Relationships Between Saline Ground Water, Soil, and Leaf Tissue Composition of the Phreatophyte Mezquite

by F. L. García-Carreño, E. Troyo-Diéguez, and J. L. Ochoa[a]

Abstract

The chemical and biochemical composition of leaf tissue from 24 mezquites (*Prosopis articulata*) was correlated with the ion content of soils and ground waters from six separate sites supporting plant growth. The peroxidase responses varied at different salinities; however, this enzyme activity decreased as the electrical conductivity of the ground water increased. Chlorophyll content of the leaves increased with the electrical conductivity (EC) of the well water, but the response was not statistically significant. The ion concentration (Ca^{++}, Mg^{++}, Na^{+}, HCO_3^{-}, and Cl^{-}), pH, and SAR (sodium adsorption ratio) in leaf tissue showed no correlation with their corresponding values for soil and ground water, confirming earlier reports on the ion-exclusion mechanism of the mezquite root system. Likewise, low molecular weight metabolites such as glycerol, amino acids, and hexoses showed no correspondence with the salt content in ground waters. Of all the studied ions, chemical parameters, and biochemical compounds, EC in the ground water, leaves, and soil in the open field midway between mezquites, as well as peroxidase activity of foliar extracts showed the highest correlation with the salinity of ground water. The results of this research suggest that measuring EC and biochemical mezquite parameters may provide an alternative to drilling to evaluate ground-water quality.

Introduction

Plant biochemical events such as changes in enzyme activities, isoenzyme patterns, and metabolite pools (including some cations) have been useful indicators of plant stress. Peroxidases, the enzymes involved in the elimination of hydrogen peroxide at the expense of a variety of hydrogen donors available in plant tissues, are one of the most useful indicators of plant stress (García-Carreño, 1991).

Mezquite (US: Mesquite, or South America: Algarrobo) species (*Prosopis* spp.) are the dominant leguminous trees in warm deserts and semiarid areas of North America. Although generally growing along water courses, mezquites often form dense spreading thickets in barren wastelands if there is sufficient ground water and a minimum annual rainfall of 70 mm (Sharifi et al., 1983).

The survival and reproduction of mezquites in desert ecosystems with large annual and seasonal climatic variations depend largely on their ability to tolerate drought (Nilsen et al., 1987). This is achieved by reducing transpiration through stomata control and osmotic adjustment, which result in the maintenance of turgor potential in the warmest seasons. In addition, mezquites tap water from underground sources with their deep and widespread root system. In sum, the phreatophytic and adaptive responses to water stress allow mezquites to produce high biomass in extremely arid environments.

Soil composition is the product of geological processes and biotic factors (Benitez, 1972). Legume trees, such as the mezquite, induce chemical changes in the soil composition beneath the plant canopy (Virginia, 1986), while climate mainly influences quantitative variations in ground water (Cargo and Mallory, 1977).

Mezquite has been the subject of numerous studies concerning water use (Nilsen et al., 1983), plant physiology (Sharifi et al., 1982; Sharifi et al., 1983; Jarrel and Virginia, 1990), association with nodulating bacteria (Jenkins et al.,

---

[a] Centro de Investigaciones Biológicas de Baja California Sur, A.C., P.O. Box 128, La Paz, B.C.S., México 23000. Fax (682) 5-36-25. (Address correspondence to first author.)

Received June 1991, revised October 1991 and January 1992, accepted February 1992.

Discussion open until March 1, 1993.

1988), and various practical applications (Felger, 1985; Cowen, 1990; Figueiredo, 1990). However, their physiological relationship to soils and ground waters of differing salinities has not been studied in detail (Felker et al., 1981; Back and Hanshaw, 1965). The aim of this study was to assess (1) the physiological response of mezquites exposed to different ground-water salinities, and (2) the chemical composition of the soil as it reacts to mezquite establishment. The results may suggest the possibility of monitoring either the chemical or biochemical parameters of the mezquite as a way to determine ground-water quality.

Plant History

Mezquite woodlands in Baja California Sur have been severely depleted by man for the production of charcoal and as a consequence of clearing the land of weeds. In fact, within our study area, most of the plants were survivors of branch cutting and their actual aerial biomass was derived from recent bud sproutings. Typical habitats of mezquites are washes, stream banks, alkali sinks, barren wastelands, or even beaches. Branches are usually eaten by domestic or wild herbivores, and very little is used as a staple food by local residents. In general, *Prosopis* pods are about 13% protein, and may contain up to 30% sucrose; however, those used in this study (*P. articulata*) had a noticeably bitter taste.

According to Jarrel and Virginia (1990), annual precipitation alone is not sufficient to support the reproduction of mezquite stands. In this study period (1987-1990), buds sprouted only in the second semester of 1990, after unusually heavy rains, when the moisture content of the soil was higher than the permanent wilting point value (PWP). The new plants quickly developed long roots towards the water table. Within a few months, several excavated plants were found to have grown to 20 cm, with roots extending 100 cm deep.

Study Site

The field work was carried out from 1987 to 1990 in a xerophytic vegetation zone located in the La Paz-El Carrizal basin (Figure 1) of Baja California Sur, México. This area, 18 km west of La Paz city, is part of the Sonoran Desert (Schmidt, 1989) and is considered to be an arid zone. The main plant community is dominated by a sarcocaulescent shrub (Wiggins, 1980). Rainfall in the area averages 180 mm, with bimodal precipitation; most rains occur in summer, with another rainy period in winter. Microclimates are common, and differences in two nearby locations have been documented (Troyo-Diéguez et al., 1990).

The water for domestic and economic activities in the La Paz area (200,000 inhabitants) is supplied by underground resources. Most of the water table is replenished from the Sierra de La Laguna Mountains, 100 km south of La Paz city. Geological factors have divided surface- and ground-water runoff into water tables of varying salinity, thus influencing water quality. Each ground water is different in its electrical conductivity "EC" (the parameter chosen in this study to assess water quality). Exploratory drilling to locate water tables is a costly prelude to meeting the demands for more water, and a natural surface indicator of water quality could help to reduce those expenditures.

Materials and Methods

Sample Collection and Analysis

Six study sites were selected surrounding wells with water of different electrical conductivities. Seasonal changes in the EC of the ground waters associated with the wells throughout the study period have been reported elsewhere (García-Carreño, 1991; García-Carreño and Ochoa, 1991). From each of these sites, four mezquites were chosen for study. Soil samples were collected beneath mezquite canopies (BC) and from a nonvegetated site midway between each mezquite (in the so called "open field," OF), at 60 to 80 cm depth using a hand posthole auger. Soils were classified according to the FAO-UNESCO system (FAO-UNESCO, 1985), adapted to the Mexican conditions by the Instituto Nacional de Estadística Geografía e Informática (INEGI) of México. Edaphic orders are listed in Table 1. Soil and water samples were analyzed for ions and other properties according to the standard techniques described in the *USDA Handbook No. 60* (Richards, 1977).

The water-table depth of all the study wells was less than 30 m (Table 1). Mezquites were selected at random from those located no more than 100 m away from the well. Branches or stems were chosen in the outer canopy oriented to the north and south, 2.0 to 3.0 m high. Samples were transported within two hours to the lab. Folioles were cut away and rinsed with distilled water on a Buchner funnel under vacuum to eliminate dust. Two grams (g) of washed folioles were homogenized for five minutes at 10° C with 10

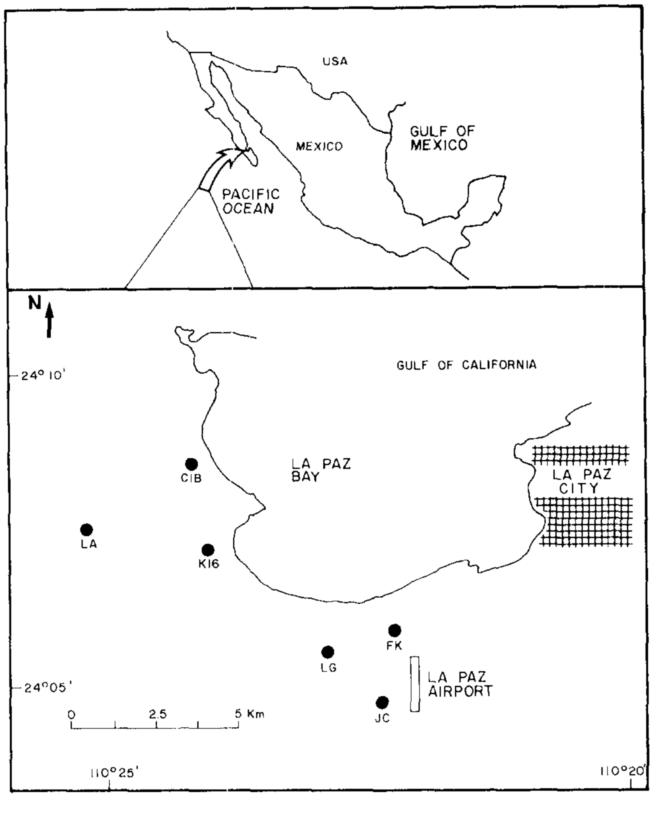

Fig. 1. Study site and wells area, La Paz, Baja California Sur, México.

Table 1. Soil and Water Sampling Sites, Water-Table Depth, Water Type, and Edaphic Orders, La Paz, Baja California Sur, México

Well code	*Geographic location*	*Depth to water table (m)*	*Mezquite sample (n)*	*Water type*	*Edaphic order*
JC	24°04′N 110°22′W	30	4	Cl-Na-Mg-Ca	Regosol
LG	24°05′N 110°23′W	18	4	Na-Cl	Yermosol
FK	24°06′N 110°22′W	12	4	Cl-Ca	Yermosol
K16	24°07′N 110°24′W	12	4	Cl-Na-HCO_3	Xerosol
LA	24°07′N 110°25′W	26	4	Cl-Na	Regosol
CIB	24°08′N 110°24′W	8	4	Cl-Na-HCO_3	Xerosol

Table 2. Chemical Composition of Soils* Supporting Natural Populations of Mezquite in a Semiarid Zone of Baja California Sur, México

Well code	*pH saturated paste*	Ca^{++}	Mg^{++}	Na^{+}	HCO_3^-	P_2O_5	NO_3
		meq l^{-1} saturation extract				*kg Ha^{-1}*	*mg l^{-1}*
JC (BC)	7.24	36	22	32.2	10	112	930
JC (OF)	7.26	79	58	26.2	8	199	1262
LG (BC)	7.35	38	17	83.2	12	68.5	1206
LG (OF)	7.20	2.8	1.2	9.4	6	34.6	1465
FK (BC)	7.13	25	14	7.1	5	16	1344
K16 (BC)	7.14	4.6	3.4	12.2	6.8	103	1067
K16 (OF)	6.84	41	18	19.7	3	143	1011
LA (BC)	7.45	9	9	49.2	13	186	980
LA (OF)	7.14	3.8	3	15.3	5.4	105	1110
CIB (BC)	6.96	2.2	1.6	2.9	2.6	84.5	1059

*Note.—In all samples CO_3 concentrations were low and insignificant for this study; meq l^{-1}: milliequivalents per liter; kg Ha^{-1}: kilograms per hectare; BC: beneath canopy; OF: open field soil between mezquites.

Table 3. Actual Land Use and Saline Variables of Soils in the Study Zone

Well code	*Actual land use*	*EC S m^{-1}*	*SAR*	*ESP %*	*Salinity class*	*Sodium hazard*
JC (BC)	No use	0.090	5.98	7.0	C3	S1
JC (OF)	Cereals	0.500	3.17	3.4	C4	S1
LG (BC)	No use	0.130	15.87	18.1	C4	S2
LG (OF)	Annual crops	0.013	6.65	8.0	C3	S1
FK (BC)	No use	0.046	1.61	1.0	C4	S1
K16 (BC)	No use	0.020	6.10	7.2	C3	S1
K16 (OF)	Annual crops	0.079	3.63	4.0	C4	S1
LA (BC)	No use	0.067	16.40	18.6	C3	S1
LA (OF)	Range cattle	0.012	8.30	9.9	C3	S1
CIB (BC)	No use	0.007	2.10	1.8	C2	S1

Note.—EC: electrical conductivity; SAR: sodium adsorption ratio; ESP: exchangeable sodium percentage; salinity class and sodium hazard according to Richards (1977); BC: beneath canopy; OF: open field.

Table 4. Chemical Composition of Ground Waters from Six Wells in a Semiarid Zone of Baja California Sur, México

Well code	*pH*	Ca^{++}	Mg^{++}	Na^{+}	HCO_3^-	$Co_3^=$	Cl^-	*TDS*	*EC*	*SAR*
		mg l^{-1}						*S m^{-1}*		
JC	6.47	33.0	37	37.7	10.0	0.0	98.0	6063	1.0	6.4
LG	6.35	2.0	3	13.6	6.4	1.0	11.0	1219	0.2	8.6
FK	6.51	22.0	10	6.2	10.0	0.0	28.4	2323	0.3	1.6
K16	6.64	10.0	11	17.2	12.0	0.0	26.4	2399	0.5	5.3
LA	7.17	1.8	5	9.3	4.6	1.2	10.6	999	0.1	5.2
CIB	7.21	8.0	7	27.1	11.0	0.0	31.2	2645	0.7	9.9

Note.—meq l^{-1}: milliequivalents per liter; S m^{-1}: Siemens/m; TDS: total dissolved solids; EC: electrical conductivity; SAR: sodium adsorption ratio.

milliliters (ml) of sodium acetate buffer (50 millimolar [mM], pH = 5.1, 1% Polyvinylpirrolidone "PVP"), and two drops of antifoam (Dow-Corning FG-10), using a Polytron cell disrupter (Polytron homogenizer) with a 7.0 millimeter (mm) diameter probe.

Peroxidase Activity Assay

Homogenized extracts of mezquite folioles were centrifuged at 3000 rpm for 10 min., and the particulate material was discarded. The supernatant protein content was assayed according to the method of Bradford (1976). Peroxidase activity (PO) was determined according to García-Carreño and Ochoa (1991): two ml of substrate guaiacol 0.16 mM in acetate buffer (pH = 5.1, 50 mM), five μl of hydrogen peroxide (30 vol), and 0.010 ml of enzymatic extract. The increase in absorbance at 470 nanometers (nm) was recorded. Enzyme activity was calculated as the change in absorbance min^{-1} and the specific peroxidase activity (SPO) as activity per mg of protein.

Low Molecular Weight Metabolites of Leaves

A 0.2 g sample of folioles was homogenized in 3 ml of methanol-chloroform mixture (2:1, v/v) using a polytron cell disruptor. The mixture after homogenization was methanol-chloroform-water (2:1:0.8, v/v/v), with the moisture obtained from vegetal tissue. The phases were allowed to separate; subsequently, 2 ml of water were added to the aqueous extract solution. Then the polypeptides, glycerol, and sugars were assayed according to Bradford (1976), Kates (1982), and Ebell (1965), respectively.

Leaf Chlorophyll Content

A 0.2 g sample of folioles was mixed with 10 ml of 80% acetone solution and extracted using the polytron homogenizer as described by Anon (1949). The supernatant of the acetonic extraction was diluted four times using 80% acetone before reading the absorbance of the extract (by spectrophotometer) at 645 and 663 nm for chlorophyll a and b, respectively. Samples were kept out of the light during the experiment to avoid photooxidation of pigments. Results are expressed as mg of chlorophyll in one g of folioles, dry weight (mg g^{-1}).

Chemical Analysis of Foliar Extract

Chemical properties (pH, SAR, Ca^{++}, Mg^{++}, Na^{+}, HCO_3^{-}, and Cl^{-} ion concentration) of foliar extract were determined according to the *USDA Handbook No. 60* (Richards, 1977).

Statistical Analysis

The ANOVA statistical procedures and LSD mean comparison were applied according to Steel and Torrie (1960) using the Statgraphics PC program.

Results

The study site is located in the La Paz-El Carrizal basin (Figure 1), where the geographical and climatic characteristics correspond to those of the Sonoran Desert. The climate in this area is highly variable, causing notable differences in ground-water quality from site to site (García-Carreño, 1991). Six different ground waters were sampled (Table 1); water tables were found between 8 to 30 m. The water types in these tables were all different except for wells K16 and CIB which had EC values of 0.5 and 0.7 S m^{-1}, respectively (Table 4). The chemical properties of soil and ground waters supporting this natural mezquite population are given in Tables 2, 3, and 4. Irrespective of edaphic order, the pH of saturated paste from sampled soils was neutral: 6.8 to 7.3 (Table 2). The same tendency was found for the pH of ground waters which varied from 6.3 to 7.2 (Table 4). As expected, the TDS was higher at higher electrical conductivities in ground waters (Table 4). The highest salinity, 0.5 S m^{-1} (measured as EC), was in the open field (OF) soil, midway between mezquites and surrounding the JC well with an EC of 1.0 S m^{-1}. In this case, Ca^{++} was found to be the dominant cation. The minimum soil salinity of 0.007 S m^{-1} was from beneath a mezquite canopy located near a well which had an EC of 0.7 S m^{-1} (CIB well). No correlation was found between the sodium content and the sodium adsorption ratio (SAR) in soils BC and foliole extracts (Figure 2).

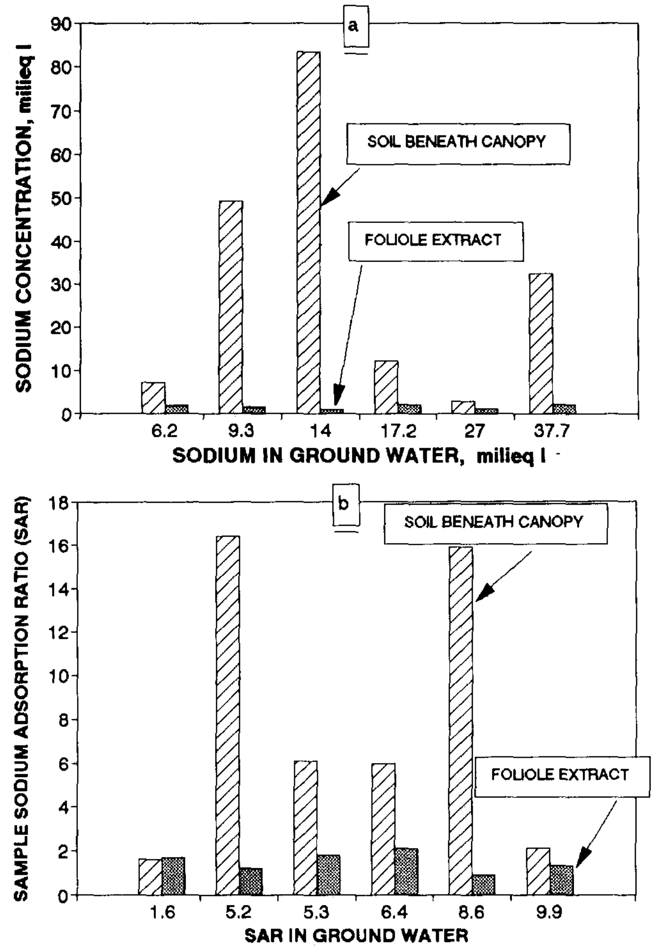

Fig. 2. a: Sodium content in soil saturated paste (beneath canopy) and the foliole extract as related to Na concentration in ground waters. b: SAR (sodium adsorption ratio) in soil (BC) and foliole extract as related to SAR in ground waters.

The relationship between ground-water electrical conductivity and leaf peroxidase activity is shown in Figure 3, in which the observed data are compared with those predicted through the regression formula. The slope of the equation was negative, indicating a reduction in peroxidase activity in plants exposed to increasing salinity. ANOVA statistical analysis of the ground-water salinity versus peroxidase enzyme activity (PO) in foliole extracts showed significant differences [$(F_{obs} = 2.864) > (F_{tables(5,28)} = 2.56)$] between plant groups from different wells (Table 7). Sodium and SAR of the ground water showed no relationship to these same parameters in the foliole extract and soil (Figure 2).

The amounts of low molecular weight metabolites (LMWM), chlorophyll content, and chemical composition of foliole extracts are shown in Tables 5 and 6. The chlorophyll content is higher in plants from wells with 0.35 and 1.04 S m^{-1} of EC (Figure 4), but the statistical analysis ANOVA showed no significant differences between the EC levels for this variable (Table 7). The most significant relationships were: (1) between ground-water, soil, and leaves EC, and (2) between ground-water EC and PO activity in foliar extracts (Table 8).

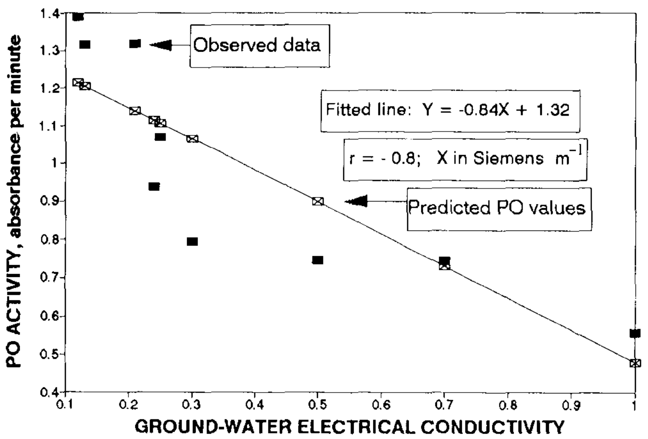

Fig. 3. Correlation between ground-water EC and peroxidase activity of mezquite leaf tissue and regression linear model (fitted line).

Table 5. Electrical Conductivity of the Solution Extract, Low Molecular Weight Metabolites (LMWM), and Chlorophyll Content (a, b, and Total) in Mezquite Leaf Tissue

Well		*LMWM*			*Chlorophyll*		
Code	*EC* *S m^{-1}*	*Glycerol*	*pptd*	*Hexoses*	*a*	*b*	*Total*
		mg g^{-1} folioles dry weight					
JC	1.0	5.29	0.08	16.17	0.014	0.0050	0.019
LG	0.2	3.17	0.07	17.20	0.018	0.0036	0.022
FK	0.3	5.47	0.05	17.94	0.020	0.0036	0.023
K16	0.5	5.47	0.10	12.20	0.023	0.0038	0.027
LA	0.1	5.20	0.08	11.17	0.022	0.0044	0.026
CIB	0.7	4.41	0.05	12.20	0.020	0.0042	0.025

Note.—EC: electrical conductivity; pptd: polypeptides.

Table 6. Chemical Composition of Folioles Extracts

Well code	*pH*	*Ca^{++}*	*Mg^{++}*	*Na^{+}*	*HCO_3^-*	*Cl^-*	*$SO_4^=$*	*TDS*	*EC*	*SAR*
				meq l^{-1}					*S m^{-1}*	
JC	6.48	1.0	1.0	2.1	1.5	3.2	0.0	6063	0.70	6.4
LG	5.69	1.3	1.4	1.0	1.3	2.7	0.3	1219	0.22	8.6
FK	6.10	1.2	1.2	1.9	1.6	2.8	0.2	2323	0.23	1.6
K16	5.90	1.3	1.4	2.1	1.9	3.0	0.3	2399	0.28	5.3
LA	6.09	1.1	1.8	1.5	1.8	2.0	0.6	999	0.15	5.2
CIB	5.58	1.0	0.8	1.2	0.9	2.3	0.1	2645	0.42	9.9

Note.—TDS: total dissolved solids; SAR: sodium adsorption ratio; meq l^{-1}: milliequavalents per liter.

Table 7. Analysis of Variance Results for Mezquite Plant Data

Variation source	*Factor*	*Degree of freedom*	*Ratio*	*Significance*
PO	Branch orientation	1	0.018	ns
PO	Individual tree	23	8.694	**
PO	EC	5	2.864	*
CHLO	EC	5	1.913	ns

Note.—df: degree of freedom; EC: electrical conductivity; PO: Peroxidase activity; CHLO: Chlorophyll "total;" ns: not significant; *: significant; **: highly significant.

Table 8. Summary of the Most Correlated Parameters in Ground Water, Soils, and Leaves of Sampled Mezquites

	Electrical conductivity, S m^{-1}				
		Soils			
Well code	*Ground water*	*BC*	*OF*	*Leaves*	*Peroxidase activity in foliole extracts*
JC	1.0	0.09	0.5	0.7	0.6
CIB	0.7	0.007	—	0.42	0.74
K16	0.5	0.02	0.079	0.28	0.74
FK	0.3	0.046	—	0.23	0.8
LG	0.2	0.13	0.013	0.22	0.94
LA	0.1	0.067	0.012	0.15	1.3

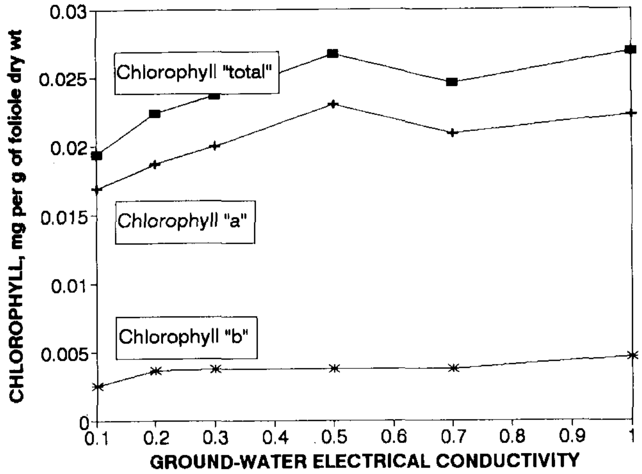

Fig. 4. Tendency of chlorphyll "total," "a," and "b" concentration in mg per gram of foliole dry weight as related to the ground-water EC.

Discussion

Stromberg et al. (in press) have shown that mezquites can survive in woodlands with water tables at depth of 30 m. This condition was considered sublethal and evidenced by low stem potential and phenotypic characteristics. Felger (1985) found mezquites having roots reaching 50 m; however, the only visible evidence of stress for these plants was a reduction in fruit production during dry seasons. Mezquite seeds sprout in the first rainy season and only when there is enough moisture to guarantee a water supply until the roots reach the water table. It appears that the final root depth ultimately depends on the depth of the water table, the capillary fringe, and other hydrogeological parameters. The difference in stress between Stromberg's and Felger's mezquites may be because the water table supporting the final root depth in Stromberg's study had lowered.

Enzyme peroxidase activity of mezquite leaf extracts seems to diminish as the electrical conductivity of the ground water increases. The correlation coefficient (less than 0.9) appears to be insufficient as an index of salinity for ground water. For Arizona mezquites, Stromberg et al. (in press) used a correlation coefficient r of -0.91 to -0.95 between leaf-water potential (midday and predawn values) and water-table depth. Their study demonstrates the difficulty of obtaining higher correlations between physiological variables and environmental parameters in wild populations.

The sodium content and sodium adsorption ratio (SAR) varied little in the solution extract of the leaf tissue (Figure 2). Although the chlorophyll content may remain unchanged in the leaves of plants exposed to harsh conditions (Kalir and Poljakoff-Mayber, 1981), it appears to be a good indicator of plant vitality. The mean chlorophyll values in mezquite foliole extract showed no significant differences between groups of plants tapping ground waters of different EC (Figure 4). The highest chlorophyll content was found in plants from water with an EC of $0.5\ \mathrm{S\ m^{-1}}$ (K16 well); thus, these plants may be considered halotolerant. However, the low molecular weight metabolites did not show important variations in total dry weight and consequently cannot be related to a given halotolerant response.

Of all the studied ions and biochemical compounds, peroxidase activity ($r = -0.803$, Figure 3) and electrical conductivity of foliole extracts showed the highest correlation with the salinity of ground water. Hence, these parameters of phreatophytes would be the most promising indicators for predicting ground-water quality in arid zones prior to digging exploratory wells. Changes in PO activity are part of the mezquite's mechanism for dealing with stress (García-Carreño, 1991). This same mechanism may also allow mezquite to adapt to different microenvironments, thus accounting for its wide distribution in arid lands. Water-related parameters such as predawn and midday water potentials, transpiration, electrical conductivity, and osmotic pressure should be tested in conjunction with biochemical stress indicators to adequately assess ground-water quality.

Abbreviation List

BC: beneath canopy; OF: open field; df: degrees of freedom; EC: electrical conductivity; F: F ratio; g: gram; LMWM: low molecular weight metabolites; ml: milliliter; mm: millimeter; mM: millimolar; nm: nanometer; PO: peroxidase; SPO: specific peroxidase activity; PVP: polyvinylpirrolidone; PWP: permanent wilting point; SAR: sodium adsorption ratio; $\mathrm{S\ m^{-1}}$: Siemens/m.

Acknowledgments

The authors wish to thank Rafael Vazquez-Duhalt (University of Alberta) for launching us in the study of peroxidase response of mezquites, Francisco de La Chica for statistical help, and Roy Bowers for the language correction. Also, thanks to three anonymous reviewers for their peer review and suggestions.

References

Anon, D. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. Plant Physiology. v. 24, pp. 1-15.

Back, W. and B. B. Hanshaw. 1965. Chemical geohydrology. In: Chow, V. T. (ed.). Advances in Hydroscience. v. 2, pp. 49-109.

Benitez, A. 1972. Captación de Aguas Subterráneas. 2a. ed. Editorial Dossat, S. A. Madrid, España. 619 pp.

Bradford, M. 1976. A rapid and sensitive method for the quantitation of micrograms sensitivities of protein utilizing the principle of protein-dye binding. Analytical Biochemistry. v. 72, pp. 248-254.

Cargo, D. N. and B. F. Mallory. 1977. Man and His Geologic Environment. 2nd ed. Addison-Wesley Publishing Co., Reading, MA, USA. 581 pp.

Cowen, R. 1990. Seeds of protection. Sciences News. v. 137, pp. 350-351.

Ebell, L. 1965. Variations in total soluble sugars of conifer tissues with method of analysis. Phytochemistry. v. 8, pp. 227-233.

FAO-UNESCO. 1985. Soil map of the world 1:5,000,000. Food and Agriculture Organization of the United Nations (FAO), Roma. 116 pp.

Felger, R. 1985. New arid land crops from Mexico. Three examples for immediate development. In: Usos y preservación de los recursos biológicos marinos y de zonas áridas. Ochoa, J. L. and Moreno-López (eds.). University of Uppsala Ed. pp. 13-24.

Felker, P., P. Clark, A. Laag, and P. 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. v. 61, pp. 311-317.

Figueiredo, A. 1990. Mesquite: history, composition, and food uses. Food Technology. Nov., pp. 118-128.

García-Carreño, F. L. 1991. Estudio de la actividad peroxidásica en hojas de mezquite (*Prosopis articulata*). Ph.D. thesis, UACPyP, CCH/UNAM, México. 80 pp.

García-Carreño, F. L. and J. L. Ochoa. 1991. The effect of saline stress on peroxidase activity in the mezquite (*Prosopis articulata*) leaf. Journal of Arid Environments. v. 20, pp. 313-319.

Gheorghe, A. 1978. Processing and Synthesis of Hydrogeological Data. Abacus Press, Tunbridge Wells, Kent, England. 390 pp.

Jarrel, W. and R. Virginia. 1990. Soil cation accumulation in a mezquite woodland: sustained production and long-term estimates of water use and nitrogen fixation. Journal of Arid Environments. v. 18, pp. 51-58.

Jenkins, M., R. Virginia, and W. Jarrel. 1988. Depth distribution and seasonal population of mesquite-nodulating Rhizobia in warm desert ecosystems. Soil Science Society of America Journal. v. 52, pp. 1644-1650.

Kalir, A. and A. Poljakoff-Mayber. 1981. Changes in activity of malate dehydrogenase, catalase, peroxidase and superoxide dismutase in leaves of *Halimione portulacoides* (L.) Aellen exposed to high sodium chloride concentrations. Annals of Botany. v. 47, pp. 75-85.

Kates, M. 1982. Techniques in Lipidology. Vol. 3, Part II. North Holland Pub. Co., Amsterdam. 610 pp.

Nilsen, E., M. Sharifi, P. Rundell, W. Jarrell, and R. Virginia. 1983. Diurnal and seasonal water relations of the desert phreatophyte *Prosopis glandulosa* (honey mezquite) in the Sonoran Desert of California. Ecology. v. 64, pp. 1381-1393.

Nilsen, E., R. Virginia, and P. Rundell. 1987. Phenology of warm desert, phreatophytes: seasonal growth and herbivory in *Prosopis glandulosa* var *torreyana* (honey mesquite). Journal of Arid Environments. v. 13, pp. 217-229.

Richards, L. A. (ed.). 1977. Diagnóstico y rehabilitación de suelos salinos y sódicos (Translation to the Spanish of the USDA Handbook No. 60). Editorial Limusa, México. 172 pp.

Schmidt, R. 1989. The arid zones of México: climatic extremes and conceptualization of the Sonoran Desert. Journal of Arid Environments. v. 16, pp. 241-256.

Sharifi, M., E. Nilsen, and P. Rundell. 1982. Biomass and net primary production of *Prosopis glandulosa* (Fabaceae) in the Sonoran Desert of California. American Journal of Botany. v. 69, pp. 760-767.

Sharifi, M., R. Virginia, P. Rundell, and W. Jarrel. 1983. Phenological patterns of current season shoots of *Prosopis glandulosa* var *Torreyana* in the Sonoran desert of Southern California. Flora. v. 173, pp. 265-277.

Steel, R.G.D. and J. W. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc., New York, USA. 481 pp.

Stromberg, J., J. Tress, S. Wilkins, and S. Clark. In press. Response of velvet mesquite to groundwater decline. Journal of Arid Environments.

Troyo-Diéguez, E., F. Delachica-Bonilla, and J. L. Fernández-Zayas. 1990. A simple aridity equation for agricultural purposes in marginal zones. Journal of Arid Environments. v. 19, no. 3, pp. 353-362.

Virginia, R. 1986. Soil development under legume tree canopies. Forest Ecology and Management. v. 16, pp. 69-79.

Wiggins, I. L. 1980. Flora of Baja California. Stanford Univ. Press, Stanford, CA, USA. 1025 pp.

ASSOCIATION OF GROUND WATER SCIENTISTS AND ENGINEERS

Membership is open to:
"those who are engaged in occupations pertaining to the supervision, regulation, or investigation of ground water or ground-water supply installations or who are teachers or students at recognized institutions in academic fields related to the study of ground water."

The purposes of this Division are:
"to cooperate with other Divisions of the N.G.W.A. in fostering ground-water research, education, standards, and techniques; to advance knowledge in engineering and science, as related to ground water; and to promote harmony between the water well industry and scientific agencies relative to the proper development and protection of ground-water supplies."

Individual membership dues in the Association of Ground Water Scientists and Engineers of $82 per year ($97 international) include a subscription to *Ground Water, Ground Water Monitoring Review,* and *The Newsletter of the Association of Ground Water Scientists and Engineers.* Membership application forms are available upon request.

National Ground Water Association, Inc.
6375 Riverside Drive
Dublin, Ohio 43017
(614-761-1711)