RECLAMATION

Managing Water in the West

Results of 2007 Soil Sampling Along the Middle Rio Grande

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Environmental Services Division
Fisheries and Wildlife Resources Group
Denver, Colorado

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Results of 2007 Soil Sampling Along the Middle Rio Grande

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Contents

Page

Introduction **1**
Methods **2**
Results **6**
Conclusions and Recommendations **13**
Literature Cited **14**

Tables

Tables *Page*

1 Description of vegetation and soils and hydrology of sample plots 7
2 Average values of parameters tested by plot type and depth 8
3 Results of statistical comparisons of soil parameters between samples collected in plots with healthy and dying native vegetation by depth 11
4 Depths of the slightly decomposed litter layer for soil samples from healthy and dying willow stand plot types 12
5 Classifications used in interpreting agricultural and soil tests in New Mexico ... 13

Figures

Figures *Page*

1 Location map of study site 2
2 Soil sample locations within vegetation communities of healthy and dying willow 4
3 Collecting soil samples to a depth of 36 inches using an auger with a 2-inch-diameter bit 5
4 Average values of parameters by plot type for the 0- to 6-inch depth 9
5 Average values of parameters by plot type for 6- to 12-inch depth 9
6 Average values of parameters by plot type for the 12- to 36-inch depth 10
7 Average values of parameters by plot type for the total 0- to 36-inch depth 10

Appendices

Appendix A – Laboratory Results of Soil Analyses
Appendix B – Photos of Sample Plots

Introduction

Flow regulation and channelization of rivers alter hydrologic regimes which in turn can change the plant species composition of riverine ecosystems (Stromberg et al. 2005). Altered water regimes have created conditions along many rivers in the Southwest in which saltcedar (*Tamarix ramosissima*) has increased while Fremont cottonwood-Goodding's willow (*Populus fremontii-Salix gooddingii*) associations have declined (Levine and Stromberg 2000).

Floodplain soils along regulated rivers may also undergo changes. Saline conditions may develop in soils that are no longer subject to the periodic overbank flooding associated with natural stream flows (Glenn et al. 1998). Without these flushing flows, salts can accumulate in the soil profile.

Along the Middle Rio Grande upstream from Elephant Butte Reservoir in southern New Mexico, a decline in the health of many Goodding's willow stands has been observed. Over the past several years, Elephant Butte Reservoir has receded (Moore 2005). As reservoir levels receded, native and exotic riparian plant species established within the reservoir's headwaters, providing areas of suitable habitat for the endangered southwestern willow flycatcher (*Empidonax traillii extimus*; SWFL). Over time, flushing flows from overbank flooding or fluctuating reservoir levels have decreased in frequency, due not only to the receding reservoir but also to reduced flows and channel degradation. As the reservoir has continued to recede, soils in some areas of the reservoir have dried, and native willow species are being replaced by exotic species, particularly saltcedar.

In other areas, however, soils that support willow stands have remained inundated with 1–3 feet (ft) for more than 10 years. These flooded conditions could presumably also be detrimental to the longevity of Goodding's willow stands, limiting the supply of oxygen to the roots which is required to provide adequate water, mineral nutrients, and certain growth hormones to riparian trees (Kozlowski 2002). For example, Hunter et al. (1987) found a loss of 64 percent of Goodding's willow following a 2.5-year flood duration downstream from Alamo Dam on the Bill Williams River. Initial stress effects are beginning to be observed in willows on the Middle Rio Grande due to long-term flooding. Adventitious roots were observed on submerged portions of willow stems, which is an adaptive strategy of flood-tolerant species following mortality of submerged roots (Kozlowski 2002).

Soil sampling was conducted upstream from and within the Elephant Butte Reservoir Conservation Pool (Figure 1) in November of 2007 in order to test the assumption that the concentration of salts increased within the rooting zone of woody plant species as reservoir levels and flushing flows decreased. Sampling was based on the hypothesis that

Figure 1.—Location map of study site.

along with changes in hydrology, salt accumulation in the soils was also a factor in the mortality of willow species.

Methods

In 2006, the first year of soil sampling, a paired sampling design was used. Healthy populations of willow were compared to dying populations located in adjacent sites. This method of sampling was found to be limited by the need to position the two types of sites near to each other to approximate similar hydrologic conditions and vegetative communities. "Healthy" stands were identified relatively when in fact all sites were located upstream from the delta where large areas of willow were declining in health. Consequently, pockets of willow that appeared to be more vigorous than adjacent stands were defined as "healthy" and did not necessarily provide quality habitat for nesting SWFLs.

The sample design was revised in 2007 to include developing stands of Goodding's willow near the delta of the receding reservoir. These stands provided a better representation of samples from a "healthy" willow population with high-quality SWFL habitat. Samples from the dying stands were collected from sites further upstream in areas that were included in the previous year's study.

In the plots with dying willow, saltcedar was typically encroaching. It appears likely that saltcedar increases soil salinity. Numerous salts and minerals are excreted by saltcedar glands (Berry 1970; Dressen and Wangen 1981; Kleinkopf and Wallace 1974; Storey and Thomson 1994; Thomson et al. 1969). Leaves and stems contain concentrations of soluble salts that are absorbed by the roots from deeper soil layers, transported though the plant, and concentrated in the leaves. The salts are eventually deposited on the soil surface under the plant (Kerpez and Smith 1987) when deciduous leaves drop or following rainfall events. Consequently, salts are redistributed over time from deep within the soil profile to become concentrated on the soil surface of floodplains. Therefore, sampling directly under saltcedar was avoided to prevent elevated salt levels caused by input from saltcedar.

Ten samples were collected in each of the respective plot types (healthy and dying), for a total of 20 plots (Figure 2). Within each of the plots, three samples were gathered from the soil profile at 0- to 6-inch (in), 6- to12-in, and 12- to 36-in depths using a 2-in-diameter auger (Figure 3). The samples were tested for a suite of parameters, including electrical conductivity (EC), which provides an indication of salt levels, and sodium adsorption ratio (SAR), which provides information on the comparative concentrations of sodium, calcium, and magnesium in the soil solution. Other parameters tested were pH, lime content, percent organic matter (OM), nitrate nitrogen (NO_3-N), phosphorous (P), potassium (K), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), calcium (Ca), magnesium (Mg), and sodium (Na), as well as an estimate of texture.

Soil samples from healthy stands of willow were statistically compared to those from dying stands using the Student's t-test of means for normally distributed data and the Mann-Whitney test of medians for data that were not normally distributed. A finding of statistically significant differences between the two areas would lend support to the conclusion that altered soils may have been a reason for the change in the condition of the vegetation, independent from effects of altered soil moisture availability alone.

The depth of litter was recorded at each sampling point to determine if there was a difference in the amount of plant litter between the plot types, which could affect the levels of available NO_3-N and P within the soil profile. In 2006, NO_3-N and P levels were statistically higher in soils among the dying willow populations, which led to the addition of this measurement in the sampling effort.

Photos were taken at each of the sites to document the condition of the plant communities at the time of sampling.

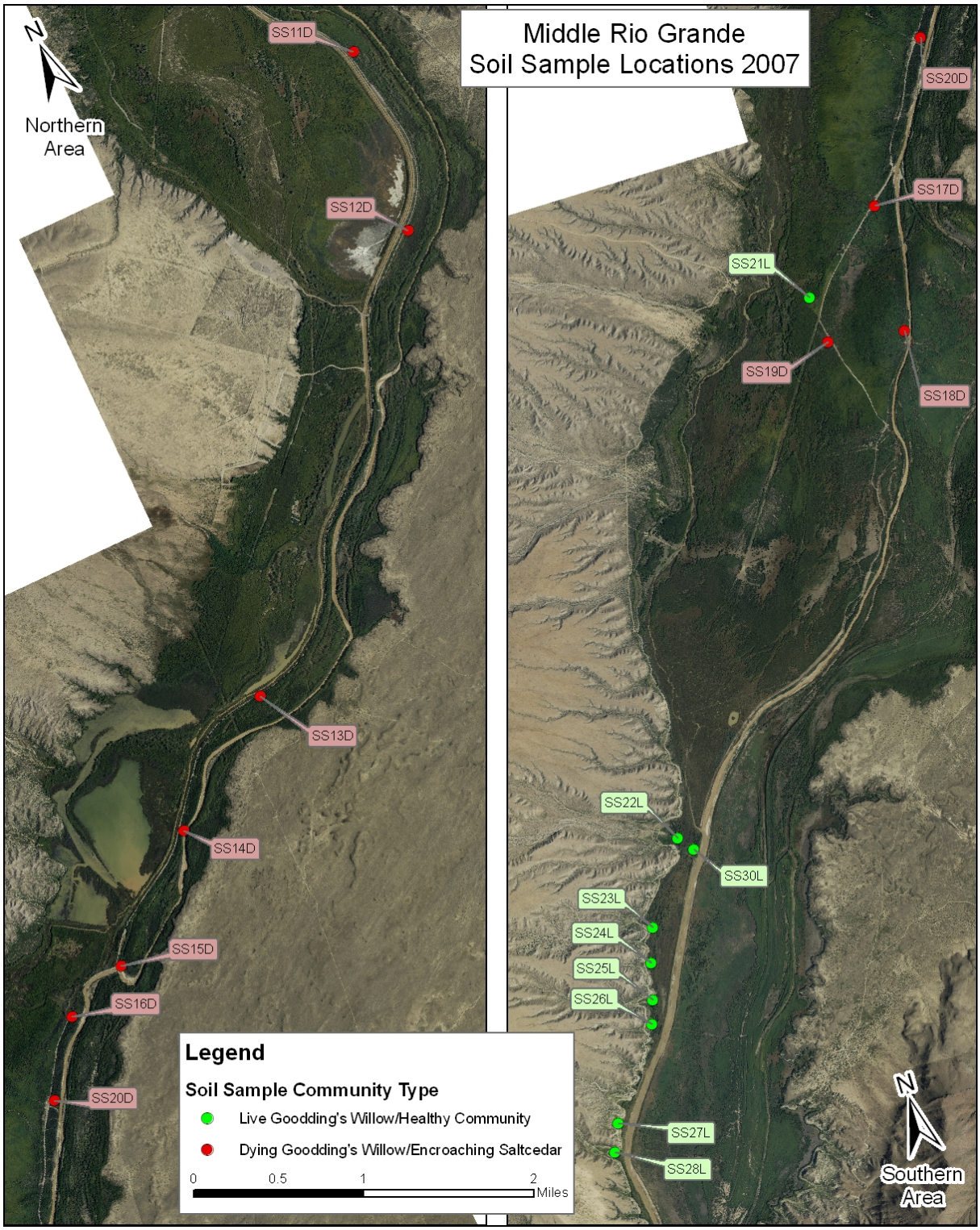

Figure 2.—Soil sample locations within vegetation communities of healthy and dying willow.

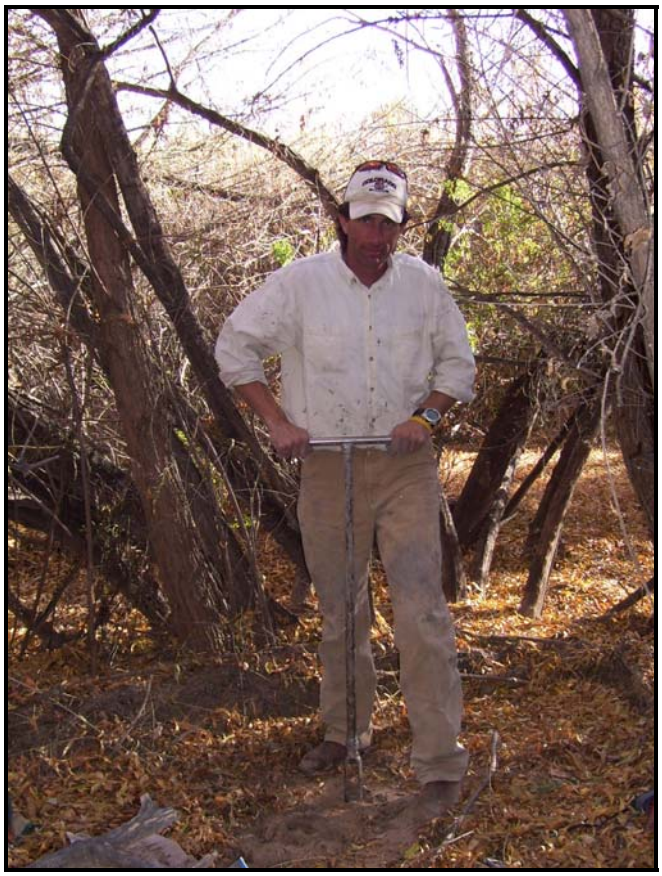

Figure 3.—Collecting soil samples to a depth of 36 inches using an auger with a 2-inch-diameter bit.

Results

Table 1 provides descriptions of the vegetation and soils and hydrology in each of the plots.

The laboratory results of the soil analyses are shown in Appendix A. The average values of the parameters tested by plot type and depth are listed in Table 2 and graphed in Figures 4 through 7.

In comparisons of soil parameters tested between the two types of plots, statistically significant differences were found for all parameters except lime content, texture estimate, and K (ppm). Soil samples associated with healthy stands had significantly higher values for EC, OM, P, Zn, Fe, Mn, Cu, Ca, Mg, Na, K (meq/L), and SAR in at least one of the depth increments than those associated with dying willow stands (Table 3). Significantly lower values were found for pH and NO_3-N in soils of the healthy plot types.

EC and SAR levels were actually significantly higher from 0- to 6-in, 6- to12-in and the total 0- to 36-in depth in soils in healthy willow stands. These results ran counter to the premise that salts in the soils were a factor in the decline of willow. Plots within the healthy type generally had a shallow water table (Table 1), where salts that have accumulated in the soil can be leached and subsequently brought to or near the surface by upward-moving water. Return flows from irrigation water may have also contributed to the salinity of the water table. In the dry soils of the dying willow stands, salts may have been leached from the rooting zone by rainwater, and these plots lacked a shallow water table that could introduce saline water into the soil profile (Naumberg et al. 2005). In any case, salt levels as indicated by EC and SAR were not high enough in either plot type to seriously interfere with the growth of plants. Saline soils are defined as those having an EC >4, and sodic soils are those with an SAR >13–15, which are levels considered to be toxic to plants (Brady 1990). The average EC values for total depth in the healthy stands and the dying stands were 2.09 and 0.92, respectively (Table 2). The average SAR values in the total depth for the plots with healthy vegetation and with dying vegetation were 3.90 and 2.08, respectively. The neutral salts found in soils—namely sodium, potassium, calcium, and magnesium—were all found to be statistically higher within at least one of the depth increments in the healthy plot samples as well. These results suggest that salts in the soil were not a component in the mortality of willow at sites along the Middle Rio Grande.

pH was significantly lower in the 12- to 36-in and total depth of soils within the healthy willow stands. The higher salinity in soils of the healthy plot type could have, in turn, influenced the pH as pH generally decreases with the addition of salts (Tucker et al. 1987; Brady 1990). pH also influences the plant availability of a number of elements, which may have been a factor in the significantly higher levels of Fe, Mn, Cu, and Zn in

Table 1.—Description of vegetation and soils and hydrology of sample plots.

	Vegetation				Soils/Hydrology		
Plot #[1]	**Indicator species**	**Percent canopy cover**	**Relative percent dead**	**Canopy height (ft)**	**Redoximorphic features**	**Depth to saturation (in)**	**Depth to standing water (in)**
11D	Saltcedar	20	40? (all downed Goodding willow)	20–25	None	Dry	Dry
12D	Goodding's willow Saltcedar (encroaching)	35	40	15–20	12–36 in	Dry	Dry
13D	Goodding's willow Saltcedar (encroaching)	65	50 (canopy)	20–30	12–36 in	Dry	Dry
14D	Saltcedar (encroaching) Goodding's willow (scattered) Coyote willow (dying) Cottonwood (unhealthy)	80	Not recorded	15–20	None	Dry	Dry
15D	Goodding's willow (dead/dying) Coyote willow (dead/dying)	65	Not recorded	20–30	None	Dry	Dry
16D	Goodding's willow (dead/dying) Coyote willow (dead/dying) Saltcedar (encroaching)	60	40	30	30–32 in	Dry	Dry
17D	Goodding's willow (dead/dying) Coyote willow (scattered) Cottonwood (scattered) Saltcedar	25	75	25	None	Dry	Dry
18D	Saltcedar Seep willow Goodding's willow (mostly dead)	25	Not recorded	20–25	None	Dry	Dry
19D	Goodding's willow (sparse) Coyote willow (dead/dying)	50	Not recorded	15	None	Dry	Dry
20D	Goodding's willow (downed/dead) Saltcedar (sparse)	40	60	30–35	None	Dry	Dry
21H	Goodding's willow Catttail (scattered)	50	NA	35	Throughout profile	26	NA
22H	Goodding's willow (regenerating) Cattail	30	NA	25	Throughout profile	12	22
23H	Goodding's willow (regenerating) Cattail	30	NA	25	Throughout profile	Surface	Surface
24H	Goodding's willow (regenerating) Cattail	30	NA	25	Throughout profile	Surface	5
25H	Goodding's willow Cottonwood	50	15 (saltcedar snags)	25	Throughout profile	Dry	Dry
26H	Goodding's willow Cottonwood (scattered) Cattail (sparse)	50	NA	20–25	Throughout profile	15	NA
27H	Goodding's willow	35	NA	20–25	Throughout profile	20	30
28H	Goodding's willow Cottonwood (scattered)	75	NA	40	Throughout profile	Dry	Dry
29H	Goodding's willow Cottonwood (sparse) Saltcedar (sparse)	40	NA	20–25	Throughout profile	Dry	Dry
30H	Goodding's willow Cattail (sparse)	50	NA	30	Throughout profile	12	16

[1]Plot numbers ending in D=Dying plot type; plot numbers ending in H=Healthy plot type.

Table 2.—Average values of parameters tested by plot type and depth.

Parameter	0- to 6-inch depth		6- to 12-inch depth		12- to 36-inch depth		Total depth	
	Healthy	Dying	Healthy	Dying	Healthy	Dying	Healthy	Dying
pH	7.40	7.50	7.51	7.60	7.33	7.74	7.42	7.61
EC (mmhos/cm)	2.55	0.75	2.02	0.89	1.70	1.12	2.09	0.92
Lime[1]	3.00	2.40	2.40	2.60	2.70	2.30	2.70	2.43
% OM	2.96	1.53	1.68	1.28	1.83	1.04	2.17	1.28
NO_3-N (ppm)	6.16	20.54	5.65	21.07	1.82	10.59	4.54	17.40
P (ppm)	9.22	6.21	7.60	5.32	5.56	3.53	7.46	5.02
K (ppm)	344.52	246.59	258.88	231.85	240.77	176.08	281.39	218.17
Zn (ppm)	2.85	1.87	2.10	1.85	2.54	1.08	2.50	1.60
Fe (ppm)	85.15	33.33	104.25	41.44	142.68	41.22	110.69	38.66
Mn (ppm)	9.09	4.02	8.58	3.32	13.49	3.33	10.39	3.56
Cu (ppm)	4.73	3.40	4.69	3.50	5.23	3.42	4.88	3.44
Texture[2]	4.70	4.40	5.00	4.60	4.60	4.10	4.77	4.37
Ca (meq/L)	15.51	5.19	12.07	6.08	11.74	6.55	13.11	5.94
Mg (meq/L)	5.51	1.89	4.85	2.45	4.15	2.85	4.84	2.40
Na (meq/L)	13.80	2.57	10.99	3.51	7.45	5.78	10.75	3.95
K (meq/L)	4.68	1.89	2.81	1.60	2.30	1.55	3.26	1.68
SAR	4.73	1.52	4.09	1.93	2.88	2.80	3.90	2.08

[1]1=low; 2=med; 3=high.
[2]1=sand; 2=loamy sand; 3=sandy loam; 4=sandy clay loam; 5=silty clay loam; 6=clay loam; 7=silty clay; 8=clay.

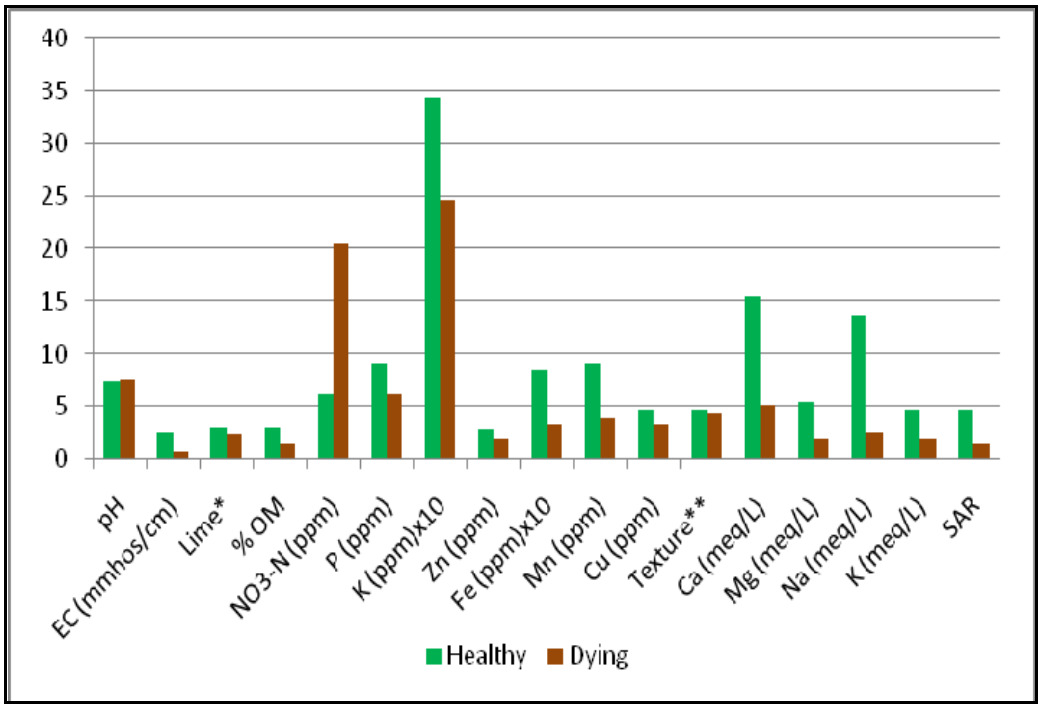

Figure 4.—Average values of parameters by plot type for the 0- to 6-inch depth.
*1=low, 2=med, 3=high.
**1=sand, 8=clay; multiply by 10 to get the true Fe and K factors.

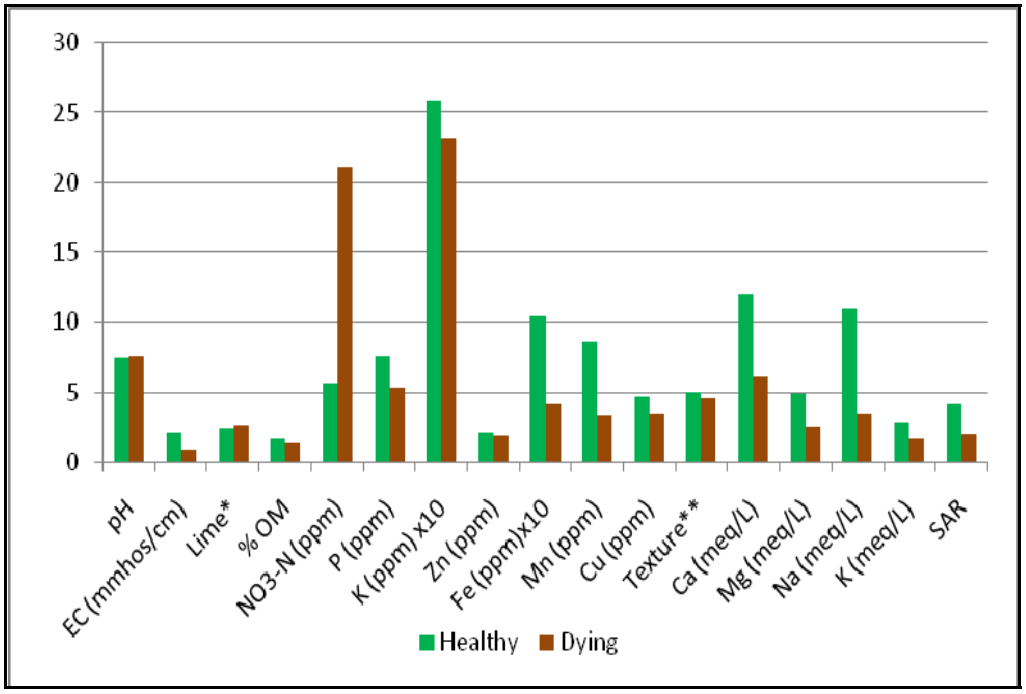

Figure 5.—Average values of parameters by plot type for the 6- to 12-inch depth.
*1=low, 2=med, 3=high.
**1=sand, 8=clay; multiply by 10 to get the true Fe and K factors.

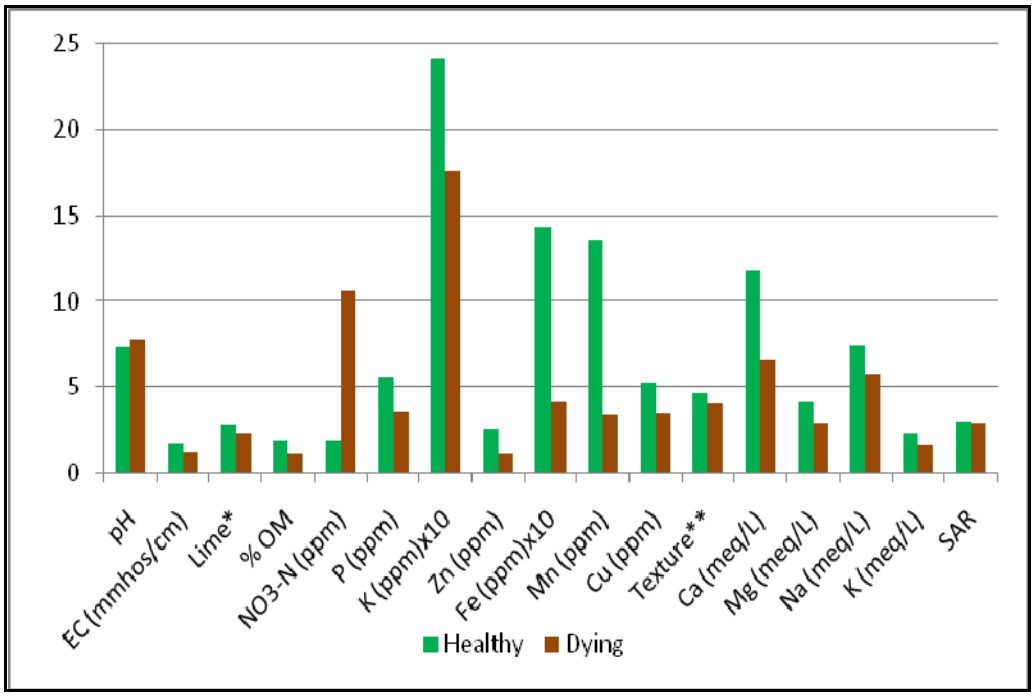

Figure 6.—Average values of parameters by plot type for the 12- to 36-inch depth.
*1=low, 2=med, 3=high.
**1=sand, 8=clay; multiply by 10 to get the true Fe and K factors.

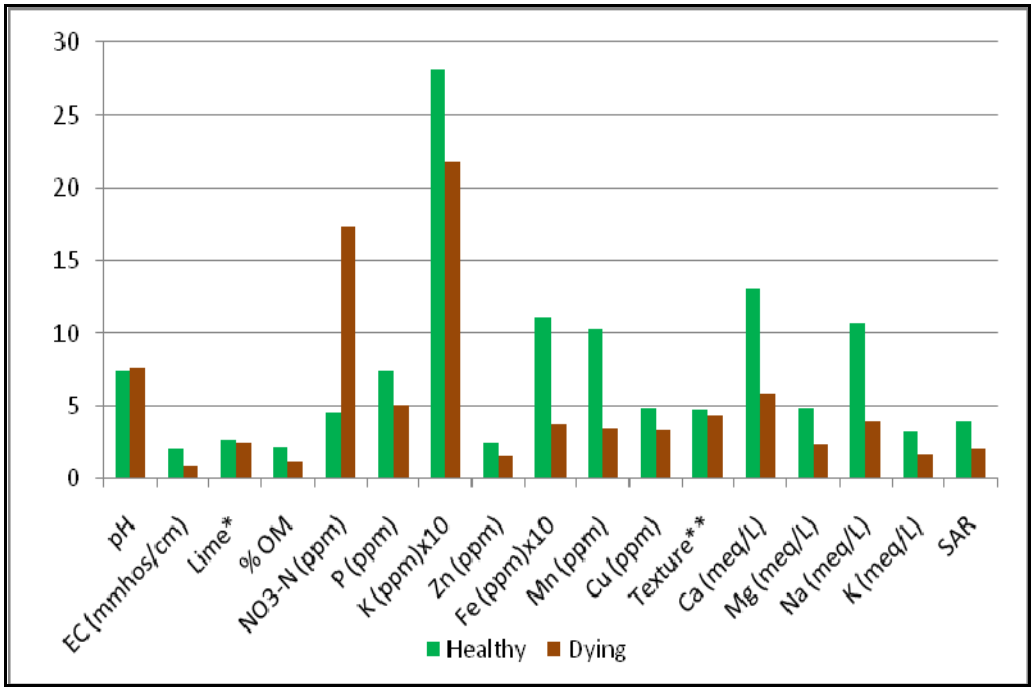

Figure 7.—Average values of parameters by plot type for the total 0- to 36-inch depth.
*1=low, 2=med, 3=high.
**1=sand, 8=clay; multiply by 10 to get the true Fe and K factors.

Table 3.—Results of statistical comparisons of soil parameters between samples collected in plots with healthy and dying native vegetation by depth. Alpha = 0.05.

Parameter	0- to 6-inch depth	6- to 12-inch depth	12- to 36-inch depth	Total depth
pH	Healthy=Dying P=0.401[1]	Healthy=Dying P=0.317[1]	Healthy<Dying P=0.011[2]	Healthy<Dying P=0.004[2]
EC	Healthy>Dying P<0.001[1]	Healthy>Dying P=0.005[1]	Healthy=Dying P=0.083[1]	Healthy>Dying P<0.001[2]
Lime	Healthy=Dying P=0.065[1]	Healthy=Dying P=0.650[2]	Healthy=Dying P=0.211[2]	Healthy=Dying P=0.159[2]
OM	Healthy>Dying P=0.026[1]	Healthy=Dying P=0.364[2]	Healthy=Dying P=0.426[2]	Healthy>Dying P=0.023[2]
NO_3-N	Healthy=Dying P=0.076[2]	Healthy<Dying P=0.045[2]	Healthy<Dying P=0.006[2]	Healthy<Dying P<0.001[2]
P	Healthy=Dying P=0.169[1]	Healthy=Dying P=0.194[1]	Healthy>Dying P=0.004[1]	Healthy=Dying P=0.073[2]
K (ppm)	Healthy=Dying P=0.097[1]	Healthy=Dying P=0.670[1]	Healthy=Dying P=0.291[1]	Healthy=Dying P=0.066[2]
Zn	Healthy=Dying P=0.186[2]	Healthy=Dying P=0.758[1]	Healthy=Dying P=0.085[1]	Healthy>Dying P=0.020[2]
Fe	Healthy>Dying P=0.028[1]	Healthy>Dying P=0.009[1]	Healthy>Dying P=0.008[1]	Healthy>Dying P<0.001[2]
Mn	Healthy>Dying P=0.013[1]	Healthy=Dying P=0.089[2]	Healthy>Dying P=0.043[1]	Healthy>Dying P<0.001[2]
Cu	Healthy=Dying P=0.234[1]	Healthy=Dying P=0.325[1]	Healthy=Dying P=0.143[1]	Healthy>Dying P=0.028[1]
Texture	Healthy=Dying P=0.802[1]	Healthy=Dying P=0.745[1]	Healthy=Dying P=0.677[1]	Healthy=Dying P=0.550[1]
Ca	Healthy>Dying P=0.002[1]	Healthy>Dying P=0.045[1]	Healthy=Dying P=0.067[1]	Healthy>Dying P<0.001[1]
Mg	Healthy>Dying P=0.006[2]	Healthy=Dying P=0.075[2]	Healthy=Dying P=0.234[1]	Healthy>Dying P=0.001[2]
Na	Healthy>Dying P<0.001[1]	Healthy>Dying P=0.002[1]	Healthy=Dying P=0.112[2]	Healthy>Dying P<0.001[2]
K (meq/L)	Healthy>Dying P=0.008[1]	Healthy>Dying P=0.024[1]	Healthy>Dying P=0.034[1]	Healthy>Dying P<0.001[2]
SAR	Healthy>Dying P=0.003[2]	Healthy>Dying P=0.021[1]	Healthy=Dying P=0.212[2]	Healthy>Dying P<0.001[2]

[1]Student's t=test of means
[2]Mann-Whitney test of medians
Highlighted boxes = significant difference at the 95% confidence level.

at least one depth increment of the healthy plot types. The availability of all of these nutrients increases as pH decreases.

The percent OM was significantly greater in the 0- to 6-in and total 0- to 36-in depth in soil samples from the healthy plot types. Moist conditions, as were common in sites with healthy willow stands, favor humus formation as plant residues undergo greater decomposition than under dry soil conditions (Kohnke and Franzmeier 1995). There may be rapid leaching of materials from leaves in the litter layer in response to wetting (Molles et al. 1995), which could have resulted in the generally higher quantities of nutrients in the soil in the healthy sites. Saturated conditions also cause Fe to be reduced to the highly soluble ferrous form (Tisdale et al. 1993), which may have contributed to a significantly higher level of available Fe in all depths of samples from healthy willow stands.

The level of NO_3-N was significantly lower in soils from healthy plot types. These results could be due to denitrification, a process that takes place in water-logged soils in which nitrate is reduced to gaseous forms and subsequently lost from the soil (Kozlowski 2002).

The litter depths for samples from both plot types are shown in Table 4. Molles et al. (1995) proposed that an accumulation of large amounts of leaf litter and woody debris observed in riparian ecosystems of the Middle Rio Grande was in part due to the absence of substantial flooding and found that experimental flooding decreased cumulative litter fall. The results of our study were not similar in that there was not a significant difference between depths of the litter layers in each plot type (P = 0.102), indicating that litter accumulation was not decreased by inundation at the healthy willow sites. Also, the theory that dying trees would contribute more leaf litter to the soil surface which could in turn lead to higher levels of N in soils of the dying plot types did not appear to be supported.

Table 4.—Depths of the slightly decomposed litter layer (Oi) for soil samples from healthy and dying willow stand plot types.

	Depth of Oi layer (inches)	
	Healthy	**Dying**
	1.00	0.13
	0.50	2.00
	1.00	1.00
	1.00	0.50
	0.75	1.00
	1.00	0.50
	2.00	0.13
	1.00	0.50
	0.25	0.50
	0.75	0.25
Avg.	0.93	0.63

Photos of all sample sites are provided in Appendix B.

Conclusions and Recommendations

Based on the soil sampling results, mortality of willows is unlikely to be linked to salt accumulation in the soils. It is also unlikely that other nutrients limited the growth of willow. Table 5 shows classifications used in interpreting agricultural soil tests in New Mexico (Herrera 2000). Though these limits should not be interpreted strictly for willow requirements in riparian soils, they do provide a general guideline. According to this classification, OM, NO_3-N, and P were the only limiting factors with averages at some depth increments falling into the low classification (see Table 2). This is not surprising since NO_3-N and P are the most limiting of plant growth nutrients. NO_3-N was actually significantly less in healthy stands than in dying stands, so low levels of NO_3-N apparently did not adversely affect the growth and vigor of willow in the study area. Also, if water is the most limiting factor affecting plant growth on the Middle Rio Grande, then limited nutrients would not be the primary cause for willow mortality.

Table 5.—Classifications used in interpreting agricultural soil tests in New Mexico.

Parameter	Classification			
	Very low	**Low**	**Moderate**	**High**
EC (mmhos/cm)	<2	2–4	4–8	8–16
% OM Sand	<0.5	0.5–1.0	1.0–1.5	>1.5
Clay	<1.0	1.0–2.0	2.0–3.0	>3.0
NO_3-N (ppm)	NA	<10	10–30	>30
P (ppm)	<7	8–14	15–22	23–30
K (ppm)	NA	<30	30–60	>60
Zn (ppm)	NA	0.5	0.5–1.0	>1.0
Fe (ppm)	NA	<2.5	2.5–4.5	>4.5
Mn (ppm)	NA	<1.0	1.0–2.5	>2.5
Cu (ppm)	NA	<0.3	0.3–1.0	>1.0
	Slightly acid	**Neutral**	**Slightly alkaline**	**Moderately alkaline**
pH	6.2–6.7	6.7–7.3	7.3–7.9	7.9–8.5

There are a number of other factors that could be affecting the condition of the native species that were not measured, including shading and competition (i.e., plant density) as well as hydrologic variables such as depth to water table, chronology (length of time since last inundation, rate of water table declines, etc.), and flooding.

Hydrology is the most probable reason for differences in the health of the two stands. Goodding's willow appears to be an obligate phreatophyte that requires permanently available shallow groundwater (Busch et al. 1992; Horton et al. 2001). Soils in the healthy plot types had more occurrences of saturation or standing water, indicating a

higher water table than in soils in the dying plot types. Redoximorphic features were noted throughout the soil profile in the samples from healthy willow stands, which would indicate prolonged inundation at some time during the year. In the profile, only a few of the samples from dying stands of willow had redox features at depths below 12 in. Horton et al. (2001) found canopy dieback of Goodding's willow increased significantly when the depth to groundwater exceeded 2.5–3 meters (m) compared to sites with a depth to groundwater less than 2.5 m. Willow mortality in the dying plot types may have been attributed to a water table that fell below this threshold, although it was impossible to know to what depth and for how long (if at all in some cases) the water table remained since samples were collected at one point in time and only to a depth of around 1 m. However, we can assume that groundwater was more available in the soils of healthy willow stands based on the data collected.

The establishment of shallow groundwater monitoring wells within each of the collection plot types is recommended. Although the implementation of monitoring wells would necessitate time and money, it would be a valuable tool in determining potential causes of willow mortality in the area. Hydrology is the factor that is most likely affecting the condition of the vegetation. Groundwater monitoring wells would provide information on the duration of flooding and soil saturation (and if either occurs) and the rate of water table decline, and also offer insight on the influence of water quality parameters to the health of Goodding's willow populations. Staff gauges could also be located in sites observed to be perpetually flooded and individual trees monitored to determine if willows do in fact survive under conditions where long-term flooding persists.

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Appendix A

Laboratory Results of Soil Analyses

		---------paste---------				----------AB-DTPA----------												
			mmhos/cm	Lime	%	----------ppm----------							Texture	----------meq/L----------				
Sample[1]	Depth[2]	pH	EC	Estimate[3]	OM	NO_3-N	P	K	Zn	Fe	Mn	Cu	Estimate[4]	Ca	Mg	Na	K	SAR
11D	1	6.9	0.5	1	0.4	5.5	4.9	50.1	0.20	11.2	1.57	0.51	1	3.0	1.0	1.6	2.5	1.1
11D	2	7.4	0.2	1	0.1	2.1	3.7	39.1	0.10	8.68	1.09	0.46	1	0.8	0.2	0.4	0.8	0.6
11D	3	7.8	0.3	1	0.1	2.1	3.4	40.8	0.07	11.2	0.82	0.45	1	1.5	0.4	0.9	1.1	0.9
12D	1	7.5	0.9	3	1.0	34.2	4.3	389	1.43	35.8	5.82	5.09	8	6.0	2.0	2.7	1.5	1.3
12D	2	7.5	0.8	3	1.0	27.7	5.6	417	1.86	71.5	4.79	5.73	8	4.7	1.8	3.0	1.5	1.7
12D	3	7.5	0.8	3	1.2	28.5	5.6	364	1.96	61.4	6.51	6.26	8	6.6	1.8	2.7	1.4	1.3
13D	1	7.3	1.0	3	2.9	53.4	7.1	444	4.77	55.6	5.77	5.31	8	9.5	2.5	2.0	2.2	0.8
13D	2	7.4	1.0	3	3.0	52.0	8.7	463	6.27	55.0	6.60	5.38	8	11.4	2.7	1.6	2.5	0.6
13D	3	7.5	0.8	3	1.8	26.2	4.3	340	1.95	60.4	4.83	5.93	8	6.7	1.8	2.7	1.3	1.3
14D	1	8.0	0.7	3	0.9	1.1	3.7	170	0.57	33.4	1.95	1.52	2	2.2	0.7	5.9	1.6	4.9
14D	2	8.0	0.7	3	0.9	1.2	3.4	121	0.46	29.0	2.10	1.43	2	1.8	0.5	5.7	1.1	5.3
14D	3	8.4	0.5	2	0.3	0.9	2.5	56.5	0.19	20.5	1.82	1.17	2	1.3	0.4	4.4	0.6	4.8
15D	1	7.6	0.5	3	2.2	2.0	4.9	255	1.55	47.4	3.30	5.39	7	3.8	1.0	1.9	1.1	1.2
15D	2	7.6	0.7	3	2.1	3.4	4.3	286	1.41	66.7	4.01	4.95	7	5.6	1.6	2.8	1.4	1.5
15D	3	7.5	1.8	3	2.0	3.6	2.8	340	1.67	59.2	5.83	6.45	7	14.1	4.5	9.5	2.9	3.1
16D	1	7.6	1.0	3	3.6	13.4	7.1	326	4.78	36.9	7.41	4.38	4	6.5	2.4	3.6	2.0	1.7
16D	2	7.6	0.9	3	2.5	9.7	7.1	345	4.15	32.2	4.77	4.28	5	5.8	2.3	3.3	2.1	1.7
16D	3	7.5	2.0	3	2.0	5.9	3.7	263	2.46	47.6	5.80	5.02	5	12.3	5.7	9.4	2.4	3.1
17D	1	7.6	0.6	3	1.2	7.7	6.2	231	1.16	27.2	3.46	3.30	5	3.7	1.6	2.4	1.4	1.5
17D	2	7.6	1.5	3	1.3	12.2	5.9	201	0.97	23.0	3.33	3.01	5	11.4	5.4	5.7	2.0	2.0
17D	3	7.4	1.5	2	0.8	13.9	4.0	101	0.67	36.6	2.20	2.57	3	11.8	5.3	5.1	2.2	1.8
18D	1	7.4	0.4	1	0.3	10.9	7.4	71.9	0.63	5.64	2.71	1.25	1	2.4	1.3	0.4	2.4	0.3
18D	2	7.7	0.2	1	0.1	5.1	5.3	59.9	0.23	5.59	1.32	0.68	1	1.4	0.7	0.4	1.5	0.4
18D	3	8.3	0.2	1	0.1	1.6	2.5	32.1	0.11	12.2	0.97	1.26	1	1.1	0.6	0.8	0.4	0.9
19D	1	7.4	1.5	3	2.2	74.6	10.6	416	2.97	60.9	6.37	6.11	6	12.9	5.6	3.7	2.9	1.2

		---------paste---------				----------AB-DTPA----------												
			mmhos/cm	Lime	%	----------ppm----------							Texture	----------meq/L----------				
Sample[1]	Depth[2]	pH	EC	Estimate[3]	OM	NO_3-N	P	K	Zn	Fe	Mn	Cu	Estimate[4]	Ca	Mg	Na	K	SAR
19D	2	7.5	2.0	3	1.2	94.7	4.9	284	2.55	95.3	3.31	7.49	7	14.8	7.7	6.8	1.7	2.0
19D	3	7.6	1.0	2	1.3	21.0	3.7	117	1.25	62.9	1.86	2.90	3	6.2	3.5	3.5	1.4	1.6
20D	1	7.8	0.3	1	0.6	2.6	5.9	113	0.66	19.4	1.86	1.17	2	1.9	0.8	1.5	1.3	1.2
20D	2	7.7	0.9	3	0.6	2.6	4.3	103	0.53	27.4	1.89	1.60	2	3.1	1.6	5.4	1.4	3.5
20D	3	7.9	2.4	3	0.8	2.2	2.8	106	0.46	40.5	2.68	2.19	3	3.9	4.5	18.8	1.8	9.2
21H	1	7.3	1.3	3	3.4	6.0	9.6	345	4.51	92.3	6.09	7.54	8	8.3	2.8	5.7	2.4	2.4
21H	2	7.5	0.9	3	2.3	2.8	8.7	325	3.59	115	5.53	7.28	8	4.9	1.8	5.1	1.3	2.8
21H	3	7.6	0.9	3	0.7	1.4	4.9	133	0.92	74.5	2.67	2.32	3	3.8	1.5	4.8	1.2	3.0
22H	1	7.4	3.0	3	3.2	7.4	8.1	365	2.00	39.9	10.1	4.37	5	19.3	5.5	15.6	5.4	4.4
22H	2	7.9	2.8	3	5.4	1.6	6.8	311	2.70	111	10.4	6.77	5	16.4	4.3	15.8	3.6	4.9
22H	3	7.3	1.2	3	0.9	0.8	6.5	137	1.21	80.4	9.51	4.05	3	5.7	1.4	6.8	1.6	3.6
23H	1	7.4	1.0	3	6.0	0.9	9.3	340	2.86	216	19.8	6.72	6	4.3	1.2	5.6	1.8	3.4
23H	2	7.4	0.8	3	1.3	1.6	6.2	247	2.01	176	9.88	5.44	7	3.8	1.2	4.6	1.4	2.9
23H	3	7.4	2.4	3	3.3	2.6	3.4	324	2.31	223	40.4	9.81	7	20.6	8.3	6.4	2.5	1.7
24H	1	7.7	1.8	3	3.3	0.6	18.0	496	2.59	121	21.0	5.82	7	2.3	1.8	16.5	1.5	11.6
24H	2	7.7	1.7	3	1.6	0.3	9.9	381	2.48	163	31.3	5.12	7	3.1	2.2	14.5	1.4	8.9
24H	3	7.4	1.7	3	3.0	0.2	7.1	412	5.48	222	40.2	9.65	7	8.2	3.3	9.4	2.3	3.9
25H	1	7.4	3.3	3	1.2	0.5	3.4	173	1.00	30.0	4.17	1.19	2	17.7	6.9	18.4	6.1	5.3
25H	2	7.4	3.7	3	1.4	0.3	3.4	193	1.04	87.1	5.02	2.36	3	16.6	7.1	24.3	5.2	7.1
25H	3	7.5	1.8	3	0.8	0.4	5.3	170	1.00	75.2	6.71	2.87	3	10.9	3.7	9.0	3.0	3.3
26H	1	7.6	3.9	3	2.9	3.4	3.4	275	2.25	49.0	5.54	1.97	2	21.8	9.7	22.8	8.1	5.8
26H	2	7.7	1.2	1	0.4	0.6	3.1	88.6	0.52	31.1	2.05	1.18	2	7.7	2.7	5.5	2.1	2.4
26H	3	7.4	1.7	3	0.9	0.5	4.6	207	1.51	99.6	8.67	3.90	3	15.0	4.8	6.6	2.7	2.1
27H	1	7.5	4.3	3	1.1	0.6	3.7	205	1.10	65.0	3.97	2.74	2	22.5	9.1	26.7	6.6	6.7
27H	2	7.6	1.7	1	0.3	0.4	2.8	87.1	0.39	33.2	1.71	1.23	2	9.9	2.9	9.6	2.1	3.8

		---------paste---------				----------AB-DTPA----------												
			mmhos/cm	Lime	%	----------ppm----------							Texture	----------meq/L----------				
Sample[1]	Depth[2]	pH	EC	Estimate[3]	OM	NO_3-N	P	K	Zn	Fe	Mn	Cu	Estimate[4]	Ca	Mg	Na	K	SAR
27H	3	7.3	1.4	2	0.9	0.4	3.4	105	0.54	62.6	3.24	2.59	2	11.3	3.1	5.3	2.0	2.0
28H	1	7.2	2.5	3	2.4	28.5	22.4	372	2.92	47.2	5.39	2.63	3	28.0	7.7	5.2	9.6	1.2
28H	2	7.2	1.6	1	0.7	4.1	3.4	146	0.68	37.6	1.27	2.06	2	13.4	4.4	6.6	4.9	2.2
28H	3	7.7	1.1	1	0.2	1.2	4.9	109	0.48	29.2	1.35	2.71	2	5.2	1.6	6.9	2.2	3.8
29H	1	7.4	2.6	3	1.8	11.4	8.4	437	2.06	62.4	4.52	4.87	4	17.5	6.2	15.2	3.1	4.4
29H	2	7.4	2.8	3	1.7	11.6	13.7	462	2.83	87.6	5.80	6.16	6	20.9	6.8	13.5	3.9	3.6
29H	3	7.4	3.0	3	1.5	9.3	8.7	432	4.89	195	7.83	7.49	8	25.4	8.5	12.5	3.5	3.0
30H	1	7.3	1.7	3	4.3	2.3	5.9	437	7.26	129	10.4	9.41	8	13.4	4.2	6.3	2.2	2.1
30H	2	7.3	3.0	3	+8.0	33.1	18.0	348	4.72	201	12.9	9.28	8	24.0	15.1	10.4	2.2	2.3
30H	3	6.4	1.8	3	6.1	1.4	6.8	380	7.09	366	14.4	6.95	8	11.3	5.3	6.8	2.0	2.4

[1]Numbers ending in D=dying plot types; numbers ending in H=healthy plot types
[2]1=0- to 6-inch; 2=6- to 12-inch; 3=12- to 36-inch
[3]1=low; 2=med; 3=high
[4]1=sand; 2=loamy sand; 3=sandy loam; 4=sandy clay loam; 5=silty clay loam; 6=clay loam; 7=silty clay; 8=clay

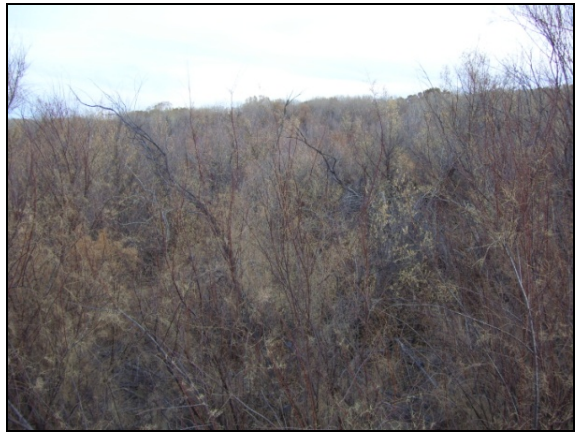
Appendix B

Photos of Sample Plots

11D - Inside

12D - Inside

12D – Outside



13D – Inside

13D – Outside

14D – Inside

14D - Outside

15D – Inside

15D – Outside

16D – Inside

16D - Outside

17D – Inside

17D – Outside

18D - Inside

19D – Inside

19D – Outside

20D – Inside

20D - Outside

21H – Inside

21H – Outside

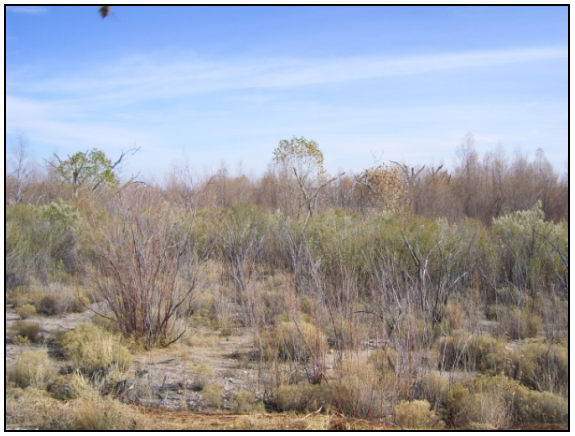
22H – Inside

22H - Outside

23H – Inside

24H – Inside

24H - Outside



25H – Inside

25H – Outside

26H – Inside

26H - Outside

27H – Inside

27H – Outside

28H – Inside

28H - Outside

29H – Inside

29H – Outside

30H – Inside

30H – Outside