RESPONSE OF GRASS SPECIES TO SOIL SALT CONTENT AND SOIL MOISTURE ON LANDS DEVELOPED FOR COALBED METHANE[1]

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Abstract: In areas where land is disturbed to extract energy resources such as coalbed methane, improper soil management may result in soils impaired by elevated salinity. The objectives of this study were to evaluate the emergence and growth of three native grass species (*Pseudorogeneria spicata, Hesperostipa comata*, and *Pascopyrum smithii*) as a function of soil salt content and matric potential. The study consisted of nine treatments, combining three soil salinity levels (0.80, 5.0 and 11.0 dS/m) and three matric potential ranges (-0.1 to -1.0, -1.0 to -7.0, and less than -7.0 bars). Seedling emergence, plant height, aboveground biomass, and belowground biomass were significantly decreased by increasing soil salinity and decreasing soil moisture. This resulted in large reductions in growth when soil moisture was decreased within a salinity treatment. Emergence for plants grown in elevated salinity increased as much as 26.7 % when moisture was high. At low soil moisture, elevated salinity resulted in emergence losses as high as 88.3 %. Losses in aboveground biomass ranged from 23.0 to 97.9 % at moderate salinity and 27.3 to 98.5% at high salinity. Results indicate that the impacts of elevated soil salinity are highly influenced by soil moisture.

Additional Key Words: land reclamation, soil salinity, soil matric potential, revegetation, and soil salvage

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Introduction

When landscapes are disturbed to extract resources such as coal or natural gas, it is imperative that soil resources are handled responsibly. Proper soil management, including removal and stockpiling of topsoil and subsoil resources prior to disturbance is necessary to achieve reclamation goals and support subsequent land uses.

Development of the energy resource coalbed methane (CBM) is rapidly increasing, generating notable controversy in the Northern Great Plains. A common method of CBM drill pad construction involves a cut-and-fill technique. During this type of construction, a cut is made and a mixture of topsoil, subsoil, and geologic stratum is pushed out onto the landscape, burying the soil resource and creating a level area for the well. Without initial soil testing and the design of a plan for topsoil salvage, valuable soil resources may be compromised due to mixing with underlying geologic material. This mixed resource may possess properties making it unsuitable for plant growth. Of interest in this study is soil salinity, which may become elevated when upper portions of the soil profile with a low salt content are mixed with underlying materials having high salt content.

Plant Responses to Soil Salinity

Generally, soil profile salt content increases with depth, with salts leaching downward from the upper horizons of most soils (Troeh and Thompson, 1993). Presence of excess salts in the root zone is a concern due to detrimental effects on plant growth via both osmotic and toxic effects. Excess salts in soil reduce the amount of water available to plants by decreasing the osmotic potential (ψ_O) of the soil (Kramer 1983). This negatively impacts overall plant growth, although root growth is normally less affected than shoot growth, resulting in increased root:shoot ratios in many salt affected plants (Mass and Hoffman 1977; Munns and Termaat 1986; Ramoliya and Pandey 2003).

In addition to its osmotic effects, soil salinity may negatively impact plants due to toxicity of the salts themselves. Prolonged transpiration by plants growing in saline soils causes salts to build up in the leaves (Munns and Termaat 1986). Salt accumulation in cytoplasm interferes with metabolism, causes loss of turgor, and results in excessive water loss and possible plant death. In addition to toxic effects, Bernstein et al. (1974) reported that nutritional deficiencies may arise due to the predominance of a certain ion, or competition among ions.

Studying Plant Salt Tolerance

Soils are often considered saline when the electrical conductivity of the soil saturated paste extract exceeds 4 dS/m (Sobek et al., 2000). Agricultural and reclamation-focused research has aimed to identify how ranges of soil salinity impact plant growth. It is believed that most plants will tolerate salinity up to a specific threshold level, at which yields decrease in an approximate linear fashion as salinity increases in the soil water (Maas, 1986).

Scientific literature includes many investigations of the salinity tolerance of plants, including many grass species (Maas and Hoffman 1977, Maas 1986, Ippolito 1992, Al-Wardy 1995, and Mer et al. 2000). As a result, many plant species have been assigned specified threshold salinity values. However, it seems that the delegation of an absolute threshold value is not representative of the dynamic relationship between soil salinity and plant growth. Plant type, soil, water, and climatic factors interact to influence the salt tolerance of a plant species (Franklin et al., 1987; Maas and Hoffman, 1977).

Effect of Soil Moisture on Salt Stress

Salt tolerance studies often employ frequent irrigation, sand cultures, or hydroponic solutions which eliminate possible water stress, focusing solely on osmotic potential. According to Ulrey et al. (1998), such conditions are actually recommended for any study of plant/salinity relationships to ensure that salinity effects on plant growth are not confounded by matric stresses. However, if soil salinity does indeed limit certain nutrients, and if its effects might be exacerbated or diminished by soil moisture, it seems that an experiment conducted under such recommended conditions may be of limited value.

The role of soil water content is of importance because it is highly correlated with soil salinity. As water is removed from the soil the resulting soil solution salt content becomes more concentrated (Killham, 1994). As a result, the total moisture stress exerted on a plant's root system becomes a function of both soil salt content and moisture stress. These forces combine to reduce the free energy of soil water, making it less available for plant uptake (Troeh and Thompson 1993). Since plants tend to respond primarily to the sum of the osmotic potential (ψ_O) of the soil solution and the soil matric potential (ψ_M), a simplified equation for total soil water potential can be written as:

$$\psi_T = \psi_O + \psi_M \tag{1}$$

with total soil water potential reflecting the additive effects of both water stress and salinity stress (Maas and Hoffman 1977).

Investigations by Wadleigh and Ayers (1945), Goldberg and Schmueli (1970), and Adiku et al. (2001) studied growth of various plants as a function of both soil salt concentration and moisture tension. Their data indicate that the level of plant response to a given salt level is modified by the extent of soil moisture depletion, with additional irrigation resulting in increased plant tolerance to salinity. These studies highlight the role of soil water in determining the magnitude of soil salinity impact on plant growth. Soils that are labeled as slightly saline may produce considerable negative impact on plants grown in water stressed environments. Conversely, the effect of a highly saline soil may be diluted in the presence of abundant soil water, lessening the negative impact on plant communities. Therefore, it is of interest in this study to observe plant responses to soil salinity under varied soil moisture conditions.

Materials and Methods

Soils for the study were obtained from a ranch located east of Sheridan, Wyoming. Soils were collected from two locations: disturbed soils located on a coalbed methane drill pad and undisturbed soil located on the rangeland adjacent to the drill pad. The disturbed soil samples consisted of a mixture of A, B, and C horizons, as well as underlying geologic stratum. Sampling depth was approximately 30 cm. The undisturbed soil samples consisted of A horizon material and were sampled at a depth of approximately 15 cm.

Composite samples were formed for each soil type, oven dried at 105˚C, and disaggregated using a mortar and pestle. Soils that passed through a 2 mm sieve were analyzed for physicochemical characteristics. Physical properties evaluated included coarse fragment percentage and particle size distribution (textural class). Chemical properties evaluated included electrical conductivity (EC_e), pH, sodium adsorption ratio (SAR), percent organic matter, and nutrient (N, P, K) content. The undisturbed soil had an EC_e of 0.85 dS/m, pH of 7.67, SAR of

0.10, 5.6 percent organic matter, and 5.2 percent coarse fragments. The textural class of the undisturbed soil was clay, with N, P, and K contents of 9.0, 3.0 and 590 mg/kg, respectively. The disturbed soil sample had an EC_e of 0.80 dS/m, pH of 7.97, SAR of 1.4, 1.4 percent organic matter, and 6.6 percent coarse fragments. The textural class of the disturbed soil was clay loam, with N, P, and K contents of 5.0, 9.0 and 130 mg/kg, respectively.

For this study, the rangeland grass species *Pseudoroegneria spicata* (bluebunch wheatgrass), *Hesperostipa comata* (needle-and-thread), and *Pascopyrum smithii* (Western wheatgrass) were grown in soils with low, medium, and high salinities of approximately 0.80, 5.0 and 11.0 dS/m, respectively. Salinity levels were based on the electrical conductivity of a soil saturated paste extract. The "disturbed soil" gathered from the coalbed methane drill pad was used for this study. The original salinity of this soil was approximately 0.80 dS/m, representing the lowest level of soil salinity. To achieve "medium" and "high" levels of salinity, soils were artificially salinized using a solution of $CaCl_2$ and deionized water. Soil salinities of approximately 0.80, 5.0 and 11.0 dS/m were achieved by the addition of 0.0, 10.0 and 25.0 percent (by weight) $CaCl_2$, respectively. Soils were then oven dried overnight at 105˚C and disaggregated again.

In addition to three salinity treatments, grasses in this study were subjected to three soil moisture treatments. Treatments were as follows:

1) High soil moisture, corresponding to a matric potential range of -0.1 to -1.0 bar,

2) Moderate soil moisture, corresponding to a matric potential range of -1.0 to -7.0 bars,

3) Low soil moisture, corresponding to a matric potential range of -7.0 bars and lower.

At a given matric potential, the corresponding water content can be determined for any soil by using a ceramic pressure plate apparatus. A sample of the soil collected at the disturbed CBM site was sent to the Montana State University Soil Testing Lab for analysis using a pressure plate apparatus. Gravimetric water content corresponding to the greatest matric potential listed for each soil moisture treatment described above were as follows: 1) 21.7 percent, 2) 13.0 percent, and 3) 8.6 percent.

Plant growth tests took place in the Plant Growth Center at Montana State University. Three salinity treatments and three soil moisture treatments were combined for a total of nine experimental treatments. Each treatment was replicated eight times, resulting in 72 experimental units per grass species.

Treatments were randomly assigned to 72 labeled pots, 15 cm in diameter by 18 cm tall. Pots were arranged on greenhouse benches in a completely random design, and were re-randomized using a random number generator every two weeks throughout the duration of the study. Empty pots were weighed and filled with soil corresponding to the specific salinity treatment. Pots were once again weighed and the mass of the pot subtracted to determine the soil mass. The mass of soil in each pot was then multiplied by the gravimetric water content corresponding to the assigned matric potential treatment. For example, a pot containing 3,000 grams of soil would require 3000g*(0.13), or 390 grams of water to reach the gravimetric water content corresponding to a matric potential of -1.0 bars. The mass of water required for each pot was calculated and added to the mass of the pot and soil to achieve a total target weight. Each pot was then placed on a scale and Plant Growth Center tap water was added until the pot reached its target weight.

After bringing each pot to its target weight via water addition, sixteen seeds were sown to a depth of one centimeter. For the following three weeks, pots were weighed daily, adding enough water to bring them to their target weights. Daily watering was necessary at this point to keep each pot in its moisture range and prevent it from losing enough water to put it into the moisture content range of another treatment. During this three week period seedling emergence was recorded for each pot.

Following the three week emergence period, emergence numbers were recorded and pots were thinned to four plants each. During weeks four through twelve a one centimeter layer of perlite was added to the surface of each pot. This material reduced surface evaporation, making it possible to water pots every three days during the growth period. At the end of week twelve, root and shoot biomass was harvested and oven-dried (70˚C) to measure aboveground biomass and belowground biomass.

<u>Statistical Analysis</u>

Plant characteristics were statistically analyzed using SigmaStat statistical software (SigmaStat 1997). Normally distributed data were analyzed using a one-way ANOVA to determine if treatment means were significantly different ($p < 0.05$). If treatment means were found to be significantly different they were separated using the Tukey test. Data that were not normally distributed were analyzed using the non-parametric one-way Kruskal-Wallis ANOVA on ranks to determine whether significant differences were present ($p < 0.05$). Treatment means found to be significantly different were separated using the Tukey test on ranks.

Results and Discussion

Overall trends show seedling emergence decreasing significantly with both increasing soil salinity and decreasing matric potential. In soils with the lowest salinity, mean emergence was similar for both *Pseudoroegneria* and *Pascopyrum* regardless of soil moisture, and significantly lower for *Hesperostipa* plants grown in the lowest soil moisture. In soils with moderate and high salinity, emergence decreased significantly as soil moisture decreased. When soil moisture was high or moderate, emergence was statistically similar for all three species, regardless of soil salinity. In fact, for all three species, highest emergence occurred in soils with elevated salinity and high moisture. Since seeds were placed near the soil surface, it is possible that water applied at the surface leached salts away from the seed. Increased water availability at the soil surface may have also diluted the effect of salts by reducing osmotic effects and ensuring that sufficient moisture was present to stimulate seed germination and emergence. When soil moisture was low there was a significant decrease in emergence in both *Pseudoroegneria* and *Pascopyrum* with increased salinity, indicating that there was not sufficient moisture present to dilute the negative effects of soil salts.

For the three species studied, seedling emergence was analyzed for percent change as a function of soil salinity and matric potential. Low soil salinity and high soil moisture were considered optimal conditions with mean emergence under these conditions and assigned zero percent change. Mean emergence under the other eight treatments was compared to this "optimal" mean emergence to produce a percent change (Table 1). As soil salinity increased, the grass species responded by either increasing or decreasing seedling emergence, depending on soil moisture. Plants grown in high soil moisture increased emergence by as much as 26.7 percent as soil salinity increased. At moderate soil moisture, emergence decreased by as much as 36.3 percent as salinity increased to 11.0 dS/m. Decreases in emergence were most dramatic under low soil moisture, with high salinity producing losses in emergence as high as 88.3 percent. Of the three species, *Pascopyrum* emergence appeared to be least affected by increasing salinity, with losses of 42.1 percent when salinity was high and soil moisture was low. Both *Pseudoroegneria* and *Hesperostipa* had seedling emergence losses in excess of 80 percent under similar conditions. These results suggest that investigators reporting impacts of salinity on seedling emergence provide biased results when the water content of the root zone is unknown. Similar bias would be introduced during a study of seedling emergence as a function of soil salinity if the moisture regime was not closely regulated or considered in the methodology.

Table 1. Percent change in seedling emergence as a function of soil salinity and matric potential.

	Matric Potential (-bars)		
EC (dS/m)	0.1	1.0	7.0
Pseudoroegneria			
0.80	0[/1]	-5.3	-26.3
5.0	-17.6	-15.8	-59.7
11.0	+7.0	-26.3	-80.7
Hesperostipa			
0.80	0	-20.0	-61.7
5.0	+26.7	-43.3	-78.3
11.0	+8.3	-36.6	-88.3
Pascopyrum			
0.80	0	-5.3	-13.7
5.0	-3.2	-14.7	-26.3
11.0	+6.3	-25.3	-42.1

[/1] Low salinity (0.80 dS/m) and high soil moisture (-0.1 bar matric potential) are considered 'optimal conditions'. Emergence under these conditions is assigned zero percent change.

Aboveground Biomass

For all three species highest aboveground biomass was produced in soils with low salinity and high soil moisture. Overall trends show seedling emergence decreasing significantly ($p<0.05$) with increasing soil salinity and decreasing matric potential. While increasing soil salinity produced significant reductions in aboveground biomass, reductions produced by declining soil moisture were much more dramatic. For example, as soil salinity increased, aboveground biomass decreased by four orders of magnitude for both *Pseudoroegneria* and *Pascopyrum*. However, as soil moisture decreased, reductions in aboveground biomass reached over 20 orders of magnitude for *Pseudoroegneria* and over 40 orders of magnitude for *Pascopyrum*.

Aboveground biomass was analyzed for percent change as a function of soil salinity and matric potential (Table 2). "Optimal" conditions resulted in the highest aboveground biomass for *Pseudoroegneria*, *Hesperostipa*, and *Pascopyrum*. By increasing salinity and decreasing soil moisture, losses in aboveground biomass were produced. Plants grown in high soil moisture decreased aboveground biomass by as much as 55.3 percent as soil salinity increased to 11.0 dS/m. At moderate soil moisture, increasing salinity produced losses in aboveground biomass as high as 95.0 percent. Large losses were also observed at low soil moisture, with aboveground biomass decreasing by as much as 98.5 percent as salinity increased. At moderate and low soil moisture, the three species responded with large reductions in aboveground biomass, regardless of soil salinity.

Table 2. Percent change in aboveground biomass as a function of soil salinity and matric potential.

	Matric Potential (-bars)		
EC (dS/m)	0.1	1.0	7.0
Pseudoroegneria			
0.80	0[/1]	-72.9	-88.6
5.0	-30.7	-90.7	-96.7
11.0	-52.4	-93.7	-97.0
Hesperostipa			
0.80	0	-84.1	-94.1
5.0	-49.4	-91.8	-94.7
11.0	-55.3	-92.4	-94.3
Pascopyrum			
0.80	0	-80.0	-96.4
5.0	-23.0	-87.5	-97.9
11.0	-27.3	-95.0	-98.5

[/1] Low salinity (0.80 dS/m) and high soil moisture (-0.1 bar matric potential) are considered 'optimal conditions'. Aboveground biomass produced under these conditions is assigned zero percent change.

Belowground Biomass

Results for aboveground biomass are similar to those seen for belowground biomass, with both increasing salinity and decreasing soil moisture reducing plant growth. This is also likely due the toxic and osmotic effects produced by elevated salt content in the soil. The presence of abundant soil moisture allows plants to overcome such negative effects, increasing uptake of both water and nutrients, thus producing more robust grasses. This may explain why large increases in grass growth were often the result of increased soil moisture, regardless of soil salinity.

Root Mass Ratio

If elevated soil salinity creates a water stressed environment, plants may allocate more resources to root production with the objective of reaching soil moisture elsewhere in the profile. The result of this resource allocation is increased root mass ratio, or dry root mass divided by total dry plant biomass (Maas 1977, Munns and Termaat 1986, and Ramoliya and Pandey 2003).

However, this trend was not observed in data collected during this study. Root mass ratios were statistically similar for both *Hesperostipa* and *Pascopyrum*, regardless of soil salinity.

A significant relationship was observed between soil salinity and root mass ratio in *Pseudoroegneria*, with increasing salinity producing significant decreases in root mass ratios, which is opposite of observations found in scientific literature. Perhaps the 18 cm depth of pots used in the study limited the capacity for maximized root production, resulting in smaller root mass ratios. It is also likely that fine and very fine roots were broken during separation from the hard clay soils, and thus were not recovered or weighed. A study conducted in a deeper or different growth medium could likely provide more realistic insight into the relationship between soil salinity and root mass ratio.

Summary

Results indicate that both stunted and healthy grasses can be produced in soils of similar salinity through the manipulation of soil moisture. This suggests that salt tolerance studies involving copious soil moisture will not likely reflect conditions encountered in the arid environments that are most affected by elevated soil salinity. Therefore, it is evident that investigators studying plant responses to soil salinity must consider the importance of soil moisture and discuss influences of soil moisture on study results.

In addition to research implications, the results of this study may also be applied to reclamation strategies for disturbed landscapes. Both emergence and aboveground biomass are especially important variables to consider during reclamation of rangelands, as maximum forage production is desired. Often, reclaimed lands are irrigated to promote seedling emergence. The addition of supplemental water, particularly during seedling emergence, may allow grasses to initially overcome the negative effects of elevated soil salinity and promote successful establishment. However, once supplemental irrigation is removed, matric stress introduced by reduced soil moisture combined with elevated salinity may severely stress young plants and compromise the reclamation effort. This is of particular concern when irrigating with water containing elevated dissolved salts. Saline irrigation waters may introduce additional salts into the soil whose negative impacts on grasses may not be immediately recognizable due to an abundance of water available at the soil surface. Considering the results in this study, irrigation should be carefully addressed when remediating disturbed areas affected by high soil salinity.

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