GRASS ESTABLISHMENT ON NATURAL GAS DRILL PADS IN WYOMING AS IMPACTED BY RECLAMATION TECHNIQUES[1]

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Abstract: In the semiarid West, establishing perennial vegetation is often difficult on newly constructed natural gas drill pads because of harsh site conditions. Southern Wyoming is characterized by low precipitation and sites can have saline and/or sodic soil and steep slopes. Twenty-five combinations of reclamation techniques were evaluated on six Devon Energy Corporation natural gas drill pads in the Washakie Basin near Baggs, Wyoming. Treatments included combinations of soil ripping, fertilizer applications, gypsum or sulfur application, chopped straw or woodchip amendments, imprinting, pitting, mulch, irrigation, fencing and site-specific seed mixes. Grass density was measured ten months after treatment implementation on five drill pads and six weeks after implementation on one drill pad. Irrigation during plant establishment was beneficial on all sites, increasing grass density 92 % on average compared to areas not irrigated. Wood chips, gypsum and fertilizer; and chopped straw, sulfur and fertilizer treatments, both with and without irrigation significantly increased grass establishment on saline-sodic soils. Irrigation and fertilizer, and fertilizer alone produced little to no grass establishment on saline-sodic soils, suggesting some treatment for the saline-sodic condition was necessary for grass establishment. Imprinting significantly increased grass densities on both saline and non-saline soils and on sloped sites by providing protected microclimates for seedling growth. Pitting produced lower grass density than imprinting, and most likely cut through the topsoil and exposed lower quality subsoil material. Straw mulch increased grass density when used in combination with irrigation, but did not increase density when used with other treatments on a site with low salinity and sodicity. On the same site, grass density was 89 % higher on average when treatments did not include fertilizer. At least one reclamation treatment on each site produced grass density of at least 80 % of that found in the adjacent native range. These reclamation techniques can significantly decrease the time required to reach plant re-vegetation requirements.

Additional Key Words: semiarid land reclamation, soil amendment, straw mulch, woodchips, pitting, imprinting

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Introduction

In the United States, the semiarid Rocky Mountain West contains important oil and gas resources. Demand for these resources has increased and greatly accelerated development in this region. However, semiarid lands are a fragile ecosystem, with unique reclamation challenges exacerbated by periodic drought. The oil and gas producing areas of the Rocky Mountain West consist largely of the sagebrush steppe ecosystem, characterized by limited soil resources, low precipitation, and predominantly shrub and grass vegetation communities. The goal of this study was to develop and demonstrate successful science-based reclamation techniques that are feasible to implement throughout the Washakie Basin gas field and the Rocky Mountain west.

The Washakie Basin of Wyoming has a harsh, semiarid climate that receives 15 to 20 cm/year (6 to 8 inches/year) of precipitation, is at an elevation of 1980 to 2070 meters (6500 to 6800 feet), and has a frost-free period of 90 to 100 days (Koss et al., 1988; Fig. 1). Soils are often thin and rocky, have relatively low levels of plant nutrients and organic matter and can have relatively high levels of salts and/or sodium.

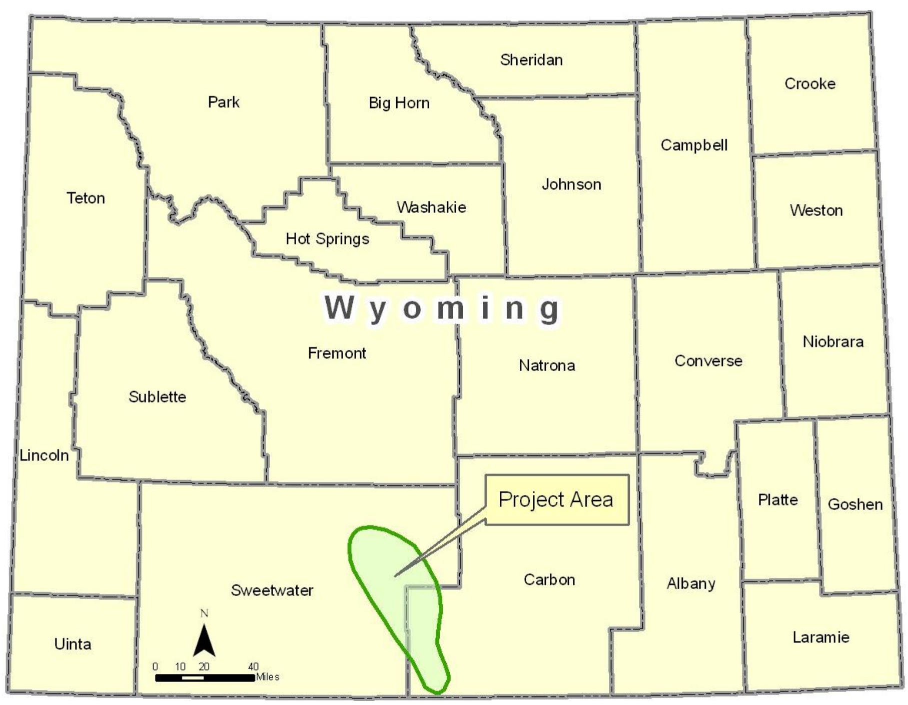

Figure 1. Location of the project area, Washakie Basin, Wyoming.

Most natural gas well sites consist of a cut and fill disturbance two to four acres in size, and host a single gas well. After completion of drilling activities, the area not used for production equipment or roads is reclaimed. Traditional reclamation techniques for the area include removing and stockpiling topsoil prior to pad construction, grading the drill pad to the approximate original contour, ripping and/or disking, applying topsoil, and seeding the site (BLM, 2000). Sites reclaimed in this manner can often take ten years or more for satisfactory vegetation communities to establish. The Bureau of Land Management reclamation criteria require that a site have 50 to 80 % of pre-disturbance cover, which is measured in an adjacent undisturbed reference area (BLM, 2000).

A variety of reclamation techniques can increase successful reclamation in areas with harsh plant growth conditions. This study tested several combinations of reclamation techniques on Devon Energy Corporation drill pads in the Washakie Basin, Wyoming. These techniques included soil ripping, fertilizer application, gypsum or sulfur application, chopped straw or woodchip amendments, pitting, imprinting, creaser-seeding, mulch, irrigation, and fencing. Sites with a variety of limiting factors, such as low precipitation, steep slopes, and high salinity and/or sodicity received these treatments.

Materials and Methods

Study Area

Six drill pads were chosen for reclamation treatment testing: Baldy Butte 4-14, Barrel Springs Unit 14-18, Creston Nose 4-18, Creston Nose 15-18, East Echo Springs 2-33, and East Echo Springs 15-33 because they exhibit the range of plant growth limitations throughout the project area. A reclamation plan was developed for each of the six drill pads, and included a seed mix, soil remediation plan, and recommended agronomic practices.

Soil samples were collected from the six drill pads. All samples were analyzed for pH, electrical conductivity (EC), sodium adsorption ratio (SAR), plant available nutrients (nitrogen, phosphorus, potassium), saturation percentage, particle size distribution (percent sand, silt, and clay) and associated textural class, organic matter content, and calcium carbonate content (percent lime) (Table 1).

Table 1. Soil analysis data for the treatment sites in the Washakie Basin, Wyoming.

Site	Sample Location	Sample Depth (cm)	pH	EC (dS/m) [1]	SAR	Nitrate (mg/kg)	Phosphorus (mg/kg)	Potassium (mg/kg)	Saturation (%)	Texture Class	Rock [2] (%)	Organic Matter (%)	Lime (%)
Creston Nose 4-18	Reclaimed Drill Pad	0 - 15.2	7.6	0.87	1.3	5.7	8.6	124	31.9	Sandy Loam		0.67	4.4
		15.2 - 61	7.8	0.69	2.6				33.0	Sandy Loam			3.5
Creston Nose 15-18	Coversoil Stockpile	0 - 15.2	7.2	0.66	0.59	12	8.3	138	33.3	Sandy Loam		0.64	0.9
	Drill Pad	0 - 15.2	7.7	2.32	9.1	13	6.3	184	50.8	Clay Loam		0.93	6.1
		15.2 - 61	7.6	5.35	11				57.9	Clay			3.2
	Reserve Pit Fill	0 - 61	7.7	5.46	11	9.4	6	193	52.0	Clay		0.57	6.6
Barrel Springs Unit 14-8	Reclaimed Drill Pad	0 - 15.2	8.0	5.21	18	15	6.5	1070	53.8	Clay Loam		0.82	7.3
		15.2 - 61	7.9	6.39	22				55.8	Clay Loam			7.6
Baldy Butte 4-14	Reclaimed Drill Pad	0 - 15.2	8.2	4.69	16				49.4	Silty Clay Loam	2		3.1
		15.2 - 61	8.1	12.8	21				53.7	Silty Clay	<2		5.6
East Echo Springs 2-33	Reclaimed Drill Pad	0 - 15.2	7.4	2.12	1.5				48.0	Clay Loam	12		1.4
		15.2 - 61	7.7	2.44	2.7				48.7	Clay Loam	4		2.3
East Echo Springs 15-33	Reclaimed Drill Pad	0 - 15.2	5.3	3.56	2.0				29.9	Sandy Loam	<2		0.3
		15.2 - 61	4.1	3.68	1.6				30.0	Sandy Loam	2		<0.1

[1]Abbreviations used are as follows: EC = electrical conductivity of a soil saturated paste extract; dS/m = decisiemens per meter; SAR = sodium adsorption ratio; mg/kg -= milligrams per kilogram; and % = percent.
[2]Rock = coarse fragments greater than 2 mm in diameter.

Reclamation Techniques

The project team identified reclamation techniques that address the limitations to plant growth at the six test sites. Three of the techniques were implemented on all of the test sites: soil compaction relief, site-specific seed mixes, and fencing. The other techniques, fertilizer application, soil amendment with gypsum or sulfur, incorporation of wood chips or chopped straw into the soil, pitting, imprinting, creaser-seeding, application of mulch, and irrigation were applied to portions of the sites to test the treatments side by side.

After topsoil application, all sites were ripped to a depth of 46 to 61 cm with an agricultural parabolic ripper to reduce soil profile compaction. The sites were ripped in two directions at a 30-degree angle. All six test sites were fenced with barbed wire and steel posts.

Based on field observation, soil salinity significantly influenced the composition of grass, forb and shrub species. This information was critical to developing the recommended seed mixes shown in Table 2. The seed mixes consist primarily of species found in the adjacent native range. Baldy Butte 4-14 was seeded May 21, 2008 and the other sites were seeded August 24-30, 2007.

Preliminary soil analyses from each drill pad location indicated that plant available nitrogen, phosphorus and potassium were within the normal range for semiarid rangelands. However, fertilizer treatments ensured that adequate nutrients were present in the soil for re-vegetation. Four of the six sites received a treatment consisting of nitrogen and phosphorus fertilizer at a rate of 100 kg N/ha and 135 kg P/ha. The dry granular form of fertilizer was topically applied to soil with a trailer mounted spreader, and was incorporated into the soil by disking. Sites having woodchips or chopped straw incorporated into the soil received additional nitrogen fertilizer.

Gypsum or sulfur soil amendments were applied to remediate the soil sodicity. The soil chemistry of the site determined the application rates. Solution grade gypsum and sulfur granules were applied to the soil surface and then incorporated with a disk. The gypsum was solution grade at 98 % purity and 100 % passing a 100 mesh screen. The sulfur was disintegrating S-granules at 90 % purity and 0.3 cm particle diameter.

To alleviate soil crusting, woodchips or chopped straw were applied and incorporated into the soil. Woodchips were the preferred material, however, it may not be possible to attain an adequate supply of woodchips, and the cost for straw is lower. The straw application rate was 2.24 Mg/ha, and the straw was chopped into 2.5 to 5 cm lengths with a disk, and incorporated to

Table 2. Seed mix and seeding rates used at the six test sites.

Common Name	Scientific Name (Cultivar)	Seeds/kg	Seeding Rate (PLS kg/ha)[1,2]	Seeds/m²
	Barrel Springs Unit 14-8			
Thickspike wheatgrass	*Agropyron dasystachym* (Critana)	339,512	4.5	152
Western wheatgrass	*Elymus smithii* (Rosana)	253,532	4.5	114
Indian ricegrass	*Oryzopsis hymenoides*	356,972	3.4	120
		Total:	**12.3**	**386**
	Baldy Butte 4-14[3], Creston Nose 4-18 and Creston Nose 15-18			
Slender wheatgrass	*Agropyron trachycaulus*	297,624	2.2	67
Thickspike wheatgrass	*Agropyron dasystachym* (Critana)	339,512	4.5	152
Western wheatgrass	*Elymus smithii* (Rosana)	253,532	2.2	57
Indian ricegrass	*Oryzopsis hymenoides*	356,972	1.1	40
Sandberg bluegrass	*Poa sandbergii*	2,308,152	0.6	129
Bottlebrush squirreltail	*Elymus elymoides*	423,288	1.1	47
		Total:	**2.8**	**217**
	East Echo Springs 2-33 and East Echo Springs 15-33			
Thickspike wheatgrass	*Agropyron dasystachym* (Critana)	339,512	2.8	95
Western wheatgrass	*Elymus smithii*	253,532	2.2	57
Bottlebrush squirreltail	*Elymus elymoides*	423,288	2.2	95
Indian ricegrass	*Oryzopsis hymenoides* (Nezpar)	356,972	2.2	80
Slender wheatgrass	*Agropyron trachycaulus* (San Luis)	297,624	2.2	67
Sandberg bluegrass	*Poa sandbergii*	2,308,152	0.6	129
		Total:	**5.0**	**276**

[1]PLS = Pure Live Seed

[2]Seeding rate is for drill seeding with 30 cm row spacing

[3]Seeding rate at Baldy Butte 4-14 was doubled because site was broadcast seeded

the 0 to 7.5 cm depth with a 61 cm diameter disk. Woodchips were applied at a rate of 246 m^3/ha, approximately 2.5 cm thick. The woodchips were loaded into trucks and dumped across the soil surface. A loader bucket mounted on a tractor spread the woodchips evenly across the soil surface. A 61 cm disk incorporated the woodchips into the top 7.5 cm of soil. Additional nitrogen fertilizer was applied to the sites receiving woodchips or chopped straw to provide additional nitrogen to compensate for microbial decomposition of the woodchips and straw. Approximately five kg of nitrogen was added for each Mg of woodchips and 10 kg of nitrogen for each Mg of straw.

Two types of imprinting equipment were tested. The Rocky Mountain Oil Field Seeder breaks up the soil surface, applies seed, and imprints the soil in one pass. First, chisel teeth on a rotating drum loosen the soil. After seed application on the soil surface, imprinting tools on a rotating drum press the seed into the soil. Each imprint creates a depression in the soil approximately 30 cm long, 15 cm wide and 7.5 cm deep. The EnerCrest Diamond Imprinter-Seeder imprints the soil and broadcasts seed. Each imprint is 30 cm long and 15 cm deep, with approximately 74,100 diamond shaped imprints per hectare.

Surface pitting creates pits approximately 15 cm deep, 91 cm long and 36 cm wide. A tractor travels on contour and pulls a tool bar equipped with specialized blades that are hydraulically lowered and lifted to cut pits into the soil. The pitted area is then drill seeded. Typically, the pits are effective at holding water and minimizing erosion for a two-year period. Approximately 5900 pits are created per hectare (Dollhopf et al., 1977).

An Enercrest Creaser-Seeder was used on one site to broadcast seed. Steel rings that penetrate approximately 10 cm into the soil seedbed are spaced every 25 cm along the length of the creaser drum. The creaser drum enhances broadcast seed to soil contact. When straw mulch is used in conjunction with seeding, the creaser has the ability to tack the straw into the soil, eliminating the need to use a crimper to anchor the straw. The rolling effect of the creaser drum flattens the straw onto the soil surface in contrast to a crimper, which leaves the straw stalks standing upright akin to a stubble field.

The straw mulch treatment consisted of 3.36 Mg straw/ha spread evenly across the surface. The straw was crimped into the soil to a 7.5 cm depth using crimper disks, followed by a cultipacker drum to firm the straw-soil contact. Additional nitrogen fertilizer application at 23 kg/ha was applied to compensate for microbial decomposition of the straw.

Portions of the six test sites received irrigation water during the crucial germination and seedling emergence period. Analysis of water chemistry prior to irrigation ensured the use of high quality water. Approximately 7.5 cm of water were applied during a four-week period following seeding. Water was delivered by trucks, stored in tanks, and applied daily with sprinklers.

Reclamation Treatment Implementation

Twenty-five reclamation technique demonstrations were developed based on soil conditions at the six test sites (Table 3). These demonstration areas ranged from 0.03 to 1.73 ha. Each of the six test sites were ripped to reduce compaction, disked, fenced to discourage grazing, and seeded with selected grass species.

Table 3. Treatment demonstrations tested at the six disturbed land test sites.

Treatment [1]
Baldy Butte 4-14
Irrigation, Enercrest Diamond Imprinter and Fertilizer
Irrigation, Enercrest Creaser-Seeder, Straw Mulch and Fertilizer
Barrel Springs Unit 14-8
Irrigation, Gypsum, Woodchips and Fertilizer
Gypsum, Woodchips and Fertilizer
Irrigation, Sulfur, Chopped Straw and Fertilizer
Sulfur, Chopped Straw and Fertilizer
Irrigation and Fertilizer
Fertilizer
Creston Nose 4-18
Irrigation and Straw Mulch
Straw Mulch
Irrigation, Straw Mulch and Fertilizer
Straw Mulch and Fertilizer
Irrigation and Fertilizer
Fertilizer
Irrigation
Control
Creston Nose 15-18
Irrigation, Straw Mulch and Fertilizer
East Echo Springs 2-33
Irrigation, Rocky Mountain Oil Field Seeder and Fertilizer
Rocky Mountain Oil Field Seeder and Fertilizer
Irrigation, Pitting and Fertilizer
Pitting and Fertilizer
East Echo Springs 15
Irrigation, Straw Mulch and Fertilizer
Straw Mulch and Fertilizer
Irrigation, Pitting and Fertilizer
Pitting and Fertilizer

[1]Prior to treatment implementation, all sites were ripped to the 46-61 cm depth, disked and seeded. All sites were fenced.

Elevated salinity at Baldy Butte 4-14 (4.69 to 12.8 dS/m) was the primary factor limiting plant establishment, and a portion of the drill pad had a slope of five to 10 %. Creston Nose 15-18 had moderate to high salinity (2.3 to 5.5 dS/m) and East Echo Springs 2-33 had slightly elevated salinity (2.1 to 2.4 dS/m and slightly to steeply sloped (10 %) areas. East Echo Springs 15-33 had moderately elevated salinity (3.6 to 3.7 dS/m) and slopes of five to 10 % across portions of the drill pad. Creston Nose 4-18 had relatively few barriers to plant establishment.

The soil was very saline (5.2 to 6.4 dS/m) and sodic (ESP ranged from 24.2 to 32.5) at Barrel Springs Unit 14-8. A gypsum soil amendment was applied to reduce the soil exchangeable sodium percentage to 10 % from 24.2 to 32.5 %. Gypsum was applied at a rate of 21.5 Mg/ha and incorporated into the zero to 20 cm soil increment. Sulfur was applied at a rate of 4.3 Mg/ha. Woodchips were applied at 246 m^3/ha, and chopped straw at 2.24 Mg/ha.

Vegetation Monitoring

Vegetation data was collected on July 10 and 11, 2008, approximately six weeks after Baldy Butte 4-14 was seeded and ten months after the other five sites were seeded. The density of plants on each well pad was measured using a one-quarter meter square, four-sided quadrat frame. Ten frames were randomly placed in each treatment area. Ten frames were also randomly placed in an adjacent undisturbed area that approximated pre-disturbance conditions found on the well pad. This served as a reference area for pre-disturbance vegetation characteristics (BLM, 2000). Plant species present in each frame were recorded. If species were not identifiable (e.g. seedling grasses), they were grouped by life-form. The number of stems per frame per plant species (density) was also recorded. Non-rhizomatous plants were counted as one stem. Non-rhizomatous plants with multiple stems radiating out from one basal root were counted as one stem (e.g. sage). Grasses and rhizomatous plants were counted by tiller or stem.

Statistical Analysis

Statistical tests determined whether plant growth in different treatment areas was significantly different at the 95 % probability level. Nearly all plant data from these six seeded drill pads were not normally distributed, therefore nonparametric statistical tests were applied. The Kruskal-Wallis analysis of variance on ranks test was used when three or more treatments were being compared. The Mann-Whitney rank sum test was used when two treatments were being compared (SigmaStat, 2006).

Precipitation

Above average precipitation fell on the project area in September and October 2007 relative to long term averages, and below average precipitation fell from April through June 2008 (Fig. 2). Although the Baggs, WY weather station reported no precipitation during June 2008, daily irrigation logs indicated notable precipitation on well pads from June 4 through 12, minimizing the need for supplemental irrigation during this period.

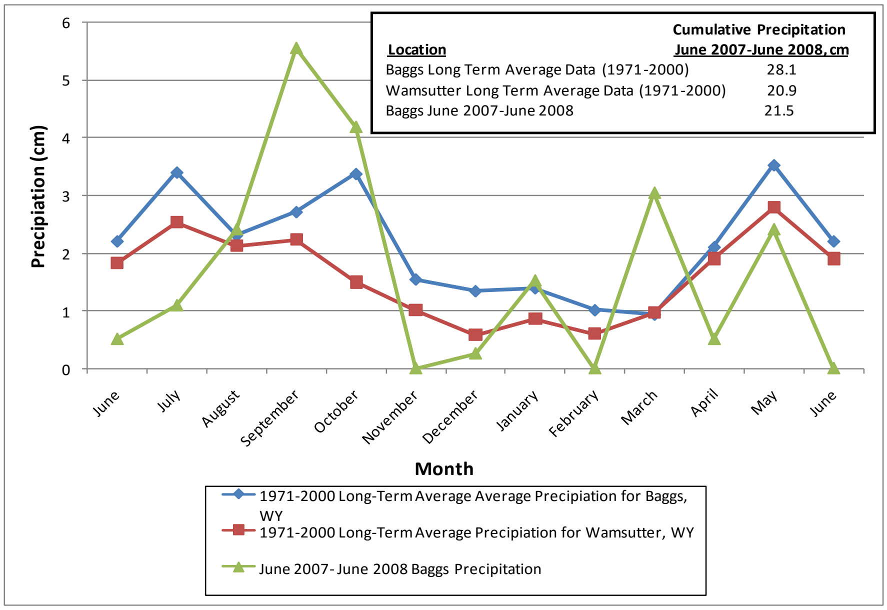

Figure 2. Comparison of precipitation received in Baggs, WY June 2007 through June 2008 to long-term averages for Baggs and Wamsutter, WY.

Results and Discussion

Baldy Butte 4-14

Grass density was significantly greater in the imprinting (EnerCrest Diamond Imprinter), fertilizer and irrigation treatment area than the straw mulch, creaser, irrigation, and fertilizer treatment, and greater than the native rangeland grass density (Fig. 3 and 4). Grass emergence was almost entirely located in the bottom of each imprint. Imprinting created protected microclimates that enhance seedling survival by providing protection from wind and sun desiccation and increased water retention.

Barrel Springs Unit 14-8

There were two treatments tested which did not address the saline-sodic soil condition: irrigation and fertilizer, and fertilizer alone (Fig. 5). These treatments had extremely low grass establishment, indicating that the tested species of vegetation will not establish without soil amendments that address the saline-sodic nature of these soils (Fig. 6). High salinity increases plant water stress (Bohn, et al., 1985) and consequently decreases seedling survival. High sodicity causes the clay loam soil to form a hard surface crust, during a wetting and drying cycle, preventing seedling emergence. In addition, high sodicity decreases soil profile hydraulic conductivity due to loss of pore space structure, and results in less water infiltration and greater runoff and erosion (Levy et al., 1998).

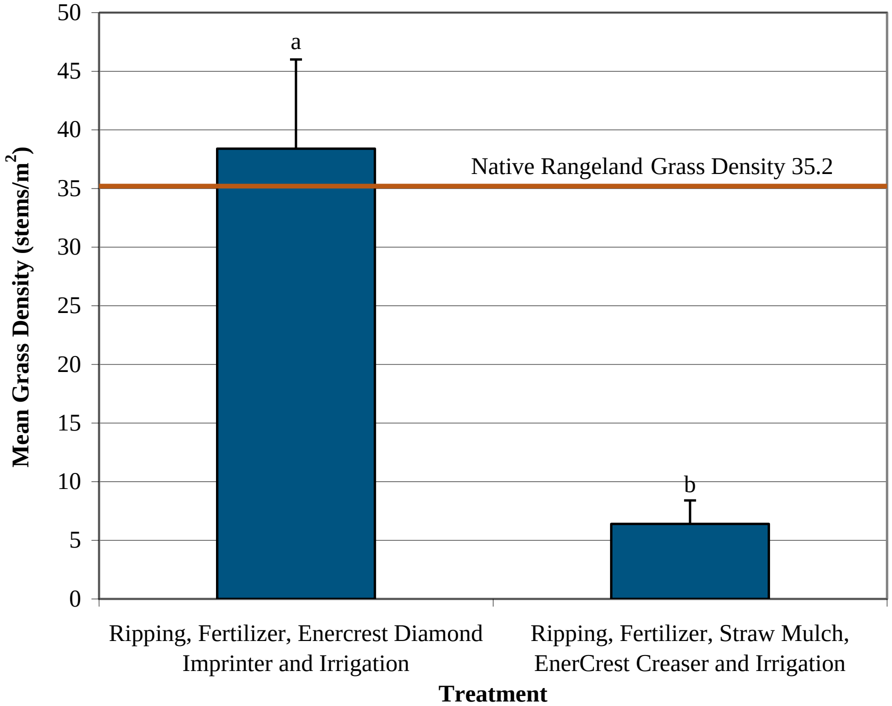

Figure 3. Grass density at Baldy Butte 4-14. Mean values capped by a different letter are significantly different ($p<0.05$), and error bars are shown.

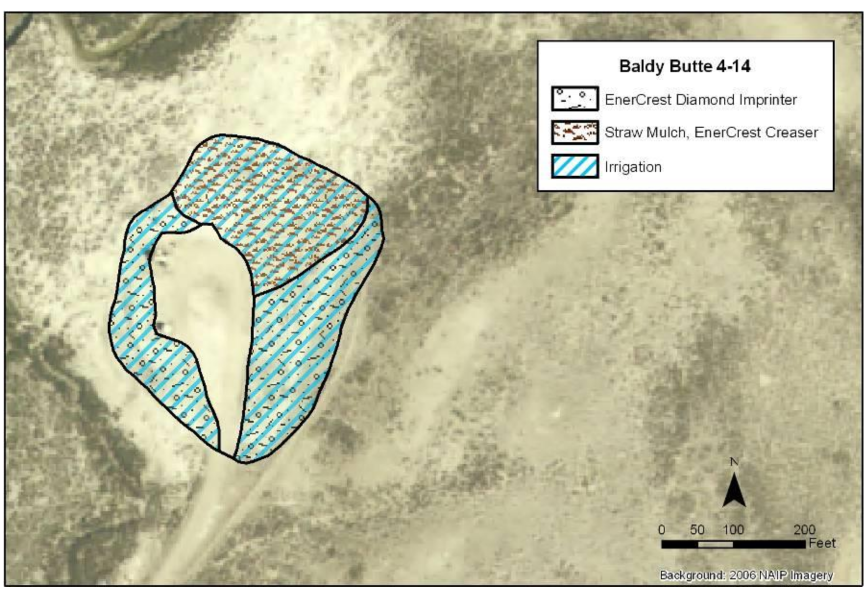

Figure 4. Illustration of reclamation treatments implemented on a 0.84 ha area at Baldy Butte 4-14.

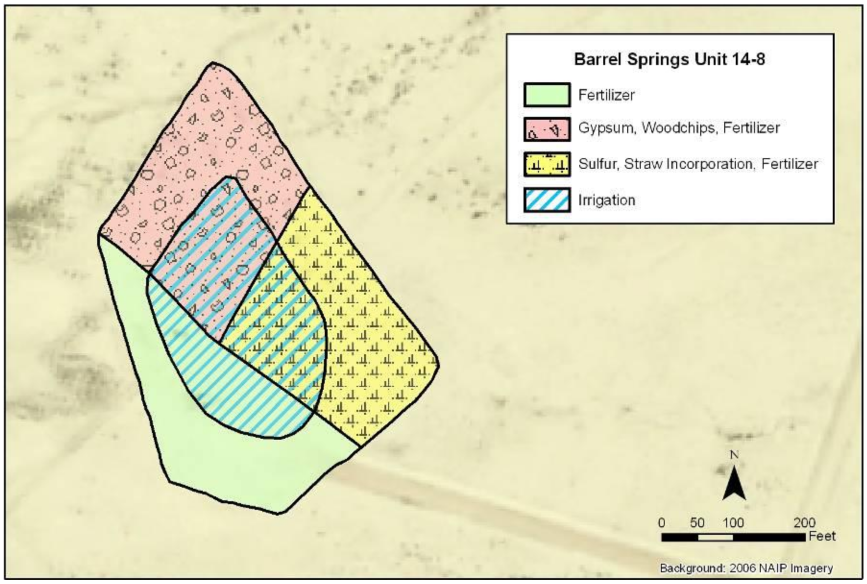

Figure 5. Illustration of reclamation treatments implemented on a 1.62 ha area located at Barrel Springs Unit 14-8.

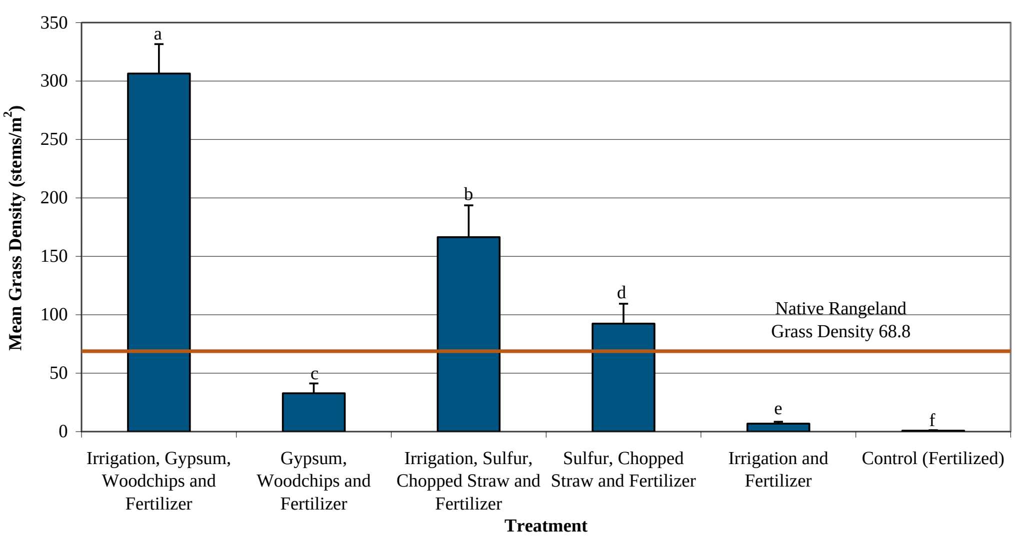

Figure 6. Grass density at Barrel Springs Unit 14-8. Mean values capped by a different letter are significantly different ($p<0.05$), and error bars are shown.

The sulfur and chopped straw treatments with and without irrigation, and the gypsum, woodchips, and irrigation treatment produced greater grass density than the native range. The gypsum, woodchips, and irrigation treatment produced significantly greater grass density than both sulfur and chopped straw treatments, but gypsum and woodchips without irrigation produced significantly less grass density than the sulfur and chopped straw treatments.

The sodic soil treatments were effective for the following reasons. First, application of woodchips or chopped straw and incorporation in the soil provides an immediate solution to soil crusting problems associated with sodic soils. Secondly, gypsum and sulfur reduce the amount of sodium on soil cation exchange sites (US Salinity Laboratory, 1954) and promote long-term soil flocculation.

<u>Creston Nose 4-18</u>

None of the treatments at resulted in greater grass densities than found on the native range. However, the native range adjacent to Creston Nose 4-18 had the greatest density measured in the project area (Fig. 7 and 8). Of the eight treatments, the straw mulch and irrigation treatment had the greatest grass density, while the straw mulch and fertilizer and the fertilizer treatments produced the least density. When comparing fertilized to non-fertilized treatments; grass density is 89 % greater on treatments where fertilizer was not applied. An example is straw mulch and irrigation compared to straw mulch, irrigation and fertilizer. The reason for decreased grass density is uncertain, but may be due to slightly elevated salt content when inorganic fertilizer dissolves into the soil solution, which impairs the ability of plants to uptake water from the soil.

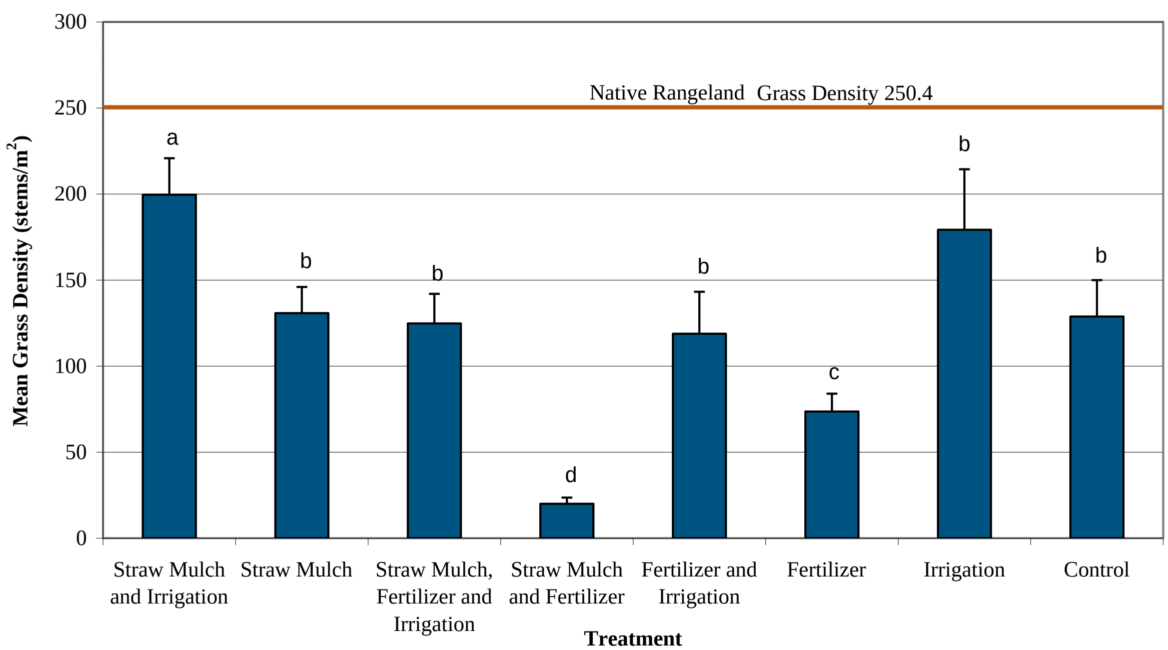

Figure 7. Grass density at Creston Nose 4-18. Mean values capped by a different letter are significantly different ($p<0.05$), and error bars are shown.

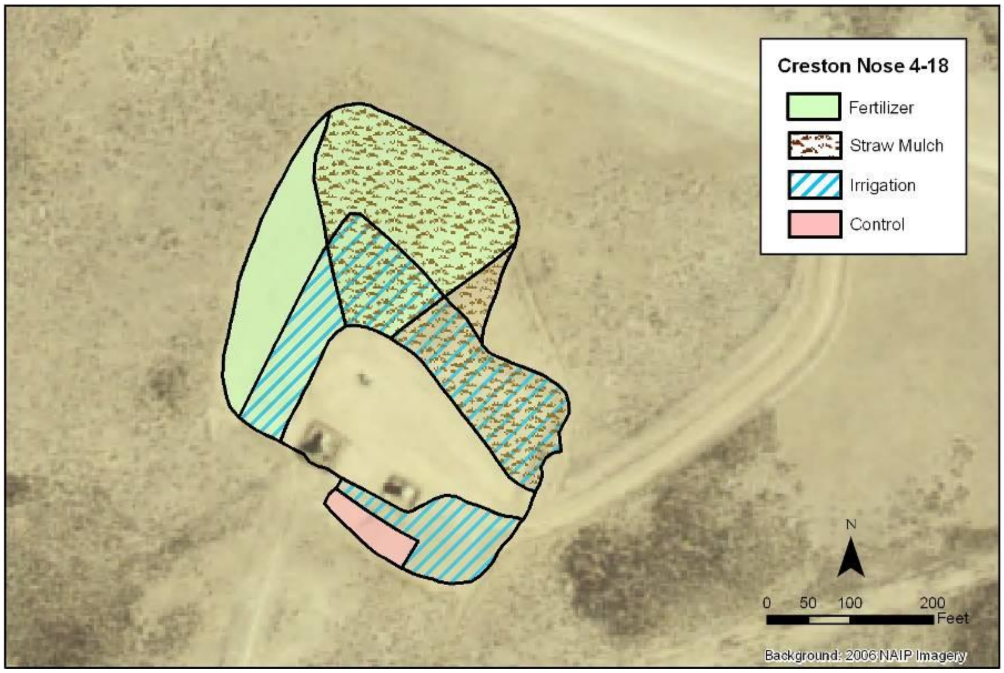

Figure 8. Illustration of reclamation treatments implemented on a 1.09 ha area at Creston Nose 4-18.

At Creston Nose 4-18, straw mulch slightly increased grass density when combined with irrigation. However, grass density was the same or decreased when straw mulch was used without irrigation (Fig. 9). Straw mulch may result in increased grass density with irrigation by slowing water loss from the seedbed as it shades the soil surface, and decreases wind desiccation. Straw mulch may be beneficial on sites with poor soil characteristics, but is not necessary on sites with low salinity and sodicity.

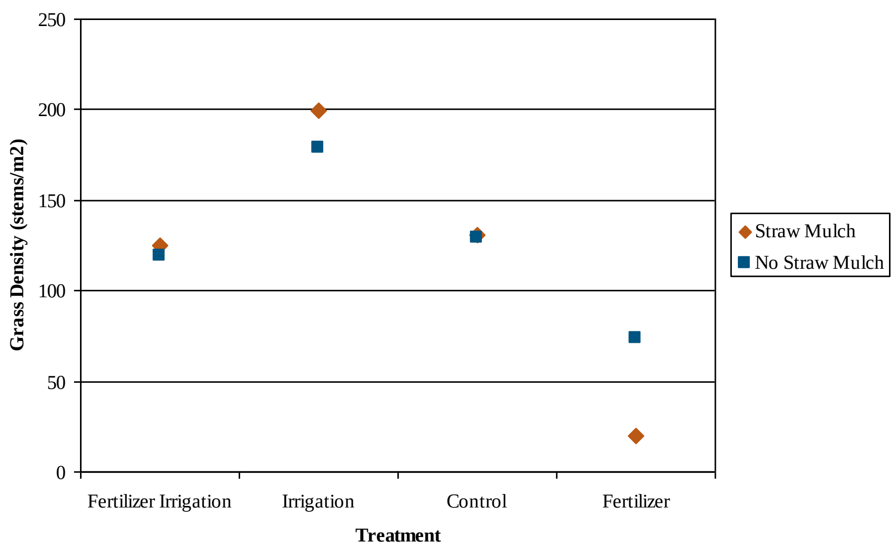

Figure 9. Effect of straw mulch on grass density at well pad Creston Nose 4-18.

Creston Nose 15-18

Creston Nose 15-18 had one treatment of irrigation, straw mulch and fertilizer. This treatment resulted in grass density of nearly four times that present in the adjacent undisturbed rangeland (Fig. 10 and 11).

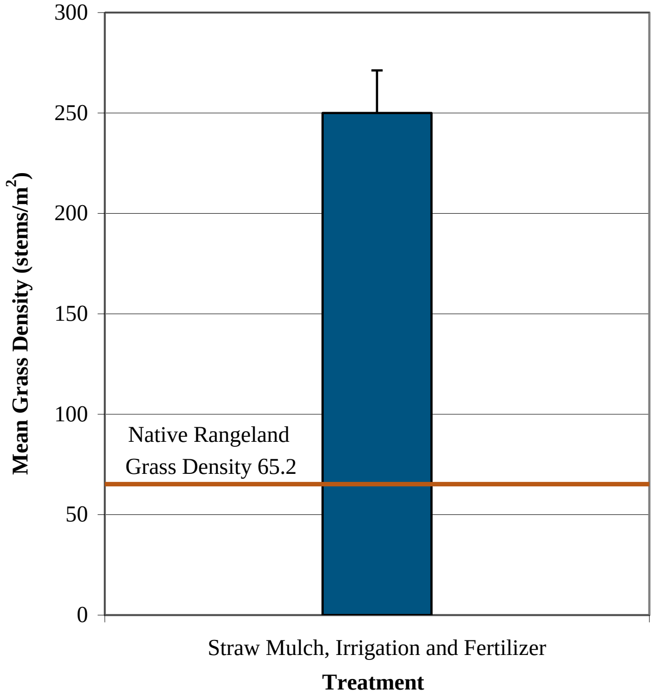

Figure 10. Grass density at Creston Nose 15-18, error bar is shown.

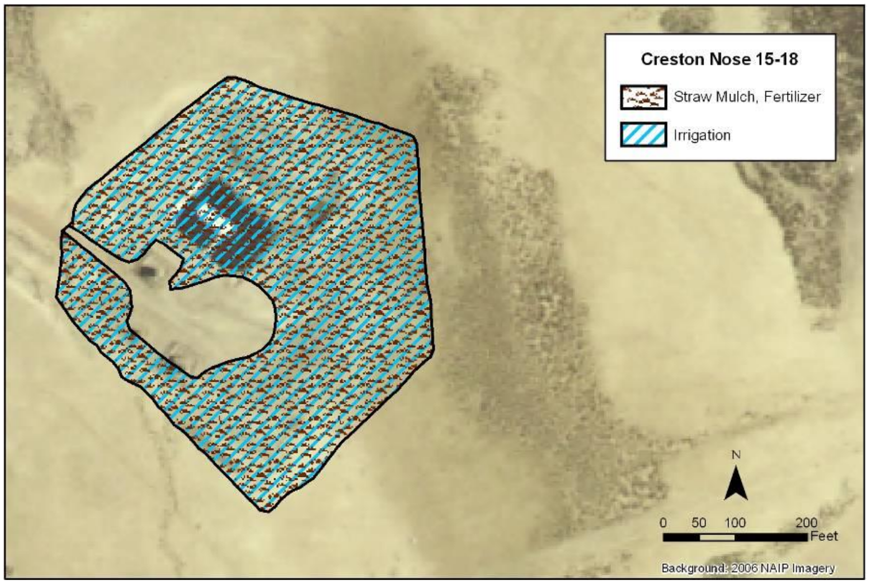

Figure 11. Illustration of reclamation treatments implemented on a 1.73 ha area located at Creston Nose 15-18.

East Echo Springs 2-33

Grass density was greater than the adjacent rangeland density for both Rocky Mountain Oilfield Seeder imprinting treatments and the pitting, irrigation and fertilizer treatment (Fig. 12 and 13). The pitting with fertilizer treatment produced a considerable grass density of 68.4 stems/m^2. Both irrigation treatments had significantly greater grass densities than non-irrigated treatments. Imprinting treatments produced greater grass density than pitting treatments, partially due to the steeper slopes in pitted areas. Pitting creates larger depressions and results in more depression area per acre than imprinting, allowing pits to retain more water than imprints. However, the pits were sometimes deeper than the topsoil found on drill pads. On these sites, pits likely cut through the topsoil exposing graded fill in the bottom of the pit. Graded fill generally has chemical and physical characteristics inferior to topsoil and may impair seed germination and seedling development. The imprinting treatment creates depressions within the topsoil, therefore seed germination and seedling development is within the favorable chemical and physical characteristics of the topsoil.

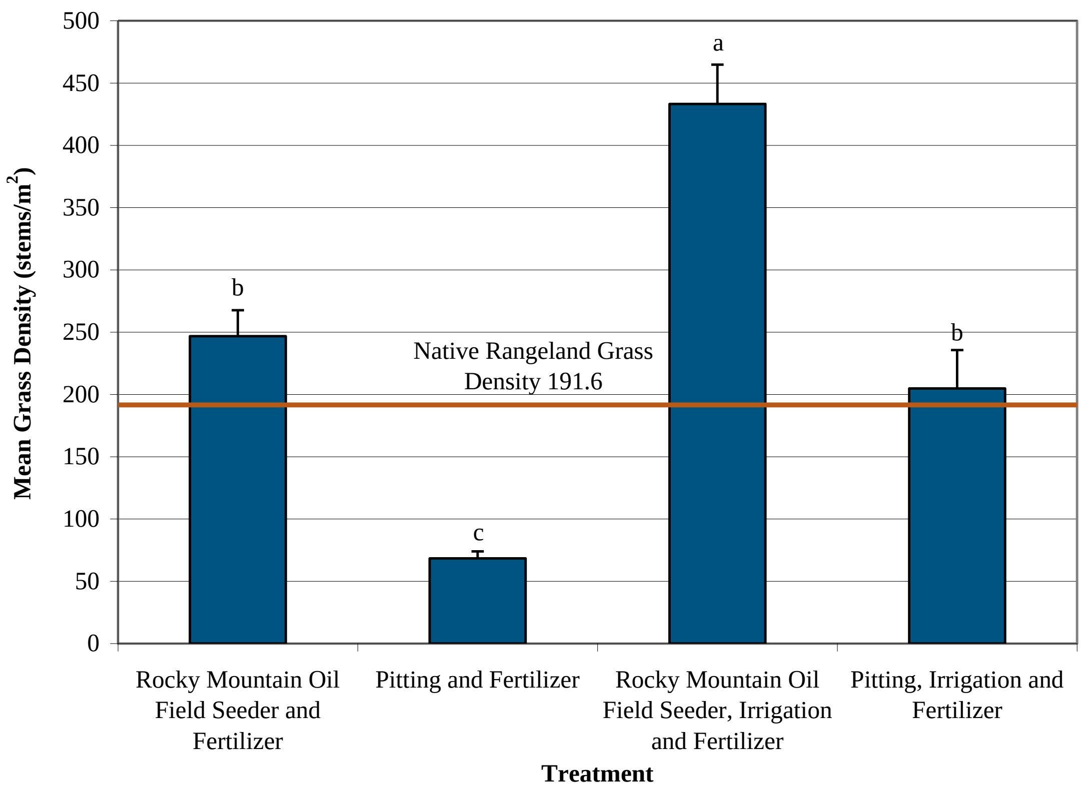

Figure 12. Grass density at East Echo Springs 2-33. Mean values capped by a different letter are significantly different ($p<0.05$), and error bars are shown.

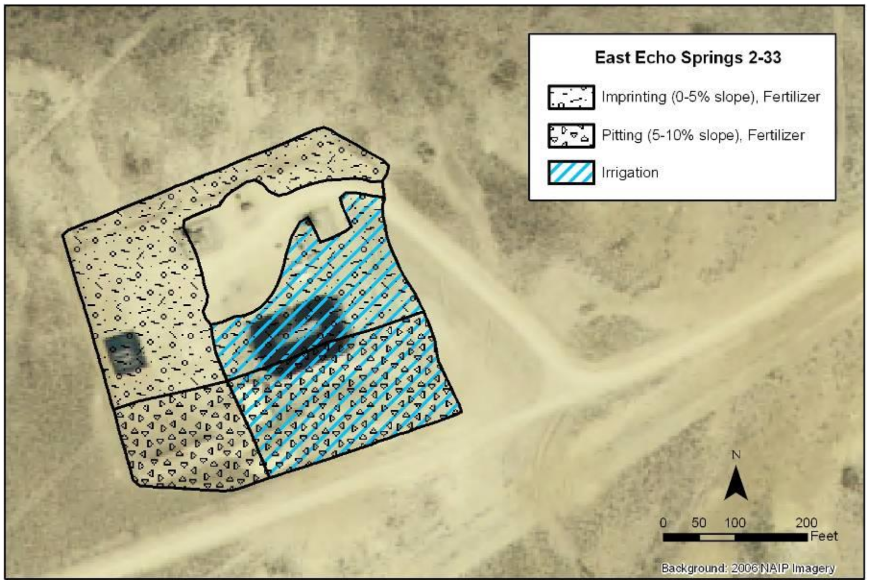

Figure 13. Illustration of reclamation treatments implemented on a 1.51 ha area at East Echo Springs 2-33.

East Echo Springs 15-33

The pitting treatment and the straw mulch irrigation treatment resulted in greater grass density than the native rangeland (Fig. 14 and 15). Irrigation also significantly increased grass density in the straw mulch treatment area. Grass density for pitting without irrigation was statistically greater than the irrigated area. This was the only location in the project area where irrigation did not increase grass density.

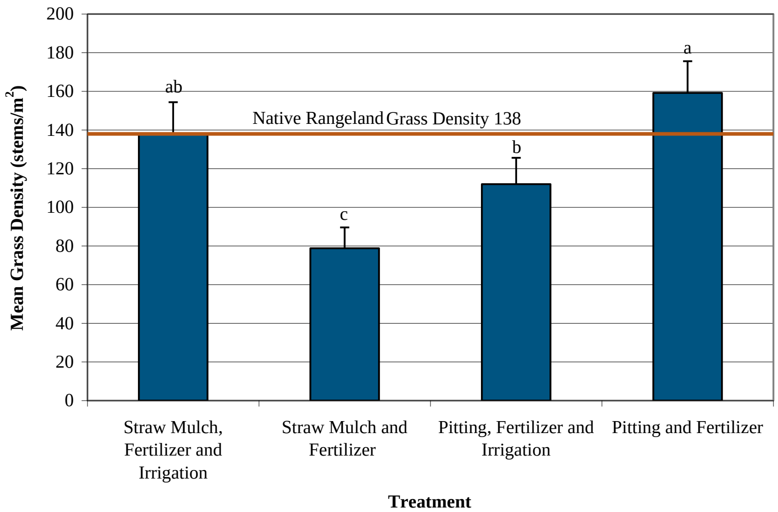

Figure 14. Grass density at East Echo Springs 15-33. Mean values capped by a different letter are significantly different ($p<0.05$), and error bars are shown.

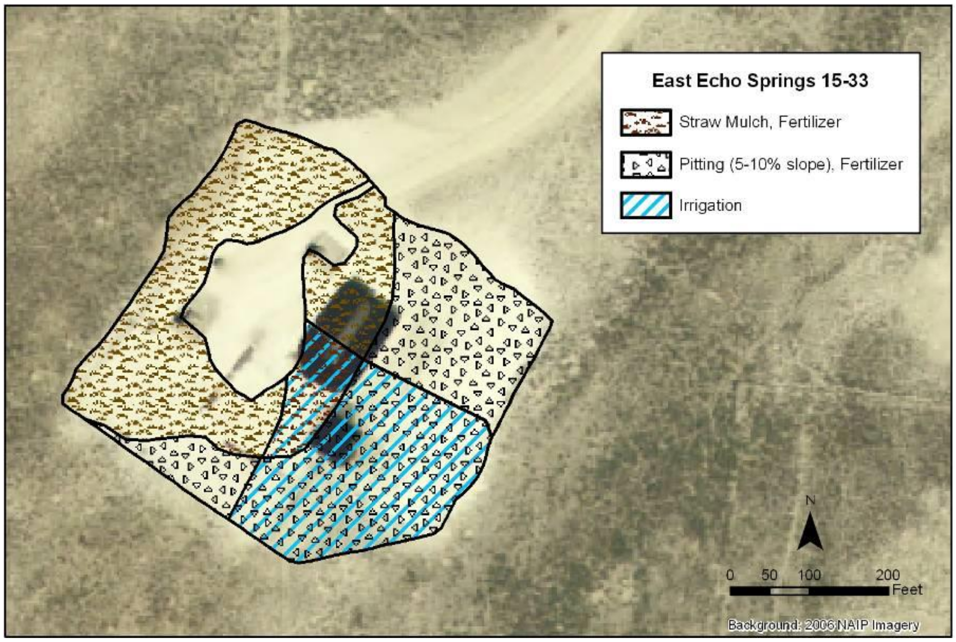

Figure 15. Illustration of reclamation treatments implemented on a 1.68 ha area at East Echo Springs 15-33.

Irrigation

On average over the six study sites, irrigation increased grass density 92 %, with the greatest increase at Barrel Springs Unit 14-8 (not shown), which increased 281 % in irrigated treatment areas (Fig. 16). Precipitation is very low in the semiarid environment of the project area, and water availability is often a limiting factor to plant growth.

Summary

Plant establishment irrigation increased grass density 92 % compared to areas not irrigated. Seeding concurrent with soil imprinting led to excellent grass establishment on areas with zero to 10 % slopes. Pitting was less effective than imprinting primarily due to larger pits that cut through topsoil, incorporating lower quality subsoil in the seedbed. The benefit of nitrogen-phosphorus fertilizer was high when soils were saline, sodic, or sandy, but minimal when soil chemical and physical characteristics were favorable for plant growth. The application of gypsum or sulfur, in conjunction with incorporation of woodchips or chopped straw in soils led to excellent grass establishment on sodic soils. These areas historically had little or no grass establishment using conventional reclamation practices.

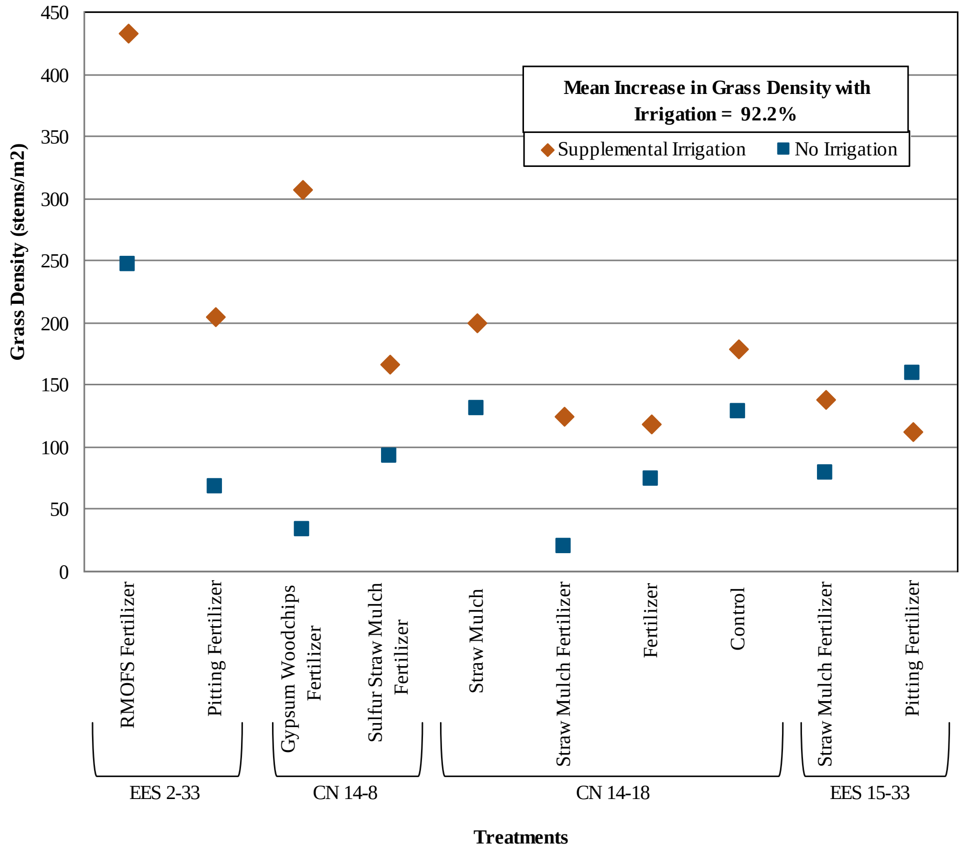

Figure 16. Comparison of grass density with supplemental irrigation and without irrigation as a function of many treatments at four different well pads.

The project showed that at sites with soils not affected by high levels of salt or sodium, tillage and seeding alone yielded excellent plant establishment results. At sites with severe sodic conditions, additional reclamation treatments were necessary to establish grass. Approximately 20 % of sites in the project area have soils with high levels of sodium. These sites require mitigation of the sodic soils using gypsum or sulfur, in conjunction with wood chips or chopped straw incorporation, irrigation for plant germination and emergence, and fertilizer to address nutrient deficiencies.

At all six test locations, one or more reclamation technique resulted in plant growth beyond expectations. At least one reclamation treatment on each site produced grass density of at least 80 % of that found in the adjacent native range. These reclamation techniques can significantly decrease the time required to reach plant re-vegetation requirements.

Acknowledgements

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Literature Cited

BLM. 2000. Record of Decision Environmental Impact Statement Continental Divide/ Wamsutter II Natural Gas Project, Sweetwater and Carbon Counties, Wyoming. Bureau of Land Management, Rawlins and Rock Springs Field Offices.

Bohn, H.L., B.L. McNeal, and G.A. O'Connor. 1985. Soil Chemistry. John Wiley and Sons, New York, NY.

Dollhopf, D.J., I.B. Jensen, and R.L. Hodder. 1977. Effects of surface configuration in water pollution control on semiarid mined lands. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio. Research Report 114.

Koss, W.L., J.R. Owenby, P.M. Steurer, and D.S. Ezell. 1988. Climatography of the U.S. No. 20: Supplement No. 1. Freeze/Frost Data. National Climatic Data Center. Asheville, NC.

Levy, G.J., Shainberg, I. and Miller, W.P. 1998. Physical Properties of Sodic Soils. In: Sumner, M.E. and Naidu, R. 1998. Sodic soils: Distribution, properties, management and environmental consequences. Oxford University Press, Inc. New York, NY.

SigmaStat. 2006. For Windows version 3.5, Build 3.5.0.54, Systat Software, Inc.

US Salinity Laboratory. 1954. Diagnosis and Improvement or Saline and Alkali Soils. Richards, L.A. (ed). Agriculture Handbook No. 60. United States Department of Agriculture.