

Growth Factors for Woody Perennials at Western Sonoran Desert Wash Revegetation

Bertin W. Anderson
Joseph A. Atkins
Roger D. Harris

Abstract—Growth factors were investigated on an experimental revegetation site in the western Sonoran Desert, located west of Blythe, Riverside County, California. Burro-weed (*Ambrosia dumosa*), creosote bush (*Larrea tridentata*), honey mesquite (*Prosopis glandulosa*), ironwood (*Olneya tesota*), and palo verde (*Cercidium floridum*) were planted in 11 desert washes over an area of 3.9 acres. Plant growth was positively associated with elevated soil electroconductivity (an indicator of salts and nutrients) and denser soils (clay rather than sand), as well as with higher irrigation rates. The association of the factors of higher electroconductivity and denser soil with plant growth was unexpected. This association represents an intercorrelation of these two soil factors, where the water retaining capacity of clay is greater when water is being regularly applied.

Five species of woody perennials were planted in an experimental revegetation effort in the western Sonoran Desert: burro-weed, creosote bush, honey mesquite, ironwood, and palo verde (LSA Associates 1992). Although some investigative work has previously been done for honey mesquite and palo verde (Anderson and Miller 1991; Anderson and Ohmart 1982, 1985), little is known about the autecological factors affecting growth of these species. The revegetation project allowed for an evaluation of some of these factors. We report on the first two years of this experiment.

Methods

Study Area

The revegetation site, located west of Blythe in western Riverside County, California, parallels the 100-foot-wide construction corridor of the Southern California Gas Company's natural gas pipeline 5000, which was installed in fall 1990. Revegetation was prescribed as

partial mitigation for temporary disturbance of habitat of the threatened desert tortoise (*Gopherus agassizii*). The habitat is characterized by gently rolling bajadas at elevations of around 500 feet. Dominant vegetation is creosote bush scrub, intersected with desert wash scrub. The general area is dry; precipitation rarely exceeds 4 inches a year, with less than 1 inch in some years.

The revegetation effort, concentrated in 11 desert washes distributed along a 13-mile stretch of the former pipeline construction corridor, is oriented east and west. The construction corridor had been cleared of vegetation, but after construction the corridor was returned to its original contours. The top layer of soil had been reserved, and this was spread to conserve the naturally occurring seed bank.

Planting Plan

The choice of revegetation species reflected the dominant woody perennials on the site prior to construction. The plan was designed to allow separate analysis of shrubs and trees. Each revegetation area consisted of a central area planted in desert wash trees: palo verde, mesquite, and ironwood. Where a naturally barren low-flow channel existed through the wash system, that area was left bare and the peripheries to the east and west were planted. The tree plantings were buffered to the east and the west by a strip of desert shrubs: creosote bush and burro-weed.

Sampling Design

A subset of the total planting was intensively sampled and monitored. Parallel grids were established prior to planting. Sample points at planting locations along the grid were randomly selected for soil analysis and subsequent growth monitoring. Sample points were distributed at 63 burro-weed, 59 creosote bush, 65 palo verde, 65 honey mesquite, and 62 ironwood planting locations. Thus a quarter—13% of the shrubs and 70% of the trees—were intensively monitored.

Each sample point was staked and flagged; other planting points were just staked. Prior to planting, a soil sample was taken at each of the 314 sample points. A 16-inch-diameter hole was drilled with a tractor-mounted auger. Soil samples were taken from the first foot of soil and from near the bottom. Holes were designed to be 8 feet deep, but in some cases rocks or dry, dense clay prevented the auger from reaching the intended depth. In each case, the depth was recorded.

In: Roundy, Bruce A.; McArthur, E. Durant; Haley, Jennifer S.; Mann, David K., comps. 1995. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Bertin W. Anderson and Joseph A. Atkins are Officers at the Revegetation and Wildlife Management Center, Inc., Blythe, CA. Roger D. Harris is a Principal with LSA Associates, Inc., 157 Park Place, Pt. Richmond, CA 94801.

Plant Installation

Since 1991 was a drought year with low prospects for revegetation success, the project was delayed until 1992. Seed was locally collected, placed in containers, and propagated in a green house during early spring of 1992. Before installation, container-grown plants were hardened outdoors near the revegetation site.

Container-grown stock was installed in April and May 1992 at densities of 100 trees or 400 shrubs per acre. Plantings of the three tree species were alternated on 15-foot centers over 1.4 acres, for a total of 92 palo verde, 91 ironwood, and 92 honey mesquites. Plantings of the two shrub species were alternated on 10-foot centers over 2.5 acres, for a total of 484 creosote bushes and 484 burro-weeds. A total of 3.9 acres was planted on parallel grids.

Soil Analysis

Soil samples were graded from -3 for sand to +3 for clay (Anderson and Ohmart 1982). Soil electroconductivity (EC) was determined from distilled water extracted from saturated soil. EC is a measure of dissolved solids, a reflection of soil salt content, and is expressed as millimhos of solute per cm of soil (mmhos/cm).

Irrigation

Irrigation systems consisted of a polyethylene 2-inch diameter mainline with 1/2 inch lateral lines placed every 10-15 feet along the main. Water was delivered to each plant through a 2-gallon per hour pressure compensating emitter. Water was brought to each site in a water truck five days per week during the growing season. Irrigation was not done during the dormant season. In year 2, as plant size increased, more water was required to sustain growth. To learn more about relationships between irrigation levels and growth, we subdivided samples of each tree species into those receiving 5, 9, 12 and 18 GPW beginning in July of the second growing season. Shrubs were divided into two groups: those receiving 5 GPW and those receiving 8 GPW.

Monitoring

Individuals planted at soil sample points were monitored each week from May through October. Monitoring consisted of measuring plant height from trunk base to the tip the tallest upstretched leaf. Growth during any period equals height at the start of the period subtracted from height at the end of the period. This, a simple measure of plant vigor, is predictably related to crown diameter (Anderson and Ohmart 1982).

Data Analysis

Multiple linear regression (MLR) was used to show relationships between growth over both seasons (SUMGR) and after additional irrigation was supplied in the second year (GR3). Because relationships between plant growth and variables affecting growth might not be simple linear relationships, the raw data were transformed in one or

two ways. First, if distributions did not approximate normal, they were transformed using log10 of the value. Secondly, because curvilinear relationships could be associated with growth, we transformed all data to z-scores, where the mean equals 0 and the standard deviation equals 1. Horseshoe shaped relationships, those where growth increases as the variable increases to a certain level then decreases precipitously as more of the variable is added, are revealed by using the square of the standardized scores in the MLR. Another simple curvilinear relationship is where, for example, growth increases as the variable increases to a point at which growth levels off as more of the variable is added over a considerable range of the variable, then, increases sharply again as the variable becomes more abundant. This can be determined by using the cube of the standardized values in the MLR involving growth. These descriptions are of positive relationships; the reverse represents negative relationships (Anderson and Ohmart 1984; Meents and others 1982).

For a clearer understanding of how the MLR results actually relate to growth, for each species we divided the sample into three groups on the basis of the variables contributing to the MLR result. For example, if two variables were involved, group 1 included all individuals greater than the mean for both variables; group 2 included all individuals where the values for these variables were less than the mean for the entire sample, and group 3 included individuals above the mean for one variable and below the mean for the other. Differences among groups for variables or growth were tested with a t-test. The form of the t-test was determined by whether or not variances in compared groups were equal at $P > .05$.

Results

Growth of Shrubs and Environmental Variables

Significant MLR equations were obtained for both shrub species but the variables involved were different (Table 1). For burro-weed the level of irrigation was significant, but not for creosote bush. Burro-weed showed an association with soil containing more clay (+soil values) at shallow levels; creosote bush was associated with clay at deeper levels. Burro-weed was complexly associated with soil EC. If surface EC levels were high, growth was stunted, but growth was better where EC at deeper levels was higher. These relationships accounted for 16% of the variance in total growth. Creosote bush, too, was stunted where surface EC levels were higher, but at deeper levels, EC apparently did not affect growth after two seasons. The environmental variables explained 11-16% of the variance associated with GR3.

Burro-weed

For the purposes of analysis we divided the burro-weed plants into three groups: (1) included those irrigated >5 GPW and with deep soil EC values >0.7 mmhos/cm (N=22); (2) irrigated levels <5 GPW and with deep soil EC values <0.7 mmhos/cm (N=18); and, (3), with these two factors

Table 1—Factors entering significant regression equations of correlations between growth and environmental variables. SS, SD=soil type near the surface and at deep levels, respectively, ZS4CB=z-score of soil from deep levels cubed, LEC1=log10 of the EC of near surface soil, ZEC1SQ=z-score of the near surface soil EC squared, LEC4CB=z-score of the deep soil EC cubed, EC4=log10 of the EC at deeper soil levels, IRR=irrigation level in gallons per week.

Species	Percent total variance acc't for	P	Variables entering MLR and associated probability levels							
			SS	SD	ZS4CB	LEC1	ZEC1SQ	LEC4CB	LEC4	IRR
Burro-weed	16	.04	.052			-.110			.030	.044
Creosote bush	11	.03		-.019		-.019				
Palo verde	18	.01		.010	-.011		-.021			
Honey mesquite	19	.01			.002					.279
Ironwood	21	.01						-.067	.190	.029

mixed (N=21). Those in group 1 grew about 10 inches more (60%) than those in group 3 (Fig. 1). Group 1 received more water during the second growing season and soil EC was significantly greater relative to plants which grew least. Assuming equal variances ($P=.1$), $t=2.54$, $P=.015$. Differences in soil type or DAH were not significant. The middle category had intermediate values for environmental variables and for growth over both seasons (SUMGR).

Creosote Bush

For purposes of analysis, the creosote bush cohort was also divided into three groups: (1) including those where SD was $>-.25$ and LEC1 was $>.05$ (N=14); (2) those where both of these variables were $<$ the values in group 1 (N=29); and (3) those where the variables were mixed (N=15). The results (Fig. 1) indicate that group 1 individuals did not

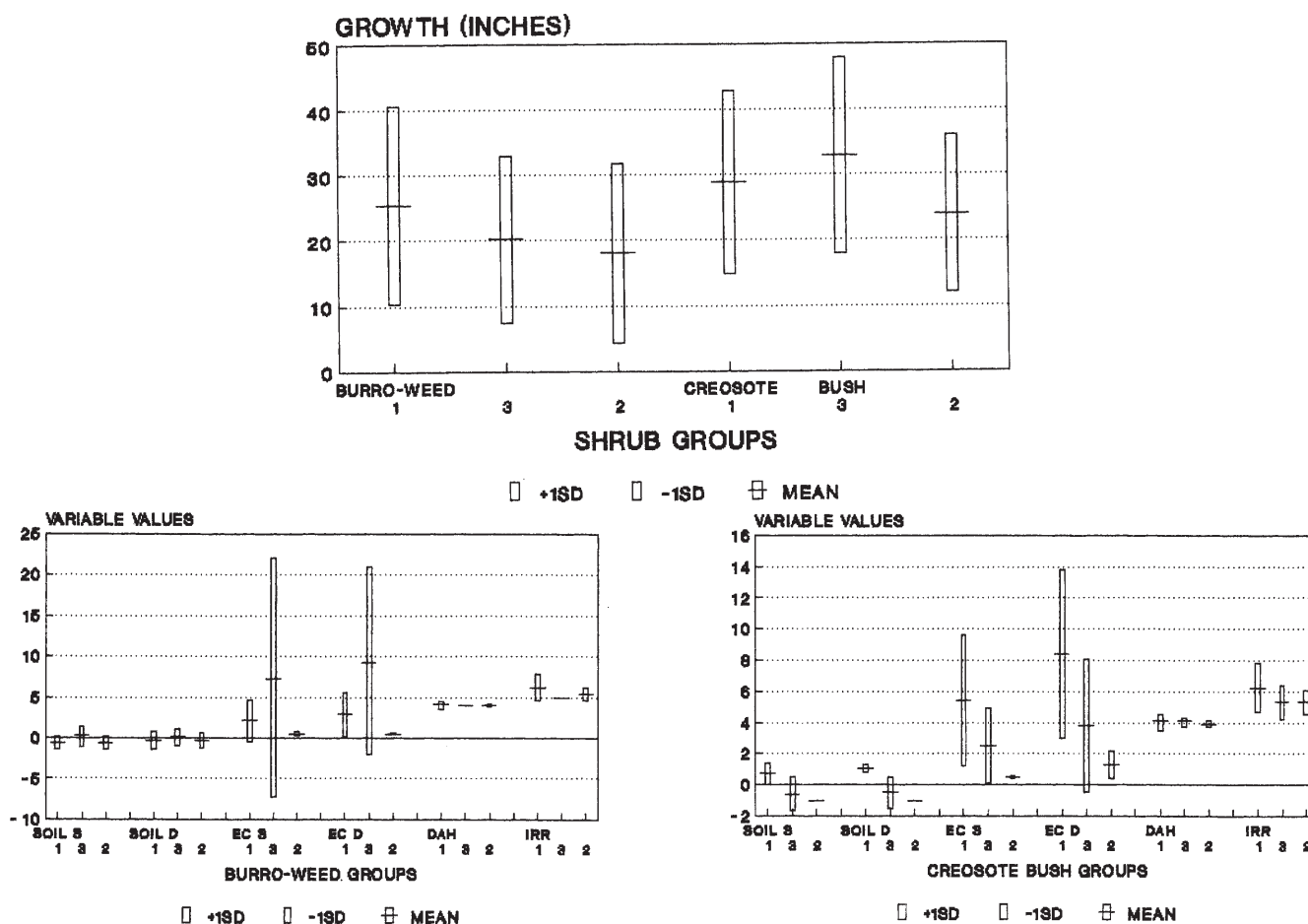


Figure 1—Growth of burro-weed and creosote bush and environmental conditions associated with each of three groups of plants. The rectangles include one standard deviation above and below the mean. Means are represented by the horizontal lines. See text for explanation of groups for each species. Soil S=soil from the surface, Soil D=a deep soil sample, EC S and EC D=soil electroconductivity near the surface and at a deep level, respectively, DAH=depth of augured hole, Irr=irrigation rate in gallons per week.

have significantly better growth than those in the group with lower irrigation and lower soil EC. However, group 3 did grow about 9 inches more (39%) than the group with lower irrigation and lower soil EC levels. This difference is statistically significant (P of equal variances = .7, $T=2.2$, 2-tailed $P=.03$). This group also had significantly higher soil salinity levels and averaged less sand in the soil, such that, when all soil samples are combined, the difference is significant ($P<.05$).

Growth of Trees and Environmental Variables

The MLR analysis revealed a significant correlation between GR3 and environmental variables for all three tree species (Table 1); four of these were curvilinear relationships. Palo verde growth related to soil type and EC levels in complex ways involving curvilinear soil and EC relationships (Table 1). These relationships explained 18% of the variance in GR3 for palo verde.

Palo verde—Palo verde trees were placed into three groups: (1) irrigated >11 GPW and with surface EC levels

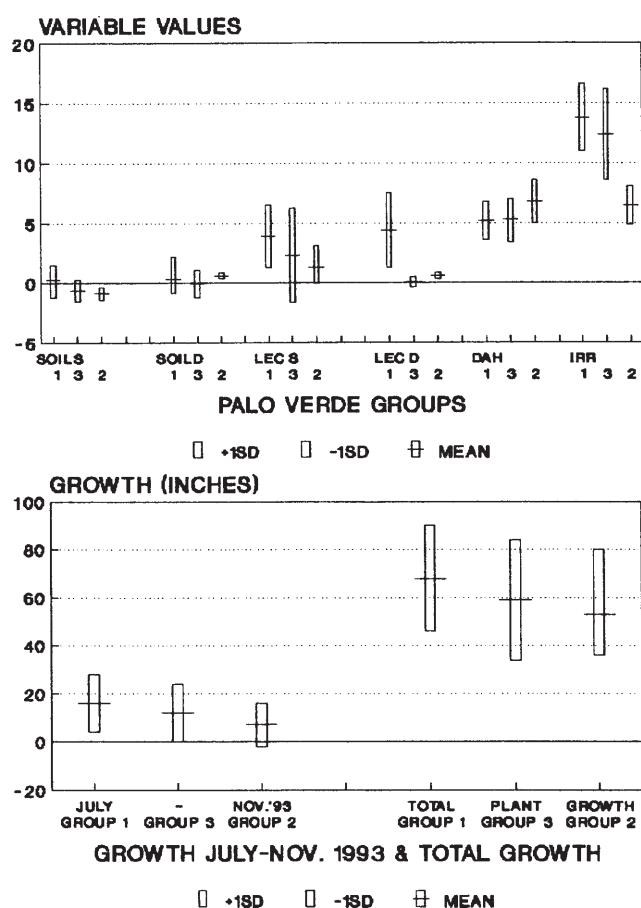


Figure 2—Growth of palo verde across two growing seasons and from July to the end of the second growing season after additional irrigation water was supplied. The top graph shows values for environmental variables associated with palo verde. Abbreviations as in Fig. 1.

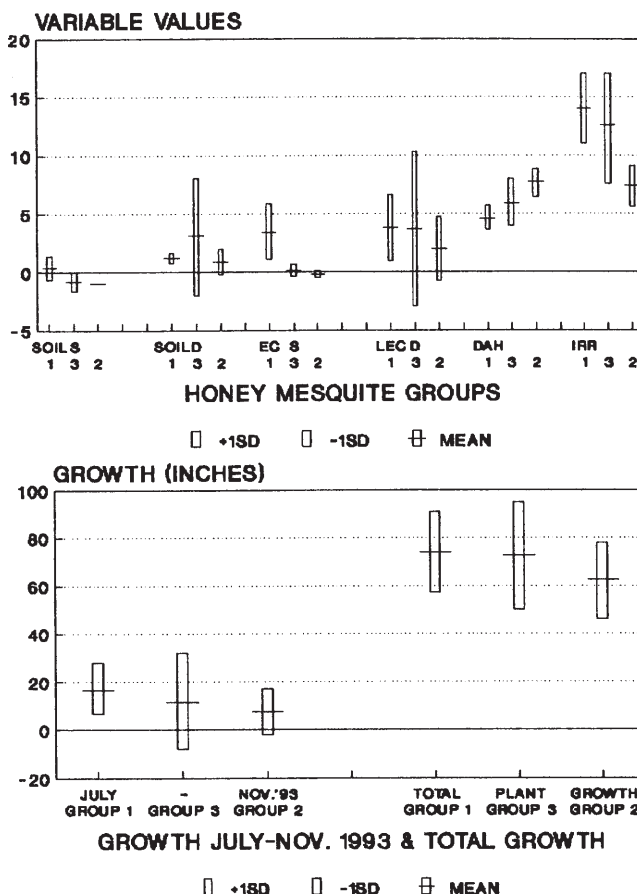


Figure 3—Growth of honey mesquite across two growing seasons and from July to the end of the second growing season after additional irrigation water was supplied. The top graph shows values for environmental variables associated with honey mesquite. Abbreviations as in Fig. 1.

>1.47 mmhos/cm ($N=24$), (2) irrigated <12 GPW and with soil EC levels <1.5 mmhos/cm ($N=12$), and (3) mixed conditions ($N=29$). Trees in group 1 grew about 15 inches more (28%) than those for group 2 (SUMGR). Assuming equal variances ($P=.3$, $t=2.3$, $P=.09$). Growth after additional irrigation was supplied the second year (GR3) in group 1 was about 9 inches more (118%) than in group 2. Again assuming equal variances ($P=.4$, $t=2.3$, $P=.03$). Group 1 had significantly more clay in the soil (+ soil type values), significantly higher soil EC levels, shallower augered holes, and was irrigated more (Fig. 2).

Honey mesquite—Honey mesquite trees were divided into three groups: (1) individuals irrigated >11 GPW and with deep soil samples averaging >.1 ($N=21$), (2) both of these variables had values less than values for group 1 trees ($N=12$), and (3) those individuals with mixed values ($N=31$, Fig. 3). SUMGR was about 11 inches (18%) greater for trees in group 1 than group 2. Assuming equal variances ($P>.9$, $t=1.94$ and $P=.063$). For GR3 growth was 9 inches greater (120%) for trees in group 1 relative to

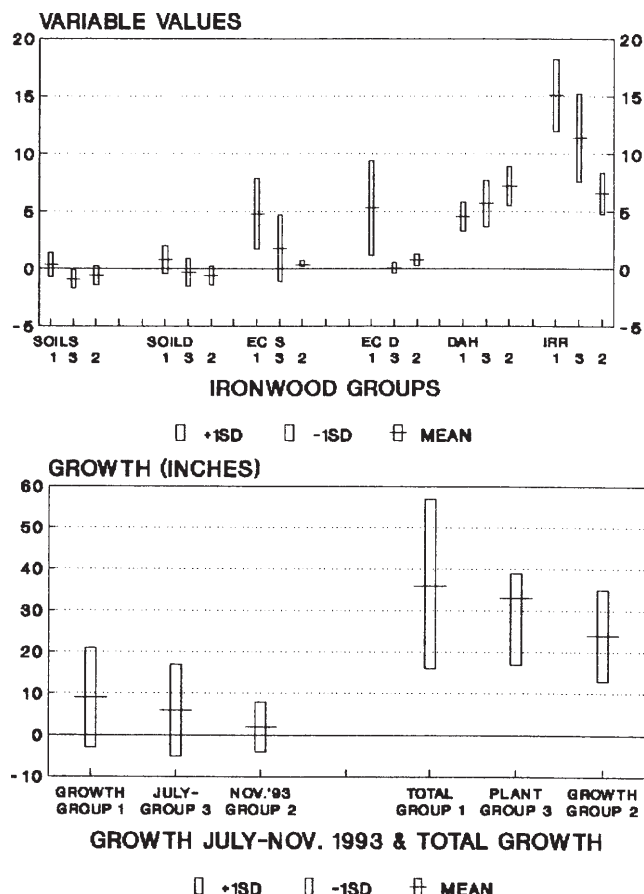


Figure 4—Growth of ironwood across two growing seasons and from July to the end of the second growing season after additional irrigation water was supplied. The top graph shows values for environmental variables associated with ironwood. Abbreviations as in Fig. 1.

group 2. Again assuming equal variances ($P=.5$), $t=2.5$ and $P=.019$. At points where group 1 trees were planted, the soil had significantly ($P<.05$) more clay and higher soil EC (Fig. 3). Depth of tillage (DAH) was significantly less and irrigation was significantly more for trees in group 2 (Fig. 3).

Ironwood—Ironwood trees were placed into three groups: (1) irrigation >11 GPW and deep soil EC values > 2.19 mmhos/cm ($N=23$), (2) smaller values than stated for group 1 ($N=10$), (3) mixed values ($N=29$., Fig. 4). SUMGR for the group 1 was 13 inches more (53%) than for group 2. Assuming equal variances ($P=.06$), $t=1.9$, $P=.07$. For GR3, trees in group 1 grew 7 inches (351%) more than trees in group 2 (Fig. 4). Assuming equal variances $P=.46$, $t=2.5$, $P=.019$.

Discussion

It is not surprising to find growth of trees and shrubs to be related significantly to soil variables. Beyond that generality, however, the nature of these relationships is

not as expected in a majority of cases. The greatest growth was associated with greater soil clay content for all three tree species, although for neither shrub species. This is not expected because the clay was unusually dense in some of the soil. Ordinarily, roots struggle to penetrate dense soil and growth is often retarded. Even more surprising was the association of high growth with increasing EC. If the soil were depauperate of nutrients, this might be expected. Anderson and Vasquez (1993) for example, found stunted growth in nutrient poor soil for cottonwood (*Populus fremontii*). But the EC levels in the current situation are relatively high, higher than might be expected for normal growth of honey mesquite. Soil EC tolerances for palo verde and ironwood are unknown. Burro-weed also grew best in the more saline, albeit somewhat sandier, soils. Salinity levels, especially above 8 mmhos/cm, are generally found to stunt growth (Anderson 1989). High growth was consistently associated with soil EC in excess of 8 mmhos/cm (Figs. 1, 2).

Deep tillage promotes growth (Anderson 1988a, 1989; Anderson and Ohmart 1982). But in this study, deep tillage was associated with poor growth. Not surprisingly, the best growth for all five species was significantly associated with larger irrigation amounts at $P=.05$ for four of them. In the fifth case, creosote bush, the best growth was associated with above average irrigation rates. The averages attained only a marginal level of statistical significance ($.1>P>.05$), but this may be biologically significant. The association of growth and water allows for the unraveling of these unexpected associations.

The correlation between soil type and soil EC was significantly positive such that the variance of one accounted for roughly 25% of the variance in the other. This means that as the amount of clay in the soil increased, soil EC also tended to increase. We have found this to be generally true in the entire lower Colorado River Valley (Anderson 1988b). This is reasonable—solutes are leached from coarse soil more readily than from dense soil, the result is lowered EC levels. Because plants tended to grow most where salinity was higher it is not surprising that soil type was also higher; more clay and higher EC tended to correspond.

The positive correlation between clay soil and high EC also explains the relationship between tillage depth and plant growth. Our auger drills to 8 feet deep in 30 seconds or less in sand. In this study area we could not drill a hole to 8 feet even in 5 minutes because the soil was so hard and dense. Areas with more clay had shallower holes and that's why growth tended to be greatest where tillage was shallowest. Before answering the question of why growth was associated with dense, saline soils, we discuss growth in relation to irrigation level.

Growth was positively associated with irrigation; that is, more water led to more growth. However, even 16 GPW, the largest amount supplied in this study, is really not very much water, and it did not lead to optimal growth. At the same time that honey mesquite receiving 16 GPW on this project grew 16-17 inches, individuals of this species on another project supplied 40-45 GPW grew 45-50 inches (Anderson, unpublished data). In context of this study, it is clay soil that retains water best. Even when water is supplied on a daily basis, sandy soils may lose

water quickly through a combination of plant use and drainage. Clay soil in desert areas may actually lose water more quickly by capillary action than, say, fine sand when water is not being frequently applied. Loss by capillary action is accelerated by the hot mid-summer desert temperatures.

Another point bears emphasizing. Laboratory analysis of soil EC is done on water pulled by a vacuum pump from soil saturated with water. When a soil with a saturated soil EC of 3 mmhos/cm is at the fringe of field capacity, the water available to a plant contains salts at a higher concentration than at saturation—perhaps as high as 9 mmhos/cm. This means that low EC levels for coarser soils are in effect often higher than soil paste extracts indicate because of water drainage from the soil. Water retention properties of dense soil dilute the salts; EC is closer to the values obtained from saturated soil. Since we do not plan to continue irrigating these plants indefinitely, what does this mean in terms of future survival?

When we stop irrigating, coarse soils will become even drier. Dense soils will lose water quickly through capillary action and salts will concentrate. Roots in these places are likely to be rather shallow, constrained by the packing action of the auger on the sides of the hole and by the density of the soil itself. Unless they find a crack through which to escape and follow a trickle of water to some point protected from dissection, these plants are likely to perish. Plants may prosper if located in washes at points where the soil is coarse enough to allow deep root penetration (facilitated by a deep augured hole) but dense enough to retain water long enough to allow the plant to remain alive between the infrequent occasions when the soil is recharged with water. The more drought tolerant species (creosote bush) have a better chance of survival than the least drought tolerant (honey mesquite). Copious research on several species, including honey mesquite and palo verde, indicates that after irrigation ceases, inadequate tillage, high soil clay content, or high EC levels, acting individually or in concert, take their toll (Anderson 1988a, 1989; Anderson and Miller 1991; Anderson and Ohmart 1982, 1985).

Acknowledgments

We thank the Southern California Gas Company for supporting the revegetation study and in particular Bob Smith, Elliot Harris, and Bruce Knapp.

References

- Anderson, B. W. 1988a. Importance of tillage to revegetating with cottonwood trees. *Restoration and Management Notes*. 6(2):4-6.
- Anderson, B. W. 1988b. Soil and salinity conditions in the Colorado River floodplain. California Department of Fish and Game. Sacramento, CA. 50 p.
- Anderson, B. W. 1989. Research as an integral part of revegetation projects. In: Abell, Dana, ed., California riparian systems conference: proceedings; U.S. Department of Agriculture Forest Service, Gen. Tech. Rep. PSW-110: 413-419.
- Anderson, B. W. and Miller, E. R. 1991. Habitat restoration at Picacho State Recreation Area. California Department of Parks and Recreation. San Diego, CA. 80 p.
- Anderson, B. W. and Ohmart, R. D. 1985. Riparian revegetation as a mitigating process in stream and river restoration. p. 41-80. In: J. A. Gore, ed., *The restoration of rivers and streams*. Butterworth Publishers. Boston, MA.
- Anderson, B. W. and Ohmart, R. D. 1982. Revegetation for wildlife enhancement along the lower Colorado River. U.S. Department of the Interior Bureau of Reclamation, Lower Colorado Region. Boulder City, NV. 225 p.
- Anderson, B. W. and Ohmart, R. D. 1984. A vegetation management study for wildlife enhancement along the lower Colorado River. U.S. Department of the Interior, Bureau of Reclamation, Lower Colorado Region. Boulder City, NV. 480 p.
- Anderson, B. W. and Vasquez, V. R. 1993. Riparian revegetation along the Santa Clara River: 1993. Valencia Co. Valencia, CA. 25 p.
- Kozlowski, T. T., Kramer, P. J., Pallardy, S. G. 1991. *The physiological ecology of woody plants*. Harcourt, Brace, Jovanovich. San Diego, CA. 720 p.
- LSA Associates, Inc. (LSA). 1992. Revegetation plan, SoCalGas Pipeline No. 5000 - Blythe segments, Riverside County, California. Southern California Gas Co. Blythe, CA. 25 p. + appendices.
- Meents, J. K., Rice, J., Anderson, B. W. and Ohmart, R. D. 1983. Nonlinear relationships between birds and vegetation. *Ecology*. 64(6): 1022-1027.