

Results of Four Revegetation Treatments on Barren Farmland in the Owens Valley, California

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Abstract—In 1991, 400 containerized fourwing saltbush (*Atriplex canescens*) shrubs were transplanted in the Owens Valley, Calif., under selected density, irrigation, fertilizer, and weed control treatments. Soil at the site, disturbed by previous agriculture, consisted of fine sand and cobbles with low electrical conductivity. Precipitation was below average the first growing season and above average the second. Results from two years demonstrated that irrigation was the most significant factor affecting survival. Planting density had little effect on survival and growth. Fertilizer had little to no effect on survival and growth the first year but increased growth the second year. Weed control increased survival and growth especially when shrubs were unirrigated and/or unfertilized or spaced close together.

The Owens Valley, in eastern California, constitutes the western edge of the Great Basin. The valley lies in the rain shadow of the Sierra Nevada mountains on the west and thus has an arid climate with low and erratic precipitation. Although precipitation is limited, snowmelt fills surface streams and recharges groundwater aquifers beneath the valley floor. Vegetation in the valley consists of a transition between Great Basin and Mojave floras; the valley floor is dominated by halophytic phreatophytes.

In the Owens Valley, the Los Angeles Department of Water and Power (LADWP) diverts these streams and pumps the aquifers to provide water to Los Angeles. Increases in pumping for export and the resulting adverse effects on the Owens Valley environment led to litigation between Inyo County and the City of Los Angeles. As partial resolution to the conflict, LADWP proposed to revegetate land that became barren due to increased water export. Thus, Inyo County and Los Angeles have begun preliminary studies to increase their knowledge of effective native plant revegetation techniques.

One revegetation study was initiated in 1991 to utilize fourwing saltbush (*Atriplex canescens*) seedlings left over from previous studies and to test various revegetation methodologies. Four treatments—irrigation, fertilization, planting density, and weed control—were selected to examine their effects on survival and growth of 400 shrubs

transplanted on barren agricultural land. Available information on these treatments was either scarce or controversial, as discussed below.

Irrigation of transplants and seeds is commonly reported as essential for arid land revegetation (Packer and Aldon 1978), although Tyson (1984) claimed it would adversely affect long-term native plant survival. Knowing the advantages of irrigation is important for planning future revegetation projects because irrigation can be labor intensive, expensive, and impossible in remote areas. Overcoming these drawbacks however, has been the topic of recent investigations (Bainbridge 1991).

Two planting densities and weed control were also used as treatments. These were intended to provide insight into whether close spacing would ameliorate the microenvironment or be detrimental due to competition for resources. To improve the microenvironment by providing shade, mulch, and erosion control, one revegetation technique involves simultaneously planting a “nurse crop” to assist plant establishment (Ostler and Allred 1978). And to decrease competition, removing weeds has been reported as essential (Kay and Graves 1983) but labor intensive. Pendleton and others (1992) reported that density does not affect survival, but close spacing has been found to decrease growth (Aldon 1981).

Half of the shrubs received fertilizer as another treatment. Fertilizer has been hypothesized to decrease a plant's drought tolerance by increasing the shoot to root ratio (Virginia and Bainbridge 1987), but a greenhouse study found that fertilizer actually increased the root to shoot ratio (Holechek 1982). Fertilizer can also increase soil salts in alkaline soils; however, Romney and others (1989) reported that small amounts of slow release fertilizer enhance plant establishment and negative results occur when researchers apply fertilizer at recommended crop rates that are too high for native shrubs.

By combining the above treatments and tracking results for five years we hope to gain a better understanding of the most effective revegetation techniques for the Owens Valley. Results from this study will be used to plan subsequent revegetation efforts and to better direct future research.

Site Description

The project site is located in the northern Owens Valley. The site was cultivated until the 1920's when it was purchased by the City of Los Angeles and taken out of production. The site was again plowed in 1969 following a

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winter of high runoff (D. Babb, LADWP, pers. comm.). Between crop production years, the land remained fallow and was used for grazing livestock. Currently the site has less than five percent vegetation cover consisting mainly of non-native weeds (LADWP unpublished).

The site has revegetation difficulties typical of abandoned agricultural lands. Cultivation created a leveled landscape with disrupted soil horizons. After abandonment, native species did not recolonize, topsoil was lost due to wind erosion, weedy species invaded, and groundwater pumping lowered the water table beneath the site.

The closest long-term weather recording station is located at the Bishop Airport, 4 km (2.5 mi.) SW of the site. Median annual precipitation recorded at this station for 48 years is 11.1 cm (4.4 in.) with 76% falling between November and March. The extreme fluctuations of precipitation result in a higher annual mean value of 13.7 cm (5.4 in.). Average winter minimum temperatures are below freezing and summer maximum temperatures are typically above 32.2 °C (90 °F) with low relative humidity.

The site is located near the toe of an alluvial fan. Due in part to the history of human disturbances in the Owens Valley, the pre-disturbance plant community is not known. Currently, rabbitbrush (*Chrysothamnus nauseosus*) is encroaching on the edges, and the site is dominated by a sparse cover of Russian thistle (*Salsola* sp.). Other species include poverty weed (*Iva axillaris*) and saltgrass (*Distichlis spicata*).

Soil at the site has been preliminarily mapped as Yellowrock-Seaman complex (Typic Torriorthents) (SCS unpublished). This soil type has developed from alluvial fan material consisting of mixed rock sources. The soil is mainly a loamy fine sand and is characterized as calcareous, well-drained and deep. Surface and 1.0 m deep electrical conductivity measurements ranged between 0.3 to 1.51 mScm⁻¹. Erosion from wind is listed as a severe potential hazard with this soil.

Groundwater pumping for irrigation occurs near the site. Although no piezometer is located on site, water levels in three nearby wells originally measured at 10.4 m–20.1 m (34.1–65.9 ft.) when installed in 1928 (from driller's well logs). They now measure 30.5 m–61 m (100.1–200.1 ft.) during the irrigation season.

Methods

Planting

The shrubs used in this study were started by Native Plants, Inc. (Utah) from seed not local to the Owens Valley. They were given to us in 1989 by Dr. Romney of the Nevada Test Site in Mercury, Nevada. In June 1990, the seedlings were transplanted from their original supercell containers and maintained for an additional one and a half years in 7.6 x 30.5 cm (3 x 12 in.) temporary tarpaper pots with open bottoms.

The study began in December 1991, when the fourwing saltbush plants were transplanted into a 46.5 x 62 m (153 x 203 ft.) livestock and rodent exclosure provided by LADWP. Planting holes were dug with a hydraulic drill mounted on a pickup truck. Holes measured 10.2 cm (4 in.) wide and

were drilled 1 m (3.3 ft.) deep to facilitate planting and rooting.

Planting consisted of removing the temporary pot from the rootball, planting in the augered hole, and then immediately watering each shrub with approximately 2 l (2.1 qt.) of water. Plants were 3 to 4 years old at the time of planting. In late January, 11 plants that had died were replaced.

Treatments

Restrictions imposed by the high- and low-density treatments and the original intention to install a drip irrigation system made it difficult to randomize treatments; thus, plants were placed in a block design and shrubs were planted in rows to simplify monitoring (Figure 1).

Shrubs receiving supplemental water were planted with a vertically placed, perforated 2.5 x 38.1 cm (1 x 15 in.) PVC pipe. These tubes were used to ensure that irrigation water would reach the roots with minimal loss to surface evaporation and to discourage weed growth. Irrigated shrubs received 2 l of water once a month from April through September in both 1992 and 1993. All irrigation pipes were covered to reduce potential water loss in the subsurface soil and to keep out wildlife.

The density treatment consisted of spacing rows either 2 m (6.6 ft.) apart for low density planting or 1 m (3.3 ft.) apart for the high density treatment. Within rows, plants were spaced 2 m apart.

Shrubs in the fertilizer treatment received 10 g (0.4 oz.) of Osmocote 18-6-12 in a 9 month release form. This rate was approximately one-third of the recommended rate for horticultural plants. The fertilizer was placed near the bottom of the augered hole to reduce access to weedy species. Unfortunately, because the soil often collapsed into the holes after augering, the fertilizer was not consistently placed at the same depth in each hole.

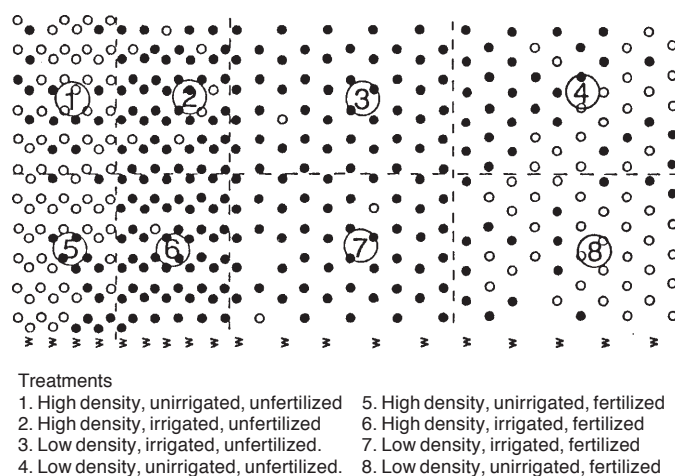


Figure 1—Planting scheme of study site showing shrub location, treatments, and live and dead shrubs after two growing seasons. Alternating rows were weeded as indicated by “w”. Open circles are dead shrubs.

Weeds, primarily Russian thistle, within 0.5 m from the shrub were hand removed in April of both years. Removal was only necessary once a year because there was little to no regrowth following initial treatment.

Soil and Precipitation Data

To characterize the soil water content, samples were collected from the site prior to planting and when planting holes were augered.

Soil water content was measured to determine whether there were preexisting differences in the site subplots. Soil water content was derived by comparing the sample's field weight with its oven-dried weight. After June 1992 a neutron soil moisture gauge was used to expedite collection of water content data. Five access tubes for the gauge were installed, one in a control site and one in each irrigation/density treatment, approximately 0.5 m (1.6 ft.) from a shrub center. Measurements were taken in April and June 1992, and March, April, July, and November 1993. In July, readings were collected weekly to track water use before and after irrigation.

A rain gauge was installed 0.6 km (0.4 mi.) NW of the study plot in December 1991 and was used to measure precipitation at the site. Precipitation records from the Bishop Airport are used to compare long range patterns to current site precipitation.

Monitoring

Survival analyses only considered those plants that were alive in March 1992. Because shrubs were planted during the winter, death after three months was attributed to transplant damage or their initial poor vigor rather than to treatment effects. Due to the length of time these plants were held, their size and quality were variable. During planting we attempted to avoid lumping any one quality within a treatment.

Growth and survival were measured in January (for size at planting), March, June, and September in 1992 and in September 1993. Growth measurements consisted of recording each shrub's greatest height and width. These were then added together to derive an index of plant size. Differences in indices were used to track growth increases. All negative differences in growth were changed to zero because these plants were either not growing significantly or branches had broken but the shrubs were still alive. The difference in growth indices between years was examined in an analysis of variance for the individual treatments and the effects of interactions between treatments. The periods between January to September 1992 (first year), September 1992 to September 1993 (second year), and between January 1992 to September 1993 (overall growth) were used to analyze changes in growth.

Results

Precipitation Results

Annual precipitation the first and second year were very different (Figure 2). Prior to the study, precipitation

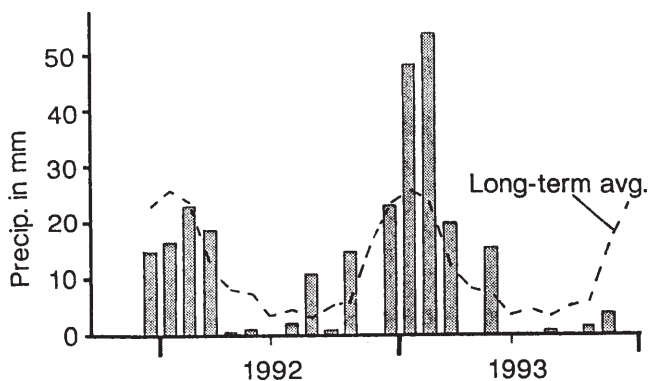


Figure 2—Monthly precipitation recorded at the study site compared to long-term trends.

in the Owens Valley had been below average for five years. Precipitation remained low, 78% of the mean, for the first year of the study. In contrast, the second year received unusually high precipitation, 142% of the mean.

Overall Survival

Of the 395 shrubs used for survival analysis, 75% survived the first growing season. The second season, an additional 36 shrubs died resulting in an 88% survival rate for that year. Overall survival of the original shrubs at the end of two years was 66%.

Single Treatment Results

Results of the four treatments appear in Table 1. Note that these "single treatment" results include combinations of the other treatments rather than representing an isolated treatment. For example, analysis of irrigated shrubs includes shrubs which did and did not receive fertilizer and weed control and that were planted in both high and low densities. It excluded all unirrigated shrubs regardless of other treatments.

Irrigation

Providing supplemental water greatly increased survival during the first dry year, 96% versus 54% (Table 1). During the second wetter year, survival rates in both the irrigated and unirrigated treatments were 98% and 70%, respectively. Overall, after two growing seasons, survival of irrigated plants was 57% higher than unirrigated plants.

Similar to survival rates, irrigation significantly increased growth the first year ($p = 0.000$). The following year there were no growth differences between the two treatments.

Density

Yearly survival differences tended to slightly favor the low density treatment. Overall, the low density treatment had an 11% greater survival rate than the high density treatment.

Table 1—Percent survival and growth index (GI) of fourwing saltbush transplants, categorized by single treatment effects. Standard error (SE) of growth index is also noted.

Treatments	% Survival			Growth index					
	Yr 1	Yr 2	All	1992		1993		Total	
				GI	SE	GI	SE	GI	SE
unirrigated	54	70	37	5	0.9	72	3.9	76	4.4
irrigated	96	98	94	12	0.6	72	1.6	84	1.9
lo density	78	92	72	8	0.7	72	2.3	79	2.6
hi density	72	83	61	9	0.8	73	3.5	81	4.0
unfertilized	78	87	68	8	0.7	62	3.3	68	3.8
fertilized	73	89	65	9	0.8	82	2.6	92	2.9
weeded	84	91	76	10	0.7	75	2.0	85	2.3
unweeded	67	84	57	8	0.8	69	3.7	75	4.2

High and low planting densities had negligible effects on shrub growth for all years. However, it is important to note that mortality, especially for the unirrigated shrubs in both density treatments, was high; thus density declined over the two year period.

Fertilizer

Fertilizer had a slightly negative effect on survival the first year, which disappeared the second growing season.

Fertilized and unfertilized shrubs exhibited similar growth rates the first year. The second year there was a significantly higher growth index for fertilized shrubs, ($p = 0.000$).

Weed Control

The first year, shrubs with weeds removed had a higher survival rate, 84% versus 67%. The second year, survival differences between the two treatments was less obvious.

Overall, 76% of the shrubs with weed control survived compared to 57% of unweeded shrubs.

First year growth was significantly greater ($p = 0.043$) for shrubs with weed control than for unweeded shrubs, with growth indices of 10 and 7, respectively. The following year, although not statistically significant, growth differences still favored shrubs with weeds removed (growth index of 75 versus 69).

Multiple Treatment Results

Treatments were analyzed in all possible combinations of one to four treatments. The following are some of the more interesting findings.

Highest overall survival rates were found in all treatment combinations which included irrigation (Table 2). In fact, survival in all but one irrigation treatment exceeded 90%. The exception, 80%, occurred when irrigation was also combined with high density, no fertilizer,

Table 2—Percent survival and growth index (GI) of fourwing saltbush transplants, categorized by multiple treatments. Applied treatments—irrigation (I), low density (LD), fertilizer (F), and weed control (WC)—are indicated by the “x”.

I	LD	F	WC	% Survival			Growth index					
				Yr 1	Yr 2	All	1992		1993		Total	
							GI	SE	GI	SE	GI	SE
	x		x	76	95	72	4	1.9	62	5.3	66	6.1
	x			56	86	48	2	2.2	56	6.5	55	7.4
x	x		x	100	96	96	16	1.7	67	4.6	83	5.3
x	x			100	100	100	13	1.7	54	4.5	68	5.2
	x	x	x	67	69	46	4	2.1	93	9.8	97	7.8
	x	x		30	57	17	2	3.2	72	11.3	74	12.9
x	x	x	x	96	100	96	14	1.7	94	4.6	108	5.3
x	x	x		96	100	96	11	1.8	76	4.7	87	5.4
			x	75	87	65	5	2.2	54	6.3	58	7.1
				41	8	3	5	2.4	60	22.6	57	25.8
x			x	96	96	92	11	1.7	78	4.7	89	5.4
x				88	91	80	6	1.8	67	5.1	72	5.8
		x	x	58	64	38	9	2.2	79	7.6	90	8.6
		x		32	62	20	9	3.0	103	10.1	113	11.5
x		x	x	100	100	100	13	1.6	76	4.4	88	5.1
x		x		100	96	96	12	1.8	66	4.6	77	5.3

and no weed removal. That same combination when unirrigated, resulted in the poorest survival of all groups, 3.4%.

Fertilizer did not necessarily improve survival. In the low density treatment, fertilizer had no effect on irrigated shrubs, but decreased survival of unirrigated shrubs. Fertilizer increased survival rates for irrigated high density plants. Effects of fertilizer on unirrigated high density shrubs was unclear.

Fertilizer increased growth for all treatment combinations during the second growing season except for high density, irrigated shrubs. That treatment combination resulted in average growth indices similar to those of the unfertilized shrubs.

Weed control was generally most beneficial when water stress was greatest, such as for unirrigated shrubs the first (dry) year. Thus, regardless of density or fertilizer treatment, unirrigated shrubs benefited from weed removal.

Although high density viewed as a single treatment resulted in only slightly lower survival rates than the low density treatment (Table 1), high plant density when combined with other “stresses”—such as no weed control or no irrigation—resulted in decreased survival (Table 2). For example, averaging survival rates for high density with no weed control revealed 50% survival, whereas those at a low density with no weed control had 65% survival. Also, high density unirrigated shrubs had 32% survival while low density unirrigated shrubs had 46% survival.

Soil Moisture

No correlation between density treatments and soil water content was apparent either before or after the study began. In April 1992, gravimetric soil moisture samples from the study plot ranged from 1.34% at the surface to 3.48% at 0.5 m in depth. Weekly neutron probe readings did not detect changes in soil moisture from irrigation treatments, possibly due to the small degree of change or because the irrigation water did not spread out as far as the access tube.

Discussion

Analysis of the applied treatments, combined with differences in precipitation during the first two growing seasons not only demonstrate that many variables interact in their effect on plant growth and survival, but also suggest reasons for conflicting results reported in the literature.

Irrigation was the most important factor contributing to fourwing saltbush survival; however, the degree to which irrigation affected survival was influenced by pre-growing season precipitation. Differences in survival rates and growth indices between irrigated and unirrigated shrubs were large after the first, dry year, but the difference narrowed after the second, wet year. This suggests that site precipitation plays an important role in survival results between irrigated and unirrigated treatments, especially when regional average precipitation is already very low. For management of revegetation sites, this finding illustrates the necessity for evaluating weather conditions after planting so that supplemental irrigation can be

provided to avoid high transplant losses. Monitoring of these shrubs will continue for several years to evaluate the long-term consequences of providing supplemental irrigation on shrub survival.

The results of the fertilizer treatment in this study were complex. Conflicting results reported in the literature may be due to differences in plant density and available water. An increase in growth was measured in all but one treatment group with fertilizer, but it is unknown if growth translates into long-term survival, especially because some treatment combinations with fertilizer resulted in slightly lower survival rates.

Results indicated that fertilizer does not decrease transplant survival if there is enough available water. Survival differences between unfertilized irrigated shrubs was the same as fertilized irrigated shrubs. It is important to note that some of the fertilizer effects may have been delayed the first growing season because either the shrubs were unable to utilize it without adequate available water or the roots did not reach the fertilizer until the second growing season. Although the fertilizer was applied at one-third of the recommended rate, a lower rate may have had less of a negative effect on survival.

Weed removal was second to irrigation in terms of its effect on survival both years, and it was second to fertilizer in its effect on growth during the second year. The importance of weed control may be correlated with water availability; it was most effective when combined with unirrigated shrubs and during the first dry year. Thus for dry sites, weed control may be a simple means of improving transplant survival and growth.

An expected trend in the data was that plants subjected to the minimal number of “stresses” during the first two years experienced higher survival rates and growth. For example, irrigated, fertilized, unweeded plants spaced far apart had 96% survival after two seasons and an average growth index of 108. In contrast, unirrigated, unfertilized unweeded plants spaced close together had an extremely low survival rate after two seasons, 3%, and a low average growth index.

Our results showed that high transplant survival could be achieved by applying treatments that minimized plant stress. But survival and vigorous growth due to applied treatments may not lead to self sustaining plant populations. After two seasons, our results show that irrigation, low density, weed control, and to a limited extent, fertilization tend to enhance transplant survival and growth, but we do not yet know the consequences of suspending the treatments. We will continue to monitor the site for long-term survival and productivity of these shrubs and for recruitment of new native plant seedlings.

Methodological Notes

The irrigation tubes were successful at delivering water beneath the surface at the immediate base of the plant but a larger tube would have been preferable because infiltration rates were low.

Placing the fertilizer at depth appeared to keep it unavailable to weeds. Fertilized shrubs did not have more or larger weeds present. Using a slow release form

allowed shrubs the opportunity to utilize it during the second year. It may have been more beneficial for the shrubs to use a smaller amount.

Weed control was relatively simple; young Russian thistle was easily removed and did not require a second treatment within the same growing season.

The open-bottom tarpaper pots worked well to keep the shrubs from becoming rootbound. But during planting, the pots should have been cut vertically several times and planted with the shrub. This would have greatly minimized root disturbance since shrub roots had grown through the tarpaper by the time they were planted.

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