RESTORATION OF BRINE WATER IMPACTED SOILS USING HALOPHYTES, SOIL DISTURBANCES, AND ORGANIC MATTER IN WEST TEXAS

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ABSTRACT

Rangelands are often contaminated with salt water during the production of hydrocarbons (oil and natural gas). Once salt water is spilled on the soil surface, vegetation cover is lost, infiltration rates decline, and erosion rates are accelerated. The purpose of this study was to determine if combining soil disturbances (ripping and furrowing) with the addition of organic matter would further enhance halophyte plant establishment. Treatments consisted of adding gin-trash or sudangrass hay to different soil disturbances. These included ripping, furrowing, or no soil disturbance. Changes in soil compaction, infiltration rates, and seedling establishment were measured. Ripping and furrowing reduced soil compaction and tended to increase infiltration rates. Adding gin-trash tended to increase infiltration rates. There were no differences between seedling establishment rates of alkali sacaton (*Sporobolus airoides)* or giant sacaton *Sporobolus wrightii*), however there was a trend toward improved seedling establishment when adding organic matter was combined with ripping or furrowing.

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INTRODUCTION

Throughout west Texas, the oil and gas industry has been vital to local, state, and national economies (Weber 2012). Unfortunately, rangelands and croplands are often contaminated with salt water during oil exploration and pumping. Brine water is produced during the drilling process and pumped to the soil surface, where it is stored in surface ponds until it can be sent to disposal sites. In addition, salt water is also produced during the pumping of hydrocarbons (i.e., oil and natural gas). Once it is pumped to the surface, salt water is separated from hydrocarbons and stored separately until it can be pumped back into the same formation where capture occurred.

Unfortunately, contamination from salt (brine) water spills is common in areas of oil development (Halvorson et al. 1989). Contamination of soils with brine water typically leads to complete loss of ground cover and accelerated erosion rates. This leads to a decrease of forage production, thereby reducing grazing value and economic returns from livestock and wildlife.

This project focused on a brine water spill situated in west Texas, in the Permian Basin area where oil and gas exploration is common. This site is typical of many salt water spills. The site is characterized by bare compacted soil with excessive runoff rates. Soil compaction estimates on the site exceed 710 kpa, which exceeds the level where root penetration is possible.

There are few options for reclaiming contaminated soils after a brine water spill. One of those methods is to put an abundance of water on the contaminated area to infiltrate the

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soil and leach the salts (Hanson et al. 1999). This method is effective, but costly. Another method that has been used to help treat brine water spills is the implementation of plants that can live in high salinity soils, which are known as halophytes. Halophytes can tolerate concentrations of salt that would normally kill 99% of other plants (Flowers et al. 2008). Once established, halophytes accumulate salts in vegetation, reducing saline content in the soil. Livestock grazing of halophytes can then be used to remove salts from the site. In addition, halophytes increase organic matter in the soil, which improves soil structure and improves infiltration rates. Once the rate of water infiltration increases, salts are leached out of the soil's upper layers which are used for plant growth.

Unfortunately, plant establishment is often difficult regardless of the level of contamination (Keiffer and Ungar 2002). An alternative method of increasing organic matter in the soil and improving infiltration would be to add commercially-available organic matter to contaminated sites. Once organic matter is added, plant establishment rates should improve because of an increase in water infiltration rates into the soil.

Burris (2017) demonstrated that halophyte establishment and persistence was further enhanced when combined with two soil disturbances, ripping and furrowing. These processes reduced soil compaction and apparently improved water infiltration. For this project, ripping and furrowing was combined by adding two commercially available types of organic matter to enhance water infiltration and plant establishment.

OBJECTIVES

1. Determine if adding organic matter on saline-contaminated soils improves water infiltration and plant establishment.
2. Determine if combining soil disturbance and adding organic matter improve water infiltration and plant establishment.

LITERATURE REVIEW

Organic matter that is added to the soil improves water infiltration and plant establishment (Evanylo and McGuinn 2000). In this study, sudangrass hay and gin-trash was added as the organic matter to improve infiltration rates and help improve the establishment of halophytes. Soil organic matter sustains many key soil functions by providing the energy, substrates, and biological diversity to support biological activity, which affects soil aggregation and water infiltration (Franzluebbers 2002). Leaving crop residues in intensive crop production systems, adds organic matter content in the soil surface which helps maintain soil aggregation and enhance infiltration (Evanylo and McGuinn 2000). Indeed, leaving residual crop material, thereby increasing organic matter, is the primary benefit of no-till farming. Organic matter physically holds more water than mineral matter; thus, increasing a soil's organic matter content should increase its water-holding capacity. On properly managed rangelands, organic matter should be adequate when standing cover remains after grazing. However, contamination with salt water causes total plant mortality and the complete loss of organic matter.

Organic matter was added to soil disturbances of ripping and furrowing to see if there was an improvement in infiltration and halophyte plant establishment. Brown and Kemper (1987) found that straw in the furrows can increase the infiltration rates and reduce soil erosion to acceptable levels. On rangelands, various mechanical treatments such as ripping, pitting, and contour furrowing have been used to create surface storage and increase water infiltration opportunity (Pikul et al. 1996).

Most plants are unable to survive in high saline soils because of ion toxicity (Hasegawa et al. 1986). Halophytes avoid ion (saline) toxicity by accumulating toxic salt ions in shoots (Flowers et al. 1977) and redistributing the excess ions to their leaves or alternate plant parts (Yeo and Flowers 1984). Alternatively, some halophytes secrete the salts into glands or bladders (Liphschitz and Waisel 1982).

Halophytes have high ion accumulation, but in order to be a practical species, they must reduce soil saline levels while providing forage for livestock and wildlife. Some halophytic species will block salt at the root cortex or root-soil interface. This is an avoidance method used by the plant but will not reduce soil saline levels (Jeschke 1984; Warnock 2003). All halophytes have unique methods to avoid ion toxicity, but when it comes to grazing value and bioaccumulation, certain species are needed in order to properly dispose of salts while providing adequate nutrition for livestock. Ideal halophytes for reclamation would accumulate salts in leaves that could be consumed by livestock to reduce total salt concentrations on contaminated sites.

Alkali sacaton (*Sporobolus airoides* [Torr.]) is a drought and salt tolerant species that provides forage for livestock and accumulates salts. It is native to Utah and is a large bunchgrass that provides excellent forage for livestock and wildlife. This species can survive on 30.5-45.7 cm of rain annually (Gould 1975) and has traditionally been used to reclaim sodic soils around oilfield sites and any other saline waste site. Because it is a large bunchgrass, it is also used to decrease soil erosion. This plant can be established by seeds or tillers and is usually more successful under soil disturbance (Gould 1975).

Giant sacaton (*Sporobolus wrightii* Munro [Scribn.]) is a native, warm season bunchgrass that can grow up to 2.4 m tall. Based on observations on other locations, It appears to be useful for revegetating saline (Lloyd-Reilley and Kadin 2002). After being established, giant sacaton should provide forage for livestock.

METHODS

The targeted site was located at 31. 284001 N, 100. 418085 W, which is approximately 12 km outside of San Angelo, Texas off U.S. Highway 277. It was a 5.7 ha-plot with extremely high soil salinity located on an old brine water spill site from the production of oil and gas. Under the surface was an alluvial rubble zone of Cretaceous cover over the older Permian impermeable clay rocks. These factors combined with sodic soils make it almost impossible for water or root penetration. Vegetation was only visible on lines running parallel to the site. (Figure 1) These "lines" are berms that were established in the 1980s in an attempt to catch runoff to dilute and leach out salts. Thus, the only vegetation growing was on the down gradient of the berms, where years of rainwater have accumulated and diluted some of the salts.

The site was divided into five blocks, divided by the berms. The divisions can be seen on Figure 1, with the first section starting at the bottom left and continuing in order until stopping at Section 5. The level of soil contamination decreases from section 1 through 5.

In 2015, each block received two soil disturbance treatments at random locations along with a control (no soil disturbance). Halophytes were planted at random locations along the two soil disturbances and along with the control. One disturbance consists of ripping the soil with a single-shanked ripper. The second soil disturbance consists of furrowing the soil with a single furrow. On alternating sides of each treatment, halophytes were planted; alkali sacaton, giant sacaton, inland saltgrass (*Distichlis spicata* L.), Bermudagrass (Giant and Common) (*Cynodon dactylon* L.), and four-winged saltbush (*Atriplex canescens* [Pursch] Nutt.). Initially, Alkali sacaton and four-winged saltbush had the lowest mortality rate and accumulated more salts than the other species. However, by the

Figure 1. Research site located 12 km south of San Angelo, Texas. The site is divided into 5 sections, with the level of saline contamination decreasing from section 1 to 5.

second year of the study, giant sacaton had readily established along both rips and furrow. For this study, alkali sacaton and giant sacaton will be used because of the ability to readily establish as demonstrated by Burris (2017).

For this study, additional rips and furrows (six of each) were placed in each block in March. Organic matter was added to three of the rips, furrows, and control groups in each block. The organic matter being used was sudangrass hay and gin-trash. Both products are readily available and relatively inexpensive. Gin-trash is a by-product produced during cotton ginning. After cotton fiber has been separated from seeds, the remaining plant material is separated resulting in gin-trash. Sudangrass hay is commonly produced in this region and used as inexpensive hay for livestock production.

In March of 2018, alkali sacaton and giant sacaton were planted along each treatment. Water infiltration rates, soil compaction, plant establishment rates, biomass production, changes in soil salt content, and salt accumulation rates were measured. Prior to establishing treatments, water infiltration rates, soil saline content, and levels of soil compaction were measured. Infiltration rates were measured by placing infiltrometers on the soil surface and measuring the rate of water disappearance in one hour. Soil compaction levels were estimated using a standard soil compaction meter. Soil samples were collected and sent to a commercial lab to measure soil salinity. Samples were collected initially and again in July.

In March, treatments (ripping, furrowing) both with and without both types of organic matter were implemented. Soil samples were taken 30 days thereafter. At that point, alkali sacaton and giant sacaton were seeded along each treatment. Seeding was done using a standard grass seeder. Both species were planted at the recommended rate of 0.91 kg/ha. Alkali sacaton was planted on the east side of each transect (treatment), and giant sacaton was planted on the west side of transect. Plant establishment was estimated in July by counting the numbers of live plants along each transect. Forage production of alkali sacaton and giant sacaton will be estimated at the end of the growing season (October) by clipping above-ground vegetation in each plot. At that time, samples will be dried at 105°C for 24 hours and weighed to estimate annual primary production. Subsamples will be sent to Dairy One, Itaca, NY for saline content analysis. For this thesis, data on soil compaction, infiltration rates, and plant establishment will be presented.

Data were analyzed using a randomized block design with sections of contamination as blocks. Differences among treatments were compared using repeated measures analysis with addition of organic matter (sudangrass, gin-trash, control) as the main effect, soil disturbance (ripping, furrowing, control) as the subplot, and day of collection as the repeated measure. Means were separated using Tukey's Protected LSD when $P < 0.05$. Data were analyzed using the statistical package JMP (SAS 2007).

RESULTS

Alkali sacaton and giant sacaton both established (11.1 vs. 8.4 seedlings per transect, respectively, SEM = 2.2). Soil disturbance (ripping vs. furrowing vs. control) did not improve ($P>0.05$) seedling establishment rate (Fig. 2). Conversely, adding organic matter improved seedling establishment rate (Fig 3.). Adding sudangrass hay increased the number of seedlings when compared to the control (no organic matter added). The interaction between soil disturbance and adding organic matter was not significant; however there was a trend toward improved seedling establishment when hay was combined with ripping (Fig. 4).

Initially, soil compaction levels were high (710 kilopascals (kpa)), and exceeded levels necessary to allow root penetration and seedling establishment. Ripping and furrowing both reduced ($P<0.05$) soil compaction levels (Fig. 5). Adding gin-trash also reduced soil compaction levels but adding hay did not (Fig. 6). The interaction between soil disturbance and adding organic matter was not significant ($P = 0.17$).

Infiltration data is presented as means with SEM only because of a limited sample size. There was a trend toward soil disturbance (furrowing and ripping) improving infiltration rates (Fig. 7). In addition, adding gin-trash appeared to improve infiltration rates (Fig. 8.).

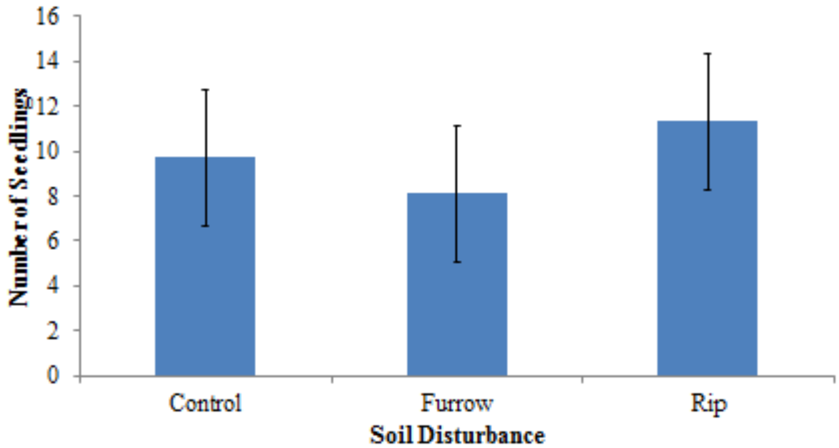

Figure 2. Seedling establishment rate along three different soil disturbances (control, furrowing, and ripping)

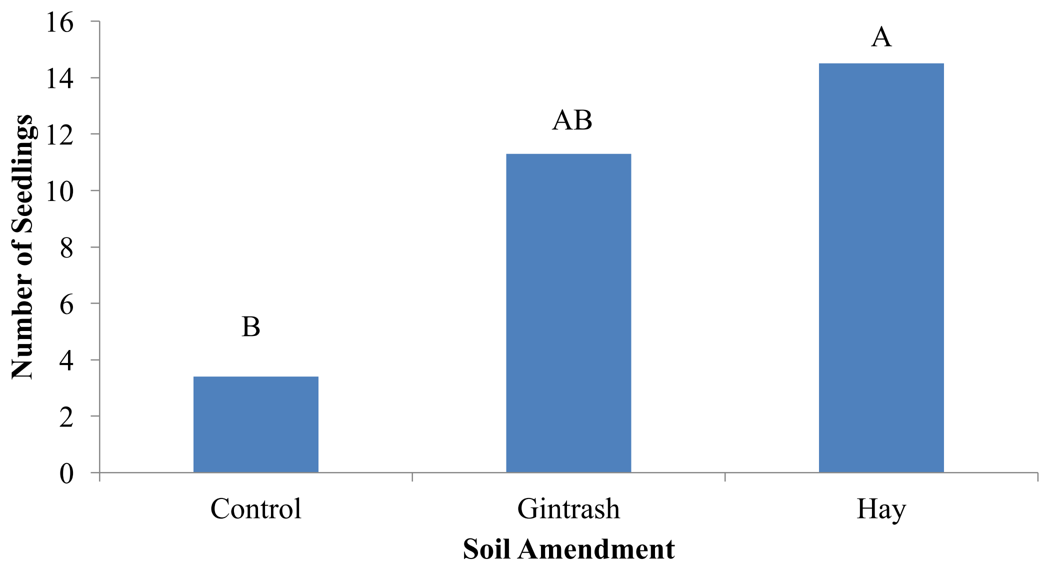

Figure 3. Seedling (alkali sacaton and giant sacaton) establishment rate with the three soil amendments (control, adding gin-trash, adding sudangrass hay)

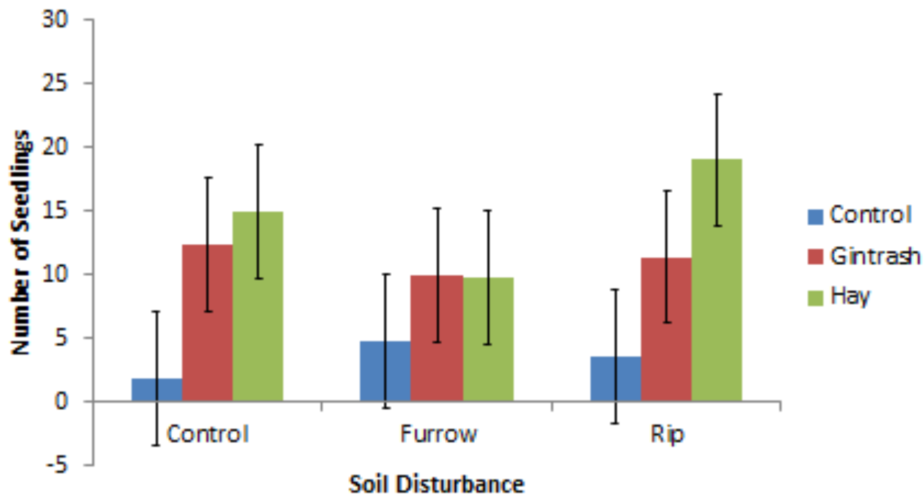

Figure 4: Seedling (alkali sacaton and giant sacaton) establishment ration after combining soil disturbance (control, furrowing, ripping) and soil amendments (control, gin-trash added, or sudangrass hay added).

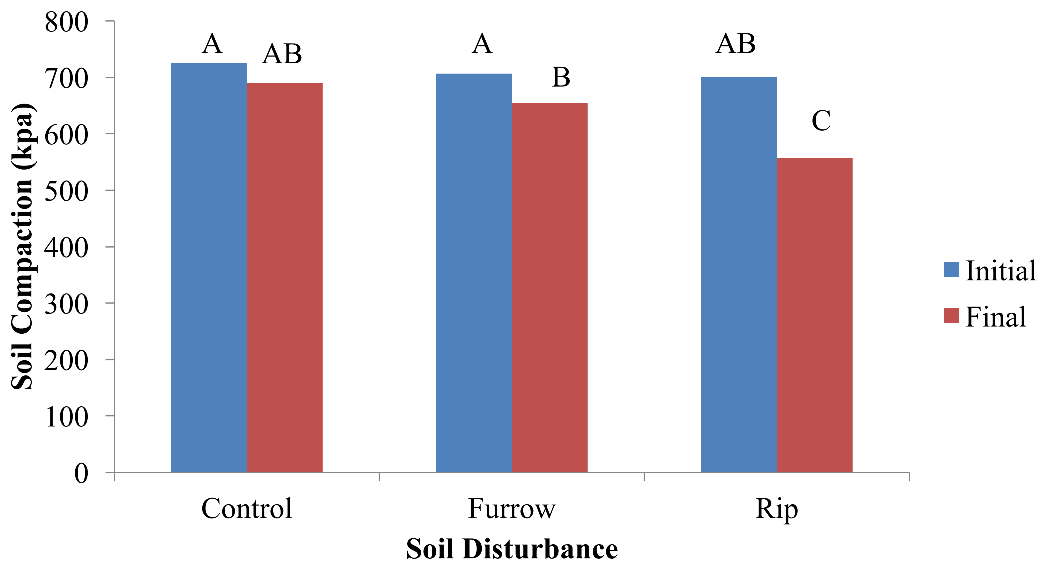

Figure 5: Initial and final soil compaction measurements with the addition of soil disturbances (control, furrowing, or ripping).

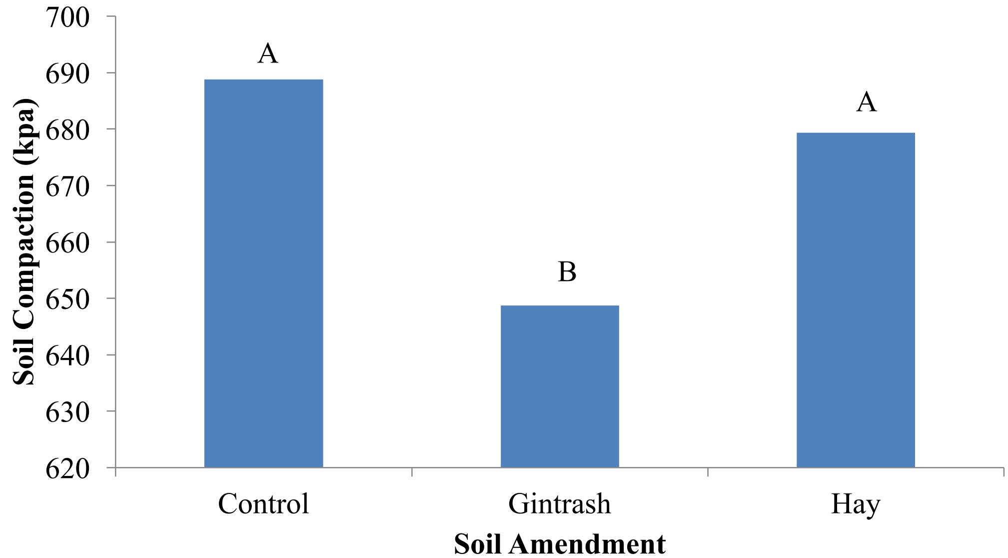

Figure 6. Soil compaction levels following the addition of soil amendments (control, adding gin-trash, adding sudangrass hay).

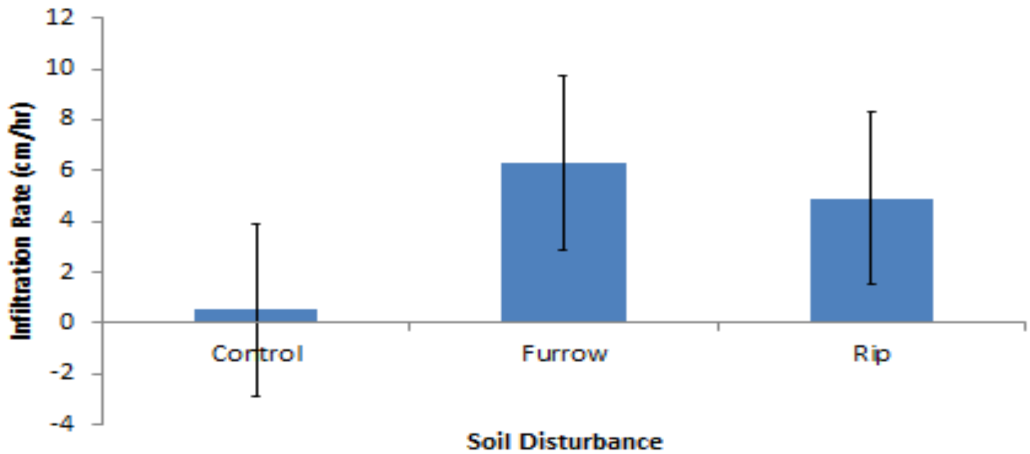

Figure 7: Infiltration rates (cm/hr) with the addition of soil disturbances (control, furrowing, ripping).

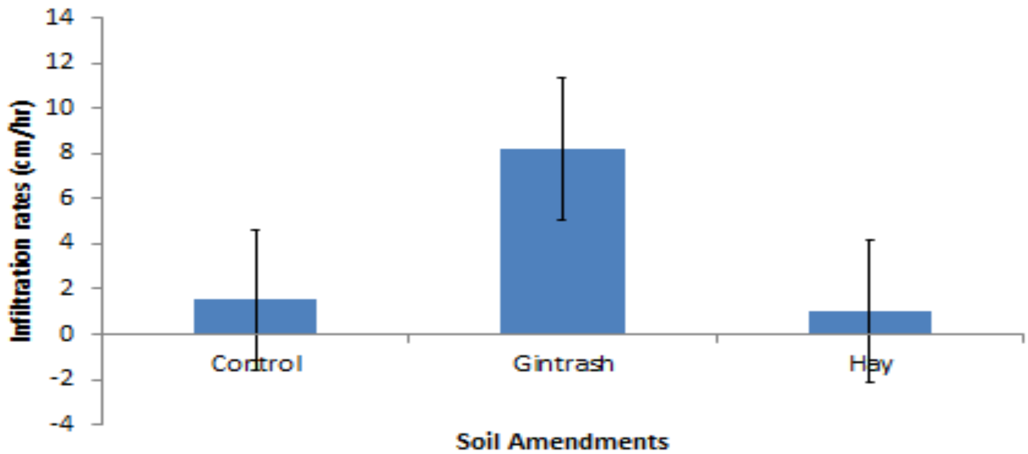

Figure 8. Infiltration rates (cm/hr) after adding soil amendments (control, adding gin-trash, adding sudangrass hay).

DISCUSSION

Based on the results of this study, soil disturbance type (ripping and furrowing), did not improve seedling establishment rate. Conversely, adding organic matter (sudangrass hay) did improve seedling establishment rate. In addition, there was a trend toward improved seedling establishment rate when the addition of organic matter was combined with soil disturbance. It is important to note, that seedling establishment rate was measured 6 months after treatments were applied. Burris (2017) observed little seedling establishment until 24 months after ripping and furrowing were applied. Over a longer period of time, more plants may establish further enhancing the potential benefit of combining soil disturbance with adding organic matter.

When initially measured, soil compaction levels exceeded the levels allowing root penetration and seedling establishment. Ripping and furrowing both tended to decrease soil compaction. Burris (2017) also illustrated that soil disturbance reduced soil compaction and improved seedling establishment rates. Soil compaction may further decrease over time with plant establishment. Bunchgrasses (i.e., alkali sacaton and giant sacaton) typically enhance organic matter and soil structure. Grass roots are typically short-lived and quickly replaced throughout the growing season, resulting in additional organic matter in the soil (Briske 1991). As organic matter is decomposed, soil structure improves thereby reducing soil compaction and enhancing further root penetration and water infiltration (Thurow 1991).

Ripping and furrowing both appeared to improve infiltration rates in this study. Infiltration rates were also apparently enhanced with the addition of gin-trash. On treatments without soil disturbance and additional organic matter, very little infiltration was observed. Bilbro and Fryrear (1991) suggested the use of mulches like gin-trash improved infiltration and water holding capacity. Gin-trash increased infiltration at our study site. As infiltration rates increase, salts should be leached out of the topsoil as water infiltrates through the soil profile.

Burris (2017) illustrated that both alkali sacaton and four-winged saltbush both readily established in the high-saline soils on this site, especially when ripping or furrowing were applied. Both readily accumulated salts in vegetation and reduced soil saline levels immediately adjacent to the plants. Establishment rates of giant sacaton were low until year two of the study conducted by Burris (2017). For this study, four-winged saltbush seedlings were not available resulting in the use of giant sacaton. If available, four-winged saltbush seedlings will be planted along all treatments in year two of this study. In addition, Australian saltbush (*Atriplex semibaccata* R. Br.) will be planted along each treatment during year two of this study. Apparently, the plant readily establishes in high-saline soils, accumulates salts in vegetation, is drought-tolerant, and is readily consumed by livestock.

This thesis project is part of a long-term project to reclaim sites contaminated with salt water, produced during the production of crude oil and natural gas. Monitoring efforts will continue on this site for the next two years, documenting seedling establishment rates, soil compaction, and changes in infiltration rates. In addition, annual above ground plant production, soil saline content, and vegetation saline content will be monitored annually.

Once vegetation is established, livestock grazing will be used to remove above ground vegetation that has accumulated salts in leaves and stems. This will allow salts to be slowly removed from the site. At this point, livestock grazing has not been active. In fact, the study site was fenced to exclude livestock grazing initially to allow vegetation establishment.

On other sites, where livestock are present, fencing may be necessary initially to allow plant establishment.

In the near future, other sites will be added to the study. These will include other locations in the Permian Basin, where oil and gas exploration has resulted in salt water contamination. While the results of the study are encouraging, results may differ when applied to different soil types or under different precipitation regimes.

IMPLICATIONS

Based on the results of this study, it appears that the use of soil disturbances (ripping and furrowing) and adding organic matter (gin-trash and sudangrass hay) is essential to improve infiltration rates and plant establishment. Once vegetation cover is depleted after releasing salt water on the site, a crust forms on the topsoil and soil structure (aggregation of soil particles) is lost resulting in a complete loss of water infiltration. Ripping and furrowing re-establishes soil structure allowing water to infiltrate. On other sites (i.e., sandy soils) soil disturbance may not be necessary to maintain adequate infiltration rates. Sandy soils are less susceptible to loss of structure and crust formation. Gin-trash and sudangrass hay were used as sources of organic matter in this study because of their availability in this region. In other regions, other sources of organic matter may be used depending on the availability and cost. Additionally, planting halophytes (alkali sacaton, giant sacaton, and four-winged saltbush) are essential for site recovery and removal of salts.

LITERATURE CITED

Benjamin, R. W., Y. Lavie, M. Forti, D. Barkai, R. Yonatan, and Y. Hefetz. 1995. Annual regrowth and edible biomass of two species of *Atriplex* and of *Cassia sturtii* after browsing. *Journal of Arid Environments* 29:63-84.

Bilbro, J.D. and Fryrear, D.W., 1991. Pearl millet versus gin-trash mulches for increasing soil water and cotton yields in a semiarid region. *Journal of Soil and Water Conservation 46*:.66-69.

Briske, D.D. 1991. Developmental morphology and physiology of grasses. In: R.K. Heitschmidt and J.W. Stuth (Editors), Grazing Management: An Ecological Perspective. Timber Press, Oregon.

Brown, M.J. and Kemper, W.D., 1987. Using straw in steep furrows to reduce soil erosion and increase dry bean yields. Journal of Soil and Water Conservation 42:187-191.

Burris, K.R., 2017. Restoration of Brine Water Impacted Soils Using Halophytes and Soil Disturbances in West Texas. M.S. Thesis, Department of Agriculture, Angelo State University, San Angelo, Texas.

Evanylo, G.K. and McGuinn, R., 2000. Agricultural management practices and soil quality: measuring, assessing, and comparing laboratory and field test kit indicators of soil quality attributes. Virgina Cooperative Extension Publication 452-400.

Flowers, T. J., P. F. Troke, and A. R. Yeo. 1977. The mechanism of salt tolerance in halophytes. *Annual Review of Plant Physiology* 28:89–121.

Flowers, Timothy J., and Timothy D. Colmer. 2008. Salinity Tolerance in Halophytes. *New Phytologist* 179.4: 945-63.

Franzluebbers, A.j. 2002. Water Infiltration and Soil Structure Related to Organic Matter and Its Stratification with Depth." *Soil and Tillage Research* 66: 197–205.

Gould, Frank W. 1975. The Grasses of Texas. Texas A&M University Press, College Station, Texas.

Halvorson, Gary A., and Kent J. Lang. 1989. Revegetation of a Salt Water Blowout Site. *Journal of Range Management* 42: 61.

Hanson, B., Grattan, S.R. and Fulton, A., 1999. Agricultural salinity and drainage. Davis: University of California Irrigation Program, University of California.

Hasegawa, P. M., R. A. Bressan, and A. K. Handa. 1986. Cellular mechanisms of salinity tolerance. *HortScience* 21:1317–1324.

Jeschke, W. D. 1984. K+–Na+ exchange at cellular membranes, intracellular compartmentation of cations, and salt tolerance, p. 37–66. In: R. C. Staples and G. H. Toenniessen (eds). Salinity tolerance in plants. Wiley, N. Y.

Keiffer, C.H. and Ungar, I.A., 2002. Germination and establishment of halophytes on brine-affected soils. *Journal of Applied Ecology* 39:402-415.

Liphschitz, N. and Y. Waisel. 1982. Adaptation of plants to saline environments: salt excretion and glandular structure, p. 197–214. In: D. N. Sen and K. S. Rajpurohit (eds). Contributions to the ecology of halophytes. Dr. W. Junk Pub., The Hague. The Netherlands.

Lloyd-Reilley, J. and Kadin, E. 2002. Big Sacaton Sporobolus wrightii Munro ex Scribn. USDA Natural Resource Conservation Service Fact Sheet, Washington, D.C.

Mikhiel, G. S., S. E. Meyer, and R. L. Pendleton. 1992. Variation in germination response to temperature and salinity in shrubby *Atriplex* species. *Journal of Arid Environments* 22:39-49.

Pikul, J.L., Wilkins, D.E., Aase, J.K. and Zuzel, J.F., 1996. Contour ripping: A tillage strategy to improve water infiltration into frozen soil. *Journal of Soil and Water Conservation* 51:76-83.

Potter, R. L., D. N. Ueckert, J. L. Petersen, and M. L. McFarland. 1986. Germination of fourwing saltbush seeds: Interaction between temperature, osmotic potential, and pH. *Journal of Range Management* 39:43-46.

Powell, A. M. 1998. Trees and shrubs of the Trans-Pecos and adjacent areas. University of Texas Press, Austin.

Thurow, T.L. 1991. Hydrology and erosion. In: R.K. Heitschmidt and J.W. Stuth (editors). Grazing Management: An Ecological Perspective. Timber Press, Oregon.

Warnock, Bonnie, J. 2003. Bioaccumulation of Salts by Halophytes as a Means of Reclaiming Saline Soils, p. 1-14, UMI Microform Inc. Ann Arbor, MI.

Weber, J.G., 2012. The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. *Energy Economics* 34:1580-1588.

Weisner, L. E., and W. J. Johnson. 1977. Fourwing saltbush (Atriplex canescens) propagation techniques. *Journal of Range Management* 30:154-156.

Yeo, A. R. and T. J. Flowers. 1984. Mechanisms of salinity resistance in rice and their role as physiological criteria in plant breeding, p. 151–171. In: R. C. Staples and G. H. Toenniessen (eds). Salinity tolerance in plants. Wiley, N. Y.