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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

by PETER FELKER*, PETER R. CLARK, A. E. LAAG and P. F. PRATT

Department of Soil and Environmental Sciences, University of California, Riverside, Riverside, California 92521

KEY WORDS

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SUMMARY

Sand culture pot experiments were carried out with Proposis seedlings in the greenhouse on a nitrogen free nutrient solution with increasing levels of sodium chloride. All species tolerated a 6,000 mg/l salinity with no reduction in growth. *P. velutina* was the only species that poorly tolerated the 12,000 mg/l salinity level. *P. articulata*, *P. pallida*, and *P. tamarugo* tolerated 18,000 mg/l NaCl with little reduction in growth and grew slightly in a salinity (36,000 mg/l NaCl) greater than seawater. This is the first legume known to grow in salinities equivalent to seawater.

INTRODUCTION

Shrubs and trees of the genus, Prosopis, family Leguminosae occur throughout the tropical and subtropical arid and semi-arid areas of the world[1], where they show potential for food and fuel production and controlling desertification[3]. 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.

* Current address: Caesar Kleberg Wildlife Research Institute, Texas A & I University, Kingsville, Texas 78363.

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METHODS

Six species of divergent backgrounds were included in this study. *Prosopis articulata* is native to Baja, Mexico; *P. pallida*, introduced into Hawaii in the 1850's grows along the seacoast; *P. chilensis* of Argentina is the best biomass producer in our field trials[5]; *P. velutina* is the predominant Arizona rangeland species; *P. glandulosa* var. *torreyana* is native to southern California deserts, and *P. tamarugo* 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. We have used the botanical nomenclature of Burkart[1] for these species. The often confused *P. chilensis* species had; 2 pair of pinnae, each pinnae was 20 cm long with 2 mm wide leaflets, and a distance of 6 mm between the 5th and 6th pair of leaflets.

Clonal material was prepared for all species as described elsewhere[6] except for *P. tamarugo*, which we have not successfully rooted from cuttings. 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 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[4] 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; $MgSO_4.7H_2O$, 9.8 g; $Ca(H_2PO_4)_2.H_2O$, 2.5 g; $CaSO_4.2H_2O$, 6.9 g; Sequestrene 138 (6% Iron) (Ciba Geigy), 2.1 g; and micronutrient stock solution, 4 ml. Two liters of the micronutrient stock (10) contained; KCl, 2.7 g; H_3BO_3, 30 g; $MnSO_4.H_2O$, 17 g; $ZnSO_4.7H_2O$, 2.7 g; $(NH_4)_6Mo_7O_{24}.4H_2O$, 2.7 g; $CuSO_4.5H_2O$, 2.4 g; and 10.8 ml, H_2SO_4 (specific gravity 1.83). The pH of the resulting macronutrient 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[2]. Mixtures of calcium and sodium salts are often used in salinity studies but the legume's need for phosphate and the problems with precipitation 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. The large root systems of the 2.5 m tall *P. articulata* and *P. pallida* trees plugged drainage holes during the latter part of the experiment, and prevented a more detailed examination of higher salinity levels. 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[7]. A computer was used to calculate delta height, and to carry out an analysis of variance and Duncan's multiple range test, if appropriate.

RESULTS

The height increase during the salinity treatments are presented in Table 1. 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

Table 1. Effect of salinity on Prosopis stem elongation

NaCl concentration (g/l)	Height increase (cm)					
	P. articulata	*P. chilensis*	*P. glandulosa* var. *torreyana*	*P. pallida*	*P. tamarugo*	*P. velutina*
			2 April–25 February			
0	73 y	31 z	44 z	44 z	4.1 z	2.8 z
6	28 z	16 z	47 z	31 z	4.7 z	16.3 z
6	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	49 z	48 z	8.3 z	54 z	4.7 z	35 z
12	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	61 z	55 y	21 z	58 y	7.9 z	1 z
18	46 z	9 z	9.3 z	34 yz	6.7 z	8 yz
			16 July–3June			
0	24 z	39 yz	49 y	37 z	18.1 y	65 z
12	35 z	55 y	50 y	44 z	9.1 z	34 z
36	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	3.7 z	27 z	18 z	24 z	4.6 z	2 z
36	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.

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 treatment. 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

Table 2. Effect of salinity on dry biomass (g) of Prosopis seedlings

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

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.

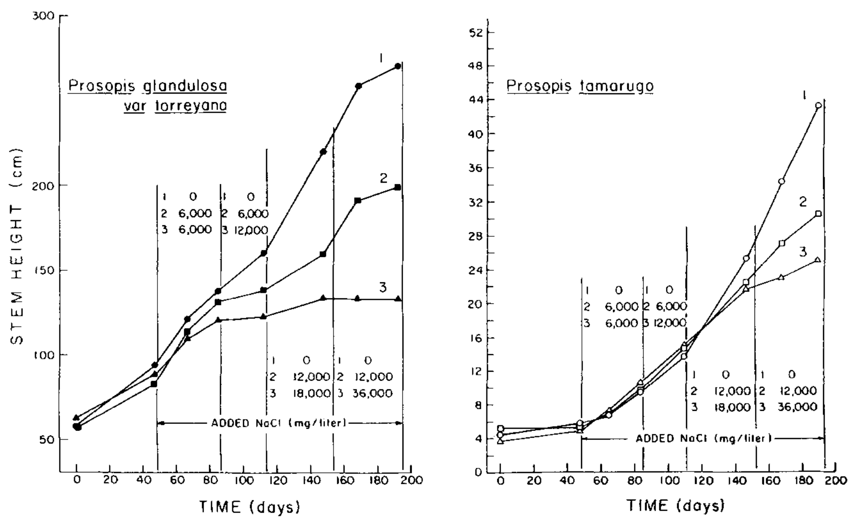

Fig. 1. Stem elongation of *Prosopis tamarugo* and *P. glandulosa* var. *torreyana* as a function of salinity. Treatments 1, 2, and 3 are the control, medium, and high salinity levels, respectively. The salinity was increased in stepwise fashion through four levels, and the concentration in mg/l for each level is given between the solid vertical lines.

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 2. 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 Fig. 1. 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.

DISCUSSION

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*[9], 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[8].

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 an earlier study[4]. 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 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 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 (Felker, *et al.*, mss).

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 establishes that more than three clonal replicates are required to over come 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.

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