

Micronutrient, Phosphorus and pH Influences on Growth and Leaf Tissue Nutrient Levels of *Prosopis alba* and *Prosopis glandulosa*

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ABSTRACT

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Nitrogen fixing trees of the genus *Prosopis* occur on many semiarid lands of the world, where they show potential for food and fuel production. Semiarid soils tend to be alkaline and low in organic matter, N, P and micronutrients. For both native woodlands and plantations, it is important to understand the response of *Prosopis* to changing fertility regimes and to develop quantitative relationships between leaf tissue mineral nutrient concentrations and productivity. The growth of two contrasting *Prosopis* species was compared on an inert artificial soil mixture with four lime [$\text{Ca}(\text{OH})_2$] treatments to vary soil pH from 6 to 9 in the greenhouse. At each lime level a factorial design, with and without phosphorus and micronutrient additions, was used. Dry biomass was related to leaf tissue levels of N, P, K, Ca, Na, Mg, Mn, Fe, Zn, Cu and soil pH. Phosphorus was the element most limiting growth. Micronutrient additions produced little change in biomass at the lower lime levels, but at the high lime levels they increased biomass in the P amended plants. At high pH (8.9), zinc appears to play a role in decreasing toxic Na levels. It was the micronutrient most correlated with enhanced biomass production. A significant negative correlation between phosphorus and zinc tissue concentrations occurred and it appears that phosphorus can reduce zinc uptake by *Prosopis*.

INTRODUCTION

Leguminous trees such as *Prosopis* spp. have potential for alleviating critical shortages of fuelwood, fodder/forage and to limit the increasing desertification of arid and semiarid, lesser developed countries. Valuable characteristics of these trees include rapid growth, wood fuel production, pod production, N-fixation, and drought and salt tolerance (Leakey and Last, 1980;

Felker, 1979; Felker et al., 1981, 1983). *Prosopis* is widely distributed in semiarid and arid regions of southwestern United States, South America and in similar regions throughout the world (Leakey and Last, 1980; Felker, 1979).

Because *Prosopis* normally grows on alkaline soils, low availability of P and micronutrients may potentially limit growth (Jarrell et al., 1982). Phosphorus is especially important because of its major involvement in successful N fixation by rhizobial nodules, and in the process of flowering and fruit set (Chapman and Carter, 1976). Unfortunately, there is little data concerning P availability in nonagronomic, semiarid soils in less developed countries. Values of sodium bicarbonate extractable P for similar soils in the United States are less than 2 mg per kg (Virginia and Jarrell, 1983; Black and Wight, 1972; El-Ghonemy et al., 1978) and thus considerably below the critical value for herbaceous crops (12 mg per kg) given by Olsen et al. (1954).

Pod production has sometimes been low on southern Arizona native stands (Felker, unpub. observations), and it is important to know if the low pod production is attributable to genetic or to nutritional deficiencies. Similarly, N fixation may be limited by plant nutrient deficiencies. If nutrient availability is limiting, existent stands might be brought to full production by comparatively cheap applications of a nonnitrogen fertilizer. Also, to fully utilize germplasm currently being developed, growth and N fixation must not be suppressed by correctable nutrient deficiencies.

The objective of this study was to determine which nutrients may be potentially most limiting to mesquite growth in soils with high pH, and what minimal or optimal levels of certain elements in plant tissue are associated with acceptable growth rates. Minimal levels established by this study may be useful as a diagnostic tool for evaluating the nutritional status of trees grown in the field. The use of foliar mineral analysis to assess the nutritional status of forest trees has been reviewed by Van den Driessche (1974).

MATERIALS AND METHODS

The availability of P and micronutrients to mesquite seedlings was varied by growing the seedlings in a relatively inert media (peat/perlite/vermiculite) with or without added P or micronutrients, and amending with one of four levels of lime to vary pH in $2 \times 2 \times 4$ factorial design. The experiment was conducted for *P. alba* (Grisebach) accession number 0166 and *P. glandulosa* var. *glandulosa* (M.C. Johnson), native to Kingsville, Texas. *Prosopis alba* (0166) is a promising, high biomass-producing species (Felker et al., 1983), common in the desert regions of South America, whereas *P. glandulosa* is found in Texas at the northern extremity of the range of *Prosopis*. The two contrasting species were selected to provide an estimate of variability of foliar nutrient concentrations among *Prosopis* species.

P. alba and *P. glandulosa* were grown in 4 l plastic pots containing peat/perlite/vermiculite (1:1:1) in the greenhouse. The potting mixture was

amended with 0 or 333 g m⁻³ pulverized superphosphate (0-48-0) granules, 0 or 1050 g m⁻³ Esmigran (Mallinckrodt Inc.), and 0, 1160, 3600, or 6000 g m⁻³ of Ca(OH)₂ (builders lime) to vary the pH. A 2 × 2 × 4 factorial randomized complete block design was replicated four times.

The elemental composition of Esmigran, as specified by the manufacturer, was S — 1.00%, B — 0.02%, Cl — 2.60%, Cu — 0.30%, Fe — 2.00%, Mn — 0.50% Mo — 0.0006%, and Zn — 1.00%. The following nutrients were added equally to all treatments: 890 g m⁻³ of gypsum (CaSO₄) for a S source, 140 g m⁻³ of ammonium nitrate (35-0-0, a low concentration used to avoid repression of nodulation), and 890 g m⁻³ of muriate of potash (0-0-60).

The pots were completely randomized and watered daily for a week to allow the lime to equilibrate after which three scarified seeds of *P. alba* (0166) or *P. glandulosa* were planted in each pot. One week after seeding a suspension of rhizobia was added that contained more than 1 million bacteria previously shown to effectively nodulate *Prosopis* (Felker and Clark, 1980). Eventually the seedlings were thinned to one seedling per pot. The seedlings were grown in the greenhouse (27°C night/34°C day temperatures) and watered with tapwater two or three times a week. The tapwater contained 800 mg l⁻¹ NaCl and had a pH of 8.5.

The shoots were harvested after 26 weeks of growth, dried at 43°C, and ground to pass through a 40-mesh screen using a Wiley mill equipped with stainless steel hardware. Tissue mineral analysis was done separately for leaves and stems.

Plant tissue analysis

One gram of plant material was digested in 10 ml concentrated nitric acid at 160–180°C for four hours in general accordance with the method of Havlin and Soltanpour (1980). This digestion method is valid for use with atomic absorption spectrophotometry and colorimetric determination of P (Havlin and Soltanpour, in prep.) and was used to avoid the explosive hazard of perchloric acid.

Using the above digestion procedure we determined the mean elemental composition of five samples of National Bureau of Standards No. 1572 citrus leaves to be within the referenced standard errors. Phosphorus was measured using the colorimetric method of Murphy and Riley (1962), and the remaining elements were measured using atomic absorption spectrophotometry. The pH of the potting media was measured in 3:1 (ml water/g potting mixture) extracts.

Tissue N was determined following micro-Kjeldahl digestion of 20 mg plant material in 1 ml of concentrated sulfuric acid and dilution to 50 ml. A modification of the salicylate–dichloroisocyanurate colorimetric method (Felker, 1977) was used to measure N. A 0.25 ml aliquot of the diluted digest was combined with 2.5 ml water in 30 ml test tubes. Five ml of phosphate buffer (pH 12.5) were added, after which the tubes were immediately

sealed with Parafilm to prevent any loss of ammonia. One ml of salicylate reagent and 0.75 ml of dichloroisocyanurate reagent were injected through the Parafilm in rapid succession with precalibrated syringes, after which the tubes were immediately resealed with Parafilm. The absorbance was read at 660 nm after a three h equilibration period at room temperature. We determined the mean N concentration of three replicate samples of the National Bureau of Standards (N.B.S.) citrus leaves described above to be 2.96%, as compared with the cited but not N.B.S.-certified value of 2.86%.

Analysis of variance (ANOVA) was done on stem and foliage results to determine treatment effects on dry weight for all treatments combined and at each lime level. ANOVA was also carried out at each lime level to determine treatment effects on foliar concentrations of P and Na. When appropriate, significant differences among the means for P and micronutrient treatment combinations were determined at each lime level using the least significance difference (L.S.D.). A Pearson product correlation matrix for plant dry weight, soil pH, and plant nutrient concentrations was done for the pooled treatments and at each lime level.

Where significant correlations existed, linear and quadratic equations were developed between biomass and leaf tissue nutrients and between selected leaf tissue nutrients. Figures containing the raw data, the best fit of the data, and the 95% confidence intervals for the equations have been plotted.

RESULTS

The foliage production of *P. alba* and *P. glandulosa* in response to P and micronutrient fertilization as a function of lime addition is presented in Fig. 1. For brevity only foliage data will be presented, but comparisons with stem data will be discussed. Stem dry weights of both species were approximately twice those of foliage, and varied similarly to foliage production in response to the experimental treatments. Seedlings grown in treatments without added P were severely stressed at the two highest lime treatments, and insufficient amounts of foliar material remained at harvest to accurately weigh or analyze these samples. However, sufficient samples of stem tissue from these treatments remained and were analyzed.

At the 0 and 1.2 kg m⁻³ lime levels, the foliar dry weights of *Prosopis alba* in P-amended treatments were significantly greater ($\alpha=0.05$ using L.S.D.) than dry weights in treatments without P (Fig. 1a). This was also true for *P. glandulosa* but the difference was not significant (at $P=0.05$). Phosphorus fertilization had a large effect on dry weight production for the 3.6 and 6.0 kg m⁻³ lime levels, since plants not receiving P had virtually no foliage, whereas those plants receiving P contained a normal amount of foliage. Also stem dry weights in both P-amended treatments were significantly larger ($\alpha=0.05$ using L.S.D.) than dry weights of stems from treatments without P.

For *Prosopis alba*, correlations between dry weight (over all lime levels)

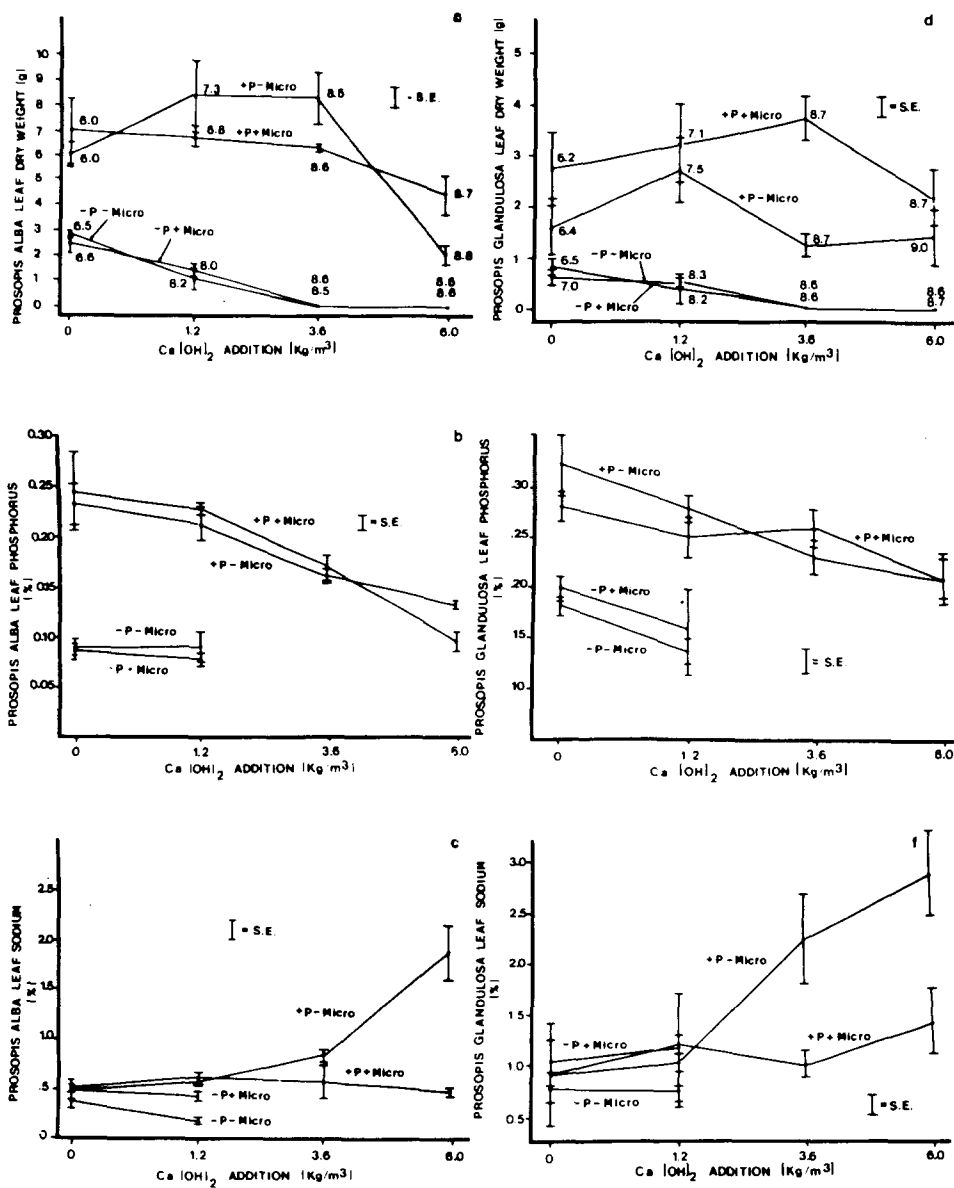


Fig. 1. Influence of increasing lime ($\text{Ca}(\text{OH})_2$) additions on leaf dry matter for *Prosopis alba* (a), and *P. glandulosa* (d); leaf tissue phosphorus concentrations for *P. alba* (b) and *P. glandulosa* (e); and leaf tissue Na concentrations for *P. alba* (c) and *P. glandulosa* (f). The vertical bars represent the standard errors (n=4). Final soil pH values are adjacent to the data points. No leaf production occurred at the 3.6 and 6.0 kg/m^3 lime levels without phosphorus amendments.

were significant for P ($r=0.59$, $P=0.0001$), pH ($r=-0.40$, $P=0.0017$), N ($r=0.45$, $P=0.002$), Zn ($r=-0.41$, $P=0.0047$), and Ca ($r=0.28$, $P=0.06$). For *P. glandulosa* (over all lime levels) significant correlations existed between dry weight and K ($r=-0.39$, $P=0.009$), Zn ($r=-0.36$, $P=0.02$), P ($r=0.34$, $P=0.02$), Mg ($r=-0.29$, $P=0.06$), N ($r=0.28$, $P=0.06$), Fe ($r=-0.30$, $P=0.07$), and pH ($r=-0.23$, $P=0.07$).

Foliar P concentrations for all treatments are presented in Figs. 1b and 1e. For both species, there was a decrease in the level of foliar P (and stem P) with increasing lime addition. In the treatment amended with P and micro-nutrients, dry weights of both species were constant or increased throughout the first three lime additions as the concentration of foliar P decreased (Fig. 1a, 1b, 1d and 1e), suggesting the seedlings were adequately supplied with P. However, since the biomass production increased from the first to the second lime level, as leaf P decreased or remained the same, less total P per plant occurred at the second lime level. This dilution effect complicates interpretation of the phosphorus fertilization needs of these plants.

The minimal concentrations of foliar P required to assure near optimal growth (i.e., the critical level), were determined from plots of dry weight versus foliar P concentrations for *P. alba* and *P. glandulosa* (Fig. 2a and 2b, respectively). In the determination of such a critical level, it is implicit that all nutrients apart from the one under test are not limiting (Richards and Bevege, 1972). However, such a situation rarely occurs under field conditions and a realistic analysis must be capable of dealing with multiple defi-

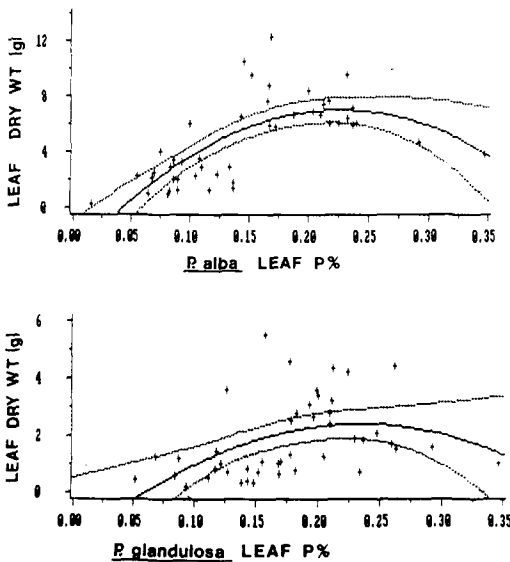


Fig. 2. Leaf tissue phosphorus concentrations as a function of leaf dry weight for *Prosopis alba* (a) and *P. glandulosa* (b), respectively. The center line is a plot of the quadratic equation providing the best fit of the data. The remaining curves delimit the 95% confidence intervals for the quadratic regression equation.

ciencies. The data of Figs. 2a and 2b indicate that P levels less than 0.1% are definitely limiting and P levels near 0.2% are close to optimal. Many mitigating nutritional factors may have influenced dry matter and P levels between these two regions. Phosphorus deficiencies may or may not occur between 0.1% and 0.2% and these situations should be evaluated on a case-by-case basis. We have attributed the low biomass values at approximately 0.14% P and 0.17% P for *P. alba* and *P. glandulosa*, respectively, to Na effects (see below) and this illustrates the complexity of the situation in the field. As a general guideline, the critical P levels of *P. alba* and *P. glandulosa* can be taken to be 0.13% and 0.16% P, respectively.

Levels of foliar P for *P. alba* over all lime levels were positively correlated with dry weight ($r=0.59$, $P=0.0001$) and with foliar levels of K ($r=0.34$, $P=0.02$), Ca ($r=0.40$, $P=0.005$), Mg ($r=0.37$, $P=0.01$), Mn ($r=0.45$, $P=0.0015$), and especially N ($r=0.61$, $P=0.0001$). In contrast, leaf P foliar levels were negatively correlated with foliar concentrations of Zn ($r=-0.31$, $P=0.03$), and Fe ($r=-0.42$, $P=0.007$).

Levels of foliar P for *P. glandulosa* over all lime levels were positively correlated with dry weight ($r=0.34$, $P=0.02$), and leaf N ($r=0.68$, $P=0.0001$) and inversely correlated with Zn ($r=-0.56$, $P=0.0001$). A plot of the quadratic equation (and accompanying curves for 95% confidence intervals) that provided the best fit of the foliar P and Zn tissue levels is presented in Fig. 3. An antagonistic effect between Zn and P absorption by legumes has been frequently reported, e.g. Adams et al. (1982).

In all treatments with 0 and 1.2 kg m⁻³ lime amendments, final soil pH values of treatments without P exceeded values of treatments receiving P (Fig. 1a and 1d). Triple superphosphate acidifies the soil (Bunt, 1976) and it is possible that the increase in *Prosopis* growth with superphosphate additions may be a result of both lowering the pH (increasing nutrient availability) and increased phosphorus supply. No differences in pH occurred among P and micronutrient treatment combinations at the 3.6 and 6.0 kg m⁻³ lime levels.

For the first three lime levels, *Prosopis* growth did not appear to be limited by micronutrients since addition of micronutrients did not significantly ($P=0.05$) affect foliar dry weights, except for the 3.6 kg m⁻³ lime treatment of *P. glandulosa*, which is explained below as relating to Na and P. However, tissue from treatments amended with micronutrients usually contained high micronutrient concentrations.

The deletion of micronutrients at the greatest lime level significantly ($\alpha=0.05$ by ANOVA) decreased the growth of *P. alba* when P was added (Fig. 1). This was also true for *P. glandulosa* but the difference was not significant (at $P=0.05$). A comparison of dry weight, pH, and leaf tissue levels for both species in the P amended high lime treatment is presented in Table 1. The pH was slightly less than 9 for these treatments. For both species the most striking differences with micronutrient additions were an increase in biomass, an increase in leaf Zn, and a decrease in leaf Na. For *Prosopis alba*

TABLE 1

Comparison of *Prosopis alba* and *P. glandulosa* leaf tissue nutrients with and without addition of micronutrients with high lime 6.0 kg m^{-3} additions

	<i>Prosopis alba</i>		<i>Prosopis glandulosa</i>	
	- micronutrients (Mean \pm SE)	+ micronutrients (Mean \pm SE)	- micronutrients (Mean \pm SE)	+ micronutrients (Mean \pm SE)
Dry weight	2.1 \pm 0.3	4.5 \pm 0.8	1.4 \pm 0.6	2.2 \pm 0.5
Soil pH	8.8 \pm 0.04	8.8 \pm 0.2	9.0 \pm 0.02	8.7 \pm 0.1
Zn (mg/kg)	13 \pm 1	29 \pm 6	23 \pm 0.9	38 \pm 6
Mn (mg/kg)	59 \pm 10	49 \pm 3	94 \pm 26	74 \pm 3
Fe (mg/kg)	63 \pm 2	63 \pm 4	200 \pm 40	146 \pm 20
Cu (mg/kg)	17 \pm 5	29 \pm 8	26 \pm 3	34 \pm 9
K (%)	1.1 \pm 0.3	1.3 \pm 0.1	1.2 \pm 0.1	1.1 \pm 0.2
Na (%)	1.9 \pm 0.3	0.46 \pm 0.03	3.3 \pm 0.4	1.9 \pm 0.3
Ca (%)	1.4 \pm 0.1	0.92 \pm 0.1	0.66 \pm 0.08	1.0 \pm 0.1
Mg (%)	0.24 \pm 0.03	0.19 \pm 0.03	0.14 \pm 0.02	0.16 \pm 0.02
P (%)	0.13 \pm 0.003	0.09 \pm 0.009	0.16 \pm 0.02	0.16 \pm 0.02
N (%)	2.7 \pm 0.3	3.0 \pm 0.03	3.2 \pm 0.3	3.6 \pm 0.4

All of the above values were supplemented with triple superphosphate at 333 g m^{-3} . SE = Standard error of the mean, $n=4$.

the decrease in leaf P to 0.09% as biomass increased with micronutrient additions may be attributable to a dilution effect, or the previously mentioned P/Zn antagonism. Additional P fertilization at this level might stimulate further biomass production.

Interestingly, the decrease in *P. alba* and *P. glandulosa* foliar dry weight with increased lime levels (Figs. 1a and 1d) is paralleled by a significant increase in foliar Na (Figs. 1c and 1f) when micronutrients are absent but not when micronutrients were added. The concentration of foliar Na remained stable at 0.5% at the two lower lime levels and did not retard growth when it increased to 0.8% at the 3.6 kg m^{-3} lime level. However, growth was suppressed when Na increased to 1.9% at the 6.0 kg m^{-3} lime level. These smal-

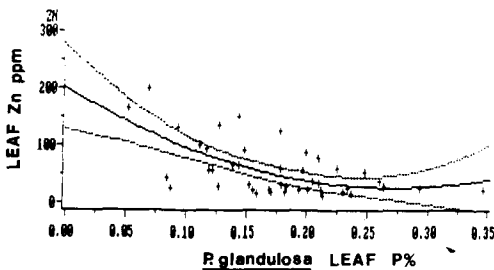


Fig. 3. *P. glandulosa* leaf tissue P as a function of leaf tissue Zn. The curves represent the best quadratic fit of the data and the 95% confidence intervals, respectively.

ler plants had a greater concentration of Na ($P=0.06$ by ANOVA) than those grown with added micronutrients, which only contained 0.5% Na (Fig. 3). These data suggest that a Na toxicity occurred at the highest lime level in the absence of micronutrients.

The relationships between dry weights and foliar Na are depicted in Figs. 4a and 4b for *P. alba* and *P. glandulosa*, respectively. Growth was severely suppressed when the concentration of foliar Na exceeded 1.0% for *P. alba* and 2.5% for *P. glandulosa*. The four data points for *P. alba* that exceeded 1.0% NaCl all occurred in the highest lime level without micronutrients and the eight data points for *P. glandulosa* that exceeded 2.5% leaf NaCl occurred in the two highest lime levels without micronutrients. Apparently, *P. glandulosa* has a higher critical toxic level of Na than *P. alba*. Results of a salinity screening trial (Rhodes and Felker, manuscript submitted) indicated that *P. alba* (0166) is less susceptible to NaCl toxicity than *P. glandulosa*. Perhaps *P. alba* was more salt-resistant because it was better able to exclude Na uptake by roots keeping foliage concentrations of Na low.

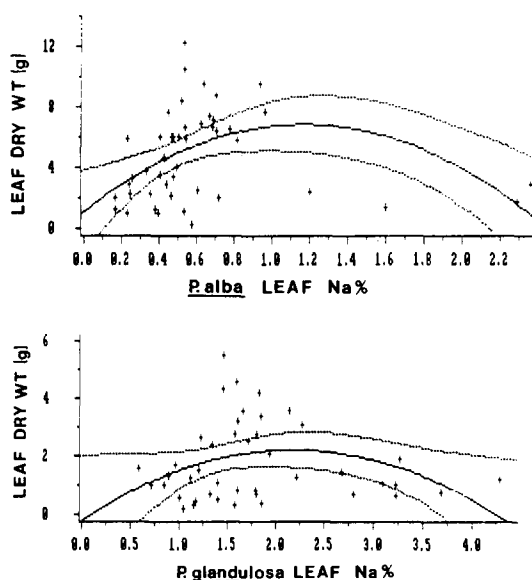


Fig. 4. Leaf tissue Na concentrations as a function of leaf dry weight for *Prosopis alba* and (a) and *P. glandulosa* (b), respectively. The center line is the quadratic equation providing the best fit of the data and the remaining lines delimit the 95% confidence intervals for the equation.

A Pearson product correlation matrix at the 6.0 kg m^{-3} lime level indicated that *Prosopis alba* dry weight was positively correlated with the foliar concentration of Zn ($r=0.91$, $P=0.004$) and Cu ($r=0.77$, $P=0.03$) but not P ($r=0.18$, $P=0.68$). However, *Prosopis alba* leaf tissue P was positively correlated with leaf Na ($r=0.67$, $P=0.07$) and negatively correlated with Zn ($r=-0.74$, $P=$

0.05) and Fe ($r=-0.86$, $P=0.006$). Leaf tissue Na and Zn levels were negatively correlated with each other ($r=-0.78$, $P=0.04$).

In contrast, for *P. glandulosa* at the 6.0 kg m^{-3} lime level, the correlations between biomass and Zn ($r=0.00$, $P=0.99$), Cu ($r=-0.06$, $P=0.89$) and P ($r=0.00$, $P=0.99$) were all nonsignificant. However, for *P. glandulosa* addition of micronutrients significantly increased the Zn and Cu concentrations while decreasing the leaf Na concentration (Table 1). Perhaps interactions between the four treatments at the 6.0 kg m^{-3} lime level obscured significant correlations between biomass production and these nutrients.

Leaf tissue manganese concentrations decreased in a similar fashion for both *P. alba* and *P. glandulosa* as the lime additions increased. The most marked drop in leaf Mn occurred between the 1.2 and 3.6 kg m^{-3} lime levels. For the P plus micronutrient additions, the *P. alba* and *P. glandulosa* concentrations dropped from $176 \pm 4 \text{ mg/kg}$ to $50 \pm 13 \text{ mg/kg}$ and from $207 \pm 29 \text{ mg/kg}$ to $95 \pm 13 \text{ mg/kg}$, respectively. Since the biomass production remained high at these lime levels, Mn concentrations of 50 mg/kg and 95 mg/kg for *P. alba* and *P. glandulosa*, respectively, are above-deficient levels.

For *P. alba*, the lowest foliar element concentrations compatible with maximum growth were achieved at the 3.6 kg m^{-3} lime level amended with phosphorus, but without micronutrients. Since ANOVA at this lime level showed no effect of micronutrients on dry weight production, these foliar concentrations may be useful as minimum diagnostic criteria for this species. These concentrations were: N — 3.0%, P — 0.16%, K — 1.2%, Ca — 1.2%, Mg — 0.23%, Na — 0.8%, Fe — 130 mg/kg, Mn — 70 mg/kg, Zn — 27 mg/kg, and Cu — 17 mg/kg.

Micronutrients had little influence on biomass production of *P. glandulosa* at the 1.2 kg m^{-3} lime level, suggesting that the leaf tissue levels in this P amended, minus micronutrient treatment would constitute the minimum diagnostic criteria. These concentrations were: N — 4.0%, P — 0.23%, K — 1.4%, Ca — 0.46%, Mg — 0.13%, Na — 1.5%, Fe — 200 mg/kg, Mn — 113 mg/kg, Zn — 20 mg/kg, and Cu — 31 mg/kg.

A comparison of these two sets of concentrations reveals that *P. alba* is higher in Ca and Mg, but lower in N, P, Na, Fe, Mn and Cu.

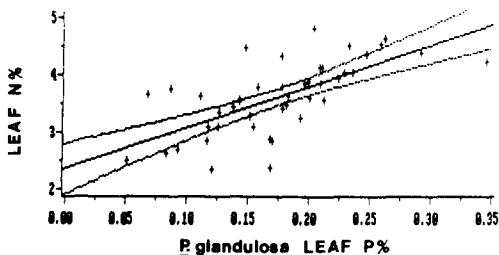


Fig. 5. *Prosopis glandulosa* leaf P% versus leaf N%. The center line is the linear equation providing the best fit of the data and the remaining lines delimit the 95% confidence intervals for the equation. A linear equation provided a better fit than a quadratic equation.

Growth of *Prosopis alba* and *P. glandulosa* was positively correlated with both P and N over all lime levels. Leaf tissue P and N concentrations were well-correlated, $r=0.68$, $P=0.0001$ for *P. glandulosa*, and $r=0.61$, $P=0.0001$ for *P. alba*, both when P was adequate and highly limiting (Fig. 5). The highly significant N—P correlation, and the high N/P ratio in the foliage (20), on an inert media containing little N suggests the importance of P for N fixation in *Prosopis*.

DISCUSSION

Leaf tissue levels of Na had high negative correlations with biomass production at high pH values (8.9) and probably will constitute a useful diagnostic criterion for biomass production on alkaline soils. It is unclear if high Na leaf tissue levels will indicate excessive saline conditions at neutral pH.

At neutral pH, the *Prosopis alba* (0166) half-sibling family is more tolerant of Na than many plants since it grew without problems in a NaCl solution of 12,000 mg/l, and only began to exhibit necrosis at a NaCl concentration of about 18,000 mg/l (Rhodes and Felker, manuscript submitted). The plants in this study were watered with tapwater that had a NaCl concentration of about 800 mg/l and this would have produced little stress at neutral pH.

Previous greenhouse studies have found that *Prosopis* seedlings had greater growth when supplemented with N than when relying solely on symbiotically fixed N (Virginia et al., 1984). Thus in these greenhouse studies, nodulated mesquite plants were still N limited. The highly significant correlations between leaf P and N indicate that N fixation should be optimized by managing P and micronutrients before considering supplementing with N in field situations. This would appear prudent, since N and P fertilizers have a similar cost per ton and since the N to P dry matter ratio is 20 to 1.

Phosphorus plays a critical multiplicative role in biomass production in *Prosopis*. For example, a one-unit increase in *Prosopis* leaf P would be associated with a 20-unit increase in leaf N and a 120-unit increase in leaf crude protein (assuming a Kjeldahl factor of 6.25). It would be of interest to know if additional P soil amendments would yield the same N and P concentration while stimulating greater N fixation and biomass production and/or if additional P would stimulate greater leaf N.

It should be cautioned that these results were obtained on an artificial, highly organic soil. While the general trends might be expected to remain the same on mineral soils, the pH values at which phosphorus deficiencies and Na toxicities become problems would be expected to vary according to soil type. High pH soils may fix phosphorus so rapidly that phosphorus additions may prove uneconomical. In these cases inoculation with endomycorrhizal fungi may prove useful and necessary.

Leaf diagnostic criteria developed here may be useful in correcting low pod production and/or protein contents. For example, foliar leaf P concen-

trations reported in this volume for the *P. chilensis* plantations in the rainless Atacama desert are 0.05% (Zelada, 1986) and considerably below leaf P critical values of 0.13% for the closely related *P. alba*. *Prosopis* leaf and pod protein concentrations have not been sufficiently high to maintain animal liveweight in this region (Zelada, 1986). While P fertilization would be difficult in this region due to the 0.5 m thick salt crust, if leaf tissue P could be raised, leaf and pod protein concentrations could be expected to follow.

CONCLUSIONS

In the experiments described above, dry weight production by two *Prosopis* species was most limited by a P deficiency and/or a Na toxicity. The minimum levels of foliar P required to assure near optimal growth for *P. alba* and *P. glandulosa* were approximately 0.13% and 0.16%, respectively. The maximal level of Na for optimal growth was 1.0% for *P. alba* and 2.5% for *P. glandulosa*. Thus, *P. alba* was more tolerant of low foliar P levels and less tolerant of high foliar Na levels than was *P. glandulosa*.

These results suggest that mesquite growth is relatively insensitive to pH from slightly acid (pH 6.0) to moderately alkaline (pH 9) soils, provided that adequate phosphorus and micronutrients are provided. Where poor growth occurs on alkaline soils in the field, phosphorus fertilization may overcome the effects of high pH on P availability. Phosphorus/zinc antagonisms may become more pronounced at higher pH's, which may be related to Na toxicity. If leaf Na levels exceed 1.0% and growth is poor, Zn fertilization should be evaluated.

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