.65</b>	<b>58.3</b>	<b>8.6</b>	<b>2</b>	<b>0</b>	<b>13.3</b>	<b>3.3</b>	
O3B4P8	148	20	26.7	13.1	2.00	0.00	110.0	9.8	16.7	3.3	86.0	11.3	9.3	1.3	1.33	0.65	2.00	0.00	55.0	34.4	2	0	3.7	1.3	
<b>O4B1P6 (V)</b>	<b>137</b>	<b>7</b>	<b>35.0</b>	<b>11.3</b>	<b>1.00</b>	<b>0.00</b>	<b>103.3</b>	<b>8.6</b>	<b>28.3</b>	<b>3.3</b>	<b>26.0</b>	<b>2.3</b>	<b>14.3</b>	<b>1.3</b>	<b>3.00</b>	<b>0.00</b>	<b>5.00</b>	<b>0.00</b>	<b>76.7</b>	<b>31.2</b>	<b>2</b>	<b>0</b>	<b>53.3</b>	<b>13.1</b>	
O6B1P11	173	31	35.0	9.8	2.00	0.00	118.3	21.4	18.3	4.0	79.3	6.9	9.7	0.7	1.67	0.65	2.67	1.31	40.0	9.8	2	0	28.3	3.3	
O6B1P12	148	3	33.3	3.3	2.00	0.00	93.3	8.6	15.0	0.0	61.3	15.4	8.0	0.0	1.00	0.00	2.00	0.00	61.7	17.3	2	0	6.5	5.6	
O6B1P13	172	3	32.3	12.2	2.00	0.00	121.7	18.2	19.0	5.9	83.3	3.5	10.7	1.3	2.00	0.00	2.00	0.00	48.3	22.9	2	0	5.0	0.0	
O6B4P4	147	3	23.3	3.3	2.00	0.00	108.3	3.3	16.7	3.3	82.7	7.3	9.3	1.3	1.00	0.00	2.00	0.00	50.0	5.7	2	0	18.3	3.3	
O7B3P10	172	20	45.3	10.5	2.00	0.00	113.3	14.2	20.3	3.3	82.0	15.7	11.0	2.0	1.67	0.65	1.00	0.00	71.7	14.2	2	0	8.3	3.3	
O7B3P11	172	23	37.7	7.7	2.00	0.00	123.3	6.5	19.3	1.3	88.0	6.0	9.0	1.1	2.00	0.00	1.00	0.00	81.7	16.3	2	0	15.0	9.8	
O7B3P3	157	9	25.0	5.7	3.00	0.00	105.0	17.0	14.3	1.3	90.0	13.8	9.3	0.7	1.33	0.65	2.00	0.00	45.0	22.6	2	0	10.0	0.0	
O7B3P8	113	9	24.0	6.0	2.33	0.65	81.7	3.3	13.7	2.6	66.7	6.5	7.3	2.4	1.00	0.00	1.67	0.65	76.7	17.3	0	0	0.0	0.0	
O7B4P11	137	21	16.0	4.1	3.00	0.00	108.3	11.8	17.0	2.0	71.3	9.1	10.0	0.0	2.00	0.00	2.67	0.65	55.0	31.5	2	0	13.3	3.3	
<b>O7B4P4 (V)</b>	<b>153</b>	<b>7</b>	<b>30.0</b>	<b>0.0</b>	<b>2.00</b>	<b>0.00</b>	<b>105.0</b>	<b>5.7</b>	<b>21.7</b>	<b>3.3</b>	<b>46.7</b>	<b>5.7</b>	<b>11.7</b>	<b>1.7</b>	<b>2.33</b>	<b>0.65</b>	<b>3.67</b>	<b>0.65</b>	<b>58.3</b>	<b>3.3</b>	<b>2</b>	<b>0</b>	<b>23.3</b>	<b>3.3</b>	
<b>O7B4P6 (V)</b>	<b>153</b>	<b>38</b>	<b>23.3</b>	<b>3.3</b>	<b>1.00</b>	<b>0.00</b>	<b>131.7</b>	<b>40.1</b>	<b>46.7</b>	<b>3.3</b>	<b>18.0</b>	<b>2.3</b>	<b>26.7</b>	<b>3.3</b>	<b>4.33</b>	<b>0.65</b>	<b>11.00</b>	<b>2.99</b>	<b>81.7</b>	<b>6.5</b>	<b>2</b>	<b>0</b>	<b>7.7</b>	<b>4.6</b>	
O7B4P8	150	0	25.0	0.0	3.00	0.00	110.0	0.0	15.0	0.0	84.0	6.4	9.0	0.0	1.50	0.80	1.50	0.80	50.0	32.0	2	0	10.0	0.0	
O8B3P14	160	0	31.7	3.3	2.00	0.00	111.7	3.3	18.3	3.3	71.3	1.3	10.0	0.0	2.00	0.00	2.00	0.00	40.0	5.7	2	0	15.0	0.0	
O8B3P15	192	14	33.3	8.6	2.00	0.00	141.7	11.8	22.3	2.8	74.0	3.9	10.7	1.3	2.00	0.00	2.33	0.65	76.7	16.3	0	0	0.0	0.0	
O9B4P14	152	31	21.7	3.3	3.00	0.00	116.7	6.5	18.3	3.3	88.7	11.4	9.7	0.7	1.00	0.00	2.00	0.00	46.7	19.9	2	0	8.3	3.3	

The controls were within Burkarts (1976) delineation of species for *P. alba*. Bold and V after the clone designates it had the morphology locally known as *vinallilo*. Branches were taken from three trees in different replications in the field for these measurements.

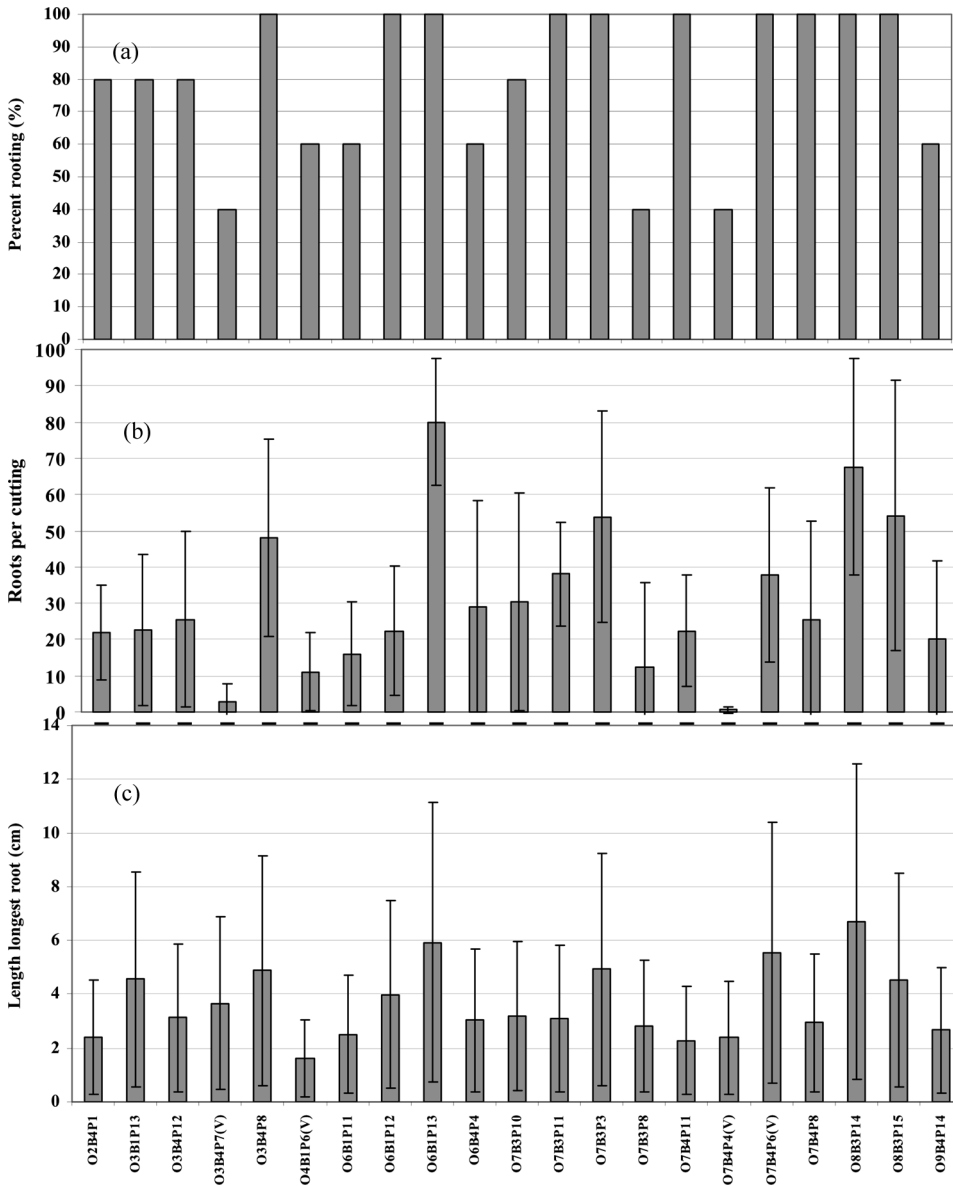
to be noted that two of the *P. alba* types, O8B3P15 and O7B3P8, had no spines at all. The great morphological differences within these salt-tolerant clones would suggest that genes for salt tolerance and leaf morphological characters are segregating more or less independently. Thus leaf morphological characters probably will not be useful in selecting *Prosopis* for growth at high salinity levels.

As can be seen in Figures 1a, 1b, and 1c there was a great difference among the salt-resistant seedlings in percentage rooting, number of roots per cutting, and length of the longest root. Ten of the 21 seedlings had 100% rooting and another four had 80% rooting. Among those with 100% rooting, as judged by the 95% confidence intervals, there were significant differences in the number of roots per cutting but not the length of the longest root per cutting. Five clones (O3B4P8, O6B1P13, O7B3P3, O8B3P14, and O8B3P15) had both 100% rooting percentages and more than 40 roots per cutting and would seem particularly promising for asexual propagation. There was a tendency for the vinalillo clones to have a lower number of roots per cutting, e.g., clones O3B4P7 (V), O4B1P6 (V), and O7B4P4 (V). There was a tendency for the clones with the greatest number of roots per cutting to also have the greatest length of the longest root, but due to the high variability in the length of the longest root measurements, this cannot be certain.

A summary of rooting characteristics by half-sib family (seed from the same tree in which the female parent is known but the male parent is not) is presented in Table 3. Due to the absence or low number of clones from some families, it was not possible to calculate significant differences among families for rooting percentages. However, there appears to be considerably more within family variability in rooting characteristics than between family variability. For example, while the percentage rooting of all clones varies from 40 to 100% and the roots per cutting among clones varies from 0.6 to 67, the family means only vary from 60 to 80% for percentage rooting and from 11 to 47 for roots per cutting. For this diploid species, these segregation ratios are reminiscent of what might occur for an F2 or later generation population. This apparent lack of half-sib family traits for rooting characters is in contrast to the growth at high salinity where family O7 was represented by eight clones, whereas families O1 and O5 had no elite clones, and families O2, O4, and O9 were represented by only one clone. This would suggest a genetic improvement strategy of first screening many parent trees for growth at high salinity and then doing a second intensive screen within the most rapidly growing families for high rooting percentages and high root number per cutting.

## Discussion

In spite of the fact that none of the mother trees had intermediate leaf morphology between *P. alba* and *P. ruscifolia* some of the progeny had the morphology of vinalillo which has been suggested to be a hybrid between *P. alba* and *P. ruscifolia*. None of these “vinalillo” progeny had significant growth advantages in saline conditions over *P. alba*. The overwhelmingly greater abundance of *Prosopis ruscifolia* over *P. alba* in the saline, high water table habitats, where the seeds of these selections were obtained, might suggest greater salt tolerance in *P. ruscifolia* than in *P. alba*. However, the foliage of *P. alba* is very palatable to cattle and goats and in this area where little forage is available, *P. alba* generally only occurs in the proximity of homes where extensive barriers to livestock grazing is provided. Due to its 15 cm long thorns, pods that are much less palatable to humans than *P. alba*, and foliage that



**Figure 1.** Rooting characteristics of 1-year-old salt-tolerant clones of *Prosopis alba*: (a) mean rooting percentages, (b) mean number of roots per cutting, and (c) mean length of the longest root. The bars indicate 95% confidence intervals.

is not regarded as being palatable to livestock, *P. ruscifolia* has been declared a national plague in Argentina (Burkart, 1976). Thus the possibility exists that the greater ecological dominance of *P. ruscifolia* over *P. alba* in these saline areas is not due to greater ability to grow in high salinity, but rather due to its ability to avoid livestock predation.

The great variability among morphological characters for clones with identical salinity tolerance suggests that genes for salinity tolerance have low linkage to



**Table 3.** Summary of *Prosopis* rooting characteristics by half-sib family

Family	Number of clones	% Rooting/ family	Roots/cutting/ family	Maximum root length (cm)/family
O2	1	80	22	2.42
O3	4	75	25	4.06
O4	1	60	11	1.63
O6	4	80	37	3.86
O7	8	83	28	3.40
O8	2	87	47	4.63
O9	1	60	20	2.67
Grand Mean		80	30.6	3.66

Family is used in the genetic not botanical context of seeds from the same mother plant.

morphological characters. It seems unlikely that a morphological character or a combination of morphological characters could be used to predict salinity tolerance.

The parallel randomized complete block field trial, from which the leaf samples for the morphological measurements were taken, will serve as a seed orchard and to evaluate silvicultural/pod characters on a yearly basis to develop a database for prediction of mature characters from seedling traits. Since *Prosopis* is self-incompatible and insect pollinated, seeds from this seed orchard will be random hybrid matings between all improved clones in this field. Alternatively, if techniques can be developed to root cuttings from mature trees, cuttings could be taken from these trees for clonal plantations. It will also be important to regress the growth rate (from 0 to 3 cm growth among these 21 seedlings) as measured at the 45 dS m<sup>-1</sup> level against the growth rate of 10-year-old trees in field trials. A review of screening woody species for growth in saline areas of Australia (Niknam and McComb, 2000) compared early growth performance in the greenhouse to field data. For *Eucalyptus*, for which there was most data, the assessment of salinity tolerance was the same in the field and greenhouse for 20 species—three were more tolerant in the field than in the greenhouse and five were less tolerant in the field than would be expected from the greenhouse.

Since quantitative traits, such as growth rate, are controlled by many genes, it will be difficult to predict the growth rates at near-maturity from growth rates measured at the seedling stage. However, since qualitative traits such as branch angle and spine characters are usually only controlled by a few genes, it may be possible to develop significant correlations for these types of traits between juvenile and mature growth stages. If so, these correlations would be helpful in predicting tree form that is related to lumber yield and quality.

In our previous works we have used priority-based, sequential selection scheme for multi-purpose criteria for fast growth, form, high pod production, and highly palatable pods to narrow more than a thousand trees in progeny trials or even aged stands to 7 to 12 clones (Alban et al., 2001; Felker et al., 2001, Velarde et al., 2003). While this may be a good strategy for *P. pallida* that has a high rooting percentage from most clones (Alban et al., 2001), this strategy is not appropriate for *Prosopis alba* since only about 25% of the clones are easily rooted with high numbers of roots

per cutting. This implies that for *P. alba*, the penultimate selection should arrive at about four times the final number of desired clones.

Alternatively, it may be possible to maintain 80% rooting percentages by continually grafting juvenile scions onto young seedlings to maintain the cuttings in a juvenile stage. The great variability in rooting between clones suggests that genetic sources for high rooting in *Prosopis alba* are available and could be incorporated using selection or classical breeding. Alternatively, through use of biotechnology only on the root system (Collier, Fuchs, Walter, Lutke, and Taylor, 2005), it may be possible to achieve commercially acceptable rooting percentages in desirable *Prosopis* clones.

The worldwide area to which this technology can be effectively utilized, is uncertain, but extensive. An FAO global network on integrated soil management for sustainable use of salt-affected soils (<http://www.fao.org/ag/agl/agll/spush/topic2.htm>) lists a total affected area of approximately 400 million ha and provides descriptions of the areas affected by salinity for many countries. According to Brinkman (1980), the areas of the world that are affected by salinity are (in millions of hectares); Africa 69.5, Near and Middle East 53.1, Asia and Far East 19.5, Latin America 59.4, Australia 84.7, North America 16.0, and Europe 20.7. We are aware of uses of *Prosopis* to combat salinity on the approximately 10 million ha of saline soils in India (Mishra and Sharma, 2003; Singh, 1996), on 25% of the 16 million ha under irrigation in Pakistan, [http://www.icid.org/cp\\_pakistan.html](http://www.icid.org/cp_pakistan.html) in the Arab Gulf states (Ahmad and Ismail, 1996), in saline Peru (Velarde et al., 2003), and on the 800,000 ha in Argentina (Ragonese, 1951). We believe the technology described here has potential to ameliorate significant portions of the world's saline areas that occur in the subtropical and tropical areas with salinities less than about 30 dS m<sup>-1</sup>.

Epstein, Kingsbury, Norlyn, and Rush (1979) the pioneers of development of plants capable of growing in high salinity, suggested using seawater irrigation to grow useful plants along the world's coastal deserts. The hot tropical coastal deserts of western, northern, and eastern Africa, and the coastal deserts of the Middle East are practically void of plants useful for feed, food, or industrial raw materials. It would be useful to examine the clones described here and from sources of *P. pallida* in Peru for these areas.

In addition to salinity reclamation, *Prosopis* can contribute more widely to ecological stabilization. The ability of *Prosopis* to fix nitrogen and the ensuing stimulation of soil organic C has resulted in large increases in soil organic C under the canopies of *Prosopis* (Geesing et al., 2000; Hibbard, Schimel, Archer, Ojima, and Parton, 2003). Due to the extensive area of semi-arid regions worldwide, an increase of 2 Mg Ha<sup>-1</sup> soil C on these regions by N fixing *Prosopis* and/or Acacias would result in 6.2 × 10<sup>9</sup> Mg of carbon sequestered, which compares favorably to 2010 projected emissions of 8.5 × 10<sup>9</sup> ton C (Geesing et al., 2000).

The financial burden of the recuperation of 400 million ha of saline lands worldwide is enormous. In the past, international donor agencies and national governments have invested large sums to recuperate these soils. However, if there is no economic incentive to maintain the soils from becoming salinized again, the effort will be futile. It is important to find a recuperation method for saline soils that would generate sufficient revenue to pay for the recuperation and to continue to be economically sustainable. As apart from other approaches and trees such *Eucalyptus* that do not have high-value wood, the wood of *Prosopis* commands very high international demand for fine furniture, flooring, and interior components (Felker and Guevara, 2003).

In summary, this article reports individual growth rates for 21 *Prosopis alba* related clones over a 4-week period at  $45 \text{ dS m}^{-1}$ , their leaf, form, and spine characters in the juvenile phase and the percentage rooting, number of roots, and length of longest root per cutting. Some of these seedlings had 100% rooting with more than 50 roots per cutting, an erect form, and no spines. Due to the high lumber quality of *Prosopis* for furniture, flooring, and architectural components, *Prosopis* lumber is in high demand. Felker and Guevara (2003) recently conducted analyses of plantations for lumber production and concluded that with clones on good sites, internal rates of return of about 20% should be possible. Furthermore, these authors suggested that one of the greatest opportunities for *Prosopis* plantations would be marginally salinized land with high groundwater. In some cases, government programs are being put in place to pay for the remediation, or in the case of the California San Joaquin Valley, the purchase and abandonment of saline soils (Felker persona communication). In the California scenario, while the maximum soil salinities of about  $14 \text{ dS m}^{-1}$  are far in excess of what can be tolerated by agricultural crops, they are much less than the  $45 \text{ dS m}^{-1}$  salinities under which these clones were selected. Should the growth rates under high salinity in the greenhouse continue to be expressed in long-term field trials, commercial clonal plantations of *Prosopis* should be possible on lands currently too saline for commercial use.

## References

- Ahmad, R. and S. Ismail. 1996. Use of *Prosopis* in Arab/Gulf states including possible cultivation with saline water in deserts. <http://www.udep.edu.pe/upadi/Prosopis/s1ctxt.pdf> (Accessed 7 Sept 2008).
- Ahmad, R. S., S. Ismail, M. Moinuddin, and T. Shaheen. 1994. Screening of mesquite (*Prosopis* spp) for biomass production at barren sandy areas using highly saline water for irrigation. *Pakistan Journal of Botany* 26:265–282.
- Alban, L., M. Matorel, J. Romero, N. Grados, G. Cruz, and P. Felker. 2001. Cloning of elite, multipurpose trees of the *Prosopis juliflora/pallida* complex in Piura, Peru. *Agroforestry Systems* 54:173–182.
- Baker, A., J. I. Sprent, and J. Wilson. 1995. Effects of sodium chloride and mycorrhizal infection on the growth and nitrogen fixation of *Prosopis juliflora*. *Symbiosis* 19:39–51.
- Brinkman, R. 1980. Saline and sodic soils, pp. 62–68, in *Land reclamation and water management*. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.
- Burkart A. 1976. A monograph of the genus *Prosopis* (Leguminosae subfam. Mimosoideae). *Journal Arnold Arboretum* 57:217–249 and 450–525.
- Collier, C., B. Fuchs, N. Walter, W. K. Lutke, and C. G. Taylor. 2005. Ex vitro composite plants: An inexpensive, rapid method for root biology. *The Plant Journal* 43:449–457.
- Cony, M. A. and S. O. Trione. 1998. Inter and intraspecific variability in *Prosopis flexuosa* and *P. chilensis*: Seed germination under salt and moisture stress. *Journal of Arid Environments* 40:307–317.
- Epstein, E., R. W. Kingsbury, J. D. Norlyn, and D. W. Rush. 1979. Production of food crops and other biomass by seawater culture, pp. 77–101, in A. Hollaender, ed., *The Biosaline concept*. Plenum Press, New York.
- Ewens, M. and P. Felker 2003. The potential of mini-grafting for large scale commercial production of *Prosopis alba* clones. *Journal of Arid Environments* 55:379–387.
- Felker, P., P. R. Clark, A. E. Laag, and P. F. Pratt. 1981. Salinity tolerance of the tree legumes mesquite (*Prosopis glandulosa* var. *torreyana*, *P. velutina*, and *P. articulata*) algarrobo

- (*P. chilensis*), kiawe (*P. pallida*) and tamarugo (*P. tamarugo*) grown in sand culture on nitrogen free media. *Plant and Soil* 61:311–317.
- Felker, P., N. Grados, G. Cruz, and D. Prokopiuk. 2003. Economic assessment of production of flour from *Prosopis alba* and *P. pallida* pods for human food applications. *Journal of Arid Environments* 53:517–528.
- Felker, P. and J. C. Guevara. 2003. Potential of commercial hardwood forestry plantations in arid lands—An economic analyses of *Prosopis* lumber production in Argentina and the United States under varying management and genetic improvement strategies. *Forest Ecology and Management* 186:271–286.
- Felker, P., C. Lopez, C. Soulier, J. Ochoa, R. Abdala, and M. Ewens. 2001. Genetic evaluation of *P. alba* (algarrobo) in Argentina for cloning elite trees. *Agroforestry Systems* 53:65–76.
- Felker, P., D. Medina, C. Soulier, G. Velicce, M. Velarde, and C. Gonzalez. 2005. A survey of environmental and biological factors (*Azospirillum* spp, *Agrobacterium rhizogenes*, *Pseudomonas aurantiaca*) for their influence in rooting cuttings of *Prosopis alba* clones. *Journal of Arid Environments* 61:227–247.
- Geesing, D., P. Felker, and R. L. Bingham. 2000. Influence of mesquite (*Prosopis glandulosa*) on soil nitrogen and carbon development: Implications for global C sequestration. *Journal of Arid Environments* 46:157–180.
- Hibbard, K. A., D. S. Schimel, S. Archer, D. S. Ojima, and W. Parton. 2003. Grassland to woodland transitions: integrating changes in landscape structure and biogeochemistry. *Ecological Applications* 13:911–926.
- Hilu, K. W., S. Boyd, and P. Felker 1982. Morphological diversity and taxonomy of California mesquites (*Prosopis*, Leguminosae). *Madrono* 29:237–254.
- Hunziker, J. H., L. Poggio, C. A. Naranjo, and R. A. Palacios. 1975. Cytogenetics of some species and natural hybrids in *Prosopis* (Leguminosae). *Canadian Journal Genetics and Cytology* 17:253–262.
- Mishra, A. and S. D. Sharma. 2003. Leguminous trees for the restoration of degraded sodic wasteland in eastern Uttar Pradesh, India. *Land Degradation and Development* 14:245–261.
- Niknam, S. R. and J. McComb. 2000. Salt tolerance screening of selected Australian woody species—a review. *Forest Ecology and Management* 139:1–19.
- Ragonese, A. E. 1951. La vegetacion de la Republica Argentina. II. Estudio fitosociologico de las salinas grandes. (The vegetation of the Argentine Republic II. Phytosociology study of the large salt flats.) *Revista Investigaciones Agricolas* V:1–2.
- Rhodes, D. and P. Felker. 1988. Mass screening *Prosopis* (mesquite) seedlings for growth at seawater salinity. *Forest Ecology and Management* 24:169–176.
- Singh, G. 1996. The role of *Prosopis* in reclaiming high-pH soils and in meeting firewood and forage needs of small farmers <http://www.udep.edu.pe/upadi/Prosopis/s1atxt.pdf>
- Velarde, M., P. Felker, and C. Degano. 2003. Evaluation of Argentine and Peruvian *Prosopis* germplasm for growth at seawater salinities. *Journal of Arid Environments* 55:515–531.
- Velarde, M., P. Felker, and D. Gardiner. 2005. Influence of elemental sulfur, micronutrients, phosphorus, calcium, magnesium and potassium on growth of *Prosopis alba* on high pH soils in Argentina. *Journal of Arid Environments* 62:525–539.