POTENTIAL REMEDIATION OF RANGELANDS AFTER BRINE WATER CONTAMINATION USING FIVE DIFFERENT GRASSES

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ABSTRACT

Recent advances in technology now allow for the use of water from the Santa Rosa formation to be used for fracking in the oil and natural gas industry. Unfortunately, water from this formation varies in salinity from 3,000 to 10,000 ppm, which may inhibit vegetation growth when spills occur. Saltwater spills with higher salinity water (80,000 ppm) cause total vegetation loss. Unfortunately, little is known regarding the impacts of brine water spills from the Santa Rosa formation. For this study, Alkali sacaton **(***Sporobolus airoides* **(**Torr.) Torr**.),** WW B-dahl Bluestem (*Bothriochloa bladhii Retz.*), Sideoats grama (*Bouteloua curtipendula Michx, Torr. var. curtipendula*), Blue grama (*Bouteloua gracillis Kunth*), and Wilman lovegrass (*Eragostis superba Peyr.*) were planted and watered with 0, 3,000, 5,000, or 10,000 ppm saline concentration for 21 days. Wilman lovegrass and Alkali sacaton exhibited the highest germination and establishment rate. Once water exceeded 5,000 ppm, germination and establishment was near zero.

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INTRODUCTION

Oil and gas production is a large part of the economy in the United States, especially in Texas. A by-product of producing oil and gas is brine water or produced water that contains large amounts of total dissolvable salts. Concentrations of total dissolved salts often reaches 80,000 ppm in produced water. When brine water spills occur, or the solution is pumped out onto the soil, it eliminates all vegetation, decreases infiltration rates, and causes excessive soil erosion (Kennedy 2020).

There have been some efforts to address ways to remediate affected areas of produced water. One way is by reseeding with halophytes, plants that can establish and persist in saline-contaminated soils (Barret-Lennard 2002). When halophytes are established, salts can be removed from the soil allowing for the re-establishment of other biological functions (Kennedy 2020, Burris 2017, Belew 2017). Once halophytes are established, ecosystem health begins to improve as water infiltration rates improve and erosion rates decline (Burris 2017, Belew 2017).

In west Texas, freshwater has been used for fracking. Fracking involves the use of large volumes of fresh water and a mixture of sand and other chemicals at high pressures to create fractures to facilitate the extraction of oil and gas that is beneath the surface. Recently, oil and gas production companies in the Permian Basin region have switched to using water from the Santa Rosa Formation. The water that comes from this area contains anywhere from 3,000 to 10,000 ppm salt (Kennedy 2020). Water from the Santa Rosa formation is stored in large pits prior to fracking. Once fracking is complete, storage ponds could potentially be

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reclaimed and returned to native vegetation. However, potential soil contamination with salts may limit any reclamation efforts. In addition, spills with frack water will potentially occur and may limit vegetation growth. For this study, five different grasses often utilized in reclamation efforts in west Texas, Alkali Sacaton *(Sporobolus airoides* **(**Torr.) Torr**.),** WW B-dahl bluestem (*Bothriochloa bladhii Retz.*), Sideoats grama (*Bouteloua curtipendula Michx, Torr. var. curtipendula*), Blue grama (*Bouteloua gracillis Kunth*), and Wilman lovegrass (*Eragostis superba Peyr.*)) were assessed for their ability to establish and persist when watered with different concentrations of salinity.

OBJECTIVES

This study assessed the establishment and persistence rate of five different grasses, commonly used in reclamation seeding efforts, as the saline concentration of water increases from 0 to 10,000 ppm.

LITERATURE REVIEW

Numerous hectares of rangelands in central and western Texas are occupied by oil and gas production sites. Although this is economically important, there is a multitude of challenges with it as well. After drilling of oil and natural gas wells, a process called hydraulic fracturing is used to open formations and improve extraction of oil and natural gas. This process involves high pressure injection of a mixture of water, sand, and chemicals (Kennedy 2020). This has been a method used for multiple decades, and it has advanced to not only fracking vertically, but operators have begun fracking horizontally after reaching the necessary vertical depth (Burson et al. 2014).

With most oil and natural gas wells, numerous barrels of brine water are extracted for every barrel of oil and natural gas extracted. After separation from the crude oil or natural gas, brine water must be disposed of through pumping it back into the same geologic formation. This is often done at high pressures to force more hydrocarbons to the surface for extraction. There is a multitude of ways that produced water can be disposed of, but the most common method today is to be re-injected into a type II class well (Cooley and Donnelly 2012).

Before the brine water is pumped back into the same formation, it is stored in storage tanks. This is where issues may arise with brine water spills, due to overflow of storage tanks or leaks within the water pits. Structural failures in brine water equipment typically result in brine water spills that damage plant life, soil quality, and ultimately environmental quality. Although there are more restrictions on how the saltwater is disposed of today, the effect of multiple years of the water being pumped on the surface as well as the occurrence of spills is still causing environmental degradation.

There are some limited options to remediate the rangelands and ecological functions following brine water spills. These include methods such as digging up the contaminated areas and relocating soils elsewhere (Vidali 2001), but this approach is often cost-prohibitive. In some cases, contaminated areas can be flooded with fresh water to leach salts from upper layers of the soil. Unfortunately, fresh water availability may be limited in some regions.

Alternatively, halophytes can be established in some situations as a remediation process. Some halophytes absorb salts through above-ground tissues. Grazing by livestock can be used to remove contaminated plant material, thereby removing salts from the spill sites. Ideally, plants utilized in reclamation efforts would readily establish and be consumed by livestock to remove the salt that is absorbed through the plant. For example, Alkali Sacaton grows in saline soils that have levels of 0.3% to 0.5% salt (Richards 1954) and is readily consumed by livestock.

In the 1990's, the world was losing up to 600,000 hectares of land just due to salinity contamination (Squires et al. 1992). Recent analysis of one ranch reported that roughly 20% of the surface area of the ranch had been lost due to oil well locations, roads, infrastructure, and contaminated salt water spills (Cody Scott, pers. comm.). The number of hectares lost from oil and gas exploration emphasizes the need for effective reclamation efforts to restore biological potential.

In addition to potential spills from high salinity water produced during the pumping of oil and natural gas, spills and contamination may occur from water used during fracking. Water pumped from the Santa Rosa formation varies from 3,000 to 10,000 ppm and may adversely affect vegetation establishment and growth. Previous efforts have illustrated that some grass and shrub species can be established after spills occur from water produced during the pumping of oil and natural gas. However, little is known regarding the impact of water spilled from the Santa Rosa formation. This study attempted to identify grass species that can be used to reclaim sites contaminated with water from the Santa Rosa formation. Alkali sacaton, WW B-dahl bluestem, Sideoats grama, Blue grama, and Wilman lovegrass are the grass species that were assessed during this project. These are all species of plants that can be found in the semiarid regions of the southwestern U.S. All are commonly used in reseeding efforts on non-contaminated sites in the southwest and are readily consumed by livestock and some wildlife.

METHODS

Thirty plants each of Alkali sacaton, Sideoats grama, Wilman lovegrass, Blue grama, and WW B-dahl bluestem were seeded in pots with a 25% sand, 75% commercially available potting soil mixture and housed in the Angelo State University Management, Instruction, and Research (MIR) Center greenhouse. Prior to planting seeds, all pots with the soil mixture were watered with saline solution at either 0, 3,000, 5,000, or 10,000 ppm total dissolvable salts for 7 days. The pre-planting watering allowed for observation of plant germination in contaminated soils and persistence after germination. Six plants of each species were randomly allocated into one of the salinity treatments. In each pot, five seeds were planted too account for any difference in germination rates amongst the different species. Following planting, watering continued at the same levels while measuring persistence, growth, and production of each species. Germinated plants remained inside of their containers for 21 days while being watered.

Electrical Conductivity (EC) were used to estimate the levels of salt concentration in the saline solution, soil, as well as the leachate that is captured. A Hach Co. CDC401 Hydraulic Conductivity Probe was used to measure the EC of the contaminated solution and the leachate. The EC of the soil was measured using a Hanna Instruments GroLine HI98331 Direct Soil Conductivity and Temperature Meter. These measurements were taken before the contaminated solution was applied to the plants as well as seven days after applying the contaminated solution.

After completing the study, above-ground growth of each plant was to be clipped, placed in a forced air-drying oven at 60 degrees C for 48 hours, ground into particle sizes small enough to pass through a 2 mm screen, and tested for nutritional and mineral analysis.

Plant material was going to be analyzed for neutral detergent fiber, crude protein, Acid Detergent Fiber, Total Digestible Nutrients, total chlorides, and mineral content in order to determine the effects of salinity on each plant species. Unfortunately, insufficient plant material remained at the study, and nutritional and mineral analysis was not possible.

The experimental design of this study was a completely randomized design with water salinity as the main effect and plant species as the secondary effect. Individual plants nested within treatment by species served as replications. Date of collection was the repeated measure. Means were separated using Tukey's protected LSD when $P < 0.05$. Data was analyzed using the statistical package JMP (SAS 2007).

RESULTS

Germination after 7 days differed by treatment and by species. Germination was highest (22.0%) for seeds watered with 0 ppm saline solution. Conversely, seeds watered with 10,000 saline solution had the lowest germination rate (0.7%). Germination rates were similar for both seeds watered with 3,000 and 5,000 ppm saline solution (8.0 and 5.3%, respectively). Wilman lovegrass had the highest germination rate (21.7%) followed by Alkali sacaton with 11.7% germination. Sideoats grama had the lowest germination rate at 1.7%.

The treatment by species interaction for 7-day germination rate also differed ($P < 0.01$) (Table 1). Germination rates declined for all species as salinity increased. No seeds germinated for Sideoats Grama, WW B-dahl bluestem, or Blue grama in the treatments of 3,000, 5,000, and 10,000 ppm. For Alkali sacaton, seedlings emerged until salinity increased to 10,000 ppm. While germination was low, some Wilman lovegrass seedlings did emerge even with 10,000 ppm salinity.

Seedling survival after 21 days of watering followed a similar pattern as 7-day germination. Both treatment and species differed. Seedling survival rates declined as salinity increased. The number of seedlings watered with 0 ppm remained relatively high (28%) while seedling survival rates were 0% for seeds water with 10,000 ppm saline solution following 21 days of watering. Wilman lovegrass had the highest survival rate (15.8%) while Sideoats grama and WW-B-dahl bluestem had the lowest 21-day survival rates (4.2%).

Table 1. Percent (%) germination following 7 days of watering five grass species with either 0, 3,000, 5,000 or 10,000 ppm saline solution.

Species	Treatment (ppm)				SEM
	0	3000	5000	10000	
Alkali sacaton	20.0^{bcd}	16.7^{bcd}	10.0^{bcd}		
Blue grama	26.7^{a}	0^{d}	0^{d}	0^{d}	4.2
Sideoats grama	3.3^{bcd}	0^{d}	0^{d}	0^{d}	4.2
Wilman lovegrass	43.3^{a}	23.3^{abc}	16.7^{bcd}	3.3^{cd}	4.2
WW-B-dahl bluestem	13.3^{bcd}	0^{d}	0^{d}	0^{d}	4.2

$^{a-d}$Means within columns and rows with different superscripts differ ($P < 0.05$).

The treatment by species interaction for 21-day survival rate also differed ($P < 0.05$) (Table 2). Survival rates declined for all species as salinity increased from 0 ppm to 3,000. Alkali sacaton was the only species in which seedlings persisted as salinity increased to 5,000 ppm. No seedlings of Blue grama, Sideoats grama, or WW-B-dahl bluestem persisted when salinity was increased to 3,000 ppm (Table 2). No seedlings persisted once salinity increased to 10,000 ppm (Table 2).

Leachate volume was not collected on the initial day. Thereafter, leachate volume differed among treatments and among days. The treatment by day interaction also differed ($P < 0.01$). Leachate volume was highest for plants watered with 3,000 ppm (279.1 ml) and lowest for plants watered with 10,000 ppm (226.1 ml). Leachate volume varied across days of watering as well. Day 0 had the highest leachate volume with days 7 and 14 having the lowest leachate volume.

The treatment by day interaction for leachate volume is reported in Table 3. While leachate volume varied greatly, these variations did not appear to be caused by treatment of day of watering; volumes did not increase or decrease in a similar manner across treatments or days of watering.

Water drainage electrical conductivity differed by treatment (Fig. 1). The treatment with 0 ppm saline concentration had the lowest level of electrical conductivity at 2.4 (ms/cm) (Fig.1). Both 3,000 and 5,000 ppm saline concentration were similar in electrical conductivity (16.1 and 16.2) (Fig. 1). The 10,000 ppm treatment group had the highest level of electrical conductivity at 33.4 (ms/cm) (Fig.1). All other interactions were similar.

The saline concentration of the soil differed by treatment. The control treatment group of 0 ppm saline concentration was significantly lower (0.59 ms/cm) than that of the

Table 2. Percent (%) survival rate following 21 days of watering five grass species with either 0, 3,000, 5,000 or 10,000 ppm saline solution.

Species	Treatment (ppm)				SEM
	0	3000	5000	10000	
Alkali sacaton	30.0[ab]	13.3[bc]	3.3[c]	0	2.1
Blue grama	30.0[ab]	0	0	0	2.1
Sideoats grama	13.3[bc]	3.3[c]	0	0	2.1
Wilman lovegrass	50.0[a]	13.3[bc]	0	0	2.1
WW-B-dahl bluestem	16.7[bc]	0	0	0	2.1

[a-c]Means within columns and rows with different superscripts differ ($P < 0.05$).

Table 3. Average leachate drainage volume of either 0, 3,000, 5,000 or 10,000 ppm for treatments watered for 21 days. Five different grass species were watered with each saline solution.

	Treatment (ppm)				
Day	0	3000	5000	10000	SEM
Initial					
0	544.2^{ab}	594.2^{a}	514.0^{b}	522.2^{b}	29.1
7	226.8^{efg}	268.7^{cde}	232.2^{def}	183.8^{fg}	29.1
14	221.5^{efg}	231.8^{defg}	204.3^{efg}	166.4^{g}	29.1
21	283.8^{cd}	310.8^{c}	303.3^{c}	257.7^{cde}	29.1

$^{a-g}$Means within columns and rows with different superscripts differ ($P < 0.05$).

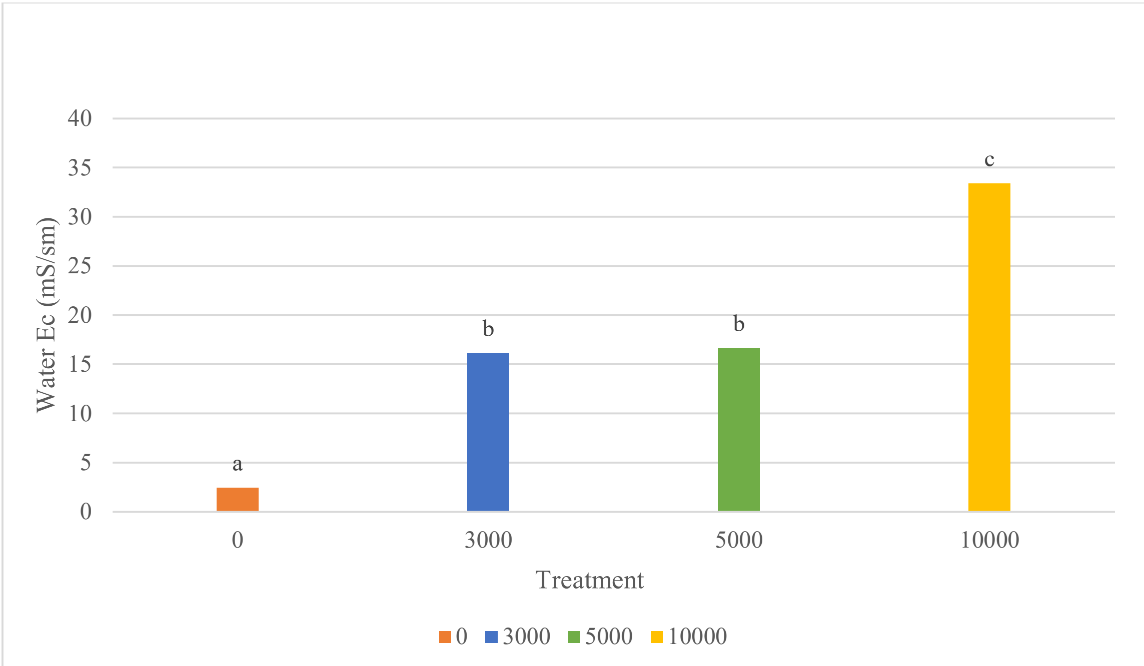

Figure 1. Average water electrical conductivity of either 0, 3,000, 5,000, and 10,000 ppm treatments. Five different grass species were watered for 21 days. Columns with different superscripts differ (P < 005)

other 3 treatment groups (Fig. 2). Treatment by species and day were similar ($P > 0.05$) with Wilman lovegrass being 5.2 (ms/cm) and the other four species being 2.8 (ms/cm) (Fig 2). Soil electrical conductivity for was highest when collected on day 7 (4.8 ms/cm) and lowest on the first day of watering (2.3 ms/cm) after seeds were planted (Fig. 2).

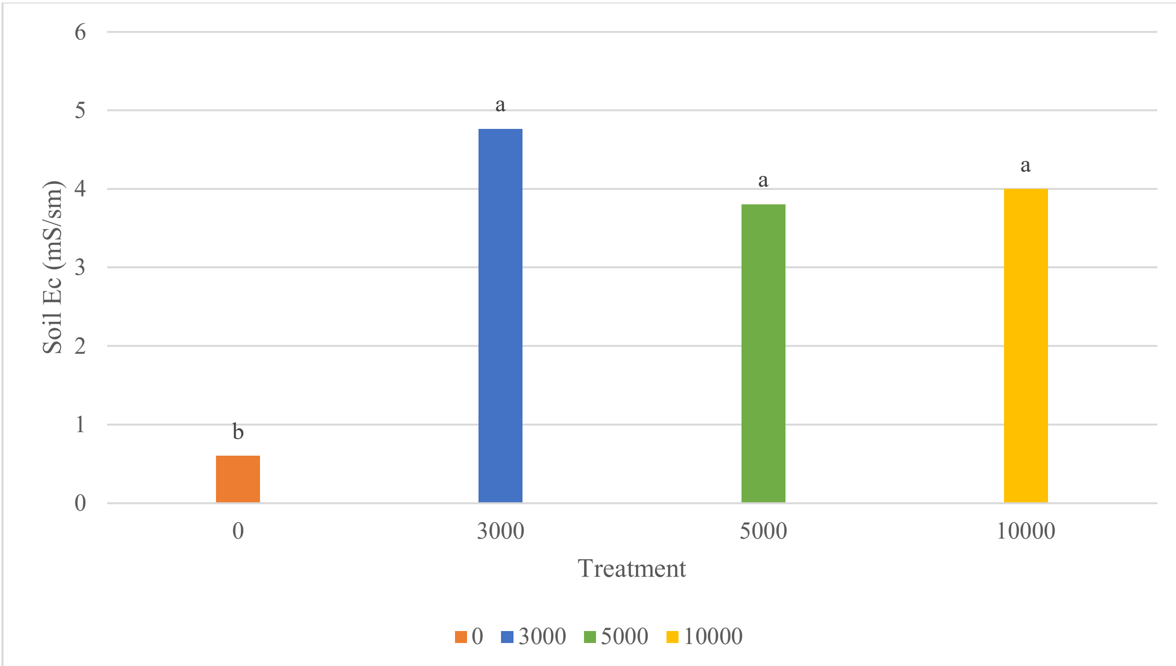

Figure 2. Average soil electrical conductivity of either 0, 3,000, 5,000, and 10,000 ppm treatments. Five different grass species were watered for 21 days. Columns with different superscripts differ ($P < 0.05$).

DISCUSSION

During this study, none of the five different species in the 5,000 or 10,000 ppm treatments readily established or survived continued watering. In previous studies, Alkali sacaton, Giant sacaton (*Sporobolus wrightii* Munro ex Scribn.), Four-winged saltbush (*Atriplex canescens* (Pursh) Nutt.), and Salt cedar (*Tamrix chinensis* Lour.) survived saline concentrations at 10,000 ppm (Culak 2022; Kennedy 2020). Potential reasoning for mortality in this study could be related to percent pure live seeds (percent PLS) of the seeds (Table 4), rather than the plants being transplanted as seedlings. The percentage of PLS for the plant species varied between the five different species. In particular, the percent PLS was notably lower for Sideoats grama and WW B-dahl bluestem. Both species had relatively low germination and establishment rates. Although five seeds per species were planted in each plot differences in percent PLS among species may have accounted for some of the differences in germination and establishment rates.

At day 7, Wilman lovegrass had the highest germination rate and the highest survival rate at day 21 in both the control and the 3,000 ppm treatment. Wilman lovegrass is commonly used in reseeding mixtures because of its high germination and establishment rate. Based on the results of this study, Wilman lovegrass should be included in reseeding mixtures when soil salinity is less than 0 to 3,000 ppm total dissolved salts.

Alkali Sacaton had a relatively high germination rate and was the only other species to survive 21 days of watering 3,000 ppm saline solution. No other species survived once salinity reached 3,000 ppm. Based on the results of this study and others (Belew 2017, Burris 2017), Alkali sacaton should also be included in reseeding mixtures salinity contamination. Conversely, few plants of Sideoats grama survived watering with 3,000 ppm saline

Table 4. Percent (%) Pure live seed (PLS) of five species used in this study.

Species	Percent Pure Live Seed (% PLS)
Alkali sacaton	95
Blue grama	97
Sideoats grama	26
Wilman lovegrass	96
WW-B-dahl bluestem	55

solution, while no Blue grama or WW B-dahl bluestem survived once soil salinity reached 3,000 ppm. Based on the results of this study, these three species do not appear to be viable candidates for revegetation work on saline soils.

Previous research has shown that Alkali sacaton, Giant sacaton, and Four-winged saltbush would survive on saline spill sites when the initial contamination exceeded 80,000 ppm total dissolved salts (Burris 2017, Belew 2017). However, in the current study seedlings did not survive watering when saline levels exceeded 5,000 ppm. In the previous studies, precipitation was the only source of water for seedling germination and establishment. Assuming precipitation salinity would be near zero may explain the differences in germination and establishment. Both studies also illustrated that soil amendments (disturbance and adding organic matter) improved infiltration rates, which should aid in moving salts from the topsoil. Providing fresh water with low salinity on spill sites should improve establishment of seedlings, thereby speeding up recovery rates. Once soil salinity declines below 3,000 ppm total dissolved salts, other species, like Sideoats grama, Blue grama, and WW-B-dahl bluestem could be seeded as well.

In addition, plants that were watered with contaminated solution appeared to have delayed growth compared to those that were watered with the 0 ppm saline solutions. Even if species germinate and survive saline sources exceeding 3,000 ppm salts, growth may be slowed, thereby slowing revegetation efforts.

There is some interest in using water from the Santa Rosa formation for irrigation purposes. Given that salinity of water from this formation ranges from 3,000 to 10,000 ppm total dissolved salts, irrigation would result in plant mortality and vegetation loss.

Water drainage electrical conductivity was similar for all species of plants with Wilman lovegrass averaging 23.2 (ms/cm) and the other four species ranging from 15-16.7 (ms/cm). Leachate electrical conductivity was highest after watering just the soils with their designated solutions with the average of all treatments being 20.8 (ms/cm); this can be expected after watering with contaminated solution for seven days consecutively. Similar to previous studies, as levels of contaminant increased (0-10,000 ppm), the water drainage electrical conductivity also increased (Culak 2022). The leachate volume was similar for all species during the study. Leachate volume was highest after the first day of watering when seeds where planted, at this point no plants had developed, with this being an explanation to why leachate volume might have been greatest. The following days of collection were similar in leachate volumes.

Soil electrical conductivity varied by treatment, with the control lower than the other treatments. Watering throughout the study with salinity ranging from 3,000 ppm to 10,000 ppm saline solution probably maintained relatively high soil salinity. In previous studies (Belew 2017; Culak 2022), Alkali sacaton, Giant sacaton, Four-winged saltbush, and Salt cedar compartmentalized salts in above-ground growth. This would allow for grazing or browsing by livestock and wildlife to remove salts from the spill site. The initial plan for this study was to collect any above-ground growth and analyze that material for salinity content. Because of limited establishment, insufficient plant material was available for this analysis in the current study.

IMPLICATIONS

Based on the results of this study, Wilman lovegrass and Alkali Sacaton can survive in moderate levels of saline contamination (≤ 5,000 ppm) when seeded. While Blue grama, Sideoats grama, and WW B-dahl bluestem are commonly used for reseeding efforts, these species will not survive when water salinity exceeds 3,000 ppm. Once soil salinity exceeds 10,000 ppm, reseeding efforts should include Alkali sacaton, Giant sacaton, Four-winged saltbush, and Salt cedar along with a water source low in salinity (0 ppm total dissolved salts).

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VITA

Jonathan Wade Garcia is the son of Joe and Mandi Garcia. He began is college education at Angelo State in the fall of 2017 and graduated with his bachelor's degree in Animal Science with a minor in Range and Wildlife Management in December of 2022. While attending Angelo State he competed in the Angelo State Bass Club in collegiate tournaments. During his time in the Bass Club, he held the position of Tournament Director, Secretary, as well as President. Jon decided in the Fall of 2020 that he would continue his education at Angelo State by pursuing his master's degree in Animal Science with an emphasis in Range Management. During the master's program, Jon worked at the Angelo State University Management, Instruction, and Research Center as a Graduate Research Assistant. After completion of his graduate studies, Jon plans on pursuing a career in Wildlife Management.