RECLAIMING SODIC SOILS FOLLOWING SALTCEDAR REMOVAL ON THE PUEBLO OF SANTA ANA, NEW MEXICO[1]

by

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Abstract. Saltcedar (*Tamarisk* spp.) is a non-native facultative phreatophyte that has infested riparian floodplains, fallow farmlands, reservoir deltas and ephemeral washes throughout the southwestern United States. Land and water managers throughout the region are implementing aggressive programs to eradicate this tree in hopes of achieving water savings and restoring native vegetation communities and wildlife habitat. In 1941, Saltcedar began aggressively colonizing the 100-year floodplain along the middle Rio Grande on the Pueblo of Santa Ana ("the Pueblo") in central New Mexico. Dense thickets formed in areas previously occupied by salt tolerant grass and riparian shrub communities. Soil assessments were conducted in 1999 on a 115-acre site to evaluate the potential for re-establishing native plant communities to the site. A soil survey was performed by evaluating soil profiles along transects systematically established throughout the study site. Textural class, pH, saturation percent, calcium, magnesium, sodium, sodium adsorption ratio (SAR) and soil apparent electrical conductivity (EC) were determined. Analyses revealed highly variable SAR values ranging between 4.1 and 78.9, with the higher values associated primarily with fine textured soils. Saltcedar was mechanically removed from the 115-acre field in winter 1999, followed by "deep-ripping" clay layers with a slip plow. Gypsum was applied to the soils at rates ranging between 10-30 t $^{ac-1}$, depending upon SAR values. A permanent sprinkler irrigation system was installed in March 2000 on 65-acres that was seeded with seven native grasses and a sterile cover crop, (*Triticum elongatus).* The 65-acre field was irrigated daily from June 15 – September 30, 2000, for salt leaching purposes. Three vegetation plots were established in each of the 10, 20 and 30 t $^{ac-1}$ gypsum zones (9 plots total) in September 2000 and were analyzed for species establishment and relative cover. This case study has demonstrated that soil reclamation for revegetation of native grasses is possible using techniques developed in agriculture. However, our study also confirms that reclamation of sodic and saline soils is an expensive undertaking.

Additional Key Words: Middle Rio Grande, bosque, restoration.

Introduction

Saltcedar (*Tamarix* spp.) is considered one of the most widespread non-native phreatophytes in the southwestern United States (Anderson, 1982). Introduced from Eurasia in the early 1800's (Robinson, 1965), this arborescent shrub has naturalized the banks of rivers, streams, arroyos and reservoirs throughout the Southwest. It's numerous biological and physiological adaptations (see DiTomaso 1996) coupled with river management activities (e.g. dams, channelization projects...) have allowed Saltcedar to establish and often out-compete native riparian flora. In the middle Rio Grande Basin of central New Mexico, concern over the imminent conversion of native riparian flora to

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saltcedar has led land managers to develop aggressive saltcedar eradication programs.

In addition to supporting one of the most extensive cottonwood (*Populus fremontii* var. *wislizenii*) gallery forests in the southwestern United States (Howe & Knopf 1991), the Rio Grande floodplain in central New Mexico once supported a diverse mosaic of riparian/wetland habitat types (Crawford et al. 1993). These habitats included riparian shrub communities (*Salix exigua, S. gooddingii, Forestiera neomexicana, Baccharis wrightii, Amorpha fruiticosa, Lycium andersonii...*) marsh communities (*Carex* sp, *Eleocharis* sp, *Junus* sp, *Equisetum hiemale...*) and saline grass meadow communities (*Distichlis stricta, Sporobolus airoides...*). Few examples of these habitat types can be found in central New Mexico today, primarily because of activities associated with agricultural development, flood control, river channelization projects and municipal development (Scurlock 1998). Many areas along the historic floodplain not developed for agriculture or municipal uses are now occupied by dense saltcedar thickets. These thickets pose a severe fire hazard to the remaining native habitat and domestic and industrial structures.

Even though many managers and conservationists in the middle Rio Grande basin realize that the sustainable solution to preserving and restoring the Rio Grande floodplain involves restoring hydrogeologic processes, the immediate need for reducing fires in the floodplain is driving landowners and managers to pursue saltcedar eradication programs. In a region with rapid population growth and limited water resources, these actions are drawing attention and financial support from policy makers concerned about evapotranspirational water "losses" by phreatophytic vegetation.

While it is encouraging that momentum is building towards reducing saltcedar from the middle Rio Grande floodplain, we believe that it is paramount to carefully evaluate the revegetation potential of a site prior to large scale removal of saltcedar. Without thorough site evaluations, wildlife habitat restoration efforts may not succeed. For example, saline and sodic soil conditions prevail in many of the proposed restoration sites within the middle Rio Grande basin. Such conditions are common to arid and semi-arid environments where evapotranspiration exceeds rainfall or in areas with shallow water tables. Water in these environments is translocated to the soil surface, is then evaporated, and the result is salt accumulations near the soil surface. In many undisturbed riparian ecosystems, saline and sodic conditions are self-mitigated by surface flooding events that occur during Spring runoff. Flooding rarely (if ever) occurs in many areas along the middle Rio Grande because of levees, agricultural water diversions and the fact that much of the present day river channel is incised. The lack of flooding and absence of leaching can result in the accumulation of soluble salts in proposed restoration areas, rendering soils incapable of supporting desirable vegetation without costly soil amendments.

This paper provides a case study of a restoration project on the Pueblo of Santa Ana in central New Mexico where saltcedar dominates the Rio Grande floodplain and sodic soil conditions limit revegetation success without substantial soil amendments. The project involves restoration of native salt-tolerant grass species to a 115-acre site cleared of saltcedar in 1999. Soil amendments were applied and native grasses were seeded in Summer 2000. This paper describes the restoration procedures we followed and the preliminary results of our efforts.

Site description

The Pueblo of Santa Ana is a Native American community with approximately 79,000-acres of contiguous reservation lands within the middle Rio Grande Valley of north-central New Mexico. The reservation is 20-miles north of Albuquerque and 24 river-miles downstream of Cochiti Dam. The landscape is generally characterized by broad desert basins and discontinuous mountain ranges (Gile, Hawley and Grossman 1981). Locally, the area consists of an undulating mesa, which leads down onto rolling plains that are interrupted by low relief hillslopes and dissected by both river and arroyo systems. The Rio Grande and one of its tributaries, the Rio Jemez, converge at the southeastern corner of the reservation. The Rio Jemez, which drains the Jemez Mountains, forms a diagonal across the southern half of the reservation until it intersects the Rio Grande. The Rio Grande flows for 6-miles through the southeastern corner of the Santa Ana Reservation from the Rio Jemez confluence south to the New Mexico Highway 44 bridge.

The Rio Grande in the area of the Santa Ana Reservation was historically a braided, relatively straight or slightly sinuous, aggrading channel with a shifting sand substrate with low banks (Lagasse 1980). As the Rio Grande migrated freely across its floodplain, it created mosaics of riparian vegetation, including cottonwood bosque, shrublands, salt-grass meadows and wetlands (Crawford 1993). Levees constructed in the 1920's and 1930's constrained the Rio Grande's floodway and reduced its tendency to meander. However, the levees did not contain a large flood event in 1941 and additional flood management projects were soon implemented. Jemez Canyon Dam was completed in 1953 just 3-miles upstream of the Rio Grande confluence. Kelner Jacks were placed within the active floodway of the middle Rio Grande in an attempt to channelize the flows. Finally, Cochiti Dam was completed in 1974 to reduce peak flows downstream and trap sediment.

While the river management activities successfully achieved their intended purposes of flood control, sediment storage and channelization, the river hydrology and its associated ecological functions have been significantly altered. In its current state, the Santa Ana reach of the Rio Grande has become an incised, slightly meandering, gravel-dominated, riffle/pool channel without a well-developed floodplain (Bureau of Reclamation, 1998 unpublished). Data analyses reveal that the average channel width through Santa Ana has narrowed approximately 274 m and incised an average of 2.4 m since the construction of Cochiti Dam (Bureau of Reclamation, unpublished). As a result, peak release flows (7000 cfs) from Cochiti Dam are unable to inundate the historic floodplain. Cottonwood and willow seedling recruitment no longer occurs and non-forested wetland habitats have dried-up as the water table has declined. Saltcedar and Russian olive now dominate the historic floodplain.

Study Area

The study area is located on the Santa Ana reservation within a 115-acre saltcedar stand on the west side of the Rio Grande. The saltcedar stand, established (according to aerial photo interpretation) after the 1941 flood, abuts a 200-acre cottonwood/ Russian olive forest to the east and a new business development to the west. The Pueblo expressed interest in reducing the fire hazard by removing the saltcedar and Russian olive from this 315-acre area and replacing it with native vegetation. The ultimate goal was to manage the area as a nature preserve for Pueblo members and guests of a newly constructed resort hotel located immediately outside the 100-year floodplain. This paper concentrates on the efforts to restore native vegetation to the 115-acre saltcedar stand.

Methods

Saltcedar Control. Saltcedar was removed by mechanical methods from November 1998-April 1999 with a variety of equipment. Large (approx. 225 horsepower) hydrostatic tractors with front mounted flail mowers were used initially to clear aboveground saltcedar biomass from the 115-acre study site. The 82.4 m wide flail mowers had 56-72 independent pin supported blades that cut and mulched saltcedar trees up to 20 cm in diameter. The cutter head worked by rotating in a clockwise manner and discharging the cut woody material down and under the machine onto the soil surface.

Once the above ground biomass was mowed, we used a rear mounted "knife-blade" plow pulled behind a D-7 bulldozer to sever saltcedar root crowns from their deeper adventitious roots at a depth of approximately 30 to 40 cm below the soil surface. A D-6 bulldozer with a front-mounted brush rake was then used to rake and stack the severed root crowns into burn piles. The root piles were burned in Spring/Summer 1999.

Soil Assessment. During July, August, and September 1999, a soil survey was conducted to document soil information (maps, descriptions, and physiochemical properties) and to assess the potential for restoring native vegetation. A secondary objective was to supplement information from an electromagnetic induction (EM) survey (Hendrickx et al. 1992) conducted the previous winter. A map displaying the results of the EM survey is provided in Figure 1.

Transects were distributed in the study area to provide a pattern for test-sites. Orientation of the transects was perpendicular to the Rio Grande channel such that areas of major soil types were traversed. The spacing interval of test-sites was approximately 90 m along each transect. A Trimble Pathfinder Pro-XL Global Positioning System (GPS) was used to determine the location of all test-sites.

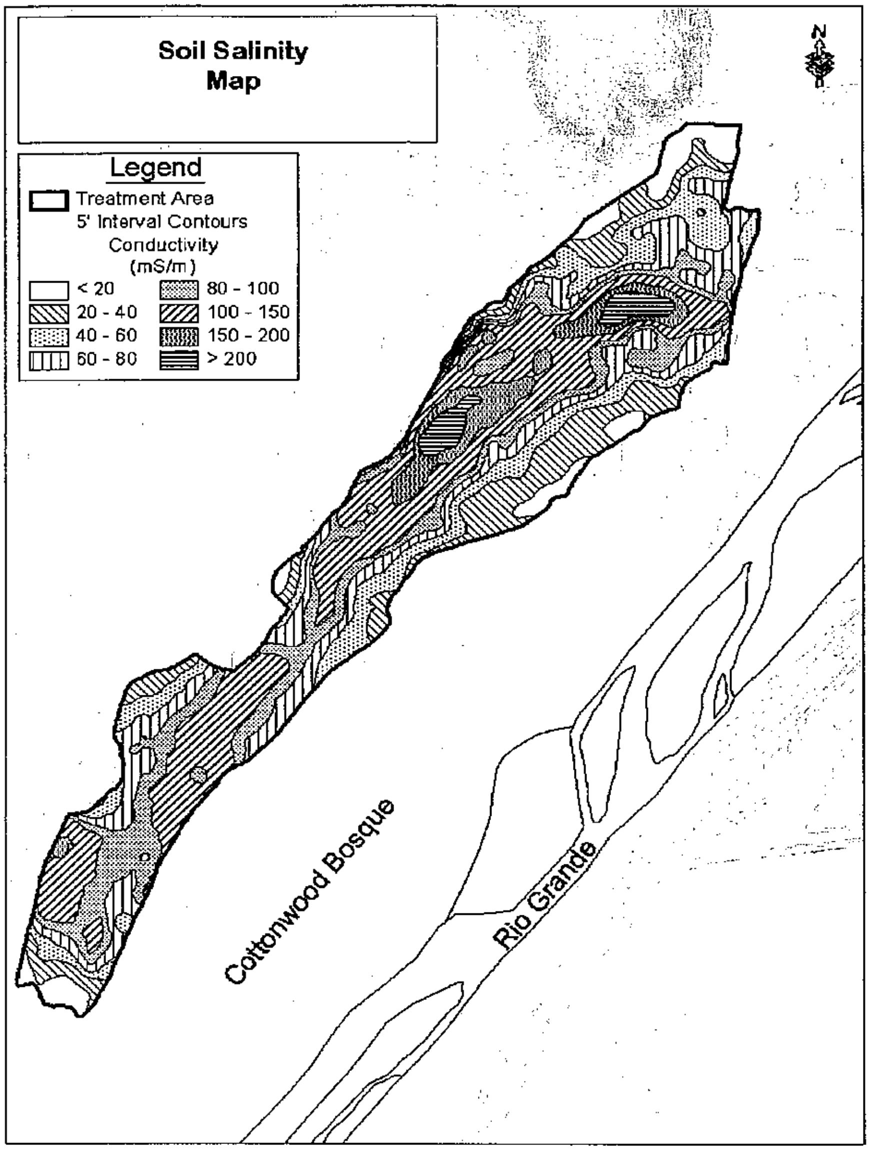

Figure 1. Map displaying results from a salinity survey conducted in 1999 using a Geonics EM-38 conductivity meter

Aerial photographs taken in 1963 and in 1998 were studied stereoscopically to provide predictions about the types and boundaries of soils. Tentative soil boundaries were drawn on the photographs, digitized, and transferred to a digital, ortho-photograph base-map. Predictions of soil types and boundaries were then investigated at the test-sites

Twenty-nine soil test-pits were excavated in the 115-acre site to a depth of approximately 150 cm and the soil profile was described at each site. Descriptions included depth, texture-by-feel, consistence, structure, effervescence, dry and moist Munsell color, and visible salts for each soil horizon. Also noted were soil type (series and phase), physiography, current vegetation, slope, aspect, and any other characteristics pertinent to pedon classification or suitability determinations.

Soil samples were collected from selected soil profiles that represented extensive soil components or were perceived to be the most limiting to the restoration effort. Soil samples were analyzed by Acculabs Inc., Durango, Colorado for pH, electrical conductivity (EC), saturation percent, calcium, magnesium, sodium,

sodium adsorption ratio (SAR), and textural class (USDA) with percent sand, silt, and clay.

The tentative soil boundaries were adjusted to reflect field observations as test-sites were described. After mapping was complete, the revised boundaries were digitized using PC-ARCINFO. Soil mapping unit delineations were named on the basis of soils that exist within them. A map unit is a collection of soil areas or miscellaneous areas that are (i) dominant or co-dominant in extent, (ii) similar soils or miscellaneous areas that may be extensive but not as extensive as the named components, and (iii) dissimilar soils or miscellaneous areas that are minor in extent. Dissimilar components are those soils, which differ enough from the named components to affect major interpretations. Conversely, similar components are those soils that differ so little from the named components that their soil interpretations for most uses and for management are similar (Soil Survey Staff 1993). The components used to name soil-mapping units were phases of soil series using surface texture, salinity, and sodicity as phase criteria. The types of soil mapping units used in this survey were consociations. The delineated areas of a consociation are dominantly a single taxon and similar soils.

A simple rating system was developed for the site to determine soil potentials for restoration of native vegetation. Several soil properties were considered for their relative contribution to the soil potential. Soil properties were weighted by horizon thickness for each sampled pedon. The numeric sum of the soil properties was the value used to determine soil potential. The highest numeric values represent soils with the lowest potential. Conversely, the lowest numeric values represent soils with the highest potential. Low potential soils require the highest level of treatment prior to revegetation and may require long-term management to maintain acceptable levels of productivity. High potential soils may require no treatment and little, long-term management.

Results and Discussion

The soils in the site have formed in mixed alluvium on the flood plain of the Rio Grande. These soils are highly complex and variable as a result of fluvial processes associated with the Rio Grande. The following are the soil-mapping units used for the site:

- Peralta loam, moderately saline and sodic
- Peralta loam, strongly saline and sodic
- Sheppard loamy fine sand, non-saline
- Sparham clay, slightly saline
- Trail sandy clay loam, very slightly saline

Descriptions of each soil mapping unit, the typical pedon for each soil series identified, ranges for chemical and physical characteristics, laboratory results from representative soil samples and soil profile descriptions were developed but are not provided in this paper. A map showing the locations of all test-sites and the extent and proportion of each soil-mapping unit was also developed but is not provided in this paper. Acreage and symbol designation is listed for each soil-mapping unit in Table 1.

A soil potential rating was developed with the data from the 12 sampled soil pedons. This rating system is used as a tool to separate low potential soils that require treatment from higher potential soils. The following soil properties and numerical ratings were used: pH $>$ 8.4 = 10, 8.4 to 7.4 = 5, $<$ 7.4 = 0; EC = laboratory measured values used; SAR * clay % / 10. Ratings were weighted by horizon thickness for each pedon. Pedon depths were normalized to 150 cm. The calculated ratings for each sampled pedon are reported below in Table 2.

Soils having index values greater than 75 have low potential and were considered to require high levels of treatment to successfully establish native vegetation. These soils may also require long term management to maintain a vigorous and healthy, plant community. High values (>75) are representative of highly saline and sodic soils or clayey textured soils. These low potential soils are represented by the Peralta loam, strongly saline and sodic soil mapping unit (Pd) and the Sparham clay, slightly saline soil mapping unit (Sp)Soils with index values less than 75 and greater than 25 are moderately saline and sodic and require lower treatment levels than soils with higher indices. These moderate potential soils are represented by the Peralta loam, moderately saline and sodic, soil mapping unit (Pr). Index values of less than 25 represent high potential soils that will likely require no treatment or long-term management prior to revegetation. The Trail sandy clay loam, very slightly saline, soil mapping unit (Tr) and Sheppard loamy fine sand, non-saline soil mapping unit (Sh) represent the high potential soils.

The data indicate that the strongly saline and sodic Peralta (Pd) soils require removal of salts prior to revegetation. Leaching is the typical method used to reclaim salt-affected soils (Tanji, 1996). Soil leaching involves dissolution of soluble salts, passage of water through the profile, and removal of salt from the plant root-zone. A general review of the chemistry for the

Table 1. Acreage and designation symbol for each soil-mapping unit in the Santa Ana Bosque Restoration Area.

Soil Mapping Unit	Mapping Unit Symbol	Acreage of Mapping unit
Peralta loam, moderately saline & sodic	Pr-1	31.7
Peralta loam, moderately saline & sodic	Pr-2	106.1
Peralta loam, strongly saline & sodic	Pd-1	86.1
Sheppard loamy fine sand, non-saline	Sh-1	12.3
Sparham clay, slightly saline	Sp-1	38.3
Trail sandy clay loam, very slightly saline	Tr-1	93.8
Trail sandy clay loam, very slightly saline	Tr-2	11.6
Trail sandy clay loam, very slightly saline	Tr-3	23.7
	*Total acreage surveyed:	403.6

*Total acreage included areas not discussed in this paper.

Pd soils shows that EC exceeds 16 mmhos/cm in most pedons. Salinity in these soils is exacerbated by sodic conditions where SAR is typically in excess of 20. In addition, these soils have finer textures and lower hydraulic conductivity than higher potential soils. Replacement and removal of exchangeable sodium and reduction of salinity in the upper 30 cm of the profile should greatly enhance revegetation efforts on the low potential soils

Following discussions with Dr. Don Suarez of the U.S. Salinity Laboratory in Davis, California, it was determined that incorporating gypsum into the soil profile would be the most efficient and timely method to reclaim the saline and sodic soils on the site. Gypsum is relatively inexpensive, has a moderate rate of reaction that is controlled by its solubility in water, and is widely used in soils containing alkaline earth carbonates (Bohn et al., 1985; Donahue et al., 1983; U.S. Salinity. Lab.1954). While gypsum appeared to be the most favorable amendment for low and medium potential soils of the project area, it was also determined that deep tillage (>100 cm) would first be required within the Pd-1 map unit prior to incorporating gypsum to break-up low permeability strata and improve drainage for salt removal.

Based on the chemical and physical analysis, soil hydraulic conductivity, and EM salinity map, the application of gypsum at the rate of 10 t $^{ac-1}$ (combined with deep ripping and limited profile mixing) followed by leaching with irrigation water would be sufficient for restoration of the majority of moderate saline-sodic soils. One location within the Pd-1 soil area, samples taken at site #29, requires a gypsum application rate of 30 t $^{ac-1}$. In the absence of more detailed lab data and since the site corresponded to the area of very high salinity (> 150 mS m^{-1} soil conductivity) on the EM survey map (Figure 1), we determined that the other high salinity areas (> 150 mS m^{-1}) should also be treated with gypsum at the rate of 30 t $^{ac-1}$.

We used the contours of the EM map (Figure 1) to define the boundaries of gypsum application rates within the 115-acre site. A high application rate (≅30 t ac^{-1}) would be used on soils with EC values in excess of 150 mS m^{-1}. A medium application rate (≅20 t ac^{-1}) would be applied to the portion of the area with EC values between 80 and 150 mS m^{-1}. A low application rate (≅10 t ac^{-1}) would be applied to the portion of the area with EC values between 40 and 80 mS m^{-1}.

Amendment Implementation.

Soil amendments were implemented in Winter 1999/2000. A slip plow was used to deep rip soils throughout the 115-acre project site. The slip plow was pulled behind a D-7 bulldozer to break-up clay lenses to a depth of approximately 1.2 m below the soil surface. The soil surface was then disked and smoothed using a land plane. Gypsum application areas were then delineated on the ground by navigating with a GPS and staking area boundaries (Figure 2). A fertilizer spreader was used to apply gypsum in amounts (10-t $^{ac-1}$, 20-t $^{ac-1}$, 30-t $^{ac-1}$) prescribed to each delineated area. Once applied, the gypsum was disked to depths of approximately 5 to 15 cm below the soil surface.

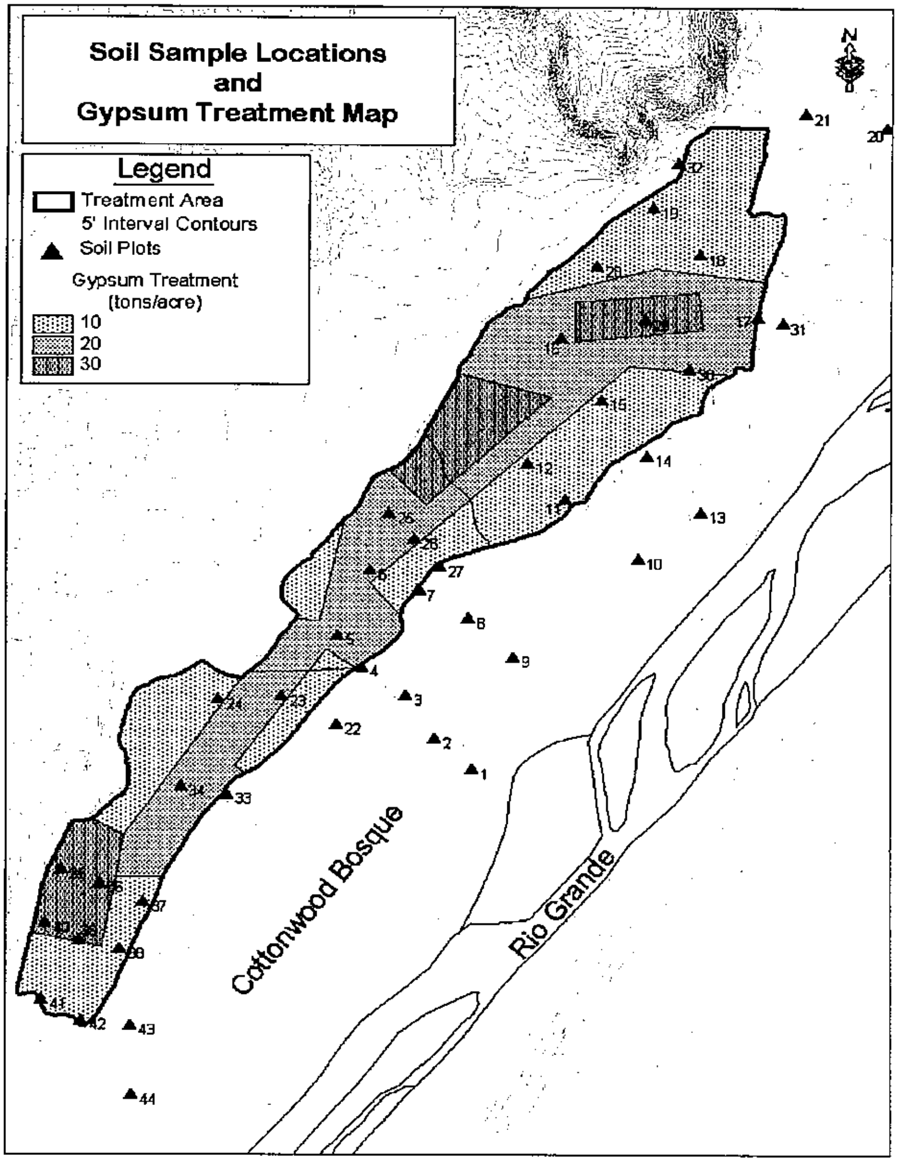

Figure 2. Soil survey map shows soil sampling locations and gypsum treatment blocks

An underground irrigation system was established on 65-acres in the northern part of the study site in March 2000. The irrigation system design assumed a groundwater well pumping capacity of 350gpm and 80psi. Different sprinkler heads and spacings were evaluated using the uniformity coefficient of Christiansen (1942). The final design, based upon an 81% uniformity coefficient, included 98'x98'x98' triangular spacing with Rainbird Sprinkler Impact 70 irrigation heads and #16 size nozzles.

Optimally, the entire 65-acre site would have been irrigated for 2-months prior to seeding grasses. This would have allowed adequate leaching of salts below the grass root zone prior to seeding. However, the pump capacity limited us to running only 3 irrigation zones (total 38 zones) at a time. Therefore, irrigation water was applied only to areas representing the highest sodium hazard (30-t $^{ac-1}$) prior to seeding. Each of these zones was irrigated 4-hours/day, 5 days/week from April 3 through June 6, 2000.

Subsequent to nearly 8 wk of the irrigation, soil samples were collected from sites randomly located in the 20 t ac^{-1} and the 30 t ac^{-1} areas. At each site,

Table 2. Numerical ratings of physical and chemical properties for each horizon and weighted mean of ratings for each pedon used for developing the soil potential ratings for the Santa Ana Bosque Restoration Area.

Site	Soil Type	Sample Depth (cm)	pH	pH Rating	Weighted pH Rating	EC mmhos/cm	EC Rating	SAR	Clay %	Rating SAR*Clay/10	Weighted Rating SAR*Clay/10	Sum of Ratings
#3	Peralta	0-15	7.8	5	0.5	1.40	1.40	4.13	17.5	7.2	0.7	2.60
#3	Peralta	15-66	8.9	10	3.3	0.73	0.73	9.18	5.00	15.3	1.5	5.60
#3	Peralta	66-99	7.8	5	1.1	10.4	10.4	23.1	18.8	94.0	9.4	20.9
#3	Peralta	99-114	7.6	5	0.5	4.24	4.24	10.4	3.80	3.9	0.4	5.10
#3	Peralta	114-150	7.6	5	0.7	11.5	11.5	17.1	12.5	53.5	5.4	17.5
											Total rating for soil pedon:	51.7
#12	Peralta	0-25	8.4	5	0.8	7.94	7.94	39.2	11.3	73.5	7.40	16.1
#12	Peralta	25-51	8.7	10	1.7	5.92	5.92	41.5	7.5	51.8	5.20	12.8
#12	Peralta	51-84	7.9	5	1.1	15.3	15.3	31.1	25.0	168	16.8	33.2
#12	Peralta	84-99	8.0	5	0.5	9.84	9.84	20.7	8.8	18.1	1.80	12.2
#12	Peralta	99-109	7.9	5	0.3	13.3	13.3	27.6	27.5	50.6	5.10	18.7
#12	Peralta	109-150	8.2	5	1.4	2.85	2.85	12.8	3.8	13.6	1.40	5.60
											Total rating for soil pedon:	98.6
#13	Trail	0-8	7.6	5	0.3	2.33	2.33	3.01	30.0	4.5	0.50	3.0
#13	Trail	8-28	7.8	5	0.7	0.98	0.98	2.06	7.50	2.1	0.20	1.8
#13	Trail	28-150	8.0	5	4.1	1.16	1.16	4.09	1.30	4.2	0.40	5.7
											Total rating for soil pedon:	10.5

Table 2. Continued.

Site	Soil Type	Sample Depth (cm)	pH	pH Rating	Weighted pH Rating	EC mmhos/cm	EC Rating	SAR	Clay %	Rating SAR*Clay/10	Weighted Rating SAR*Clay/10	Sum of Ratings
#27	Peralta	0-8	7.8	5	0.3	3.05	3.05	7.52	40.0	15.0	1.5	4.8
#27	Peralta	8-30	8.6	10	1.3	3.53	3.53	22.7	10.0	34.1	3.4	8.3
#27	Peralta	30-53	7.9	5	0.8	14.0	14.0	25.9	23.8	92.4	9.2	24.0
#27	Peralta	53-86	7.8	5	1.1	7.87	7.87	13.5	6.30	18.3	1.8	10.8
#27	Peralta	86-150	8.0	5	2.2	2.94	2.94	11.1	2.50	12.0	1.2	6.3
											Total rating for soil pedon:	54.1
#29	Peralta	0-38	8.0	5	1.3	22.8	22.8	42.8	7.50	80.2	8.00	32.1
#29	Peralta	38-79	8.3	5	1.3	38.9	38.9	78.9	17.5	368	36.8	77.0
#29	Peralta	79-109	8.6	10	2.0	16.0	16.0	46.8	6.30	58.4	5.80	23.9
#29	Peralta	109-140	8.6	10	2.0	6.37	6.37	41.7	3.80	31.2	3.10	11.5
#29	Peralta	140-150	7.9	5	1.3	21.5	21.5	43.8	31.3	114	11.4	34.1
											Total rating for soil pedon:	178.6
#33	Peralta	0-41	7.6	5	1.4	15.3	15.3	16.4	18.8	82.1	8.2	24.9
#33	Peralta	41-61	7.5	5	1.4	15.9	15.9	19.9	27.5	72.9	7.3	24.6
#33	Peralta	61-89	7.7	5	0.9	16.5	16.5	24.2	10.0	44.4	4.4	21.8
#33	Peralta	89-150	8.3	5	2.1	3.56	3.56	18.1	1.30	9.40	0.9	6.6
											Total rating for soil pedon:	77.9

Table 2. Continued.

Site	Soil Type	Sample Depth (cm)	pH	pH Rating	Weighted pH Rating	EC mmhos/cm	EC Rating	SAR	Clay %	Rating SAR*Clay/10	Weighted Rating SAR*Clay/10	Sum of Ratings
#35	Jocity	0-56	7.8	5	1.8	5.06	5.06	13.6	53.8	269.0	26.9	33.8
#35	Jocity	56-81	8.3	5	0.8	6.19	6.19	34.9	12.5	72.6	7.3	14.3
#35	Jocity	81-127	7.9	5	1.5	9.56	9.56	21.2	50.0	317.4	31.7	42.8
#35	Jocity	127-150	8.1	5	0.8	9.42	9.42	22.6	1.30	4.7	0.5	10.7
											Total rating for soil pedon:	101.6
#38	Jocity	0-10	7.6	5	0.3	2.50	2.50	6.34	35.0	14.8	1.50	4.30
#38	Jocity	10-51	7.6	5	1.3	11.4	11.4	15.8	51.3	216	21.6	34.3
#38	Jocity	51-81	7.7	5	1.0	19.7	19.7	24.0	33.8	162	16.2	36.9
#38	Jocity	81-109	7.8	5	0.9	15.2	15.2	22.5	5.00	20.6	2.1	18.2
#38	Jocity	109-150	8.0	5	1.4	8.55	8.55	14.6	2.50	10.3	1.00	11.0
											Total rating for soil pedon:	104.8
#43	Peralta	0-13	7.69	5	0.4	1.41	1.41	2.39	16.3	3.2	0.3	2.20
#43	Peralta	13-114	8.32	5	3.3	1.19	1.19	1.97	3.80	4.9	0.5	5.00
#43	Peralta	114-150	8.09	5	1.3	13.3	13.3	23.0	11.3	64.7	6.5	21.0
											Total rating for soil pedon:	28.2

Table 2. Continued.

Site	Soil Type	Sample Depth (cm)	pH	pH Rating	Weighted pH Rating	EC mmhos/cm	EC Rating	SAR	Clay %	Rating SAR*Clay/10	Weighted Rating SAR*Clay/10	Sum of Ratings
#48	Peralta	5-56	7.8	5	1.8	2.25	2.25	5.03	46.3	85.3	8.5	12.6
#48	Peralta	56-97	8.2	5	1.3	1.68	1.68	8.91	3.80	8.9	0.9	3.90
#48	Peralta	97-150	7.9	5	1.8	2.24	2.24	3.78	37.5	51.9	5.2	9.30
											Total rating for soil pedon:	25.8
#49	Jocity	0-15	7.6	5	0.5	1.80	1.80	3.15	16.3	5.10	0.5	2.80
#49	Jocity	15-51	8.1	5	1.2	2.91	2.91	10.7	32.5	80.9	8.1	12.2
#49	Jocity	51-112	7.8	5	2.0	8.23	8.23	10.9	21.3	92.5	9.2	19.5
#49	Jocity	112-150	8.2	5	1.3	0.65	0.65	3.07	1.30	1.00	0.1	2.10
											Total rating for soil pedon:	36.5
#51	Sparham	0-10	7.8	5	0.3	0.71	0.71	2.43	60.0	9.70	1.00	2.00
#51	Sparham	10-58	7.9	5	1.6	1.77	1.77	6.18	57.5	113	11.3	14.6
#51	Sparham	58-150	7.8	5	3.1	6.08	6.08	8.91	37.5	206	20.6	29.8
											Total rating for soil pedon:	46.4

samples were collected in 25 cm increments to a depth of 100 cm. Samples were analyzed by Acculabs, Inc. for pH, EC, and SAR. Mean EC for the 20 t ac^{-1} and the 30 t ac^{-1} areas was 5.0 and 6.8 mmhos cm^{-1}, respectively. Mean SAR for the 20 t ac^{-1} and the 30 t ac^{-1} areas was 9.8 and 14.8, respectively. We determined that the EC and SAR levels in the primary root-zone (0 to 25 cm) were suitable for the establishment of native, salt-tolerant vegetation.

Revegetation. The 65-acre area was seeded on June 13, 2000 with seven native grass species (*Hilaria jamesii, Sporobolus airoides, Sporobolus cryptandrus, Distichlis spicata* var. *stricta, Elymus riparius, Elymus canadensis* and *Bouteloua gracilis*) and a sterile cover crop (*Triticum elongatus).* Seeds were applied using a rangeland seed drill at a rate of 15.25pls/lbs per acre. Large seed was drilled to an approximate depth of 0.65 cm below the surface. Small seed (*Sporobolus* spp *& Distichlis* sp.*)* was trickle seeded. Immediately after seeding, irrigation water was applied to all zones for approximately 2-hrs/day (total 18 hours/day), 6 days/week from June 14 – October 16, 2000.

Nine vegetation-monitoring plots were established in October 2000 throughout the 65-acre site to estimate vegetation cover. Three 50 meter circular plots containing four 25m transects extending from the plot center-point were established in each of the 10, 20 and 30 t ac^{-1} gypsum zones (9 plots total). Basal vegetation cover was recorded using the point-intercept method (Mueller-Dombois & Ellenberg, 1974). While the vegetation data has not been thoroughly analyzed, preliminary results indicate that the highest plant cover was found in the zones receiving gypsum treatments of 30 t ac^{-1}. However, these sites are dominated by *Triticum elongates* (see Figure 3).

Preliminary analysis indicates that *T. elongatus* had significantly greater cover (ANOVA, F = 23.9, Multiple Comparison test p< .01) in the 30 t ac^{-1} treatment zones than in either of the other gypsum treatment zones. We suspect that *T. elongatus* was more successful in the 30 t ac^{-1} zones because of a combination of differences in soil texture and pre-seeding irrigation treatments in these zones. However, more thorough data analyses will be required to validate this hypothesis. At this time, no other vegetation analyses have been conducted.

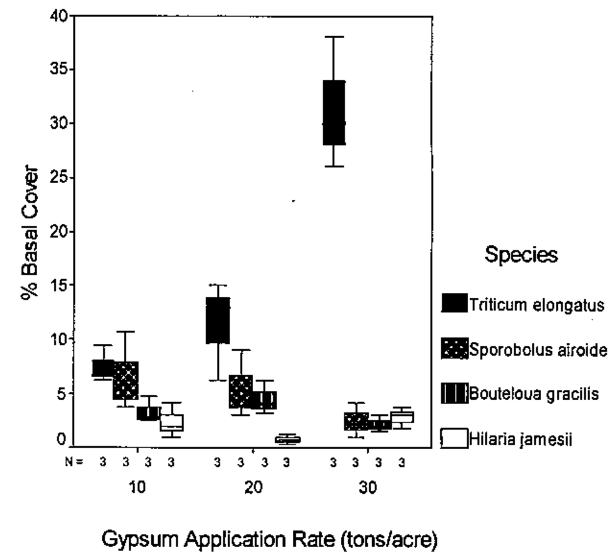

Figure 3. Boxplots showing percent basal cover of select grass species in gypsum treatment areas.

Conclusions and Recommendations

The presented case study of Saltcedar removal and reclamation of sodic soils at the Pueblo of Santa Ana leads to the following conclusions and recommendations.

1. Aerial photographs from 1935 and anecdotal information by the elders of Santa Ana Pueblo indicate that our study site was saline long before Saltcedar invaded the area. This demonstrates that Saltcedar has not been the cause of soil salinization and sodification. These two processes are a result of high evaporation rates, low precipitation rates, and shallow ground water tables. Saltcedar has invaded both highly saline and sodic areas as well as locations with benign soil conditions.

2. Revegetation is straightforward and cost effective in areas with relatively low apparent soil electrical conductivities and without sodicity. However, in areas with high soil salinity and sodicity revegatation requires expensive soil reclamation measures.

3. This case study has demonstrated that soil reclamation for revegetation of native grasses is possible using techniques developed in agriculture. However, our study also confirms that reclamation of sodic and saline soils is an expensive undertaking. Therefore, we agree with Anderson (1998) who states "....in the absence of enormous and perpetual subsidies,

restoration is actually impossible..."

4. This case study has also demonstrated that salinity surveys using the EM38 ground conductivity meter together with soil feasibility studies allow us to inexpensively evaluate the potential for revegetation of riparian areas in the Rio Grande Valley.

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