RESPONSE OF GRASS SPECIES TO SOIL SALT CONTENT AND COVERSOIL DEPTH ON LANDS DEVELOPED FOR COALBED METHANE

by

Melissa Deanne Mitchem

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Land Rehabilitation

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 2005

© COPYRIGHT

by

Melissa Deanne Mitchem

2005

All Rights Reserved

APPROVAL

of a thesis submitted by

Melissa Deanne Mitchem

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dr. Douglas J. Dollhopf

Approved for the Department of Land Resources and Environmental Science

Dr. Jon Wraith

Approved for the College of Graduate Studies

Dr. Bruce McLeod

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University - Bozeman, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Melissa Mitchem

ACKNOWLEDGMENTS

Many thanks to Dr. Douglas Dollhopf, for all of his guidance and assistance throughout my graduate education. I would also like to thank Dr. Jim Bauder for support and guidance as a committee member, and the Department of Energy (DOE) for research funding. Thanks also go to Dr. Bret Olson for serving on my committee and providing guidance and editorial advise. Additionally, I would like to recognize the Plant Growth Center staff for their help, the Reclamation Research Unit for the use of their laboratory facilities, as well as the Brannamen family and Jay Gilbertz for access permission and assistance in collecting my soil samples. Thanks also go to family and friends for support and motivation throughout my academic career.

TABLE OF CONTENTS

Page

LIST OF TABLES viii

LIST OF FIGURES xii

ABSTRACT xvi

1. INTRODUCTION 1

2. LITERATURE REVIEW 6

Plant Responses to Soil Salinity 6
Salinity and Soil Water Potential 8
Studies of Plant Salt Tolerance 9
Effect of Soil Moisture on Salt Stress 12
Native Soils and Minesoils 16
Soil Replacement 19

3. MATERIALS AND METHODS 21

Study Species 21
Study Soils 21
Study No. 1: Response of Grass Species to Soil Salinity and Soil Matric Potential 24
Salinity Treatments 24
Matric Potential Treatments 25
Experimental Design 26
Statistical Analysis 29
Study No. 2: Response of Grass Species to Coversoil Depth Over a Saline Substrate 30
Experimental Design 30
Soil Moisture 30
Soil Nutrient Content 31
Greenhouse Methodology 32
Statistical Analysis 35

4. RESULTS AND DISCUSSION 36

TABLE OF CONTENTS-Continued

Study No. 1: Response of Grass Species to Soil Salinity and Soil Matric Potential 36
ANOVA Results For Emergence 36
Pseudorogeneria 36
Hesperostipa 36
Pascopyrum 39
Emergence Correlation Results 41
ANOVA Results For Plant Height 42
Pseudorogeneria 42
Hesperostipa 43
Pascopyrum 46
Plant Height Correlation Results 48
ANOVA Results For Aboveground Biomass 49
Pseudorogeneria 49
Hesperostipa 52
Pascopyrum 54
Aboveground Biomass Correlation Results 57
ANOVA Results For Belowground Biomass 59
Pseudorogeneria 59
Hesperostipa 60
Pascopyrum 63
Belowground Biomass Correlation Results 65
Impacts of Salinity and Soil Moisture on Grass Species 67
Changes in Seedling Emergence 67
Changes in Aboveground Biomass 70
Questioning Threshold Salinity Levels 72
Study No. 2: Response of Grass Species to Coversoil Depth Over a Saline Substrate 73
Emergence 73
Plant Height 74
Aboveground Biomass 75
Belowground Biomass 77

5. SUMMARY 80
Study No. 1: Response of Grass Species to Soil Salinity and Soil Matric Potential 80
Study No. 2: Response of Grass Species to Coversoil Depth Over a Saline Substrate 81

TABLE OF CONTENTS-Continued

LITERATURE CITED 84

APPENDICES 88

APPENDIX A- Study No. 1: Data and Statistical Output 89
APPENDIX B- Study No. 2: Data and Statistical Output 186

LIST OF TABLES

Table Page

1. Salinity ranges affecting plant growth (Sandoval et al., 1973) 10

2. Salt tolerance threshold values for plant species (Adapted from Franklin et al., 1987) 11

3. Soil variables and analytical techniques used 22

4. Physiochemical characteristics analyzed for disturbed and undisturbed soil samples. 23

5. Percentages of $CaCl_2$ added to soil samples to attain target soil salinities 24

6. Gravimetric water content corresponding to soil moisture treatments 26

7. Experimental Treatments 27

8. Gravimetric water content of several soils at -1.0 bar matric potential 31

9. Results of soil nutrient analysis along with recommended nutrient levels. 32

10. Results of Spearman Rank Order Correlation comparing seedling emergence to soil salinity and matric potential 42

11. Results of Spearman Rank Order Correlation comparing plant height to soil salinity and matric potential 49

12. Results of Spearman Rank Order Correlation comparing aboveground biomass to soil salinity and matric potential 57

13. Results of Spearman Rank Order Correlation comparing belowground biomass to soil salinity and matric potential 66

14. Percent change in seedling emergence as a function of soil salinity and matric potential 68

LIST OF TABLES-Continued

15. Percent change in aboveground biomass as a function of soil salinity and matric potential 70

16. Emergence data (% per pot) for *Pseudorogeneria* 90

17. Means and standard error for *Pseudorogeneria* emergence 90

18. Emergence data (% per pot) for *Hesperostipa* 98

19. Means and standard error for *Hesperostipa* emergence 98

20. Emergence data (% per pot) for *Pascopyrum* 106

21. Means and standard error for *Pascopyrum* emergence 106

22. Plant height (cm) data for *Pseudorogeneria* 114

23. Means and standard error for *Pseudorogeneria* plant height 114

24. Plant height data (cm) for *Hesperostipa* 122

25. Means and standard error for *Hesperostipa* plant height 122

26. Plant height data (cm) for *Pascopyrum* 130

27. Means and standard error for *Pascopyrum* plant height 130

28. Aboveground mass (g/plant) data for *Pseudorogeneria* 138

29. Means and standard error for *Pseudorogeneria* aboveground mass 138

30. Aboveground mass (g/plant) data for *Hesperostipa* 146

31. Means and standard error for *Hesperostipa* aboveground mass 146

32. Aboveground mass (g/plant) data for *Pascopyrum* 154

33. Means and standard error for *Pascopyrum* aboveground mass 154

34. Belowground mass (g/plant) data for *Pseudorogeneria* 162

LIST OF TABLES-Continued

35. Means and standard error for *Pseudorogeneria* belowground mass 162

36. Belowground mass (g/plant) data for *Hesperostipa* 170

37. Means and standard error for *Hesperostipa* belowground mass 170

38. Belowground mass (g/plant) data for *Pascopyrum* 178

39. Means and standard error for *Pascopyrum* belowground mass 178

40. Data for *Pseudorogeneria* percent emergence 187

41. Means and standard error for *Pseudorogeneria* emergence 187

42. Data for *Hesperostipa* percent emergence 189

43. Means and standard error for *Hesperostipa* emergence 189

44. Data for *Pascopyrum* percent emergence 191

45. Means and standard error for *Pascopyrum* emergence 191

46. Data for *Pseudorogeneria* plant height (cm) 193

47. Means and standard error for *Pseudorogeneria* plant height 193

48. Data for *Hesperostipa* plant height (cm) 195

49. Means and standard error for *Hesperostipa* plant height 195

50. Data for *Pascopyrum* plant height (cm) 197

51. Means and standard error for *Pascopyrum* plant height 197

52. Data for *Pseudorogeneria* aboveground mass (g/plant) 199

53. Means and standard error for *Pseudorogeneria* aboveground mass. 199

54. Data for *Hesperostipa* aboveground mass (g/plant). 201

55. Means and standard error for *Hesperostipa* aboveground mass 201

LIST OF TABLES-Continued

56. Data for *Pascopyrum* aboveground mass (g/plant) 203

57. Means and standard error for *Pascopyrum* aboveground mass. 203

58. Data for *Pseudorogeneria* belowground mass (g/plant) 205

59. Means and standard error for *Pseudorogeneria* belowground mass. 205

60. Data for *Hesperostipa* belowground mass (g/plant). 207

61. Means and standard error for *Hesperostipa* belowground mass. 207

62. Data for *Pascopyrum* belowground mass (g/plant) 209

63. Means and standard error for *Pascopyrum* belowground mass 209

LIST OF FIGURES

Figure Page

1. Removal and stockpiling of topsoil and subsoil prior to land disturbance. 1

2. Replacement of stockpiled topsoil and subsoil following land disturbance 2

3. Cut-and-fill technique resulting in burial and mixing of the soil resource 4

4. Total soil moisture stress as a function of soil salt content and percent soil moisture. From Wadleigh and Ayers (1945)... 14

5. Average weight of bean plants as a response of soil salt content and soil moisture tension. From Wadleigh and Ayers (1945). 15

6. Distribution of soluble salts and carbonate for a natural soil, old, and new minesoil. Adapted from Schafer et al., (1980). 18

7. Moisture release curve for disturbed soil material 26

8. Diagram of coversoil depth treatments 33

9. *Pseudorogeneria* emergence (%) grouped according to salinity treatment Treatments within a specific salinity followed by the same letter are not statistically significant ($p>0.05$). Error bars represent standard error.. 37

10. *Pseudorogeneria* emergence (%) grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant ($p>0.05$). Error bars represent standard error. 37

11. *Hesperostipa* emergence (%) grouped according to salinity treatment Treatments within a specific salinity followed by the same letter are not statistically significant ($p>0.05$). Error bars represent standard error.. 38

LIST OF FIGURES-Continued

12. *Hesperostipa* emergence (%) grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error.. 38

13. *Pascopyrum* emergence (%) grouped according to salinity treatment Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error. 40

14. *Pascopyrum* emergence (%) grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error.. 40

15. *Pseudorogeneria* height grouped according to salinity treatment Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error. 44

16. *Pseudorogeneria* height grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error. 44

17. *Hesperostipa* height grouped according to salinity treatment Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error 45

18. *Hesperostipa* height grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error. 45

19. *Pascopyrum* height grouped according to salinity treatment Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error 47

20. *Pascopyrum* height grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error 47

LIST OF FIGURES-Continued

21. *Pseudorogeneria* aboveground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error. . 51

22. *Pseudorogeneria* aboveground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error 51

23. *Hesperostipa* aboveground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error . . 53

24. *Hesperostipa* aboveground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error 53

25. *Pascopyrum* aboveground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error . . . 55

26. *Pascopyrum* aboveground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error 55

27. *Pseudorogeneria* belowground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error. . . 61

28. *Pseudorogeneria* belowground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error. 61

29. *Hesperostipa* belowground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error . . . 62

LIST OF FIGURES-Continued

30. *Hesperostipa* belowground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error.. 62

31. *Pascopyrum* belowground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error . . 64

32. *Pascopyrum* belowground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not statistically significant (p>0.05). Error bars represent standard error.. 64

33. Relative productivity of plants as a function of increasing soil salinity. Generalized by Brady and Weil (1999) from data of Carter (1981). 74

34. Means and standard error for plant height. Treatments followed by the same letter are not significantly different (p> 0.05) 75

35. Means and standard error for aboveground biomass. Treatments followed by the same letter are not significantly different (p> 0.05) 76

36. Means and standard error for belowground biomass. Treatments followed by the same letter are not significantly different (p> 0.05) 78

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 i) soil salt content and matric potential, and ii) coversoil depth overlying a saline substrate.

The first 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. A correlation analysis showed matric potential to be more significantly correlated to seedling emergence and growth than soil salinity. 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. Irrigation will be an important factor in revegetation of saline soils. Also, investigators studying plant growth on saline soils must closely consider the impact of soil moisture on study results.

For the second study, a substrate consisting of a mixture of soil and geologic stratum was salinized to an EC of 11.0 dS/m. Non-saline coversoil was applied on top of the saline substrate at depths of 0, 5, 10, 15, 30 and 45 centimeters. Aboveground and belowground biomasses were significantly greater with increased coversoil depth, with depths of 15, 30 and 45 cm producing similar results. Results suggest that coversoil is necessary to improve plant growth on a saline substrate, but applications of less than 45 cm may be adequate.

1. INTRODUCTION

When landscapes are disturbed to extract resources such as coal or natural gas, it is imperative that the soil resource is handled responsibly. Improper management of soil resources during any land disturbance may result in unnecessary impairment and reduced plant growth capability. Proper soil management is necessary to achieve reclamation goals and support subsequent land uses.

For surface and open pit mining of coal and other minerals, the Surface Mining Control and Reclamation Act (SMCRA) of 1977 (U.S. Congress, 1977) established performance and reclamation standards nationwide, including strict guidelines for the management of soil resources. As outlined in Section 515, topsoil (A horizon) and subsoil (B and C horizons) must be removed and stockpiled separately (Figure 1).

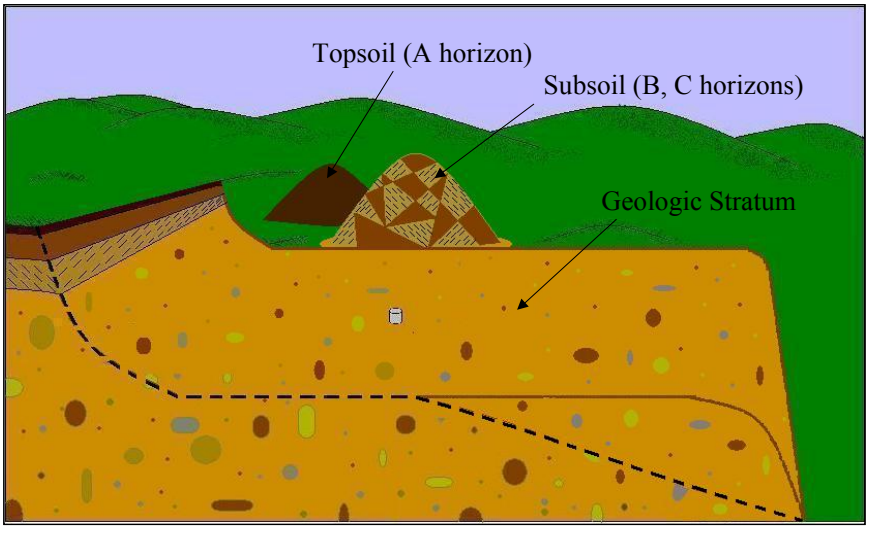


Figure 1. Removal and stockpiling of topsoil and subsoil prior to land disturbance

Following mining, land is returned to its original contour, stockpiled soils are replaced, and the area is seeded (Figure 2). Strict guidelines are in place, ensuring that resource developers are held responsible for reclamation and that surface owners are protected.

Controls and regulations set forth by SMCRA have ensured surface owner protection and environmental reclamation throughout the coal mining industry. However, there is a relatively young resource extraction industry experiencing tremendous growth in the United States and which is not subject to the controls of SMCRA. This industry is coalbed methane (CBM), which extracts the natural gas methane from underground coal seams. A particularly active zone for CBM development lies in the Powder River Basin (PRB), an area straddling Montana and Wyoming. Development of CBM has become controversial in this area, resulting in increased scrutiny over possible environmental effects stemming from extraction of this resource.

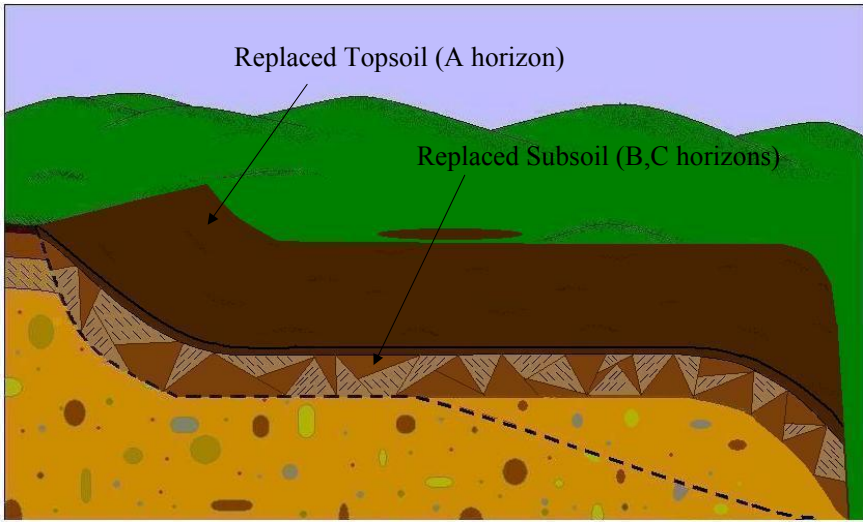


Figure 2. Replacement of stockpiled topsoil and subsoil following land disturbance.

Under the scope of the CBM development plan in the PRB, a significant amount of land has been, and will be disturbed. According to a 2003 Environmental Impact Statement prepared for the Wyoming portion of the PRB, between 50,000 and 80,000 new CBM wells are projected to be drilled by 2010 (USDI, 2003). This EIS predicts the size of drill pad surface disturbance to be as large as 0.28 ha (0.7 acres). Using this estimate with an average projection of 65,000 new wells by 2010, well construction can create approximately 18,400 ha (45,500 acres) of surface disturbance in Wyoming alone. However, this estimate does not include additional land disturbance created by roads, pipelines, compressor stations and water treatment facilities required for CBM production.

During construction of a CBM drill pad, a cut-and-fill technique is often utilized when a well is to be placed on rolling topography. During this type of construction, a dozer is used to make a cut into the surface, pushing a mixture of topsoil, subsoil and geologic stratum out onto the landscape, burying the soil resource (Figure 3). This creates a level area for installation of the well, but may also create a substrate that is unsuitable for vegetation growth. This is one reason many land owners in the Powder River Basin are urging for similar SMCRA-like regulations to be created for the CBM industry, ensuring adequate environmental reclamation and protection of surface owners' land and livelihoods (Swartz, 2004).

In mined areas where proper soil management is not implemented, topsoil and subsoil resources may be lost due to mixing with underlying geologic stratum material. This mixed resource may possess one or several properties making it unsuitable for plant

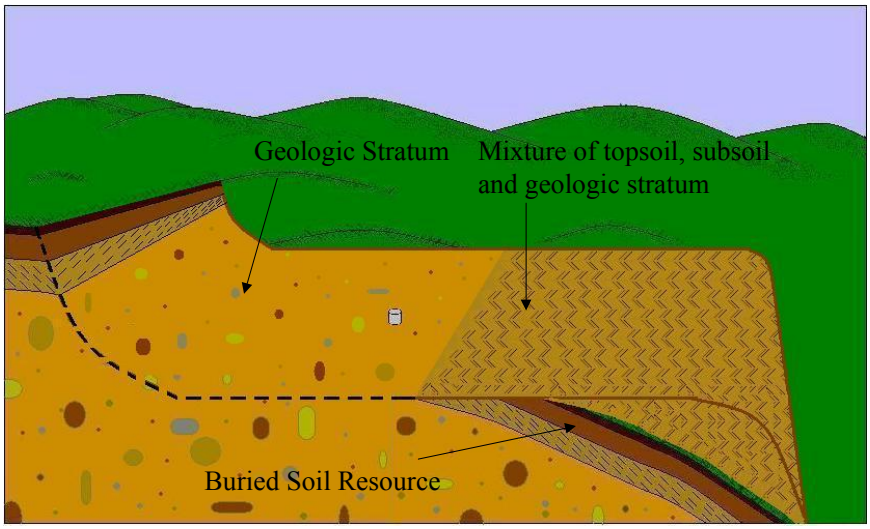


Figure 3. Cut-and-fill technique resulting in burial and mixing of the soil resource.

growth. Of interest in this study is soil salinity, which may become elevated when upper portions of the soil profile with low salt content are mixed with underlying materials having high salt content. A better understanding of effects of elevated soil salinity on plant communities may aid in determining the amount of negative impact caused by improper soil management during CBM development.

In areas impacted by elevated soil salinity, an outside soil resource (coversoil) is often brought in to reclaim the area and make it suitable for plant growth. Coversoil application is a successful but costly solution. Costs associated with this method increase with every inch of soil applied. For example, Pioneer Technical Services (Butte, MT) estimates that the cost to stockpile coversoil resources with a dozer is $\$1.66/m^3$. The cost for hauling this soil resource to the project site is $\$0.76/m^3/km$, and an additional $\$1.66/m^3$ is required to spread the soil resource. Using these estimates, it would cost approximately $32,234 to apply 45 cm of coversoil to a 0.41 ha (1 acre) drill pad,

assuming a 48 km (30 mi) round-trip haul distance. Many additional costs are also involved, meaning that significant expense is involved with every inch of coversoil applied. A 45 cm (18 inch) thickness is commonly used for reclamation, but there is a possibility that similar plant growth could be achieved with less coversoil. To make the reclamation process cost effective and to conserve resources it would be helpful to have a better estimate of plant performance over a saline substrate as a function of coversoil thicknesses.

The purpose of this investigation was to characterize the response of three grass species to soil salt content and coversoil depth. Specific objectives were as follows:

1. to determine how grass seedling emergence and growth are affected by soil salinity and soil matric potential.
2. to determine how much coversoil is required to facilitate grass growth over a saline substrate.

2. LITERATURE REVIEW

Plant Responses to Soil Salinity

Generally, soil profile salt concentration increases with depth. Salts such as chlorides, sulfates, nitrates, and some carbonates and bicarbonates of sodium, potassium, magnesium and calcium are soluble, leaching downward from the upper horizons of most soils (Troeh and Thompson, 1993). If the upper portion of the soil profile, containing a low salt content, is mixed with underlying soil material, the resulting soil resource may be impaired due to a greater salt content. Although sources of salinity are varied, there is worldwide concern over the constraint of soil salinity on plant growth. The effects of salinity are exacerbated in arid environments, where dry conditions and high evaporation rates reduce downward leaching and keep salts near the surface. The presence of salts in soils is a concern because of their detrimental effect on plant growth.

When exposed to soil salinity, the earliest response of a non-halophyte (or salt intolerant) plant is to reduce leaf growth. An investigation by Munns and Termaat (1986) studied leaf elongation in barley, wheat, Egyptian clover, white clover and white lupine in response to soil salinity. Possible causes of reduced leaf growth included: osmotic effects in the shoot, salt toxicity in the shoot, osmotic effects in the roots, and salt toxicity in the root. It was concluded that exposure to salt in the form of NaCl affected root metabolism primarily through an osmotic effect, causing a water deficit and retarding leaf elongation. Such an osmotic effect reduces the amount of water available to plants by decreasing the osmotic potential (ψ_O) of the soil, which is produced

by solutes present in

the soil water (Kramer 1983). Plants have an osmotic potential of their own, resulting from dissolved solutes in the plant tissue. The osmotic potential in a plant root is normally stronger than that of the soil, facilitating water movement into the plant root as a result of a gradient in potentials. However, as the salinity of the soil solution increases, its osmotic potential becomes increasingly negative. For every 1 dS/m increase in soil salinity, osmotic potential decreases by -0.36 bars (Richards, 1969). The gradient is reversed, and plants must now exert additional energy to obtain water from the saline soil leaving less energy available for growth (Troeh and Thompson, 1993). Root growth is normally less affected then 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 also produce negative long term effects 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 the cytoplasm interferes with metabolism, and build-up in the cell wall causes loss of turgor and excessive water loss. Salt accumulation in older leaves will cause death if high concentrations are reached. 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. Saline soils containing the Cl^- ion may decrease nutrient availability, as Cl^- inhibits the uptake of nitrogen in the form of NO_3^-. Salt content, soil fertility, plant species, and transpiration rates all influence the severity of long term effects.

While salinity affects plants in many ways physiologically, Maas and Hoffman (1977) noted in their review that overt injury symptoms seldom occur except under extreme salinization. Salt-affected plants usually appear normal, but with stunted growth and darker green leaves which may be thicker and more succulent.

Salinity and Soil Water Potential

Soil salinity is often expressed using electrical conductivity, or EC, which is directly related to the concentration of soluble salts in solution. Soil salinity is commonly measured by determining the electrical conductivity of a soil saturated paste extract (EC_e) at 25EC (Richards, 1969). Units of decisiemens per meter (dS/m) will be used to convey EC throughout this document. EC can also be expressed in terms of osmotic potential using the relationship $\psi_O = -0.36*EC$ (Mass and Hoffman, 1977; Richards, 1969). Osmotic potential, as discussed earlier, limits plant available water as solute concentrations increase and the ψ_O of the soil water becomes more negative.

Soil matric potential also influences water availability. Matric potential (ψ_M) is a measure of how strongly soil water is attracted to the soil solids, or matrix (Troeh and Thompson, 1993). Matric potential will have a negative value unless the soil is completely saturated, and becomes more negative as water content decreases and the attraction between water particles and the soil matrix becomes stronger. As matric potential becomes more negative, plants must exert more energy in order to obtain water from the soil. The relationship between matric potential and soil water content can be portrayed graphically with a moisture release curve (Killham, 1994). Soil texture,

porosity and bulk density all interact to determine moisture content, making moisture release curves different for each type of soil (Kramer, 1983).

The forces produced by osmotic (ψ_O) and matric (ψ_M) potentials combine with other forces such as gravity (ψ_G) and pressure (ψ_P) potentials to reduce the free energy of soil water, making it less available for plant uptake (Troeh and Thompson, 1993). The combination of these forces produces total soil water potential (ψ_T), which can be expressed using the equation:

$$\psi_T = \psi_O + \psi_M + \psi_G + \psi_P.$$

Since plants tend to respond to the sum of the osmotic potential of the soil solution and the soil matric potential (Maas and Hoffman, 1977), the equation can be simplified for the purpose of this investigation to:

$$\psi_T = \psi_O + \psi_M,$$

with total soil water potential reflecting the additive effects of both water stress and salinity stress.

Studies of 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). For purposes such as agriculture and reclamation, researchers have aimed to identify how ranges of soil salinity impact plant growth (Table 1). Investigators seeking threshold values will evaluate the growth of a particular plant species at various levels of salinity to determine the level at which yield is impaired. Most plants will tolerate salinity up to this threshold

level, at

Table 1. Salinity ranges affecting plant growth (Sandoval et al., 1973)

EC_e (dS/m)	Effect on plant growth
< 2.0	Negligible
2.0 - 4.0	Slight
4.0 - 8.0	Moderate
8.0 - 16.0	Severe
> 16.0	Very severe

which yields decrease in an approximate linear fashion as salinity increases in the soil water (Maas, 1986). However, the assignment 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).

Franklin et al. (1987) reviewed scientific literature specifically pertaining to plant salt tolerance and threshold salinity values. Of interest were studies by Maas (1986) and Maas and Hoffman (1977). The threshold soil salinity level for alfalfa, clover, foxtail, lovegrass, and orchardgrass ranged between 1.5 - 2.0 dS/m (Table 2). Threshold soil salinity levels ranged from greater than 2 dS/m to 3.9 dS/m for standard-crested wheatgrass, fescue, vetch, and wildrye. Ryegrass, and fairway-crested and tall-wheatgrass species had threshold soil salinity levels that ranged from 5.6-7.5 dS/m.

Mer et al. (2000) studied the response of several plant species to increasing levels of soil salinity. Germination of wheat (*Triticum aestivum*), gram (*Cicer arietinum*) and mustard (*Brassica juncea*) was completely inhibited in soils when salinity exceeded 4

Table 2. Salt tolerance threshold values for plant species (adapted from Franklin et al., 1987)

Common Name	Botanical Name	Threshold EC dS/m	% Yield Loss Per 1 dS/m Increase In Soil Salinity Above Threshold
Alfalfa	*Medicago sativa*	2.0	7.3
Clover	*Trifolium -hybridum, -repens, -pratense*	1.5	12
Fescue, tall	*Festuca elatior*	3.9	5.3
Foxtail, meadow	*Alopecurus pratensis*	1.5	9.6
Lovegrass	*Eragrostis sp.*	2.0	8.4
Orchardgrass	*Dactylis glomerata*	1.5	6.2
Ryegrass, Perennial	*Lolium Perenne*	5.6	7.6
Vetch, common	*Vicia angustifolia*	3.0	11.0
Wheatgrass,stand standard crested	*Agropyron sibiricum*	3.5	4.0
Wheatgrass, fairway crested	*Agropyron cristatum*	7.5	6.9
Wheatgrass, tall	*Agropyron elongatum*	7.5	4.2
Wildrye, beardless	*Elymus triticoides*	2.7	6.0

dS/m. Root and shoot growth of these plants were significantly reduced in soils with a salinity of 4 dS/m. Barley (*Hordeum vulgare*) appeared to be more tolerant, exhibiting poor germination in soils with salinity above 8 dS/m. Barley plants experienced reduced growth by increasing soil salinity over the range of 0-8 dS/m, and seedlings growing in soils with salinity above 12 dS/m ceased growing and eventually died. All four species

reduced growth in response to increased soil salinity. This reduction was attributed to decreased water uptake by roots facilitated by a lowered osmotic potential. Plants in this study were watered every other day and not subjected to any specified water stress.

Ippolito (1992) found that growth of smooth brome, clover, reed canarygrass, cicer milkvetch, timothy, and creeping meadow foxtail was not impaired when soil salt contents were less than the threshold values of 1.0-2.5 dS/m. Above the threshold, a 7.8-18.5% decrease in yield was measured for each 1.0 dS/m increase in soil salinity. In a similar study, Al-Wardy (1995) evaluated two alfalfa (*Medicago sativa*) cultivars, Archer and Ladak. Results showed no difference between the salinity tolerances of the two cultivars. Yield of alfalfa decreased as the soil salt content exceeded a 0.35 dS/m threshold, with losses in dry shoot matter of 8% per 1.0 dS/m increase in soil salinity above the threshold for Archer and a 7% loss for Ladak. Plants in the above studies were grown in hydroponic solutions, with solution salinity adjusted to approximate the salinity of a soil saturated paste extract.

Effect of Soil Moisture on Salt Stress

The majority of crop salt tolerance studies reviewed include frequent irrigation, which masks the influence of matric potential on water availability (Maas and Hoffman 1977; Franklin et al., 1987). Studies using frequent irrigation, sand cultures, or hydroponic solutions eliminate the matric potential factor, focusing solely on osmotic potential. According to Ulrey et al. (1998), such conditions are actually recommended for any study of plant/salinity relationships. Their review of plant salt tolerance literature

suggests that, " among the most critical elements of a salt-tolerance study is the maintenance of adequate soil moisture and soil fertility, so that salinity effects on plant growth are not confounded by matric or nutrient stresses." However, if soil salinity does indeed limit certain nutrients, and if its effects might be exacerbated or lessened by soil moisture, it seems that an experiment conducted under such recommended conditions may be of limited value. Data obtained in such conditions could not be extrapolated to real world scenarios, where soil water content fluctuates.

The role of soil water content is of importance because it is highly correlated with soil salinity. As soils dry down, salinity is exacerbated. As plants remove water from the soil, the resulting soil solution salt content becomes more concentrated (Killham, 1994). As water is depleted by evaporation and transpiration, plants experience greater salt and moisture stress. The total moisture stress exerted on a plant's root system becomes a function of soil salt content and moisture stress. A graph from Wadleigh and Ayers (1945) illustrates this relationship, with total moisture stress at its highest when high salt contents are combined with low soil moisture (Figure 4). Because saline and drought conditions often occur together in arid climates, plant tolerance to the combined effects of water and salinity stress is of considerable concern.

In 1945, Wadleigh and Ayers studied growth of bean plants as a function of soil salt concentration and moisture tension. Trends in their study showed marked reduction in growth resulting from greater soil salinity. Data also indicated that the level of plant response to a given salt level was modified by the extent of soil moisture depletion.

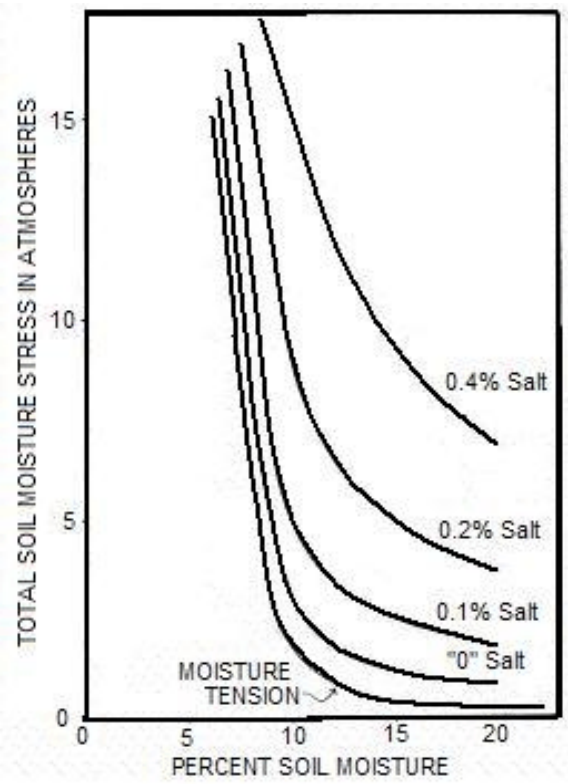


Figure 4. Total soil moisture stress as a function of soil salt content and percent soil moisture. From Wadleigh and Ayers (1945).

Figure 5 illustrates this response, with bean growth decreasing as a function of percent salt, but showing a modified response due to percent soil moisture.

A study by Goldberg and Schmueli (1970) indicated that trickle or drip irrigation applied in order to maintain soil water just below field capacity resulted in greater plant tolerance to salinity. Greater water availability resulted in a decreased moisture stress component.

Sepaskhah (1977) also found the harmful effects of salts on crops to vary according to the water status of the soil. Soybean (*Glycine max*) plants were grown in soils with EC_e values of 3.0, 5.0 and 10.0 dS/m. Plants were either watered to field

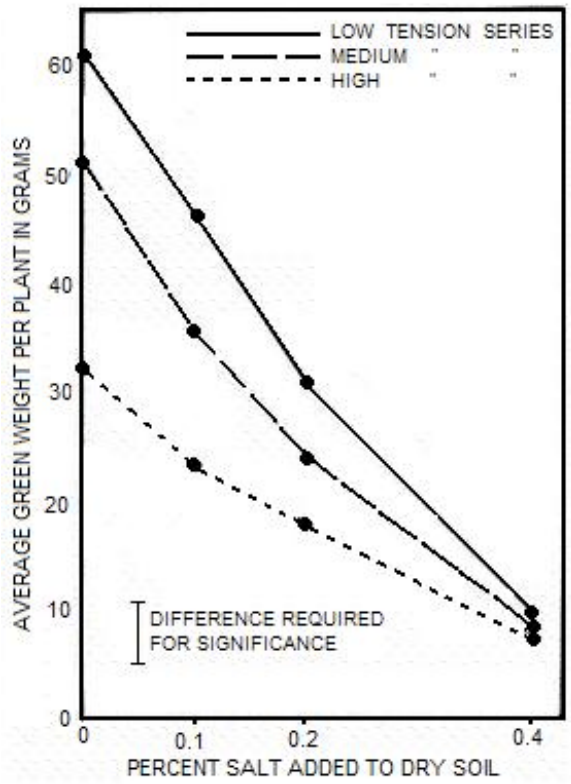


Figure 5. Average weight of bean plants as a response of soil salt content and soil moisture tension. From Wadleigh and Ayers (1945).

capacity every other day or not watered for several days until severe wilting occurred to induce water stress. Shoot mass was significantly reduced at the highest level of salinity but was not influenced by water stress. Root mass was significantly reduced as a function of salinity and was significantly reduced by water stress late in the growing season.

Adiku et al. (2001) studied growth of common bean (*P. Vulgaris*) under varied soil water and salinity conditions. Plants were grown in soils with EC_e values ranging from 1.76 to 5.99 dS/m. Soil water potential was maintained between -0.5 and -1.0 bars to create water stress-free conditions. To create water stressed conditions, soil water

potential was maintained at around -6.0 bars. At moderate salinity levels under water

stress-free conditions the reduction in dry matter production was less than that of plants growing in low salinity, water stressed conditions. High levels of salinity combined with water stress produced the most drastic growth reductions.

These studies highlight the role of soil water in determining the extent 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 effects of a highly saline soil may be diluted in the presence of abundant soil water, lessening the negative impact on plant communities. Considering these principles, it seems counterintuitive to assign any concrete threshold salinity value at which plant growth is negatively impacted. However, such studies of salinity impact on plant growth as a function of soil moisture are in the minority. Therefore, it is of interest in this study to observe plant responses to soil salinity under varied soil moisture conditions.

Native Soils and Minesoils

Elevated soil salinity may become a problem on disturbed landscapes if the practice of soil removal and stockpiling is not utilized and natural soils are lost due to mixing with underlying materials. Natural soils are the product of processes acting over thousands of years and have achieved some form of equilibrium with their soil forming environment (Sencindiver and Ammons, 2000). The texture, structure, and chemical properties of natural soils are several of many factors which make them uniquely suited for specific ecological communities.

In mined areas where the soil resource has not been salvaged properly, the resulting product is a minesoil, developing from a mixture of geologic stratum and soil. Minesoils often have very different properties compared with adjacent natural soils, and while these properties may approach and someday be similar to those of natural soils, some properties may remain forever changed (Sencindiver and Ammons, 2000).

A study by Wali and Freeman (1973) in North Dakota compared undisturbed soils to nearby minesoils that had naturally revegetated over a time period of 0-53 years. Soil data revealed significant differences between the mined and unmined sites, with the minesoils having higher pH, salt content, exchangeable sodium, total phosphorus and clay content, as well as less organic carbon. Minesoils also exhibited sparse vegetation with lower species diversity when compared to unmined soils. It was also noted that elevated salinity due to sodium appeared to be a serious problem in reclamation. The investigators concluded the use of additional topsoil to be a promising reclamation treatment for the disturbed landscape.

A study conducted in semi-arid Saskatchewan, Canada by Anderson (1977) analyzed 28-40 year old mine spoils composed mainly of glacial till materials. The A horizons were found to be thin and weakly expressed when compared to nearby natural soils with A horizons up to 15 cm thick. The minesoils, however, did indicate evidence of development, with slight increases in pH with depth and general increases in EC and soluble sodium percentage with depth. These data indicate soluble salt leaching and the establishment of a depth distribution similar to undisturbed soils in the region. The results of this study suggest that the translocation of soluble soil materials may be a fairly

rapid process, measured in years to decades. Also, carbonate distribution in the mine spoils did not match that of undisturbed soils, with an estimate of thousands to tens of thousands of years to leach completely.

In Colstrip, Montana, soil characteristics were analyzed in old minesoils, new minesoils, and natural soils, with ages of 50 years, 6 years, and approximately 33,000 years, respectively (Schafer et al., 1980). This study indicated natural soils as having less salts than old minesoils, which in turn had less than new minesoils (Figure 6). An accumulation of salts between 150 and 200 cm in new minesoils is indicative of downward leaching processes. Both old and new minesoils had carbonates distributed relatively evenly throughout their profiles. This contrasts sharply with carbonate distribution in natural soils, with concentrations occurring at depths below 50 cm (Figure 6). Schafer et al. (1980) estimated that 6,000 to 30,000 years would be required for carbonate distribution in both mine soils to resemble that of adjacent natural soils.

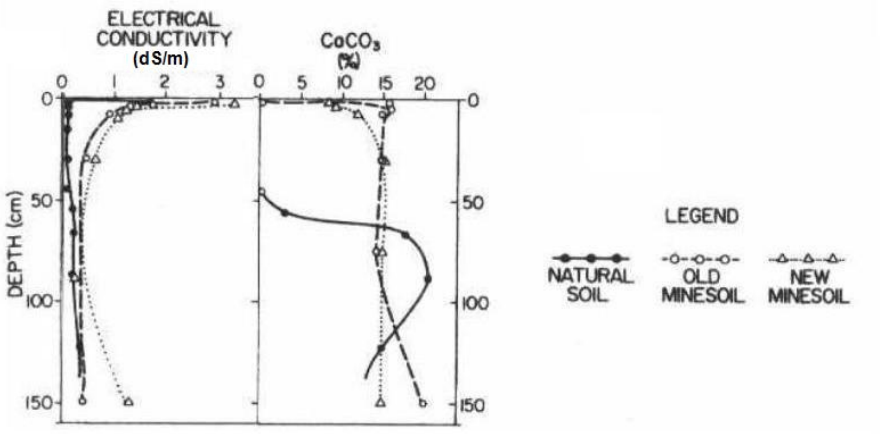


Figure 6. Distribution of soluble salts and carbonate for a natural soil, old, and new minesoil. Adapted from Schafer et al., (1980).

Soil Replacement

When a soil resource is lost due to mixing with underlying materials or is not salvaged properly the establishment of a successful plant community may become challenging. A common reclamation technique used in such scenarios is the placement of an outside soil resource on top of the disturbed area to create a substrate suitable for plant establishment.

Grandt (1978) performed an early test of horizon replacement. Corn (*Zea mays* L.) planted on mine overburden produced ten year average yields of 5488 kg/ha. Investigators then applied approximately 38 cm of topsoil gathered from an adjacent site to a portion of the old spoils. Average corn yields were 7580 kg/ha on the portions with coversoil, and 4760 kg/ha on portions without.

A greenhouse evaluation by Dancer and Jansen (1981) found topsoil materials generally producing better plant growth than did B or C soil horizon materials. A mixture of B and C horizons, however, was commonly equal to or better than B horizon materials alone. Similarly, Power et al. (1981) found their North Dakota field study plots producing higher yields when topsoil was replaced over subsoil, as compared to plots where a mixture of topsoil and subsoil was used. For native grasses, the optimum coversoil thickness was determined to be a 90 cm, composed of topsoil overlying subsoil.

Barth and Martin (1984) studied perennial grass response to coversoil thickness over minesoils with a variety of characteristics. The coversoil used was a mixture of A, B, and C horizons. Results indicated grass yields to be highest when 100 cm coversoil

was used over acidic spoil materials. When the underlying spoil was sodic, 70 cm of soil produced maximum yields. For spoils that were neither acidic nor sodic, 50 cm was adequate.

Keammerer et al. (1992) examined plant characteristics for several Montana mine waste sites that had been reclaimed in the early 1980s. Various thicknesses of coversoil had been placed over the acidic and metal rich tailings. Coversoil thicknesses ranged from approximately 8 to 56 centimeters. Overall, the study did not detect any trends in vegetation production as a function of coversoil thickness.

Numerous additional field and greenhouse studies have been conducted to evaluate plant growth as a function of soil replacement over minesoil materials. Results are varied, depending on plant species and the properties of both the substrate and the cover material used. However, such soil replacement generally improves plant production in field studies where the minesoils were physically or chemically unsuitable (Dunker and Barnhisel 2000).

3. MATERIALS AND METHODS

Study Species

Grass species chosen for this study are all members of the existing plant community at the soil collection site. Munshower (1998) reviewed studies of these species to determine their usefulness in reclamation, providing the following information. *Pseudoroegneria spicata* A. Love (bluebunch wheatgrass) is a native, perennial, cool season bunchgrass found throughout the western Unites States. *Pseudoroegneria* has very good drought tolerance, and poor to moderate salinity tolerance, with 66% growth reduction at 7 dS/m. *Hesperostipa comata* A. Love (needle-and-thread) is also a native, perennial, cool season bunchgrass common to the prairies, plains and foothills of the West. *Hesperostipa* has very good drought tolerance and is fairly tolerant of salinity. The third species, *Pascopyrum smithii* (western wheatgrass) is a native, perennial, cool season grass. It is a sod-former with strong, spreading rhizomes. *Pascopyrum* has good drought tolerance, and fair to good salinity tolerance with significant growth reductions at 4 to 7 dS/m.

Study Soils

Soils for the study were obtained in July 2003 from a privately owned ranch located east of Sheridan, Wyoming (NE1/4NW1/4SEC32T55NR83W). Soils were collected in 114-liter containers from two locations: disturbed soils located on a coalbed methane drill pad, and undisturbed soil located on rangeland adjacent to the drill pad.

Disturbed soil consisted of a mixture of A, B, and C horizons, as well as underlying geologic stratum. Sampling depths were approximately 30 cm. Undisturbed soil consisted of A horizon material, and were sampled at a depth of approximately 15 cm. Soil from the disturbed site was used in Study No. 1, and both disturbed and undisturbed soils was used in Study No. 2.

Samples of disturbed and undisturbed soil were analyzed for physiochemical characteristics (Table 3). Composite soil samples were oven dried at 105 degrees Celsius and were then disaggregated with a mortar and pestle. Soil that passed through a 2 mm sieve was used for all analyses. Soil particles larger than 2 mm in diameter were

Table 3. Soil variables and analytical techniques used.

Variable	Analytical Technique
EC_e (dS/m)	Water saturated paste extract. USDA Handbook 60, Method 3a, 4b (U.S. Salinity Laboratory Staff, 1969)
pH	Water saturated paste extract. USDA Handbook 60, Method 3a, 21c (U.S. Salinity Laboratory Staff, 1969)
SAR	USDA Handbook 60, Method 20b (U.S. Salinity Laboratory Staff, 1969)
% OM	Modified Walkley-Black, Method 29-3.5.2 (ASA, 1982)
% Coarse Fragments	Sieved 2mm fraction, measured % fragments greater than 2mm. (ASTM, 1993)
Particle size distribution	Hydrometer method (Palmer and Troeh 1995)
Nitrate	KCl extraction, Method 38-3 (ASA, 1982)
Phosphorus	Olsen sodium bicarbonate extraction, Method 24-5 (ASA, 1982)
Potassium	Ammonium acetate extraction, Method 13-3.5 (ASA, 1982)

classified as coarse fragments (Munn et al., 1987). Physical properties evaluated

included coarse fragment percentage, and particle size distribution (textural class). Chemical properties evaluated included electrical conductivity (EC), pH, sodium adsorption ratio (SAR), percentage organic matter (OM), and nutrient (N, P, K) content (Table 4). The undisturbed soil had an EC_e of 0.85 dS/m, pH of 7.67, SAR of 0.10, 5.6 % organic matter (mass basis), and 5.2 % coarse fragments (mass basis). The textural class of the undisturbed soil was clay, with extractable 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 % organic matter (mass basis), and 6.6 % coarse fragments (mass basis).

Table 4. Physiochemical characteristics analyzed for disturbed and undisurbed soil samples.

Parameter	Undisturbed Soil	Disturbed Soil
EC_e (dS/m)	0.85	0.80
pH	7.67	7.97
SAR	0.10	1.4
% OM (mass basis)	5.6	1.4
% Coarse Fragments (mass basis)	5.2	6.6
% Sand (mass basis)	14.3	43.0
% Silt (mass basis)	30.0	27.1
% Clay (mass basis)	55.6	29.9
Textural class	Clay	Clay loam
N (mg/kg)	9.0	5.0
P (mg/kg)	3.0	9.0
K (mg/kg)	590	130

The textural class of the disturbed soil was clay loam, with extractable N, P, and K contents of 5.0, 9.0 and 130 mg/kg, respectively.

Study No. 1: Response of Grass Species to Soil Salinity and Soil Matric Potential

Salinity Treatments

For this study, *Pseudoroegneria*, *Hesperostipa*, and *Pascopyrum* were grown in soils with low, medium, and high salinities of approximately 0.80, 5.0 and 11.0 dS/m, respectively. Salinity levels are 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, the soil was artificially salinized using a solution of $CaCl_2$ and deionized water. Through an iterative process, $CaCl_2$ was added incrementally until the approximate salinities of 5.0 and 11.0 dS/m were attained. Table 5 lists the amount of $CaCl_2$ used to reach each desired soil salinity.

Salinized soils were created by weighing out 5000 grams of disaggregated soil. The required amount of $CaCl_2$ was weighed and added to 1.0 liter of deionized water.

Table 5. Percentages of $CaCl_2$ added to soil samples to attain target soil salinities.

Target EC (dS/m)	% $CaCl_2$ added (by weight)
0.80	0.0
5.0	0.10
11.0	0.25

The solution was stirred until the $CaCl_2$ was completely dissolved, then added to the soil and thoroughly mixed by hand. The soil was then oven dried overnight at 105 degrees Celsius, then disaggregated again. Small samples were removed from each batch of

salinized soil and measured for EC using a saturated paste extract to determine that the salinization process attained the desired target level. The average salinity of soils with a target EC of 11.0 dS/m was 10.97 dS/m, with a standard deviation of 0.79 dS/m. The average salinity of soils with a target EC of 5.0 dS/m was 5.04 dS/m, with a standard deviation of 0.62 dS/m.

Matric Potential Treatments

In addition to the three salinity treatments, grasses in this study were subjected to three soil moisture treatments. The 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.

A sample of the soil collected at the disturbed CBM site was sent to MSU's Soil Testing Lab for analysis using a ceramic pressure plate apparatus. The gravimetric water content of the sample was measured at various levels of matric potential. Results of this analysis are presented in the form of a moisture release curve (Figure 7). The three moisture treatments are denoted on this figure by three zones, which incorporate a range of matric potentials. Upon watering, pots in this study contained the gravimetric water

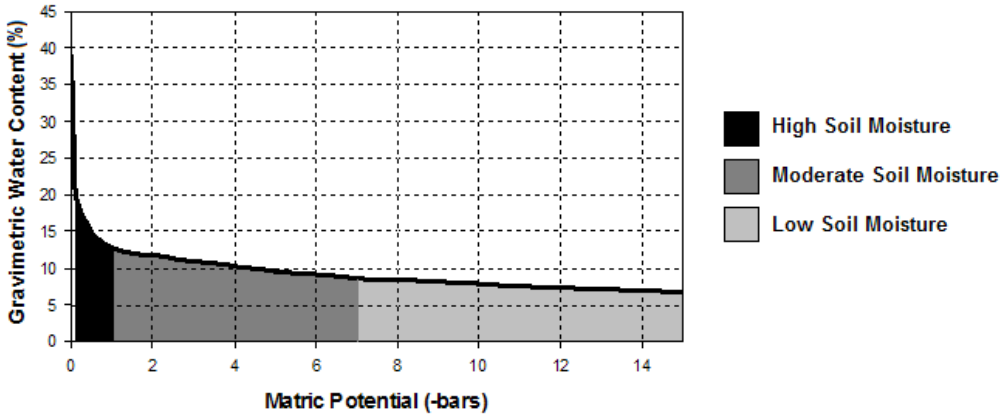


Figure 7. Moisture release curve for disturbed soil material.

content corresponding to the highest matric potential in each range. Constant watering would be required to maintain this matric potential level. Constant water application was not feasible in this study, so soils dried down over time, producing a range of matric potentials for each treatment rather than a fixed value. Table 6 shows gravimetric water content corresponding to the upper matric potential of each soil moisture treatment, as determined by the pressure plate analysis.

Experimental Design

The three salinity treatments and the three matric potential treatments were combined for a total of nine treatments, listed in Table 7. Each treatment was replicated

Table 6. Gravimetric water content corresponding to soil moisture treatments

Soil moisture treatment	Maximum matric potential (-bars)	Gravimetric water content (%)
High	0.1	21.7
Moderate	1.0	13.0
Low	7.0	8.6

eight times, for a total of 72 experimental units per grass species. Pots were arranged in a completely random design, and were re-randomized every two weeks. Plant growth tests took place in the Plant Growth Center (PGC) at Montana State University during the months of January 2004 through August 2004.

The nine experimental treatments were randomly assigned to 72 labeled plastic pots, 15 cm in diameter by 18 cm tall. A coffee filter was placed in the bottom of each pot to prevent soil loss through the drainage holes. Each pot was first weighed and then filled with the soil corresponding to the salinity treatment. Pots were filled to approximately one centimeter of the top. The pots were once again weighed, and the mass of the pot was subtracted to arrive at the soil mass. Then, the mass of soil in each pot was 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

Table 7. Experimental treatments

Treatment	EC (dS/m)	Matric Potential (-bars)
A	0.80	0.1
B	0.80	1.0
C	0.80	7.0
D	5.0	0.1
E	5.0	1.0
F	5.0	7.0
G	11.0	0.1
H	11.0	1.0
I	11.0	7.0

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 the scale, and PGC 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, the emergence of seedlings was noted for each pot. Throughout the study, supplemental lighting was provided to maintain a 14-hour photo period. Day temperatures were maintained at 23 degrees Celsius and night temperatures were maintained at 18 degrees Celsius.

Following the three week emergence period, final emergence numbers were recorded, and pots were thinned to four plants each. For those pots having less than four emerged seedlings, additional seeds were sown, and watered with 50 ml of water daily until four seedlings were present. The establishment of four seedlings was usually attained in three to five days.

At the start of week four, 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, the

following variables were measured:

- Plant height- Distance from the soil surface to the end of the longest leaf for each plant. The heights of the four plants in each pot were averaged to produce one value per pot.
- Aboveground biomass- Shoot biomass was harvested by clipping plants one centimeter above the soils surface, drying approximately 72 hours in a 70 degree Celsius oven, and weighing on a Mettler H31AR balance. The total above ground biomass for each pot was divided by four to produce an average biomass per plant.
- Belowground biomass- Root biomass was harvested by mechanically separating roots from the soil by hand. Roots were dried in a 70 degree Celsius oven for approximately 72 hours and weighed on a Mettler H31AR balance. The total below ground biomass for each pot was divided by four to produce an average biomass per plant.

Statistical Analysis

Plant characteristics were statistically analyzed using SigmaStat statistical software (Sigma Stat 1997). The majority of data were not normally distributed with equal variance, preventing a two-way ANOVA. Normally distributed data were analyzed using a one-way ANOVA to determine if treatment means were significantly different ($p < 0.05$). 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 ($p < 0.05$). If treatment means were found to be significantly different, they

were separated using the Tukey test. In addition, the Spearman Rank Order Correlation analysis was performed to evaluate the nature of correlations between plant characteristic data and treatment variables.

Study No. 2: Response of Grass Species to Coversoil Depth Over a Saline Substrate

Experimental Design

For this study, *Pseudoroegneria* , *Hesperostipa*, and *Pascopyrum* were planted in tubes containing various depths of native coversoil overlying a saline substrate. The treatments for this study consisted of six different coversoil thicknesses: 0, 5, 10, 15, 30, and 45 centimeters. These six treatments were replicated eight times for a total of 48 experimental units per grass species. The disturbed soil collected at the CBM drill pad was salinized with a solution of $CaCl_2$ to a target EC of 11 dS/m for use as a saline substrate. The resulting soils had a mean EC of 11.05 dS/m, with a standard deviation of 0.62 dS/m. The undisturbed rangeland soil (EC= 0.85 dS/m) was used as coversoil.

Soil Moisture

For this study, it was desirable to look at plant growth as a function of coversoil thickness alone. To minimize the water stress component, plants in this study were subjected to moderate soil moisture conditions. Using methods described previously, substrate and coversoil samples were sent to MSU's Soil Testing Lab for moisture content analysis using a pressure plate apparatus. The moisture content of the two study

soils was evaluated at a matric potential of -1.0 bars. As shown in Table 8, the water content of the two soils differed considerably at this tension, with the substrate and coversoil containing 13.0 and 27.2% water, respectively. Such a difference in gravimetric water content is largely attributed to textural differences. The coversoil, classified as clay, held greater amounts of water due to its finer texture. In order to make the water holding capabilities of the two soils comparable, sand was added to the coversoil until a mixture was achieved possessing similar moisture holding properties to the substrate. By increasing the sand content of the coversoil six-fold, this goal was achieved. The coversoil mixture now held 13.6% water at a matric potential of -1.0 bars, which was much more comparable to the value of 13.0% for the substrate material (Table 8).

Soil Nutrient Content

It was also desirable to evaluate the two soils for nutrient content. Samples of each soil were sent to Energy Labs in Billings, Mont. for analysis of N, P and K. Results were compared to the soil nutrient levels considered minimum for grass establishment, as recommended by Lichthardt and Jacobsen (1992). Both soils were deficient in nutrients (Table 9), so appropriate amounts of fertilizer (11-52-0 and 46-0-0) and potassium in the form of KCl were added to the soils to raise nutrient levels to recommended target levels.

Table 8. Gravimetric water content of several soils at -1.0 bar matric potential.

Soil Material	Gravimetric water content (%) at -1.0 bar
Substrate	13.0
Coversoil	27.2

Coversoil/sand mixture	13.6

Greenhouse Methodology

Plants were grown in polyvinylchloride (PVC) tubes, approximately 10 centimeters (4 inches) in diameter and 61 centimeters in length. The six treatments were randomly assigned to 48 tubes, which were arranged in a completely random design in MSU's Plant Growth Center and re-randomized every two weeks throughout the study. Tubes were split lengthwise, and held together with a PVC cap and adjustable metal band. A diagram of the tubes and treatments is shown in Figure 8.

Each tube was marked on its interior to designate the appropriate depths of substrate and coversoil. The tubes were then assembled and each tube was weighed. A coffee filter was placed inside the PVC cap to prevent soil loss through the drainage hole. Dry substrate soil was poured into each tube to the appropriate level. Each tube was then weighed to determine the mass of substrate present in the tube. Next, dry coversoil was poured into each tube to the desired level. The tubes were once again weighed to determine the mass of coversoil in each tube.

Table 9. Results of soil nutrient analysis along with recommended nutrient levels.

Nutrient	Substrate (kg/15 cm 0.41 ha-slice)	Coversoil Mixture (kg/15 cm 0.41 ha-slice)	Recommended [/1] (kg/15 cm 0.41 ha-slice)
N	8.1	1.6	9
P	4.5	4.7	14.4
K	117	310	180

[/1] Lichthardt and Jacobsen (1992)

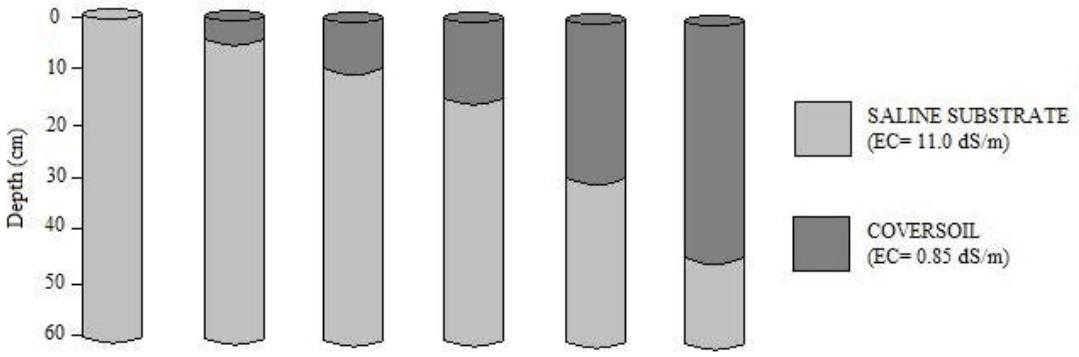


Figure 8. Diagram of coversoil depth treatments.

Using the mass of each soil type contained in each tube, a calculation was performed to determine the mass of water that should be added to bring the gravimetric water content of the soil profile to the amount corresponding to a matric potential of -1.0 bar. Similar to Study No. 1, this mass of water was added to the mass of the tube and soil to produce a target weight for each tube. For example, a tube containing 6,000 g substrate and 3,000 g coversoil would require 6,000 g*(.130) + 3,000 g*(.136), or 1,188 g water to contain the gravimetric water content corresponding to the desired matric potential of -1.0 bars. Sufficient PGC tap water was then added to each tube to achieve its target weight.

Following watering, ten seeds were sown into each tube. For the following three weeks, tubes were weighed every three days, adding enough water to bring them up to their target weights. While weighing, notes were taken on the number of emerged seedlings in each tube. Day temperatures were maintained at 23 degrees Celsius and night temperatures were maintained at 18 degrees Celsius. Additional lighting was

provided as necessary to maintain a 14-hour photo period.

Following the three week emergence period, final emergence numbers were recorded, and tubes were thinned to two plants each. For those tubes having less than two emerged seedlings, additional seeds were sown, and watered with 50 ml water daily until two seedlings were present. The establishment of two seedlings was usually attained in three to five days.

During weeks four through twelve, tubes were weighed and watered once every three days. At the end of this growth period, the following growth characteristics were measured:

- Plant height- Distance from the soil surface to the end of the longest leaf for each plant. The heights of the two plants in each pot were averaged to produce one value per pot.
- Aboveground biomass- Shoot biomass was harvested by clipping plants one centimeter above the soils surface, drying approximately 72 hours in a 70 degree Celsius oven, and weighing on a Mettler H31AR balance. The total above ground biomass for each pot was divided by two to produce an average biomass per plant.
- Belowground biomass- Root biomass was harvested by mechanically separating roots from the soil by hand. Roots were dried in a 70 degree Celsius oven for approximately 72 hours and weighed on a Mettler H31AR balance. The total below ground biomass for each pot was divided by two to produce an average biomass per plant.

Statistical Analysis

Plant characteristics were statistically analyzed using SigmaStat statistical software (SigmaStat 1997). Normally distributed data were analyzed by species, using a one-way ANOVA to determine if treatment means were significantly different ($p < 0.05$). 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 ($p < 0.05$). If treatment means were found to be significantly different, they were separated using the Tukey test.

4. RESULTS AND DISCUSSION

Study No. 1: Response of Grass Species to Soil Salinity and Soil Matric Potential

ANOVA Results for Emergence

Pseudoroegneria Figure 9 shows graphs of *Pseudoroegneria* emergence grouped according to soil salinity treatment. At low salinity, emergence was not different among soil moisture treatments, although measured values for treatment means revealed a decline in emergence as soil moisture decreased. At moderate and high soil salinity, emergence was similar in soils with high and moderate soil moisture and less in soils with the lowest moisture.

Figure 10 shows graphs of *Pseudoroegneria* emergence grouped according to soil moisture treatment. In treatments with high soil moisture, *Pseudoroegneria* emergence was not different among soil salinity levels. In fact, at high soil moisture, percent emergence was greatest in soils with the greatest salt content. At moderate soil moisture, mean emergence decreased slightly with greater salinity, although not significantly. Under low soil moisture conditions, elevated salinity reduced emergence under moderate and high soil salinity.

Hesperostipa Figure 11 shows graphs of *Hesperostipa* emergence grouped according to soil salinity treatment. Under low soil salinity, *Hesperostipa* emergence was similar among soils with high and moderate soil moisture, and less for low soil

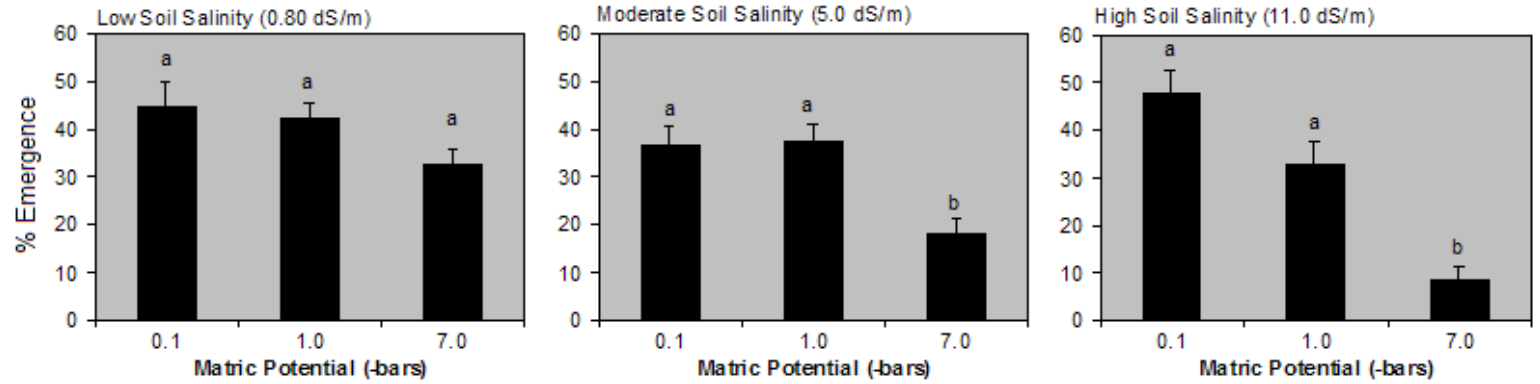


Figure 9. *Pseudoroegneria* emergence (%) grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

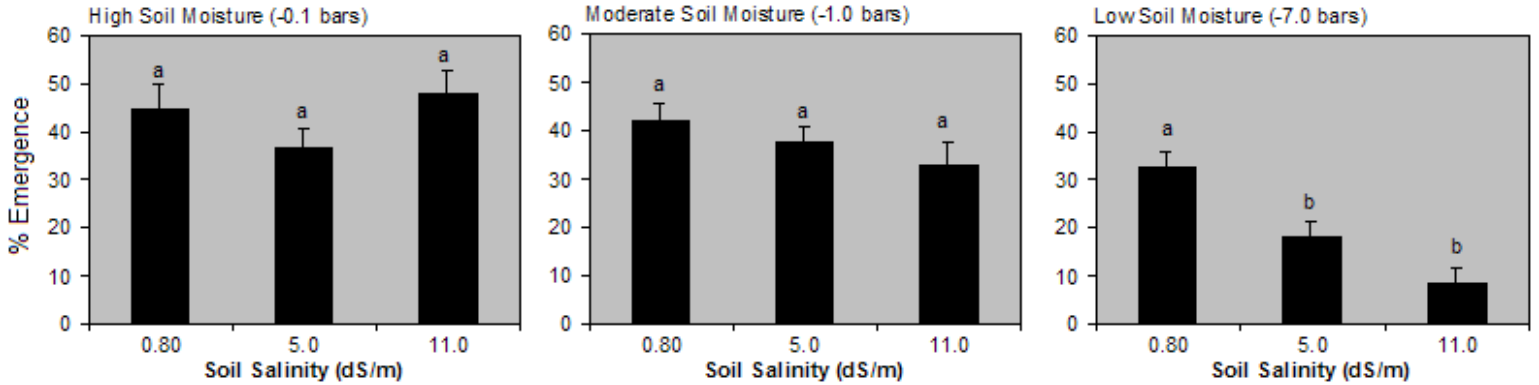


Figure 10. *Pseudoroegneria* emergence (%) grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

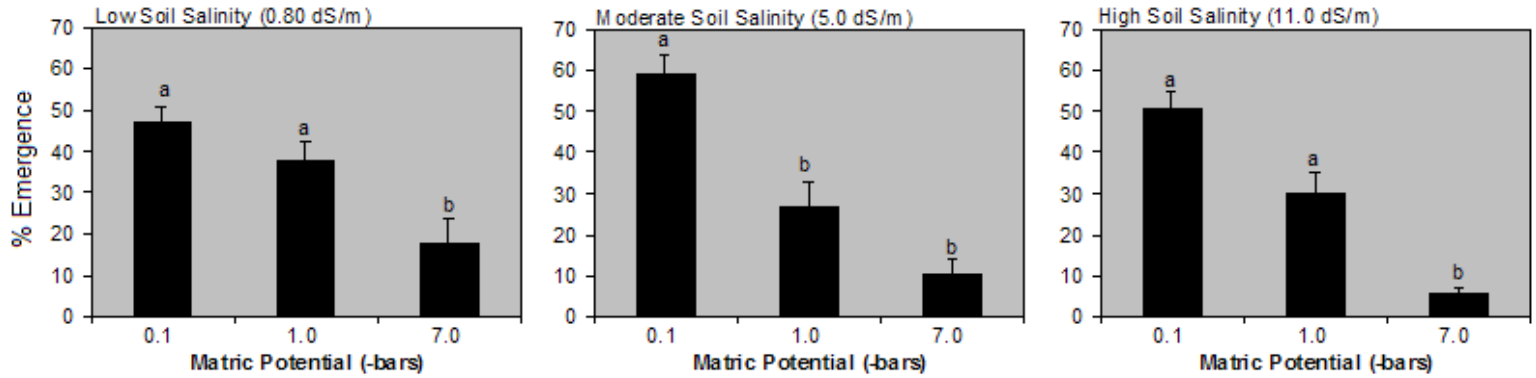


Figure 11. *Hesperostipa* emergence (%) grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

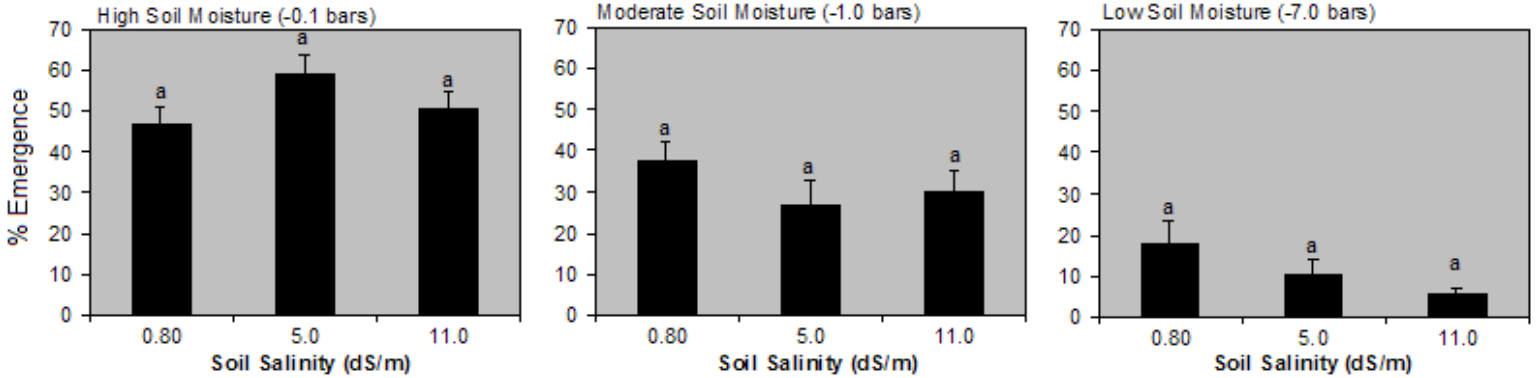


Figure 12. *Hesperostipa* emergence (%) grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

moisture. At moderate soil salinity, emergence was similar for both moderate and low soil moisture treatments. Higher emergence was recorded for moderate salinity/high soil moisture conditions. At high soil salinity, emergence was similar for high and moderate soil moisture, with emergence under low soil moisture being reduced.

Figure 12 shows graphs of *Hesperostipa* emergence grouped according to soil moisture treatment. In treatments with high soil moisture, *Hesperostipa* emergence was not different among soil salinity levels. In treatments with moderate soil moisture, there were no significant differences in emergence among the three levels of salinity. Treatments with low soil moisture showed similar trends, with salinity levels producing statistically similar emergence results.

Pascopyrum Figure 13 shows graphs of *Pascopyrum* emergence grouped according to soil salinity treatment. At low salinity, *Pascopyrum* mean emergence decreased slightly with decreased soil moisture, though there were no significant differences between treatments. At moderate soil salinity, significant reductions in emergence were detected between the low soil moisture and high soil moisture treatments. At high soil salinity, *Pascopyrum* emergence was similar in treatments with moderate and low soil moisture, and higher at high salinity/high moisture conditions.

Figure 14 shows graphs of *Pascopyrum* emergence grouped according to soil moisture treatment. In treatments with high soil moisture, *Pascopyrum* emergence was not different among soil salinity levels. In fact, under high soil moisture, percent emergence was highest in soils with the highest salt content. Under moderate soil

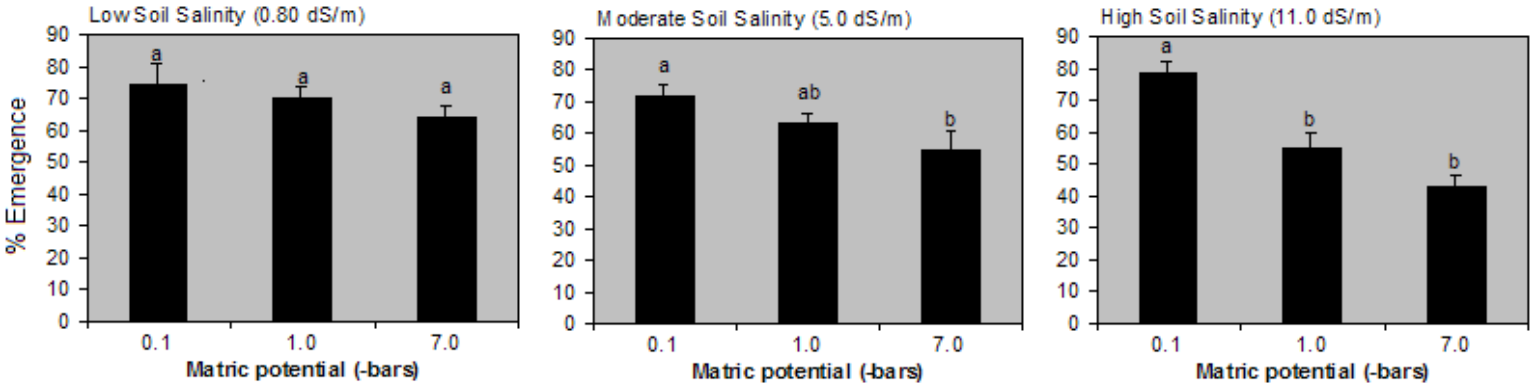


Figure 13. *Pascopyrum* emergence (%) grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

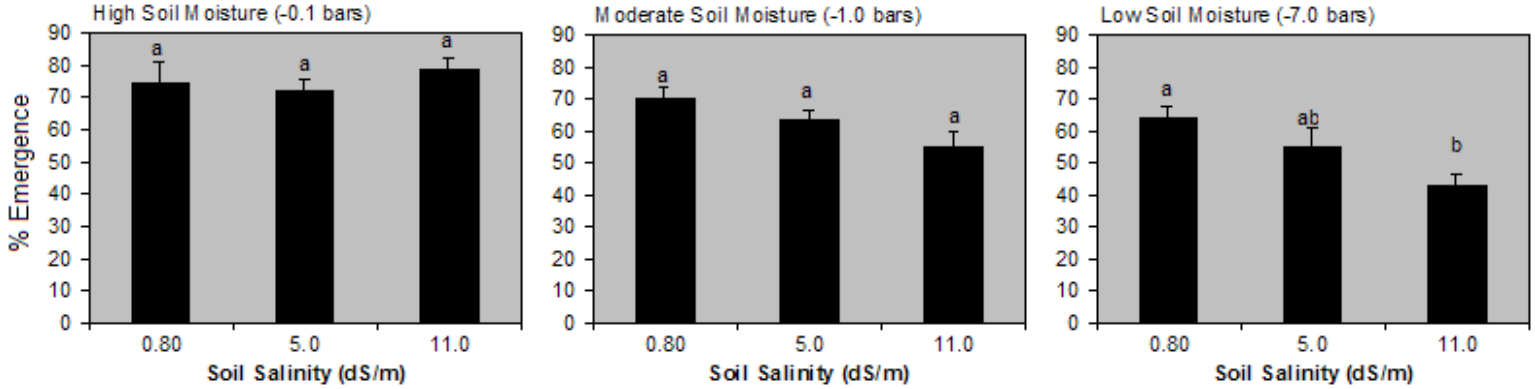


Figure 14. *Pascopyrum* emergence (%) grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

moisture, emergence was not affected by soil salinity, although graph trends indicate declining emergence as soil salinity increases. At low soil moisture conditions, reductions in emergence were significant only between high and low soil moisture treatments.

Emergence Correlation Results

Seedling emergence was correlated with both soil salinity and matric potentials (Table 10). Across all three species, the Spearman correlation coefficient (rs) for soil salinity was negative, suggesting a negative correlation exists between emergence and salinity. As soil salinity increases, seedling emergence decreases. Soil matric potential produced positive rs values, indicating a positive correlation between seedling emergence and matric potential. As matric potential values increase, so does seedling emergence. For all three species, greater correlations were produced between emergence and matric potential, indicated by rs values closer to ±1. This suggests that while seedling emergence is influenced by both salinity and matric potential, there is a greater correlation with matric potential.

Results from the correlation analysis affirm the ANOVA results discussed above. In this study, mean emergence values often remained similar among matric potential treatments, regardless of soil salinity. While greater soil salinity noticeably reduced emergence, larger decreases in emergence were observed with declining soil moisture content. Since seeds were placed near the soil surface, it is possible that water applied at the surface was able to transport salts downward and away from the seed. Greater water

Table 10. Results of Spearman Rank Order Correlation comparing seedling emergence to soil salinity and matric potential.

Species	Dependent Variable	Independent Variable	rs	P value
Pseudoroegneria	% Emergence	Soil salinity	-0.24	0.0387
	% Emergence	Matric potential	0.58	<0.0001
Hesperostipa	% Emergence	Soil salinity	-0.11	0.3390
	% Emergence	Matric potential	0.78	<0.0001
Pascopyrum	% Emergence	Soil salinity	-0.27	0.0237
	% Emergence	Matric potential	0.56	<0.0001

availability at the soil surface may have also diluted the effect of the present salts by reducing their osmotic effects and ensuring that sufficient moisture was present to stimulate seed germination and emergence.

ANOVA Results for Plant Height

Pseudoroegneria Figure 15 shows graphs of *Pseudoroegneria* plant height grouped according to soil salinity treatment. At low soil salinity, *Pseudoroegneria* plant height was reduced with decreasing soil moisture content. Plants grown in low salinity/high soil moisture conditions were, on average, twice the size of plants grown in low salinity/low soil moisture conditions. At moderate soil salinity, there was a significant reduction in plant height between high and low soil moisture treatments. Plants grown in moderate salinity/high soil moisture conditions were over three times taller than those grown in moderate salinity/low soil moisture conditions. Results for *Pseudoroegneria* plants grown in high soil salinity showed similar plant height at

moderate and low soil moisture, with taller plants at high soil moisture. Plants grown in high salinity/high soil moisture conditions were three times taller than those grown in high salinity/low soil moisture conditions.

Figure 16 shows graphs of *Pseudoroegneria* plant height grouped according to soil moisture treatment. When grown in high soil moisture, plant height was similar under low and moderate soil salinity, and lower only under high soil salinity. Under moderate soil moisture, plant height was similar under moderate and high soil salinity, and greater at high soil moisture. Plants grown in moderate soil moisture/low salinity conditions were twice the height of those grown in moderate soil moisture/high salinity conditions. Similar results were seen for plants grown under low soil moisture. Again, plant height was similar at moderate and high soil salinity, and were greater in low salinity soils. Plants grown in low soil moisture/low salinity conditions were nearly twice the height of those grown in low soil moisture/high salinity conditions.

Hesperostipa Figure 17 shows graphs of *Hesperostipa* plant height grouped according to soil salinity treatment. Under low soil salinity, mean plant height decreased with decreasing matric potential. Statistically significant decreases were seen between the high and low moisture treatments, with average plant heights doubling with high soil moisture. Similar results were observed for *Hesperostipa* plants growing in moderate soil salinity, with height decreasing as matric potential decreased. Height decreases were

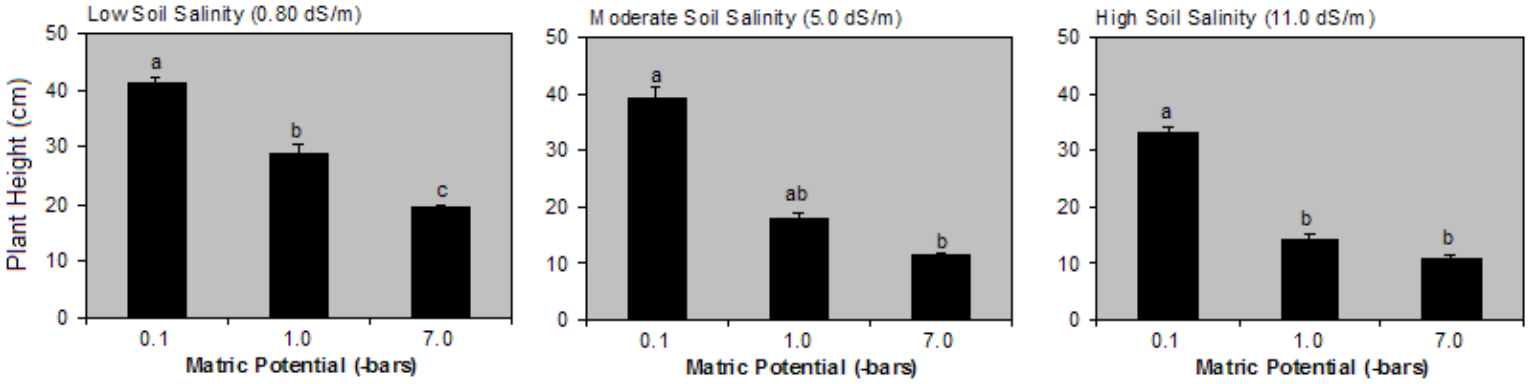


Figure 15. *Pseudoroegneria* height grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

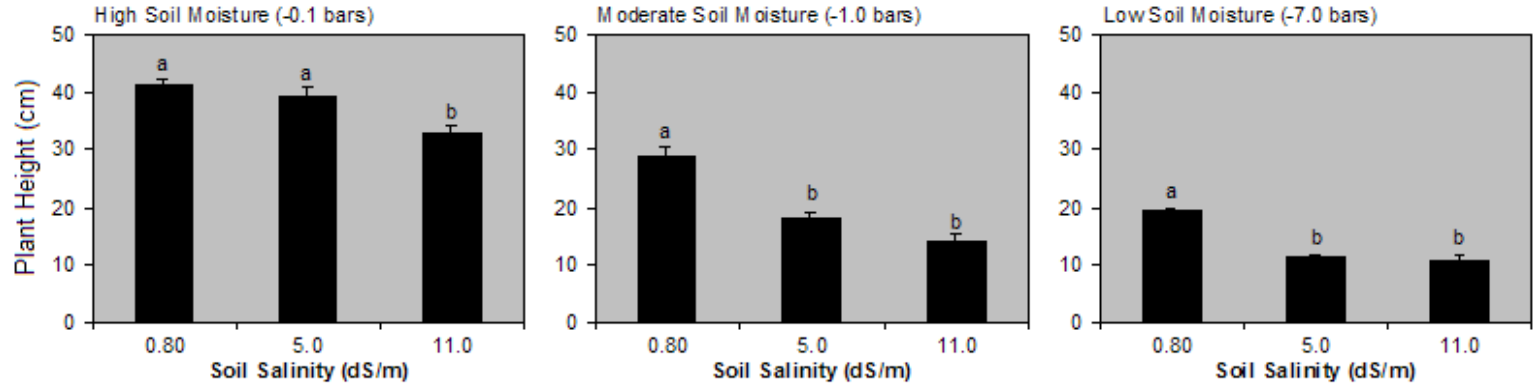


Figure 16. *Pseudoroegneria* height grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

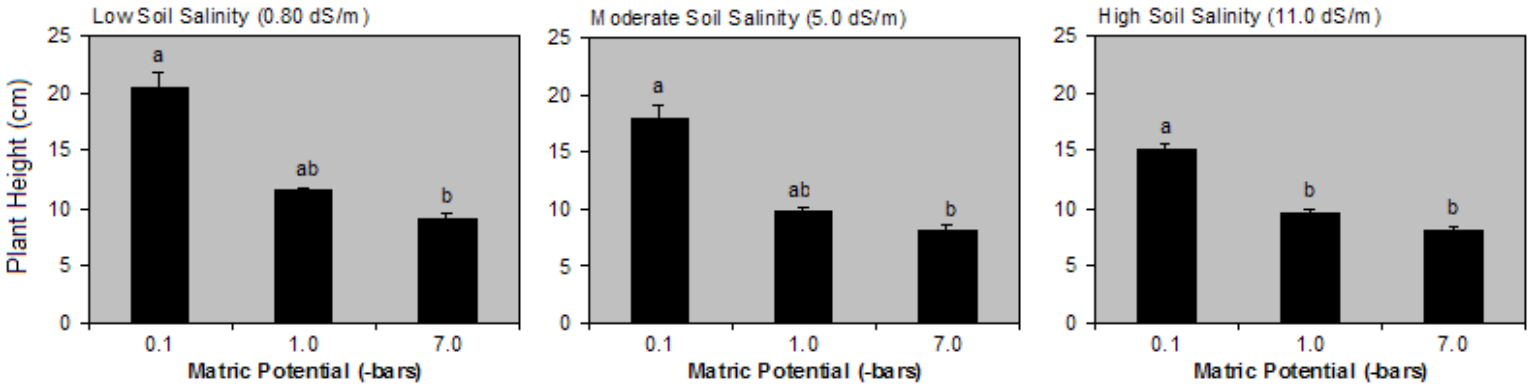


Figure 17. *Hesperostipa* height grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different (p>0.05). Error bars represent standard error.

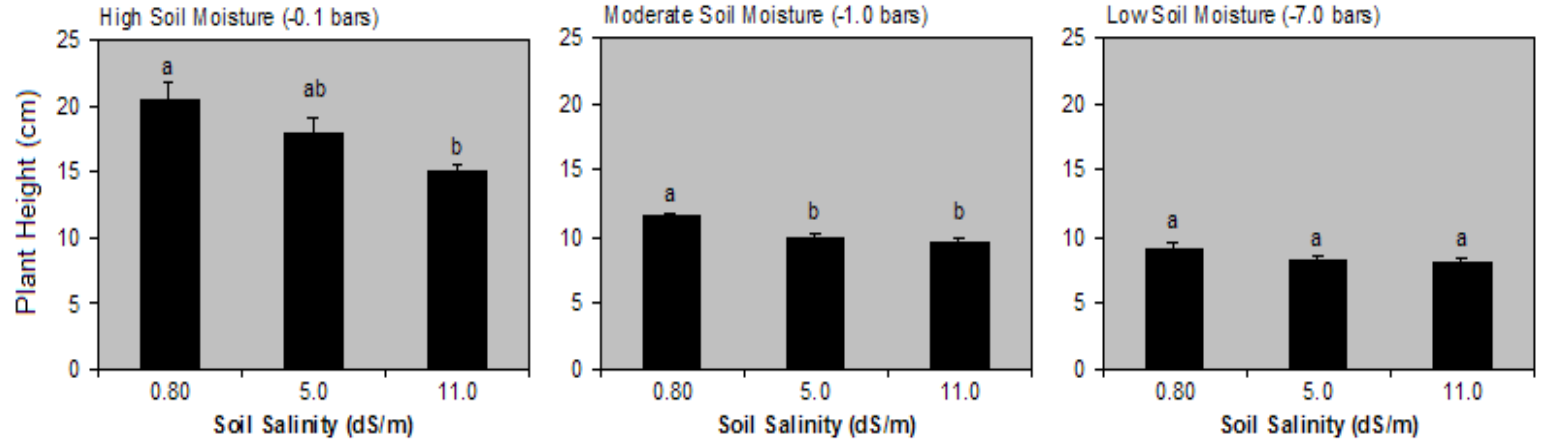


Figure 18. *Hesperostipa* height grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different (p>0.05). Error bars represent standard error.

statistically significant between the high and low moisture treatments, with average plant heights doubling with high soil moisture. At high salinity, matric potential also influenced plant height, with plants growing in moderate and low soil moisture having statistically similar heights, and greater heights under high soil moisture. Again, plants with high soil moisture were almost double the height of those with low soil moisture when grown in highly saline soil.

Figure 18 shows graphs of *Hesperostipa* plant heights grouped according to soil moisture treatment. When grown in high soil moisture, plant height was different between low and high salinity treatments. Plant height was statistically similar between low and moderate salinity, and between moderate and high salinity. At moderate soil moisture, plants were taller under low soil salinity, with plant height remaining similar under both moderate and high soil salinity (Figure 19). At low soil moisture, soil salinity did not affect *Hesperostipa* plant height, with similar heights among the three soil salinity treatments.

Pascopyrum Figure 19 shows graphs of *Pascopyrum* plant height grouped according to soil salinity treatment. Plants growing in low salinity soil showed significant reductions in plant height among all three soil moisture treatments. Mean height in the low salinity/high soil moisture treatment was over three times larger than the low salinity/low soil moisture treatment. This trend was observed across soil moisture treatments regardless of soil salt content, with mean plant height decreasing with a decrease in soil moisture.

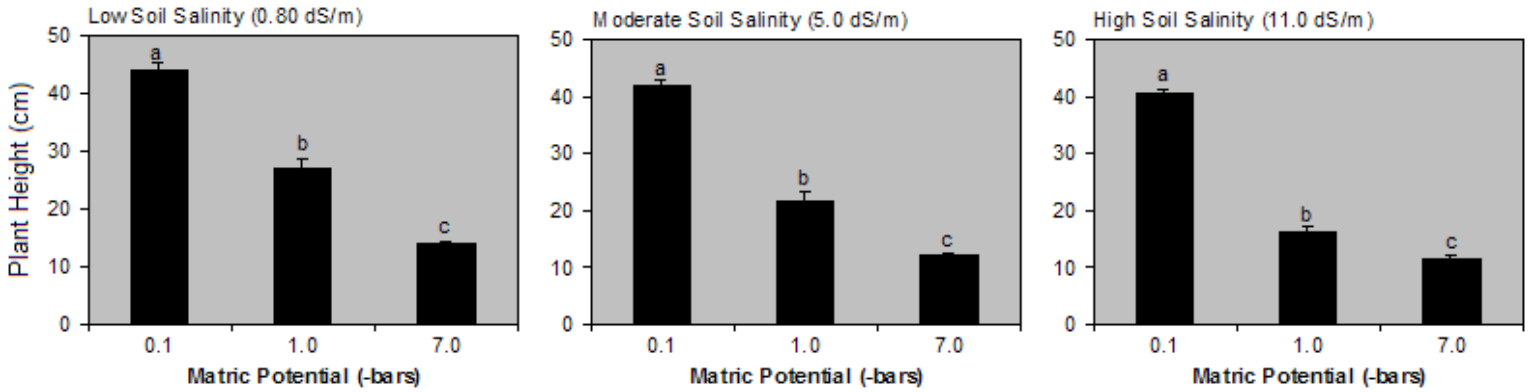


Figure 19. *Pascopyrum* height grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different (p>0.05). Error bars represent standard error.

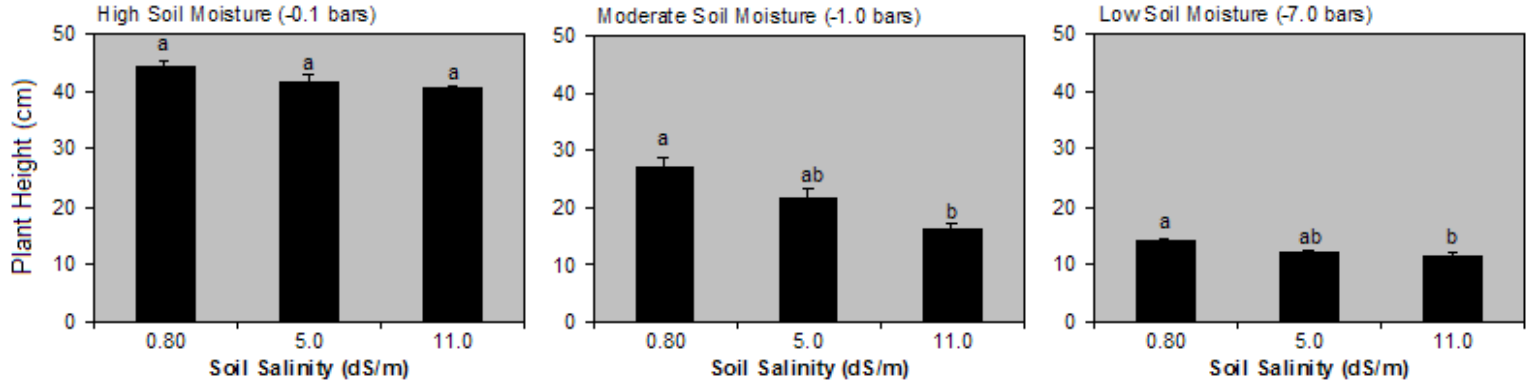


Figure 20. *Pascopyrum* height grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different (p>0.05). Error bars represent standard error.

Figure 20 shows graphs of *Pascopyrum* plant height grouped according to soil moisture treatment. At high soil moisture, mean plant height was statistically similar across all three salinity treatments. At moderate soil moisture, mean plant height was similar between low and moderate soil salinity, and between moderate and high soil salinity. A significant height reduction was seen between low and high salinity only. A similar trend was observed in plants grown under low soil moisture treatments, with similar mean plant heights observed between low and moderate salinity, as well as between moderate and high salinity. A significant height reduction was seen between low and high salinity only.

Plant Height Correlation Results

The Spearman Rank Order Correlation test was performed to compare plant height to both soil salinity and matric potentials. Results are presented in Table 11. Across all three species, the Spearman correlation coefficient (rs) for soil salinity was negative, suggesting a negative correlation exists between plant height and salinity. As soil salinity increases, plant height decreases. Soil matric potential produced positive rs values, indicating a positive correlation between plant height and matric potential. As matric potential values increase, so does plant height. For all three species, greater correlations were produced between plant height and matric potential, indicated by significant rs values closer to ±1.

The correlation analysis affirms the ANOVA results discussed above. In this study, mean plant height often remained similar among matric potential treatments,

Table 11. Results of Spearman Rank Order Correlation comparing plant height to soil salinity and matric potential.

Species	Dependent Variable	Independent Variable	rs	P value
Pseudoroegneria	Plant Height	Soil salinity	-0.41	<0.0001
	Plant Height	Matric potential	0.81	<0.0001
Hesperostipa	Plant Height	Soil salinity	-0.26	0.0259
	Plant Height	Matric potential	0.87	<0.0001
Pascopyrum	Plant Height	Soil salinity	-0.22	0.0656
	Plant Height	Matric potential	0.92	<0.0001

regardless of soil salinity. While greater soil salinity produced some significant reductions in plant height, the majority of significant decreases were observed with declining soil moisture. Decreasing soil moisture also produced larger reductions in plant height. Because plant height is a result of water uptake, reduced growth is seen under high salinity and low soil moisture, where water availability is most limited. Salts present on the soil affect plant growth through toxic and osmotic effects. The presence of abundant soil moisture allows plants to overcome such negative effects, likely resulting in similar plant heights in high and low salinity soils.

ANOVA Results for Aboveground Biomass

Pseudoroegneria Figure 21 shows graphs of *Pseudoroegneria* aboveground biomass grouped according to soil salinity treatment. At low soil salinity, *Pseudoroegneria* aboveground biomass was reduced under moderate and low soil

moisture conditions. Plants growing in low salinity/high soil moisture conditions had over eight times the aboveground biomass of those plants growing in low salinity/low soil moisture conditions. Plants growing in moderate soil salinity had significant reductions in aboveground biomass between high and low soil moisture. Plants growing in moderate salinity/high soil moisture conditions had over 20 times the mean aboveground biomass when compared to those plants growing in moderate salinity/low soil moisture conditions. Similarly, *Pseudoroegneria* growing in high salinity treatments decreased aboveground biomass with decreasing soil moisture. Significant reductions were seen under both moderate and low soil moisture conditions. Plants growing in high salinity/low soil moisture conditions had over 16 times the aboveground biomass of those plants growing in high salinity/low soil moisture conditions.

Figure 22 shows graphs of *Pseudoroegneria* aboveground biomass grouped according to soil moisture treatment. When comparing *Pseudoroegneria* aboveground biomass across soil moisture treatments, significant reductions with greater soil salinity are seen, although they are not as large as those seen under decreasing soil moisture. Under high soil moisture conditions, aboveground biomass was reduced with elevated soil salinity. Plants growing in low salinity/high soil moisture conditions had over twice the aboveground biomass compared with plants growing in high salinity/high soil moisture conditions. Under moderate soil moisture, plants growing in moderate and high salinity soils produced statistically similar aboveground biomass. Mean aboveground biomass was higher in low salinity soils, with *Pseudoroegneria* plants producing over

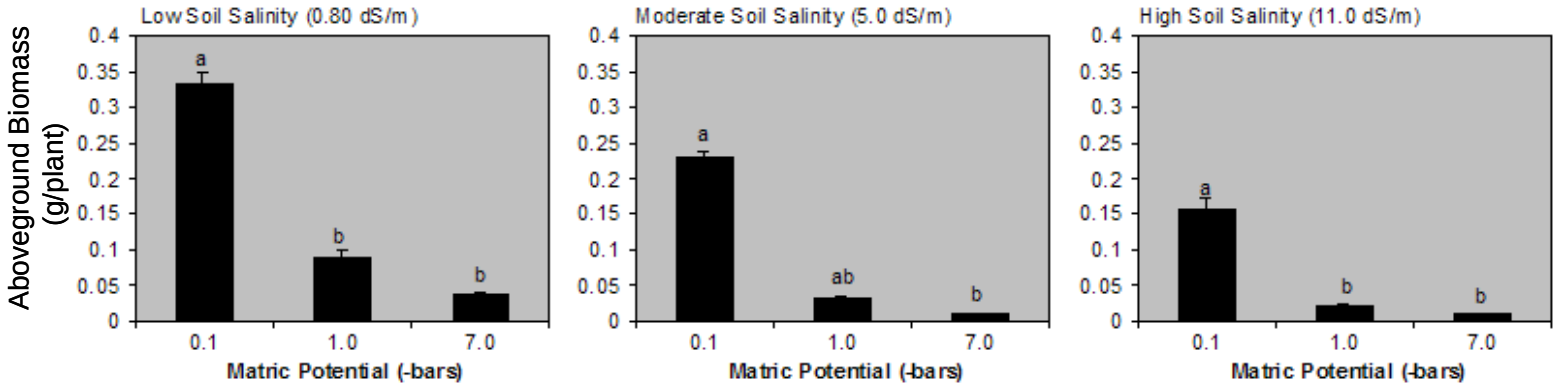


Figure 21. *Pseudoroegneria* aboveground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

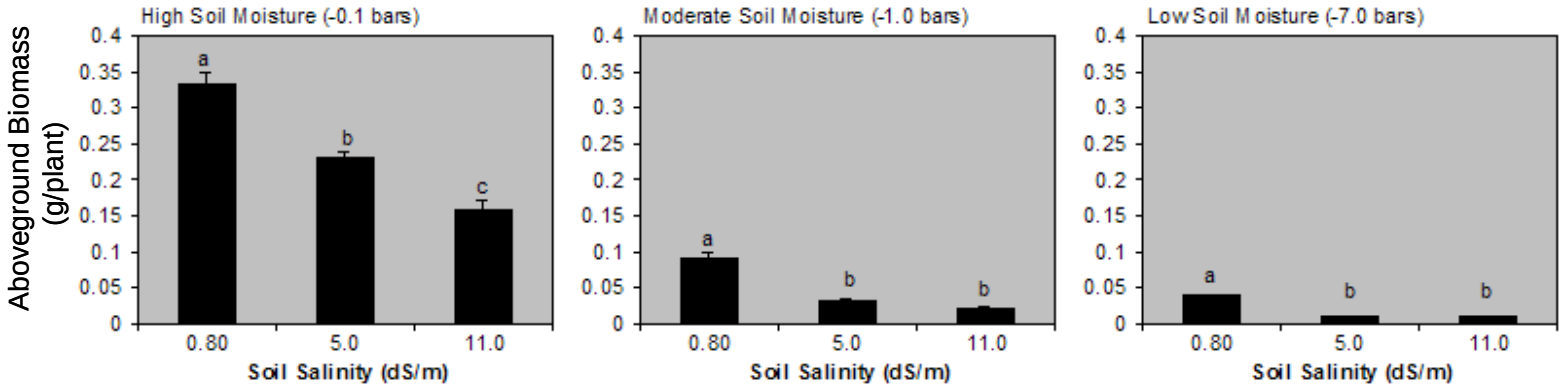


Figure 22. *Pseudoroegneria* aboveground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

four times the aboveground biomass of plants grown in soils with high salinity. Similar results were seen for plants growing in low soil moisture conditions. There was no difference in mean aboveground biomass for moderate and high salinity soils. Aboveground biomass increased over three times for plants grown in low soil salinity.

Hesperostipa Figure 23 shows graphs of *Hesperostipa* aboveground biomass grouped according to soil salinity treatment. At low soil salinity, *Hesperostipa* aboveground biomass was reduced between high and low soil moisture conditions. Plants growing in low salinity/high soil moisture conditions had over 16 times the aboveground biomass of those plants growing in low salinity/low soil moisture conditions. Plants growing in moderate soil salinity conditions also had large reductions in aboveground biomass as soil moisture decreased. *Hesperostipa* aboveground biomass was reduced under both moderate and low soil moisture conditions. Plants growing in moderate salinity/high soil moisture conditions had over nine times the mean aboveground biomass when compared to those plants growing in moderate salinity/low soil moisture conditions. Similarly, *Hesperostipa* growing in high salinity treatments decreased aboveground biomass with decreasing soil moisture. Significant decreases were seen under moderate and low soil moisture conditions. Plants growing in high salinity/low soil moisture conditions had over seven times the aboveground biomass of those plants growing in high salinity/low soil moisture conditions.

Figure 24 shows graphs of *Hesperostipa* aboveground biomass grouped according to soil moisture treatment. When comparing *Hesperostipa* aboveground biomass across

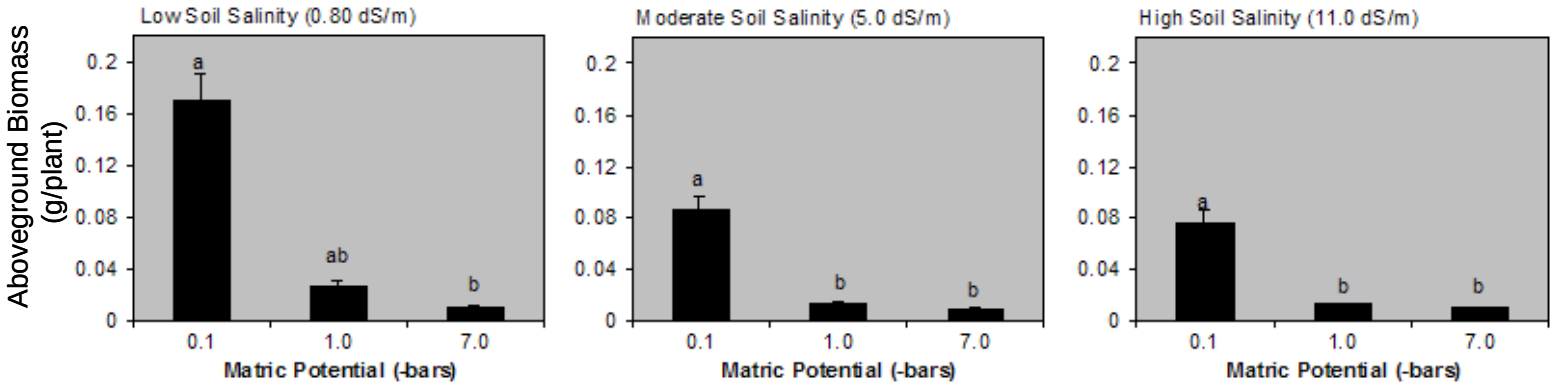
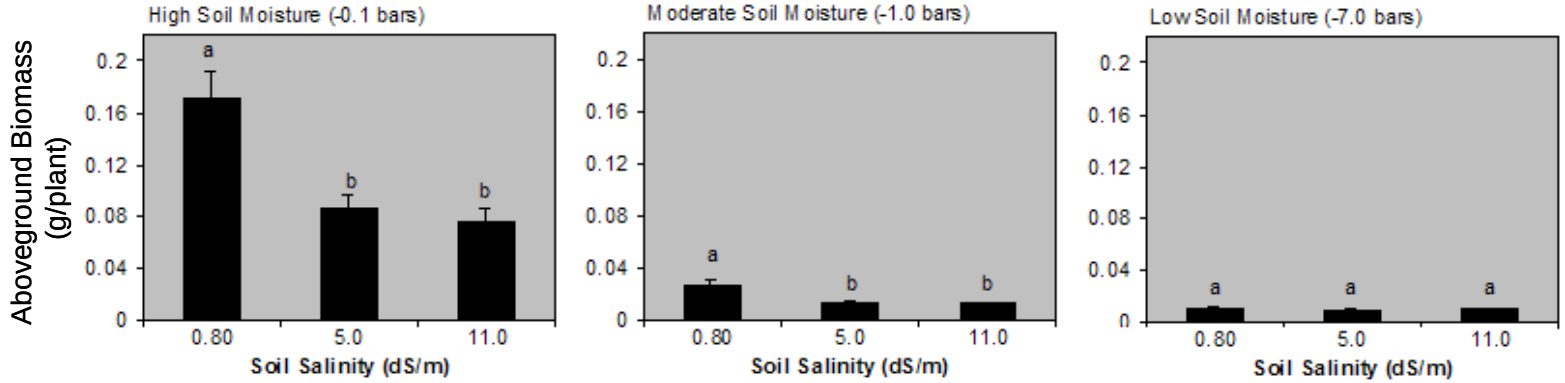


Figure 23. *Hesperostipa* aboveground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different (p>0.05). Error bars represent standard error.

Figure 24. *Hesperostipa* aboveground biomass grouped according to soil moisture treatment. Treatments within a specific



moisture treatment followed by the same letter are not significantly different (p>0.05). Error bars represent standard error.

soil moisture treatments, significant reductions with greater soil salinity are seen, although they are not as large as those seen under decreasing soil moisture. Under high soil moisture conditions, aboveground biomass was reduced with elevated soil salinity. Plants growing in moderate and highly saline soils had similar mean aboveground biomass. Aboveground biomass doubled for those plants growing in high salinity/high soil moisture conditions. Plants growing in moderate soil moisture conditions produced statistically similar aboveground biomass in both moderate and high salinity soils. Mean aboveground biomass was higher in low salinity soils, with *Hesperostipa* plants producing twice the aboveground biomass of plants grown in soils with moderate and high salinity. Plants growing in low soil moisture conditions produced similar mean aboveground biomass, regardless of soil salinity.

Pascopyrum Figure 25 shows graphs of *Pascopyrum* aboveground biomass grouped according to soil salinity treatment. At low soil salinity, *Pascopyrum* aboveground biomass was reduced between high and low soil moisture conditions. Plants growing in low salinity/high soil moisture conditions had over 27 times the aboveground biomass of those plants growing in low salinity/low soil moisture conditions. Plants growing in moderate soil salinity conditions also had large reductions in aboveground biomass as soil moisture decreased. Aboveground biomass was reduced between high and low soil moisture conditions. Plants growing in moderate salinity/high soil moisture conditions had over 37 times the mean aboveground biomass when compared to those plants growing in moderate salinity/low soil moisture conditions.

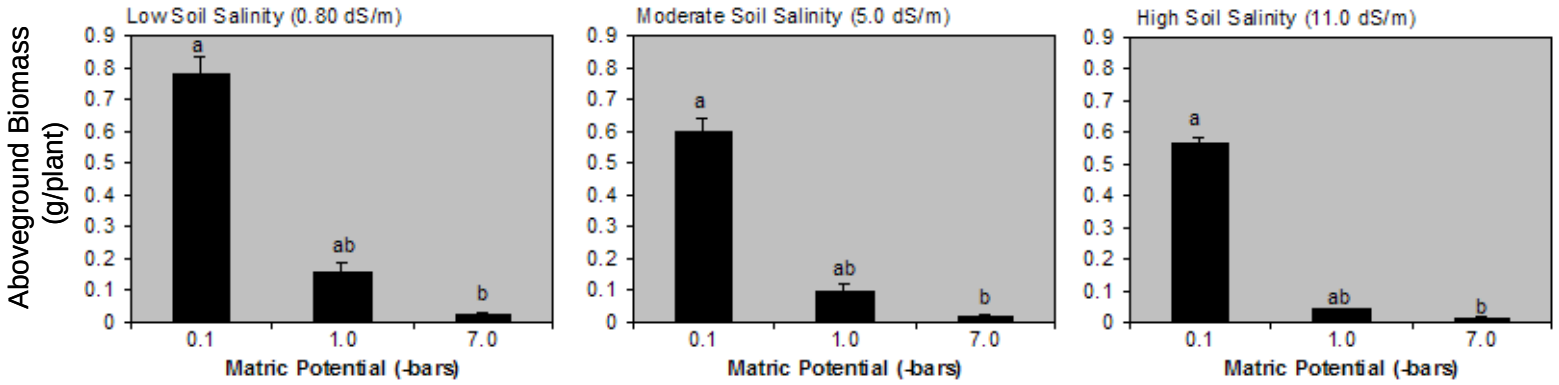
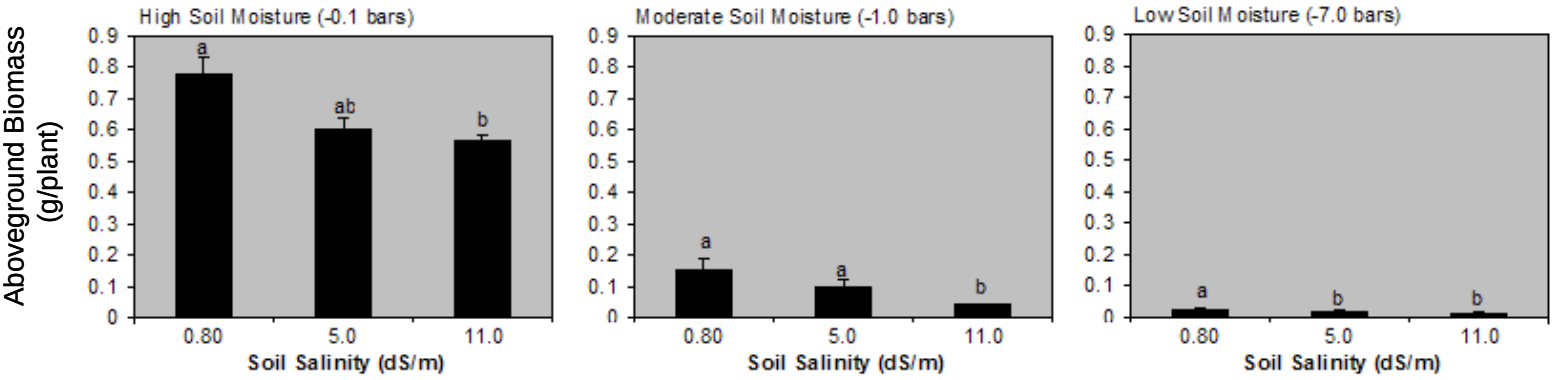


Figure 25. *Pascopyrum* aboveground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

Figure 26. *Pascopyrum* aboveground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

Similarly, *Pascopyrum* growing in high salinity treatments decreased aboveground biomass with decreasing soil moisture. Significant decreases were seen under salinity/low soil moisture conditions. Plants growing in high salinity/low soil moisture conditions had over 47 times the aboveground biomass of those plants growing in high salinity/low soil moisture conditions.

Figure 26 shows graphs of *Pascopyrum* aboveground biomass grouped according



to soil moisture treatment. Comparing *Pascopyrum* aboveground biomass across soil moisture treatments, significant reductions with greater soil salinity are seen, although they are not as large as those seen under decreasing soil moisture. Under high soil moisture conditions, aboveground biomass was reduced between low and high soil salinity. Plants growing in low salinity/high soil moisture conditions had slightly more (1.4 times) the aboveground biomass compared with plants growing in high salinity/high soil moisture conditions. Under moderate soil moisture, plants growing in low and moderate salinity soils produced statistically similar aboveground biomass. Mean

aboveground biomass was higher in low salinity soils, with *Pascopyrum* plants producing over four times more aboveground biomass as compared to plants grown in soils with high salinity. Plants growing in low soil moisture conditions produced similar mean aboveground biomass in moderate and high salinity soils. Aboveground biomass increased for plants grown in low soil salinity.

Aboveground Biomass Correlation Results

The Spearman Rank Order Correlation test was performed to compare aboveground biomass to both soil salinity and matric potentials. Results are presented in Table 12. Across all three species, the Spearman correlation coefficient (rs) for soil salinity was negative, suggesting a negative correlation exists between aboveground biomass and salinity. As soil salinity increases, aboveground biomass decreases. Soil matric potential produced positive rs values, indicating a positive correlation between aboveground biomass and matric potential. As matric potential values increase, so does aboveground biomass . For all three species, greater correlations were produced between aboveground biomass and matric potential, indicated by significant rs values closer to ±1. This suggests that aboveground biomass is more strongly correlated with soil moisture. The correlation analysis affirms the ANOVA results discussed above. While greater soil salinity produced many significant reductions in aboveground biomass, decreases produced by declining soil moisture were much larger, reaching over 20 orders of magnitude for *Pseudoroegneria* and over 40 orders of magnitude for *Pascopyrum*.

Table 12. Results of Spearman Rank Order Correlation comparing aboveground biomass to soil salinity and matric potential.

Species	Dependent Variable	Independent Variable	rs	P value
Pseudoroegneria	Aboveground Biomass	Soil salinity	-0.43	<0.0001
	Aboveground Biomass	Matric potential	0.84	<0.0001
Hesperostipa	Aboveground Biomass	Soil salinity	-0.21	0.0845
	Aboveground Biomass	Matric potential	0.90	<0.0001
Pascopyrum	Aboveground Biomass	Soil salinity	-0.27	0.0237
	Aboveground Biomass	Matric potential	0.93	<0.0001

These results are similar to those seen for plant height, and are also likely due to 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 the uptake of both water and nutrients, thus producing more robust grasses. Very large increases in biomass were often the result of greater soil moisture, regardless of soil salinity.

In this study, the aboveground biomass of plants often varied in soils containing the same salt content. Small and robust grasses could be produced in soils of similar salinity by manipulating soil moisture. Such findings have implications for those investigators studying soil salinity and plant growth. Results may be easily biased by selecting only one moisture regime, or by not elucidating the moisture regime used in the study. Therefore, investigators studying plant responses to soil salinity must consider the importance of soil moisture and discuss the 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. Aboveground biomass is an especially important variable to consider during reclamation of rangelands, as maximum forage production is desired. Considering the results in this study, irrigation will be an important factor when remediating disturbed areas affected by high soil salinity.

ANOVA Results for Belowground Biomass

Pseudoroegneria Figure 27 shows graphs of *Pseudoroegneria* belowground biomass grouped according to soil salinity treatment. For treatments with low soil

salinity, plants grown in moderate and low soil moisture were statistically similar in respect to belowground biomass, and produced lower biomass than plants grown in high soil moisture. Plants grown in low salinity/high moisture conditions had over five times the root mass of plants grown in low salinity/low moisture conditions. *Pseudoroegneria* grown in soil with moderate salinity also had significant decreases in belowground biomass under moderate and low soil moisture. Plants grown in moderate salinity/high moisture soils had over 15 times the belowground biomass compared with plants grown in moderate salinity/low moisture soils. For the high salinity treatments, plants grown in moderate and low soil moisture were statistically similar, and also had lower mean belowground biomass. Plants grown in the high salinity/high moisture treatments had over 14 times the mean root mass compared with plants grown in high salinity/low soil moisture conditions.

Figure 28 shows graphs of *Pseudoroegneria* belowground biomass grouped according to soil moisture treatment. At high soil moisture, belowground biomass was similar in moderate and high salinity soils, and was higher in soils with low salinity. Plants grown in high moisture/low salinity conditions had almost three times the belowground biomass of those plants grown in high moisture/high salinity conditions. At moderate soil moisture, moderate and high salinity soil produced similar belowground biomass. Plants grown in moderate moisture/low salinity conditions had almost seven times the belowground biomass of those plants grown in moderate moisture/high salinity conditions. At low moisture, the moderate and high salinity soils again produced statistically similar belowground biomass. The low moisture/low salinity treatment

produced more belowground biomass, and over eight times the biomass of the low moisture/high salinity treatment.

Hesperostipa Figure 29 shows graphs of *Hesperostipa* belowground biomass grouped according to soil moisture treatment. For treatments with low soil salinity, plants grown in moderate and low soil moisture were statistically similar in respect to belowground biomass, with lower biomass than plants grown in high soil moisture. Plants grown in low salinity/high moisture conditions had over eleven times the belowground biomass of plants grown in low salinity/low moisture conditions. *Hesperostipa* grown in soil with moderate salinity also had decreases in belowground biomass under moderate and low soil moisture. Plants grown in moderate salinity/high moisture conditions had more root mass, over six times that of plants grown in moderate salinity/low moisture conditions. Similar responses were observed in high salinity soils. Plants grown in high moisture soils had more root mass, and almost nine times the belowground biomass compared with plants grown in moderate salinity/low moisture soils.

Figure 30 shows graphs of *Hesperostipa* belowground biomass grouped according to soil moisture treatment. At high soil moisture, belowground biomass was similar in both moderate and high salinity soils, and was higher in soils with low salinity. *Hesperostipa* grown in high moisture/low salinity conditions had almost twice the belowground biomass of those plants grown in high moisture/high salinity conditions. At moderate soil moisture similar results were observed, with moderate and high salinity

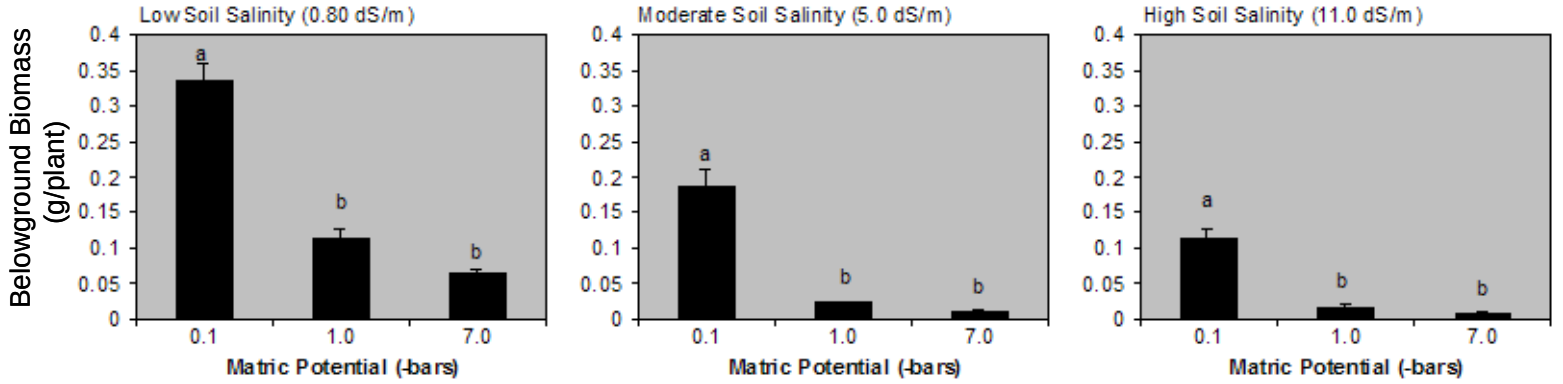


Figure 27. *Pseudoroegneria* belowground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

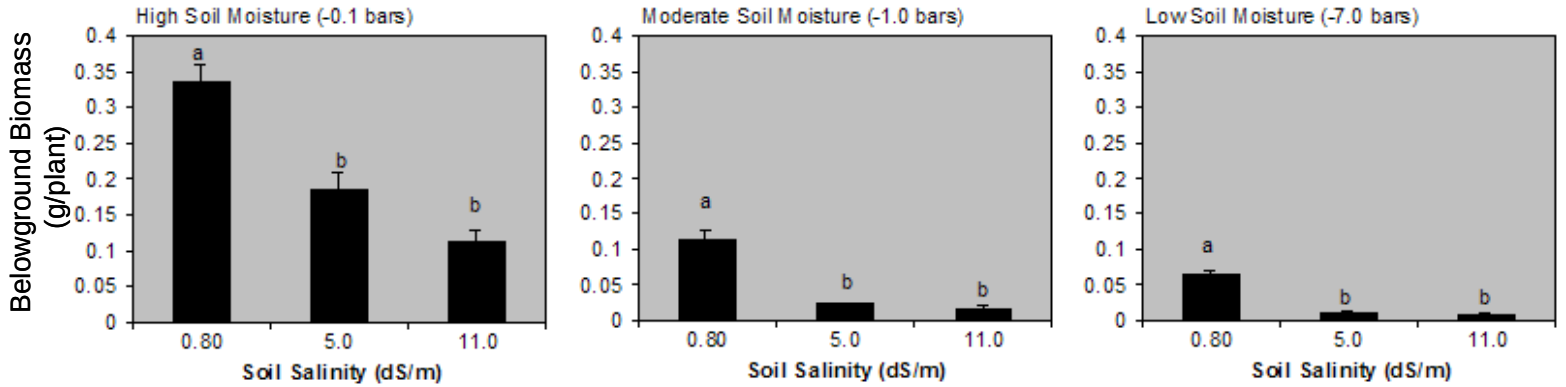


Figure 28. *Pseudoroegneria* belowground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

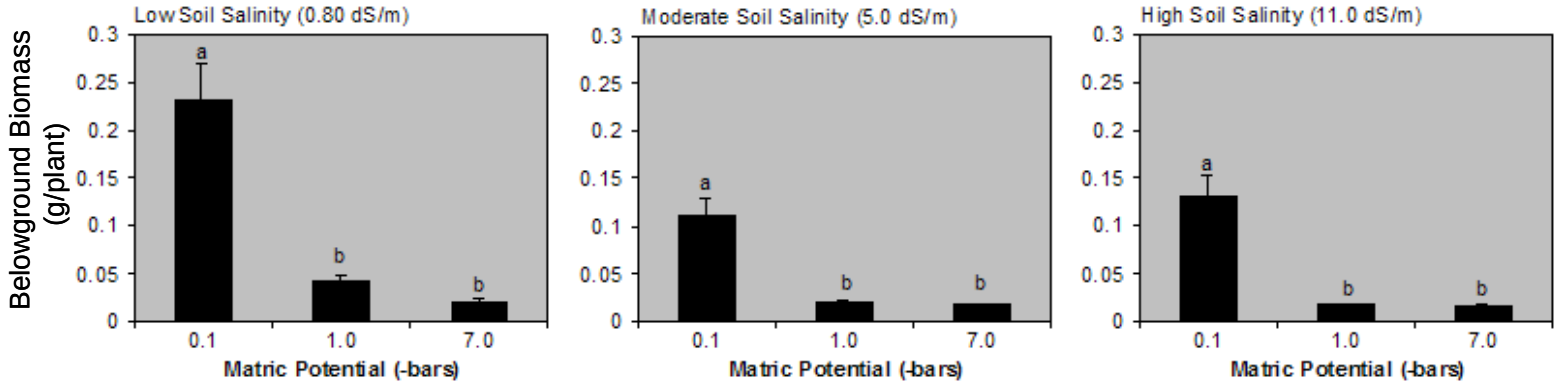


Figure 29. *Hesperostipa* belowground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

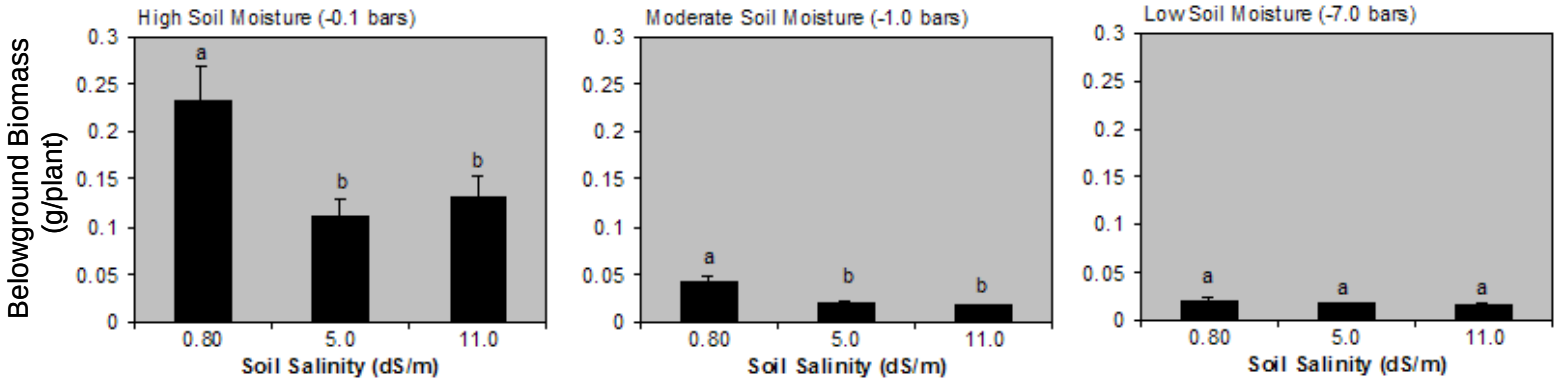


Figure 30. *Hesperostipa* belowground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

soil producing statistically similar belowground biomass. Plants grown in moderate moisture/low salinity conditions had twice the belowground biomass of those plants grown in moderate moisture/high salinity conditions. At low soil moisture, treatments produced similar mean belowground biomass, regardless of soil salinity.

Pascopyrum Figure 31 shows graphs of *Pascopyrum* belowground biomass grouped according to soil salinity treatment. For treatments with low soil salinity, plants grown in high and moderate soil moisture were statistically similar in respect to belowground biomass, and produced higher biomass than plants grown in low soil moisture. Plants grown in low salinity/high moisture conditions produced over eleven times the root mass of plants grown in low salinity/low moisture conditions. *Pascopyrum* grown in soil with moderate salinity showed significant decreases in belowground biomass between high and low soil moisture. Plants grown in moderate salinity/high moisture soils had over six times the belowground biomass compared with plants grown in moderate salinity/low moisture soils. For the high salinity treatments, plants grown in moderate and low soil moisture were statistically similar, and also had lower mean belowground biomass than those plants grown in high moisture conditions, which had almost nine times the root mass of the other treatments.

Figure 32 shows graphs of *Pascopyrum* belowground biomass grouped according to soil moisture treatment. When evaluating belowground biomass grouped according to soil moisture treatment, decreasing mean belowground biomass with greater soil salinity

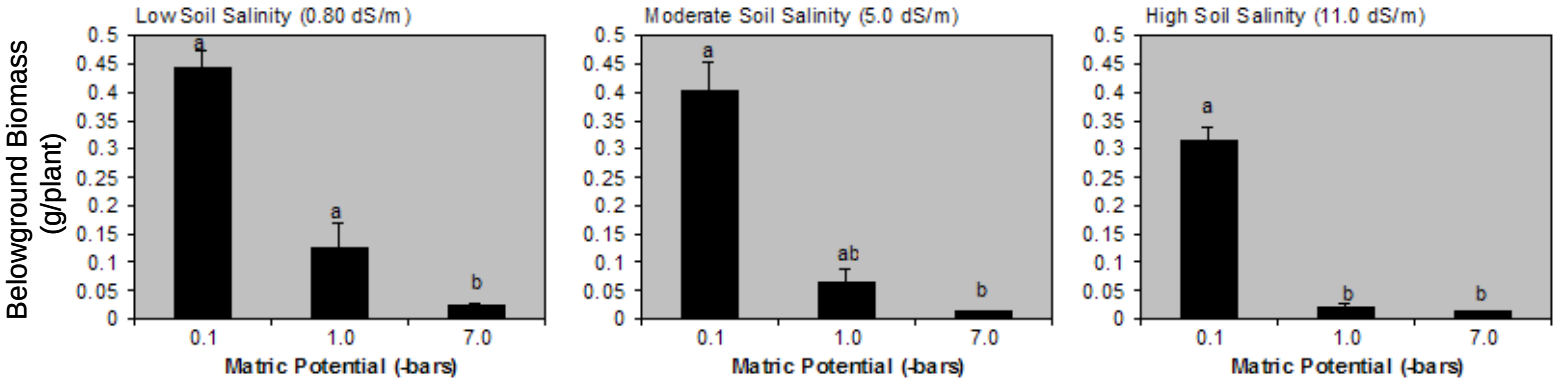


Figure 31. *Pascopyrum* belowground biomass grouped according to salinity treatment. Treatments within a specific salinity followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

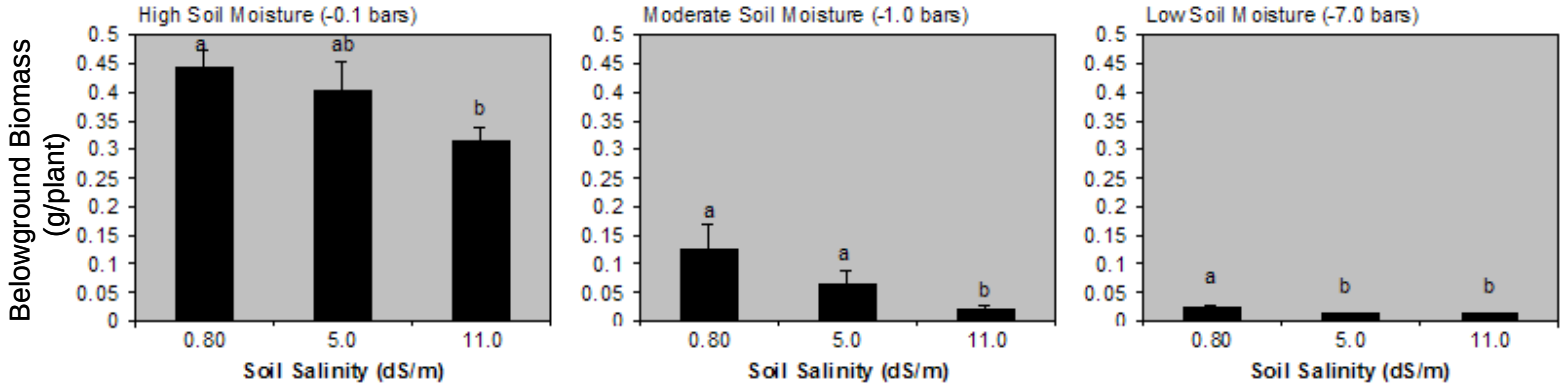


Figure 32. *Pascopyrum* belowground biomass grouped according to soil moisture treatment. Treatments within a specific moisture treatment followed by the same letter are not significantly different ($p>0.05$). Error bars represent standard error.

was the overall trend. At high soil moisture, belowground biomass was different between low and high salinity treatments. At moderate soil moisture, moderate and high salinity soils produced similar belowground biomass, with a significant decrease in biomass in high salinity soils. Plants grown in moderate moisture/low salinity conditions had almost three times the belowground biomass of those plants grown in moderate moisture/high salinity conditions. At low soil moisture, the moderate and high salinity soils again produced statistically similar belowground biomass, with the low moisture/low salinity treatment producing more belowground biomass.

Belowground Biomass Correlation Results

The Spearman Rank Order Correlation test was performed to compare belowground biomass to both soil salinity and matric potentials. Results are presented in Table 13. Across all three species, the Spearman correlation coefficient (rs) for soil salinity was negative, suggesting a negative correlation exists between belowground biomass and salinity. As soil salinity increases, belowground biomass decreases. Soil matric potential produced positive rs values, indicating a positive correlation between belowground biomass and matric potential. As matric potential values increase, so does belowground biomass . For all three species, greater correlations were produced between belowground biomass and matric potential, indicated by rs values closer to ± 1, as well as consistent p-values of 0.000. This suggests that belowground biomass is more strongly correlated with soil moisture.

Table 13. Results of Spearman Rank Order Correlation comparing belowground biomass to soil salinity and matric potential.

Species	Dependent Variable	Independent	rs	P value
Pseudoroegneria	Belowground biomass	Soil salinity	-0.54	<0.0001
	Belowground biomass	Matric potential	0.74	<0.0001
Hesperostipa	Belowground biomass	Soil salinity	-0.28	0.0161
	Belowground biomass	Matric potential	0.78	<0.0001
Pascopyrum	Belowground biomass	Soil salinity	-0.31	0.0080
	Belowground biomass	Matric potential	0.87	<0.0001

The correlation analysis affirms the ANOVA results discussed above. While greater soil salinity produced many significant reductions in belowground biomass, reductions produced by declining soil moisture were much larger, reaching over fifteen orders of magnitude for *Pseudoroegneria* and over eleven orders of magnitude for *Hesperostipa* and *Pascopyrum*. These results are similar to those seen for aboveground biomass, although the decreases are smaller. Much like aboveground biomass, these results are 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 the uptake of both water an nutrients, thus producing more robust roots. In turn, the greater production of root mass facilitates even more water uptake, giving those plants growing in high soil moisture conditions the largest advantage. Belowground biomass is an important variable to consider during reclamation of rangelands, as maximum water uptake is required to maximize forage

production. Greater root production is also beneficial due to fine roots contributing to both soil organic matter and greater water retention in upper soil profiles.

Impacts of Salinity and Soil Moisture on Grass Species

Changes in Seedling Emergence

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 assigned a zero percent change. Mean emergence under the other eight treatments was compared to this "optimal" mean emergence to produce a percent change (Table 14).

At elevated soil salinity, 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 at greater soil salinity. At moderate soil moisture, emergence decreased by as much as 36.3 percent at a salinity of 11.0 dS/m. Decreases in emergence were largest under low soil moisture, with high salinity reducing emergence up to 88.3 percent. Across all three species, treatments with elevated salinity produced increases in emergence when soil moisture was high. This is likely due to an abundance of water near the soil surface which encouraged germination. It is also likely that modest salinity may enhance germination f these species. At moderate and low soil moisture, elevated salinity produced decreases in emergence. Of the three species, *Pascopyrum* emergence appeared to be least affected by greater salinity,

Table 14. Percent change in seedling emergence as a function of soil salinity and matric potential.

EC (dS/m)	Matric Potential (bars)		
	-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] Emergence under low salinity (0.80 dS/m) and high soil moisture (-0.1 bar matric potential) is considered optimal and is assigned zero percent change.

with losses of 42.1 % when salinity was high and soil moisture was low. Both *Pseudoroegneria* and *Hesperostipa* experienced seedling emergence losses in excess of 80 % 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. The results for *Hesperostipa* emergence can be used as an example (Table 14). When observing seedling emergence under high soil moisture conditions, elevated soil salinity appears to have no negative impact whatsoever. An investigator studying salt tolerance

would conclude that *Hesperostipa* was a tolerant species if emergence was studied under such conditions. However, by decreasing soil matric potential to -7.0 bars, large decreases in emergence are observed, with losses ranging from 61.7 to 88.3 %. We would no longer conclude that *Hesperostipa* is a salt tolerant species with such emergence losses, and possibly suggest the use of remediation techniques when trying to grow *Hesperostipa* on a disturbed soil with a salinity of 5.0 dS/m or greater.

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. For example, a study by Mer et al. (2000) reported that the germination of three study species was completely inhibited when soil salinity exceeded 4 dS/m. The moisture regime for this study included irrigation on alternate days with an undisclosed amount of water. Had this study been conducted hydroponically, or under moisture stress, entirely different conclusions may have been reached.

Changes in Aboveground Biomass For the three species studied, aboveground biomass 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 aboveground biomass under these conditions assigned a zero percent change. Mean aboveground biomass under the other eight treatments was compared to this "optimal" mean emergence to produce a percent change (Table 15).

At elevated soil salinity, grass species responded by decreasing aboveground biomass production. "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 at a soil salinity of 11.0 dS/m. At moderate soil moisture, greater 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 high soil moisture, *Pascopyrum* was least affected by elevated

Table 15. Percent change in aboveground biomass as a function of soil salinity and matric potential.

EC (dS/m)	**Matric Potential (-bars)**		
	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] Aboveground biomass under low salinity (0.80 dS/m) and high soil moisture (-0.1 bar matric potential) is considered optimal and is assigned zero percent change.

salinity. At moderate and low soil moisture, the three species responded with large

reductions in aboveground biomass, regardless of soil salinity. No species in particular stood out as being more salt tolerant when moisture was limiting.

These comparisons reinforce the importance of soil moisture's role in plant/salinity interactions. When assessing the loss in plant production as a function of soil salinity, soil moisture must be addressed because its manipulation creates wide variation in aboveground biomass.

For example, it is common to use hydroponic greenhouse methods to assess losses in plant production due to elevated salinity. Ippolito (1992) and Al-Wardy (1995) added salts to hydroponic solutions to create electrical conductivities ranging from 0.5 to 12.2 dS/m. Salinities of these hydroponic solutions were then transformed to reflect the salinity of a soil system. Ippolito (1992) concluded that threshold soil salinity levels for the grass species studied fell between 1.0 and 2.5 dS/m, with any increase beyond this point markedly decreasing production. Al-Wardy (1995) reported a 0.35 dS/m soil salinity threshold for two alfalfa cultivars, also with decreased production beyond that value. In such hydroponic studies, moisture stress is absent due to an abundance of water. Would we believe alfalfa to retain the reported salinity tolerance of 0.35 dS/m in an arid rangeland environment? Our results indicate production for any plant species growing in a saline soil will vary greatly with the amount of moisture present on the soil environment.

Questioning Threshold Salinity Levels Through study of soil salinity and plant response, investigators often report "loss in production" values, meaning that for every increase in soil salinity beyond a certain threshold value, there will be a loss in plant production. Decades of such studies have resulted in the generalized threshold level of 4.0 dS/m, a value at which plant production is believed to decrease significantly. However, findings of this study reject the idea of an unqualified threshold value, and reinforce the importance of soil moisture in determining the extent to which soil salinity will impact plant production.

For example, a study of plant salt tolerance may report that a certain grass species has a salinity tolerance of 3.0 dS/m. This type of conclusion leads the reader to believe that a lower salt content, such as 1.0 or 2.0 will have no impact on plant production. However, if the study that produced this threshold value was conducted at high moisture content, or if the moisture was not closely regulated, the actual effect of salinity on plant growth may be masked by an abundance of water.

Similarly, consider the circumstances of a land reclamation scientist assessing the impact of a highly saline (11.0 dS/m) soil on the growth of *Pseudoroegneria spicata*. A hydroponic greenhouse investigation may lead to the conclusion of a 50% reduction in aboveground production at a salinity level of 11.0 dS/m. This value is similar to the *Pseudoroegneria* production losses at 11.0 dS/m in this study when an abundance of water was present. However, accounting for losses in production as a function of soil moisture, there is the possibility of production losses in excess of 90% at a 11.0 dS/m salinity level under low moisture conditions.

In this study, plant responses to soil salinity were highly influenced by soil moisture, indicating that threshold salinity levels may not exist at all. It is most likely that any increase in soil salinity, from 0 dS/m to 30 dS/m will negatively impact plant growth, and that the severity of this impact may be manipulated via soil moisture content. If this is the case, many graphic portrayals of plant salinity tolerance contained in soil science textbooks, showing 100% relative productivity up to a specified threshold level, with decreases in productivity as salinity increases, may have limited validity (Figure 33).

Study No. 2: Response of Grass Species to Coversoil Depth Over a Saline Substrate

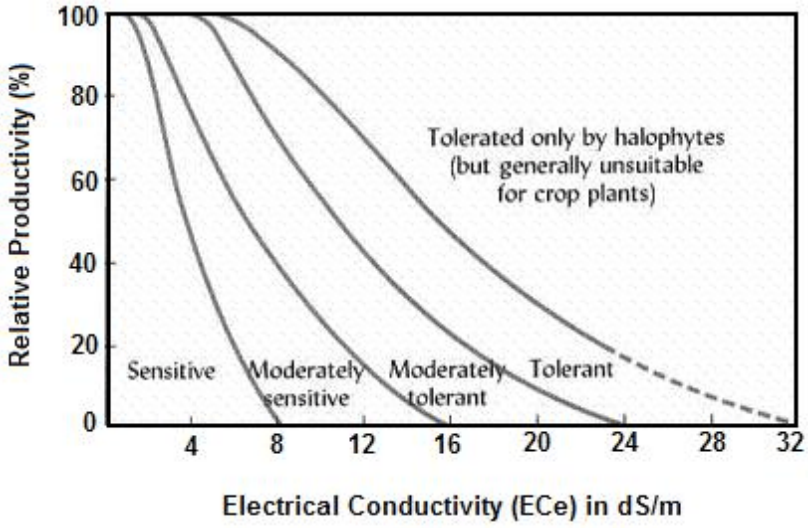
Emergence

For all three grass species studied, the percent emergence was statistically similar across all coversoil depths. Even the seeds sown directly into the saline substrate (EC_e =

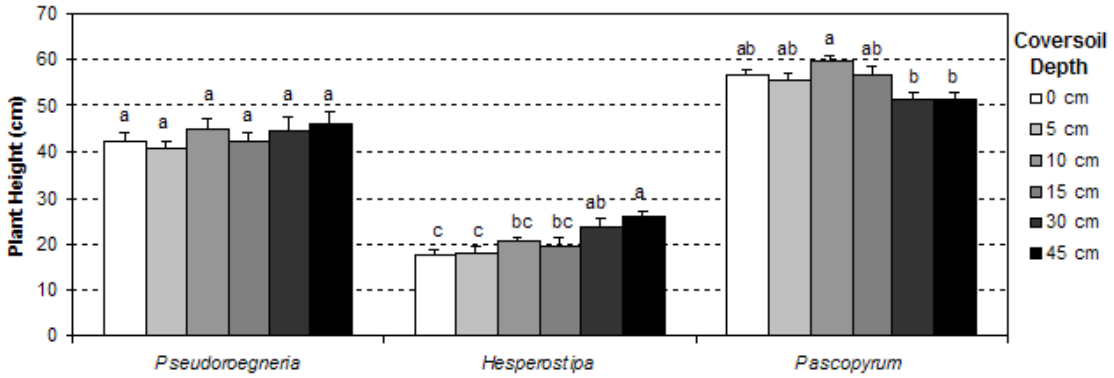
Figure 33. Relative productivity of plants as a function of increasing soil salinity. Generalized by Brady and Weil (1999) from data of Carter (1981).

11.0 dS/m), with no coversoil present, produced mean emergence percentages similar to, and often higher than, those sown into coversoil. Seeds respond to their immediate environment, with proper moisture and temperature conditions triggering germination and emergence. Therefore, conditions near the surface would contribute to seedling emergence, regardless of the depth of coversoil underlying them. Since water was applied at the surface throughout this study, this likely created an environment near the surface that contained adequate moisture, despite the salinity of the soil, resulting in uniform emergence across all six treatments. Additionally, it is possible that modest soil salinity, in the presence of soil moisture, enhanced the germination and emergence of these grass species.

Plant Height



Mean heights for *Pseudoroegneria* were statistically similar across all soil depths



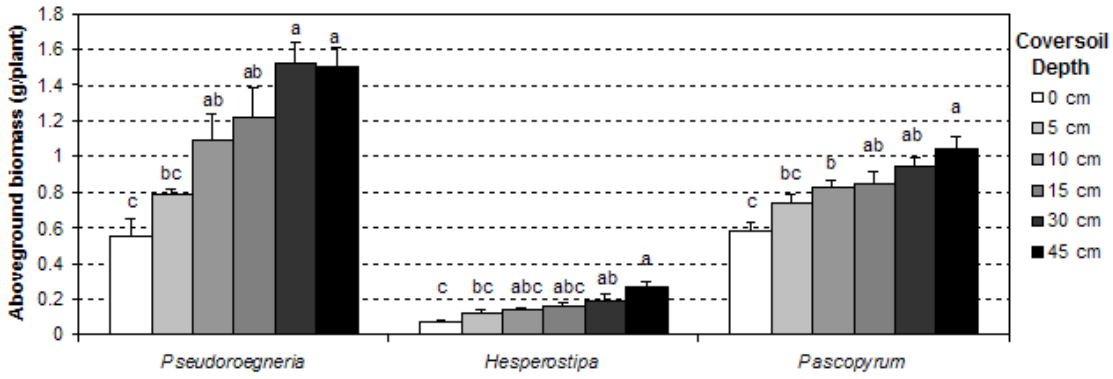
(Figure 34). Trends indicate *Pseudoroegneria* plant height was greatest for plants grown in 45 cm of coversoil, and least for plants grown in 5 cm.

Mean plant height for *Hesperostipa* was tallest in 45 cm of coversoil, and significantly taller than plants grown in 0, 5, 10, and 15 cm of coversoil (Figure 34). Mean height of plants grown in 30 cm of coversoil was the second tallest, and was similar to plants grown in 10, 15 and 45 cm of coversoil. *Hesperostipa* plants with the shortest mean height were found in tubes with 0 cm of coversoil, but were found to be similar to those plants grown in 5, 10 and 15 cm of coversoil.

Pascopyrum plants were tallest when grown in 10 cm of coversoil, and were taller than those plants grown in 30 and 45 cm of coversoil (Figure 34). However, plants grown in 10 cm of coversoil were of similar heights to those plants grown in 0, 5, and 15 cm of coversoil.

Figure 34. Means and standard error for plant height. Treatments within species followed by the same letter are not significantly different ($p>0.05$).

The evaluation of plant height as a function of coversoil produced varied results for the three species studies. Greater coversoil depth did not necessarily result in taller



plants. However, producing the tallest plants is not necessarily the goal in reclamation of rangelands and the establishment of high quality forage. As we will see in the subsequent evaluations of aboveground biomass production, the tallest plants are not always the most robust.

Aboveground Biomass

Pseudoroegneria plants produced an overall increase in aboveground biomass as coversoil depth increased. The 30 cm depth treatment produced the greatest mean aboveground biomass, with statistically similar results seen in plants grown in 10, 15 and 45 cm of coversoil (Figure 35). Lowest mean aboveground biomass was produced by

Figure 35. Means and standard error for aboveground biomass. Treatments within species followed by the same letter are not significantly different ($p>0.05$).

plants grown in 0 cm coversoil, which had less than half the aboveground biomass of plants grown in 30 cm coversoil. Similarly low biomass was produced by plants grown in 5 cm of coversoil.

Hesperostipa plants also produced an overall increase in aboveground biomass as coversoil depth increased (Figure 35). The 45 cm depth treatment produced the greatest mean belowground biomass, with statistically similar results seen in plants grown in 15 and 30 cm of coversoil. Lowest mean aboveground biomass was produced by plants grown in 0 cm coversoil, with plants producing less than one-third the aboveground biomass of plants grown in 45 cm coversoil. The results for plants grown in 5, 10 , and 15 cm coversoil depths were statistically similar to those plants grown in 0 cm coversoil..

Similar results were seen for *Pascopyrum*, with mean aboveground biomass also increasing with coversoil depth (Figure 35). Like *Hesperostip*a, the 45 cm depth treatment produced the greatest mean belowground biomass, with statistically similar results seen in plants grown in 15 and 30 cm of coversoil. Lowest mean belowground biomass was produced by plants grown in 0 cm coversoil, with similarly low results for plants grown in a 5 cm coversoil depth.

The results seen for aboveground biomass suggest that coversoil is necessary to improve grass production over a saline substrate. Plants grown in 0 cm of coversoil produced consistently low aboveground biomass, with greater biomass as the depth of coversoil increased. However, the maximum coversoil application may not be necessary to maximize forage production on disturbed rangelands. For the three species studied, coversoil depths of 15, 30 and 45 cm produced statistically similar results for aboveground biomass. Considering the costs involved in coversoil application, substantial time, soil resources and expense could be spared if, for example, a 30 cm cover was applied instead of 45 cm.

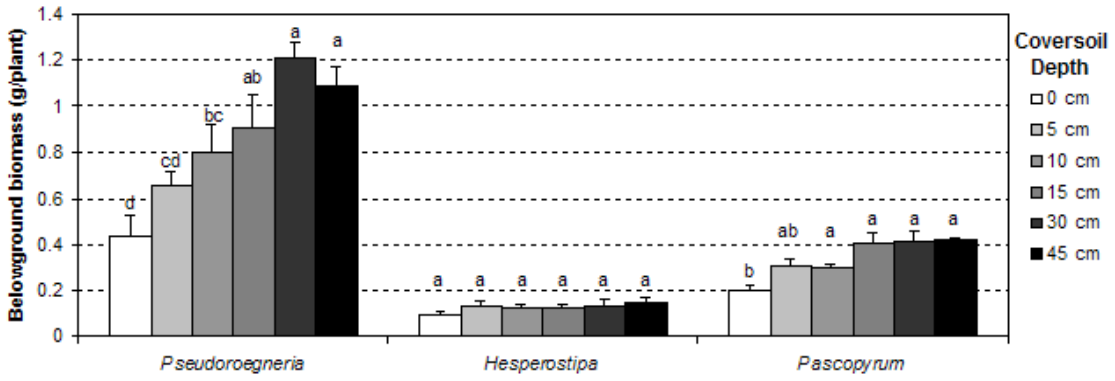


Figure 36. Means and standard error for belowground biomass. Treatments within species followed by the same letter are not significantly different ($p>0.05$).

Belowground Biomass

Pseudoroegneria belowground biomass was highest in 30 cm coversoil, and similar to biomasses produced in 15 and 45 cm of coversoil (Figure 36). Plants grown in 0 cm of coversoil had the lowest belowground biomass, less than half the production of plants grown in 30 cm coversoil. Belowground biomass in 0 cm coversoil was statistically similar to biomasses produced in 5 and 10 cm of coversoil.

Mean *Hesperostipa* belowground biomass production was similar across all treatments (Figure 36). Data trends indicate plants produced maximum mean belowground biomass when grown in 45 cm of coversoil, and lowest belowground biomass when grown in 0 cm coversoil (Figure 36). However, statistical analysis showed *Pascopyrum* mean belowground biomass was highest for plants grown in 45 cm of coversoil, and was statistically similar to biomasses produced in 5, 10, 15 and 30 cm of coversoil (Figure 36). Plants grown in 0 cm of coversoil had the lowest belowground biomass, a bit less than half the production of plants grown in 45 cm coversoil.

Belowground biomass in 0 cm coversoil was statistically similar to biomasses produced in 5 and 10 cm of coversoil.

Much like aboveground biomass, belowground results indicate that coversoil application improves root production for grasses grown over a saline substrate. Plants grown in 0 cm of coversoil produced consistently low aboveground biomass, with increased production as the depth of coversoil increased. Several studies reviewed suggested that root production was impacted by soil salinity to a lesser extent than shoot production (Maas and Hoffman 1977; Munns and Termaat 1986; Ramoliya and Pandey 2003). This was certainly the case for *Hesperostipa*, with statistically similar results reported for belowground biomass across all treatments. For those species showing a significant response to increased coversoil depth, the maximum coversoil application of 45 cm may not be necessary to maximize the root production and water uptake capabilities of grasses . For the three species studied, coversoil depths of 15, 30 and 45 cm produced statistically similar results for belowground biomass. These results agree with those seen for aboveground production, again suggesting that some expense may be spared through the application of a thinner coversoil layer such as 30 cm.

5. SUMMARY

In areas where land is disturbed to extract energy resources such as coalbed methane, improper soil management on drill pads may result in soil impaired by elevated salinity. The objectives of this study were to evaluate the emergence and growth of three grass species (*Pseudoroegneria spicata*, *Hesperostipa comata*, and *Pascopyrum smithii*) as a function of i) soil salt content and matric potential, and ii) coversoil depth overlying a saline substrate.

Study No. 1: Response of Grass Species to Soil Salinity and Soil Matric Potential

A greenhouse study was conducted to assess the growth of three range grasses as a function of soil salt content and soil 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 (-0.1to -1.0, -1.0 to -7.0, and less than -7.0 bars).

For the three grass species studied, seedling emergence, plant height, aboveground biomass, and belowground biomass decreased with increasing soil salinity and decreasing soil moisture. Greater soil salinity produced the largest reductions as soil moisture was decreased. Greater salinity caused as much as a 26.7 percent increase to a 88.3 percent decrease in seedling emergence, depending on soil moisture. Elevated salinity consistently lowered aboveground biomass production, with losses ranging from 27.3 to 98.5 percent at a soil salinity of 11.0 dS/m. These results suggest that the effects of elevated soil salinity on seedling emergence and growth are highly influenced by soil moisture. The importance of soil moisture was affirmed with a correlation analysis,

which showed matric potential to be more strongly correlated to seedling emergence and growth than soil salinity. It is likely that the presence of abundant soil moisture acts to mask the negative osmotic effects associated with elevated salinity.

Considering the results of this study, irrigation during emergence will be an important factor when remediating disturbed areas impacted by elevated soil salinity. By increasing the soil moisture content, emergence will increase and plants will be more robust. Aboveground production is an important factor to consider, especially during rangeland revegetation, as maximum forage is desired.

The results of this study also pertain to investigators studying soil salinity and plant growth. Apparently, soil moisture plays an integral role when evaluating the negative impacts of elevated soil salinity. Results may be easily biased through the selection of only one moisture regime, or by not thoroughly elucidating the moisture regime used in the study. Additionally, the designation of specific threshold levels for salt tolerance may be of limited value. It is doubtful that any threshold level is applicable outside of the moisture conditions used in the study. Therefore, it is crucial that investigators studying plant responses to soil salinity consider the importance of soil moisture and discuss its influences on study results.

Study No. 2: Response of Grass Species to Coversoil Depth Over a Saline Substrate

The objective of this study was to evaluate plant growth as a function of coversoil depth overlying a saline substrate. For this greenhouse study, a mixed substrate consisting of soil and geologic stratum was collected from a disturbed coalbed methane

drill pad. This material was salinized to an EC of 11.0 dS/m and placed in the bottom of PVC tubes. Non-saline coversoil was collected from nearby undisturbed rangeland, and was applied on top of the saline substrate at depths of 0, 5, 10, 15, 30 and 45 centimeters, for a total of six treatments. Three grass species were grown in the tubes, and evaluated for seedling emergence, plant height, aboveground biomass, and belowground biomass.

For each species, seedling emergence was statistically similar across all coversoil depths. In tubes containing coversoil, the soil immediately surrounding the seeds were not saline, resulting in similar emergence regardless of the depth of the underlying coversoil. In addition, similar emergence across treatments with and without coversoil was likely the result maintaining a high moisture content near the surface due to frequent surface water application.

Results for plant height varied across the three study species. Plant height was often similar across treatments, and a thicker coversoil application did not necessarily result in taller plants. However, the tallest plants were not always the most robust.

For the species studied, aboveground biomass and belowground biomass were consistently low when grown in 0 cm coversoil, with increased biomass as the depth of coversoil increased. For one species (*Hesperostipa*), root production was unaffected by coversoil depth, suggesting that elevated salinity may impact root production to a lesser extent than shoot production. Due to much statistical similarity between treatment means, there is no apparent ideal thickness for coversoil application. However, for each species, coversoil depths of 15, 30 and 45 cm produced statistically similar results for aboveground and belowground biomasses, indicating that the maximum application may

not be necessary to maximize production.

The substrate used in this study is indicative of an area where the soil resource has been lost due to mixing. The resulting substrate not only has elevated salinity, but has lost many properties such as structure and organic matter content in undisturbed soils. It is apparent that coversoil is necessary to improve grass production in areas where the soil resource has been lost due to disturbance. While 45 cm is commonly applied, this study suggests that similar plant performance may be achieved with a thinner coversoil layer such as 30 cm. A thinner application will also conserve soil resources, as well as spare thousands of dollars in expenses.

LITERATURE CITED

Adiku, S.G.K., M. Renger, G. Wessolek, M. Facklam, and C. Hecht-Bucholtz. 2001. Simulation of the dry matter production and seed yield of common beans under varying soil water and salinity conditions. Agric. Water Manag. 47:55-68.

Al-Wardy, M.M. 1995. Determination of salinity response of two alfalfa cultivars. M.S. Degree Thesis, Colorado State University. 134 p.

Anderson, D.W., 1977. Early stages of soil formation on glacial till mine spoils in a semi-arid climate. Geoderma 19:11-19.

ASA (American Society of Agronomy). 1982. Methods of Soil Analysis, Part 2-Chemical and Microbiological Properties, A.L. Page, (ed): Amer. Soc. Agron. And Soil Sci. Soc. Of America. Madison, WI. 2nd edition.

ASTM (American Society of Testing Materials). 1993. Standard practice for dry preparation of soil samples for particle-size analysis and determination of soil constants. Method D421-85.

Barth, R.C., and B.K. Martin. 1984. Soil depth requirements for revegetation of surface-mined areas in Wyoming, Montana and North Dakota. J. Environ. Qual. 13:399-404.

Bernstein, L., L.E. Francois, and R.A. Clark. 1974. Interactive effects of salinity and fertility on yields of grains and vegetables. Agron. J. 66:412-421.

Brady, N.C., and R.R. Weil. 1999. The Nature and Properties of Soils. Upper Saddle River, New Jersey: Prentice-Hall Inc.

Carter, D.L. 1981. "Salinity and Plant Productivity," in CRC Handbook Series in Nutrition and Food. Boca Raton, Florida: CRC Press.

Dancer, W.S., and I.J. Jansen. 1981. Greenhouse evaluation of solum and substratum materials in the southern Illinois coal field. I. Forage crops. J. Environ. Qual. 10:396-400.

Dunker, R.E., and R.I. Barnhisel. 2000. Cropland Reclamation. P. 323-369. *In* Barnhisel, R.I., R.G. Darmody, and W.L. Daniels (ed.) Reclamation of Drastically Disturbed Lands, Agronomy Monograph no. 41. Madison Wisconsin: American Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc.

Franklin, W.T., L.E. Sommers, R.K. Jump, E.G. Siemer, J.E. Cipra and R.E. Danielson.

1987. Salt tolerance study- Phase I. Summary, conclusions and recommendations of salt tolerance study. Colorado State University, Fort Collins.

Goldberg, D., and M. Schmueli. 1970. Drip irrigation: a method used under arid and desert conditions and soil salinity. Trans. Amer. Soc. Agr. Eng. 13(1):38-41.

Grandt, A.F. 1978. Reclaiming mined land in Illinois for row crop production. J. Soil Water Conserv. 33:242-244.

Ippolito, J.A. 1992. Determination of salinity threshold levels for selected grass and legume forage species. M.S. Degree Thesis, Colorado State University. 95 p.

Jones, C. and J. Jacobsen. 2004. Phosphorus cycling, testing and fertilizer recommendation. Nutrient Management Module, Montana State University Extension Service, Bozeman.

Keammerer W.R., D. Arthur and A. Keunstling. 1992. Anaconda Longterm Vegetation Monitoring Project 1988-1990 Smelter Hill and Butte Sites. Keammerer Ecological Consultants Inc., Boulder, CO. Report prepared for ARCO, Anaconda, MT.

Killham, K. 1994. Soil Ecology. Cambridge, NY: Cambridge University Press.

Kramer, P.J., 1983. Water Relations of Plants. New York: Academic Press.

Lichthardt, J.J. and J.S. Jacobsen. 1992. Fertilizer guidelines for Montana. Extension Service, EB 104. Montana State University, Bozeman.

Maas, E.V. and N.C. Hoffman. 1977. Crop salt tolerance - current assessment. J. Irrig. Drain. Div., Amer. Soc. Civil Eng. 103 (IR2):115-134.

Maas, E.V. 1986. Salt tolerance of plants. Applied Agric. Res. 1:12-26. Springer-Verlag, New York.

Mer, R.K., P.K. Prajith, D.H. Pandya, and A.M Pandey. 2000. Effect of salts on germination of seeds and growth of young plants of *Hordeum vulgare*, *Triticum aestivum*, *Cicer arietinum*, and *Brassica juncea*. J. Agron. and Crop Science. 185:209-217

Munns, R., and A. Termaat. 1986. Whole plant responses to salinity. Aust. J. Plant Physiol. 13:143-60.

Munshower, F.F. 1998. Grasses and grasslike species for revegetation of disturbed lands in the Northern Great Plains and adjacent areas with comments about some

wetland species. Reclamation Research Unit Publication No. 9805. Montana State University. Bozeman, MT.

Palmer, R.G., and F.R. Troeh. 1995. Introductory soil science laboratory manual, 3rd edition. Oxford University Press, New York.

Power, J.F., F.M. Sandoval, R.E. Ries, and S.D. Merril. 1981. Effects of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. Soil Sci. Soc. Am. J. 45:124-129.

Ramoliya, P.J., and A.N. Pandey. 2003. Effect of salinization of soil on emergence, growth and survival of seedlings of *Cordia rothii*. Forest Ecol. Manage. 176:185-94.

Richards, L.A. (ed.). 1969. Diagnosis and Improvement of Saline and Alkali Soils. Agricultural Handbook No. 60. United States Department of Agriculture, Washington D.C.

Sandoval, F.M., J.J. Bond, J.F. Power, and W.O. Willis. Lignite mine spoils in the Northern Great Plains - characteristics and potential for reclamation. p. 1-24. *In* M.K. Wali (ed.) Some environmental aspects of stripmining in North Dakota. North Dakota Geological Survey Educational Series 5.

Schafer, W.M., G.A. Nielsen, and W.D. Nettleton. 1980. Minesoil genesis and morphology in a spoil chronosequence in Montana. Soil Sci. Soc. Am. J. 44:802-807.

Sencindiver, J.C., and J.T. Ammons. 2000. Minesoil genesis and classification. p. 595-613. *In* Barnhisel, R.I., R.G. Darmody, and W.L. Daniels (ed.) Reclamation of Drastically Disturbed Lands, Agronomy Monograph no. 41. Madison Wisconsin: American Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc.

Sepaskhah, A.R. 1977. Effects of soil salinity levels and plant water stress at various soybean growth stages. Can. J. Plant Sci. 57:925-27.

Sigma Stat. (1997). Software Program. Jandel Scientific. San Rafael, CA.

Sobek, A.A., J.G. Skousen, and S.E. Fisher, Jr. 2000. Chemical and physical properties of overburdens and minesoils. p. 77-104. *In* Barnhisel, R.I., R.G. Darmody, and W.L. Daniels (ed.) Reclamation of Drastically Disturbed Lands, Agronomy Monograph no. 41. Madison Wisconsin: American Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc.

Swartz, E. 2004. Testimony submitted on September 4th to the: Committee on Resources, Subcommittee on Energy and Resources, 1626 Longworth HOB, Washington, D.C., 20515. Powder River Basin Resource Council Press Release, available at http://www.powderriverbasin.org/press_releases/swartz_testemony.shtml.

Troeh, F.R., and L.M. Thompson. 1993. Soils and Soil Fertility, 5th edition. New York, NY: Oxford University Press.

Ulery, A.L., J.A. Teed, M.T. van Gnuchten, and M.C. Shannon. 1998. SALTDATA: A Database of Plant Yield Response to Salinity. Agron. J. 90:556-562.

United States Congress. 1977. Surface Mining Control and Reclamation Act of 1977. PL-95-87.

United States Department of the Interior (USDI). 2003. Final Environmental Impact Statement and Proposal Plan Amendment for the Powder River Basin Oil and Gas Project. Bureau of Land Management. Wyoming State Office. Buffalo Field Office. 1425 Fort St. Buffalo, WY. 82834

Wadleigh, C.H., and A.D. Ayers. 1945. Growth and biochemical composition of bean plants as conditioned by soil moisture tension and salt concentration. Plant Physiology 20:106-32.

Wali, M.K., and P.G. Freeman. 1973. Ecology of some mined areas in North Dakota. p. 25-48. *In* M.K. Wali (ed.) Some environmental aspects of stripmining in North Dakota. North Dakota Geological Survey Educational Series 5.

APPENDICES

APPENDIX A

STUDY NO. 1: DATA AND STATISTICAL OUTPUT

Table 16. Emergence data (% per pot) for *Pseudoroegneria*.

	Treatment								
Replication	A	B	C	D	E	F	G	H	I
1	37.5	43.75	37.5	31.25	43.75	12.5	75	37.5	6.25
2	25	43.75	25	56.25	37.5	12.5	50	56.25	0
3	50	25	25	43.75	37.5	18.75	37.5	37.5	0
4	37.5	56.25	25	25	18.75	12.5	37.5	18.75	6.25
5	75	43.75	31.25	43.75	31.25	18.75	25	12.5	6.25
6	43.75	37.5	31.25	37.5	50	6.25	50	43.75	25
7	37.5	50	50	25	37.5	31.25	50	25	12.5
8	50	37.5	37.5	31.25	43.75	31.25	56.25	31.25	12.5

Table 17. Means and standard error for *Pseudoroegneria* emergence.

Treatment	% Emerged	Standard Error
A	44.531	5.207403
B	42.188	3.288152
C	32.813	3.068689
D	36.719	3.81592
E	37.5	3.340766
F	17.969	3.221176
G	47.656	5.273954
H	32.813	4.976227
I	8.594	2.87808

ANOVA Results for *Pseudoroegneria* Emergence Under Low Salinity

One Way Analysis of Variance

Data source: BBWpots emergence data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.544)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	44.531	14.729	5.207
B	8	0	42.188	9.300	3.288
C	8	0	32.813	8.680	3.069

Source of Variation	DF	SS	MS	F	P
Between Groups	2	615.234	307.617	2.436	0.112
Residual	21	2651.367	126.256		
Total	23	3266.602			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.112).

Power of performed test with alpha = 0.050: 0.264

The power of the performed test (0.264) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

ANOVA Results for *Pseudoroegneria* Emergence Under Moderate Salinity

One Way Analysis of Variance

Data source: BBWpots emergence data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.747)

Group Name	N	Missing	Mean	Std Dev	SEM
D	8	0	36.719	10.793	3.816
E	8	0	37.500	9.449	3.341
F	8	0	17.969	9.111	3.221

Source of Variation	DF	SS	MS	F	P
Between Groups	2	1956.380	978.190	10.162	<0.001
Residual	21	2021.484	96.261		
Total	23	3977.865			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.963

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
E vs. F	19.531	3	5.631	0.002	Yes
E vs. D	0.781	3	0.225	0.986	No
D vs. F	18.750	3	5.405	0.003	Yes

ANOVA Results for *Pseudoroegneria* Emergence Under High Salinity

One Way Analysis of Variance

Data source: BBWpots emergence data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.391)

Group Name	N	Missing	Mean	Std Dev	SEM
G	8	0	47.656	14.917	5.274
H	8	0	32.813	14.075	4.976
I	8	0	8.594	8.140	2.878

Source of Variation	DF	SS	MS	F	P
Between Groups	2	6220.703	3110.352	19.165	<0.001
Residual	21	3408.203	162.295		
Total	23	9628.906			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
G vs. I	39.063	3	8.673	<0.001	Yes
G vs. H	14.844	3	3.296	0.073	No
H vs. I	24.219	3	5.377	0.003	Yes

ANOVA Results for *Pseudoroegneria* Emergence Under High Soil Moisture

One Way Analysis of Variance

Data source: BBWpots emergence data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.929)

Group Name	**N**	**Missing**	**Mean**	**Std Dev**	**SEM**
A	8	0	44.531	14.729	5.207
D		8	0	36.719	10.793 3.816
G	8	0	47.656	14.917	5.274

Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Between Groups	2	507.813	253.906	1.370	0.276
Residual	21	3891.602	185.314		
Total	23	4399.414			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.276).

Power of performed test with alpha = 0.050: 0.099

The power of the performed test (0.099) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

ANOVA Results for *Pseudoroegneria* Emergence Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: BBWpots emergence data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.337)

Group Name	N	Missing	Mean	Std Dev	SEM
B	8	0	42.188	9.300	3.288
E	8	0	37.500	9.449	3.341
H	8	0	32.813	14.075	4.976

Source of Variation	DF	SS	MS	F	P
Between Groups	2	351.563	175.781	1.410	0.266
Residual	21	2617.188	124.628		
Total	23	2968.750			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.266).

Power of performed test with alpha = 0.050: 0.104

The power of the performed test (0.104) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

ANOVA Results for *Pseudoroegneria* Emergence Under Low Soil Moisture

One Way Analysis of Variance

Data source: BBWpots emergence data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.870)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	32.813	8.680	3.069
F	8	0	17.969	9.111	3.221
I	8	0	8.594	8.140	2.878

Source of Variation	DF	SS	MS	F	P
Between Groups	2	2386.068	1193.034	15.935	<0.001
Residual	21	1572.266	74.870		
Total	23	3958.333			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.999

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
C vs. I	24.219	3	7.917	<0.001	Yes
C vs. F	14.844	3	4.852	0.007	Yes
F vs. I	9.375	3	3.065	0.101	No

Spearman Rank Order Correlation for *Pseudoroegneria* Emergence

Spearman Rank Order Correlation

Data source: BBWpots emergence data in BBWpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
% Emerged	-0.244
	0.0387
	72

	Water Treatment
% Emerged	0.579
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 18. Emergence data (% per pot) for *Hesperostipa*.

	Treatment								
Replicatio n	A	B	C	D	E	F	G	H	I
1	31.25	18.75	12.5	81.25	6.25	0	50	18.75	6.25
2	50	37.5	31.25	50	12.5	0	43.75	18.75	12.5
3	37.5	31.25	0	50	12.5	12.5	56.25	37.5	6.25
4	56.25	50	12.5	62.5	18.75	31.25	37.5	12.5	0
5	50	25	50	75	31.25	6.25	50	56.25	0
6	68.75	31.25	18.75	50	50	6.25	75	37.5	0
7	37.5	50	12.5	62.5	25	6.25	50	37.5	6.25
8	43.75	56.25	6.25	43.75	56.25	18.75	43.75	18.75	12.5

Table 19. Means and standard error for *Hesperostipa* emergence.

Treatmen t	% Emerged	Standard Error
A	46.875	4.258657
B	37.5	4.724556
C	17.96875	5.594847
D	59.375	4.724556
E	26.5625	6.442353
F	10.15625	3.723399
G	50.78125	3.994538
H	29.6875	5.249096
I	5.46875	1.844053

ANOVA Results for *Hesperostipa* Emergence Under Low Salinity

One Way Analysis of Variance

Data source: NT Emergence Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.946)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	46.875	12.045	4.259
B	8	0	37.500	13.363	4.725
C	8	0	17.969	15.825	5.595

Source of Variation	DF	SS	MS	F	P
Between Groups	2	3479.818	1739.909	9.092	0.001
Residual	21	4018.555	191.360		
Total	23	7498.372			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.001).

Power of performed test with alpha = 0.050: 0.937

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. C	28.906	3	5.910	0.001	Yes
A vs. B	9.375	3	1.917	0.382	No
B vs. C	19.531	3	3.993	0.026	Yes

ANOVA Results for *Hesperostipa* Emergence Under Moderate Salinity

One Way Analysis of Variance

Data source: NT Emergence Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.332)

Group Name	N	Missing	Mean	Std Dev	SEM
D	8	0	59.375	13.363	4.725
E	8	0	26.563	18.222	6.442
F	8	0	10.156	10.531	3.723

Source of Variation	DF	SS	MS	F	P
Between Groups	2	10048.828	5024.414	24.253	<0.001
Residual	21	4350.586	207.171		
Total	23	14399.414			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
D vs. F	49.219	3	9.672	<0.001	Yes
D vs. E	32.813	3	6.448	<0.001	Yes
E vs. F	16.406	3	3.224	0.081	No

ANOVA Results for *Hesperostipa* Emergence Under High Salinity

One Way Analysis of Variance

Data source: NT Emergence Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Failed (P = 0.046)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Emergence Data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
G	8	0	50.000	43.750	53.125
H	8	0	28.125	18.750	37.500
I	8	0	6.250	0.000	9.375

H = 18.137 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
G vs I	119.000	5.950	Yes
G vs H	49.000	2.450	No
H vs I	70.000	3.500	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Hesperostipa* Emergence Under High Soil Moisture

One Way Analysis of Variance

Data source: NT Emergence Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.587)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	46.875	12.045	4.259
D	8	0	59.375	13.363	4.725
G	8	0	50.781	11.298	3.995

Source of Variation	DF	SS	MS	F	P
Between Groups	2	654.297	327.148	2.175	0.139
Residual	21	3159.180	150.437		
Total	23	3813.477			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.139).

Power of performed test with alpha = 0.050: 0.221

The power of the performed test (0.221) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

ANOVA Results for *Hesperostipa* Emergence Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: NT Emergence Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.776)

Group Name	N	Missing	Mean	Std Dev	SEM
B	8	0	37.500	13.363	4.725
E	8	0	26.563	18.222	6.442
H	8	0	29.688	14.847	5.249

Source of Variation	DF	SS	MS	F	P
Between Groups	2	507.813	253.906	1.042	0.370
Residual	21	5117.188	243.676		
Total	23	5625.000			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.370).

Power of performed test with alpha = 0.050: 0.054

The power of the performed test (0.054) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

ANOVA Results for *Hesperostipa* Emergence Under Low Soil Moisture

One Way Analysis of Variance

Data source: NT Emergence Data in NTpots_2004stats.SNB

Normality Test: Failed (P = 0.041)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Emergence Data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
C	8	0	12.500	9.375	25.000
F	8	0	6.250	3.125	15.625
I	8	0	6.250	0.000	9.375

H = 4.274 with 2 degrees of freedom. (P = 0.118)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.118)

Spearman Rank Order Correlation for *Hesperostipaa* Emergence

Spearman Rank Order Correlation

Data source: NT Emergence Data in NTpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
% emerged	-0.114
	0.339
	72
	Water Treatment
% emerged	0.783
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 20. Emergence data (% per pot) for *Pascopyrum*.

	Treatment								
Replication	A	B	C	D	E	F	G	H	I
1	87.5	87.5	56.25	75	62.5	50	75	50	43.75
2	81.25	68.75	62.5	56.25	62.5	37.5	68.75	68.75	43.75
3	68.75	56.25	75	62.5	56.25	81.25	93.75	50	37.5
4	31.25	81.25	62.5	75	62.5	62.5	87.5	56.25	50
5	75	68.75	50	75	50	43.75	81.25	43.75	25
6	81.25	62.5	68.75	68.75	62.5	31.25	68.75	62.5	56.25
7	93.75	68.75	56.25	93.75	75	68.75	68.75	37.5	37.5
8	75	68.75	81.25	68.75	75	62.5	87.5	75	50

Table 21. Means and standard error for *Pascopyrum* emergence.

Treatment	% Emerged	Standard Error
A	74.21875	6.727051
B	70.3125	3.493856
C	64.0625	3.688105
D	71.875	3.917395
E	63.28125	2.996813
F	54.6875	5.993626
G	78.90625	3.531092
H	55.46875	4.48794
I	42.96875	3.430899

ANOVA results for *Pascopyrum* emergence under low salinity

One Way Analysis of Variance

Data source: emergence data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.561)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	74.219	19.027	6.727
B	8	0	70.313	9.882	3.494
C	8	0	64.063	10.432	3.688

Source of Variation	DF	SS	MS	F	P
Between Groups	2	419.922	209.961	1.108	0.349
Residual	21	3979.492	189.500		
Total	23	4399.414			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.349).

Power of performed test with alpha = 0.050: 0.063

The power of the performed test (0.063) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

ANOVA results for *Pascopyrum* emergence under moderate salinity

One Way Analysis of Variance

Data source: emergence data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.069)

Group Name	N	Missing	Mean	Std Dev	SEM
D	8	0	71.875	11.080	3.917
E	8	0	63.281	8.476	2.997
F	8	0	54.688	16.953	5.994

Source of Variation	DF	SS	MS	F	P
Between Groups	2	1181.641	590.820	3.677	0.043
Residual	21	3374.023	160.668		
Total	23	4555.664			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.043).

Power of performed test with alpha = 0.050: 0.464

The power of the performed test (0.464) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
D vs. F	17.188	3	3.835	0.034	Yes
D vs. E	8.594	3	1.918	0.381	No
E vs. F	8.594	3	1.918	0.381	No

ANOVA results for *Pascopyrum* emergence under high salinity

One Way Analysis of Variance

Data source: emergence data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.577)

Group Name	N	Missing	Mean	Std Dev	SEM
G	8	0	78.906	9.987	3.531
H	8	0	55.469	12.694	4.488
I	8	0	42.969	9.704	3.431

Source of Variation	DF	SS	MS	F	P
Between Groups	2	5325.521	2662.760	22.499	<0.001
Residual	21	2485.352	118.350		
Total	23	7810.872			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
G vs. I	35.938	3	9.343	<0.001	Yes
G vs. H	23.438	3	6.094	<0.001	Yes
H vs. I	12.500	3	3.250	0.078	No

ANOVA Results for *Pascopyrum* Emergence Under High Soil Moisture

One Way Analysis of Variance

Data source: emergence data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.708)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	74.219	19.027	6.727
D	8	0	71.875	11.080	3.917
G	8	0	78.906	9.987	3.531

Source of Variation	DF	SS	MS	F	P
Between Groups	2	205.078	102.539	0.526	0.598
Residual	21	4091.797	194.847		
Total	23	4296.875			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.598).

Power of performed test with alpha = 0.050: 0.049

The power of the performed test (0.049) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

ANOVA Results for *Pascopyrum* Emergence Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: emergence data in WWpots_2004stats.SNB

Normality Test: Failed (P = 0.017)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: emergence data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
B	8	0	68.750	65.625	75.000
E	8	0	62.500	59.375	68.750
H	8	0	53.125	46.875	65.625

H = 5.612 with 2 degrees of freedom. (P = 0.060)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.060)

ANOVA Results for *Pascopyrum* Emergence Under Low Soil Moisture

One Way Analysis of Variance

Data source: emergence data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.109)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	64.063	10.432	3.688
F	8	0	54.688	16.953	5.994
I	8	0	42.969	9.704	3.431

Source of Variation	DF	SS	MS	F	P
Between Groups	2	1787.109	893.555	5.467	0.012
Residual	21	3432.617	163.458		
Total	23	5219.727			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.012).

Power of performed test with alpha = 0.050: 0.703

The power of the performed test (0.703) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
C vs. I	21.094	3	4.667	0.009	Yes
C vs. F	9.375	3	2.074	0.327	No
F vs. I	11.719	3	2.593	0.183	No

Spearman Rank Order Correlation for *Pascopyrum* Emergence

Spearman Rank Order Correlation

Data source: emergence data in WWpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
% emerged	-0.267
	0.0237
	72
	Water Treatment
% emerged	0.560
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 22. Plant height (cm) data for *Pseudoroegneria*.

	Treatment								
Replication	A	B	C	D	E	F	G	H	I
1	36.6	19.1	19.3	36.4	19.1	11.1	36.7	11.6	12.2
2	43.4	34.6	19.4	35.2	18	11.2	29.9	16.5	9.6
3	44.9	28.2	20.5	45.5	19.2	9.7	33.1	16	8.9
4	43.3	32.2	21.2	46.8	11.9	12.5	29.2	12.1	12.6
5	45	30.3	17.7	38.9	19.2	10.6	32.1	8.2	8.9
6	38.8	26.9	21	31	20	10.6	33.7	16.5	12.5
7	40.9	32.1	18.7	42.1	19.6	11.5	36.8	12.6	10
8	36.3	27.4	17.3	37.2	17.4	13.4	32.8	18.7	12.8

Table 23. Means and standard error for *Pseudoroegneria* plant height.

Treatment	Average Plant Height (cm)	Standard Error
A	41.15	1.25627
B	28.85	1.681517
C	19.3875	0.514239
D	39.1375	1.894535
E	18.05	0.927747
F	11.325	0.411335
G	33.0375	0.977595
H	14.025	1.221496
I	10.9375	0.615844

ANOVA Results for *Pseudoroegneria* Height Under Low Salinity

One Way Analysis of Variance

Data source: BBWpots Avg plant height data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.088)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	41.150	3.553	1.256
B	8	0	28.850	4.756	1.682
C	8	0	19.388	1.454	0.514

Source of Variation	DF	SS	MS	F	P
Between Groups	2	1905.161	952.580	76.489	<0.001
Residual	21	261.529	12.454		
Total	23	2166.690			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. C	21.762	3	17.442	<0.001	Yes
A vs. B	12.300	3	9.858	<0.001	Yes
B vs. C	9.462	3	7.584	<0.001	Yes

ANOVA Results for *Pseudoroegneria* Height Under Moderate Salinity

One Way Analysis of Variance

Data source: BBWpots Avg plant height data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Failed (P = 0.021)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Avg plant height data in BBWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
D	8	0	38.050	35.800	43.800
E	8	0	19.150	17.700	19.400
F	8	0	11.150	10.600	12.000

H = 19.877 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
D vs F	126.000	6.300	Yes
D vs E	66.000	3.300	No
E vs F	60.000	3.000	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pseudoroegneria* Height Under High Salinity

One Way Analysis of Variance

Data source: BBWpots Avg plant height data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.169)

Group Name	N	Missing	Mean	Std Dev	SEM
G	8	0	33.038	2.765	0.978
H	8	0	14.025	3.455	1.221
I	8	0	10.937	1.742	0.616

Source of Variation	DF	SS	MS	F	P
Between Groups	2	2291.781	1145.890	152.001	<0.001
Residual	21	158.313	7.539		
Total	23	2450.093			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
G vs. I	22.100	3	22.766	<0.001	Yes
G vs. H	19.013	3	19.586	<0.001	Yes
H vs. I	3.088	3	3.181	0.086	No

ANOVA Results for *Pseudoroegneria* Height Under High Soil Moisture

One Way Analysis of Variance

Data source: BBWpots Avg plant height data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.206)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	41.150	3.553	1.256
D	8	0	39.137	5.359	1.895
G	8	0	33.038	2.765	0.978

Source of Variation	DF	SS	MS	F	P
Between Groups	2	285.528	142.764	8.743	0.002
Residual	21	342.897	16.328		
Total	23	628.425			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.002).

Power of performed test with alpha = 0.050: 0.926

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. G	8.112	3	5.678	0.002	Yes
A vs. D	2.013	3	1.409	0.587	No
D vs. G	6.100	3	4.270	0.017	Yes

ANOVA Results for *Pseudoroegneria* Height Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: BBWpots Avg plant height data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.254)

Group Name	N	Missing	Mean	Std Dev	SEM
B	8	0	28.850	4.756	1.682
E	8	0	18.050	2.624	0.928
H	8	0	14.025	3.455	1.221

Source of Variation	DF	SS	MS	F	P
Between Groups	2	940.323	470.162	34.035	<0.001
Residual	21	290.095	13.814		
Total	23	1230.418			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
B vs. H	14.825	3	11.282	<0.001	Yes
B vs. E	10.800	3	8.219	<0.001	Yes
E vs. H	4.025	3	3.063	0.101	No

ANOVA Results for *Pseudoroegneria* Height Under Low Soil Moisture

One Way Analysis of Variance

Data source: BBWpots Avg plant height data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.110)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	19.388	1.454	0.514
F	8	0	11.325	1.163	0.411
I	8	0	10.937	1.742	0.616

Source of Variation	DF	SS	MS	F	P
Between Groups	2	364.151	182.075	83.993	<0.001
Residual	21	45.522	2.168		
Total	23	409.673			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
C vs. I	8.450	3	16.233	<0.001	Yes
C vs. F	8.063	3	15.489	<0.001	Yes
F vs. I	0.388	3	0.744	0.859	No

Spearman Rank Order Correlation for *Pseudoroegneria* Plant Height

Spearman Rank Order Correlation

Data source: BBWpots Avg plant height data in BBWpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
Avg Plant Height (cm)	-0.413
	0.000
	72

	Water Treatment
Avg Plant Height (cm)	0.811
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 24. Plant height data (cm) for *Hesperostipa*.

	Treatment								
Replication	A	B	C	D	E	F	G	H	I
1	18.5	12.2	8.1	20	10.2	6.8	11.6	10.5	8.3
2	23.3	12.6	10.4	17.6	10.8	9.6	17.4	10	7.3
3	14.8	11.2	8.7	10.2	9.8	9.1	14.5	10.5	9.6
4	23.3	11.3	8.9	20.3	9.9	9.3	14.5	8.7	7.4
5	15.1	11.6	8.8	17.5	10.6	6.9	14.9	8.4	6.5
6	24.8	11.9	11.2	20	9.8	7.6	14.2	9.3	7.9
7	22.9	11.3	8.5	21.1	7.6	8.4	16.4	9.2	8.8
8	20.8	10.8	8.4	15.7	10	7.8	16.4	9.2	8.8

Table 25. Means and standard error for *Hesperostipa* plant height.

Treatment	Plant Height (cm)	Standard Error
A	20.4375	1.373465
B	11.6125	0.208256
C	9.125	0.383476
D	17.8	1.261518
E	9.8375	0.345345
F	8.1875	0.382397
G	14.9875	0.632297
H	9.475	0.277585
I	8.075	0.353427

ANOVA Results for *Hesperostipa* Height Under Low Salinity

One Way Analysis of Variance

Data source: NT Height Data in NTpots_2004stats.SNB

Normality Test: Failed (P = 0.009)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Height Data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
A	8	0	21.850	16.800	23.300
B	8	0	11.450	11.250	12.050
C	8	0	8.750	8.450	9.650

H = 20.037 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
A vs C	126.500	6.325	Yes
A vs B	65.500	3.275	No
B vs C	61.000	3.050	No

ANOVA Results for *Hesperostipa* Height Under Moderate Salinity

One Way Analysis of Variance

Data source: NT Height Data in NTpots_2004stats.SNB

Normality Test: Failed (P = 0.029)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Height Data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
D	8	0	18.800	16.600	20.150
E	8	0	9.950	9.800	10.400
F	8	0	8.100	7.250	9.200

H = 18.065 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
D vs F	120.000	6.000	Yes
D vs E	64.500	3.225	No
E vs F	55.500	2.775	No

ANOVA Results for *Hesperostipa* Height Under High Salinity

One Way Analysis of Variance

Data source: NT Height Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.235)

Group Name	N	Missing	Mean	Std Dev	SEM
G	8	0	14.988	1.788	0.632
H	8	0	9.475	0.785	0.278
I	8	0	8.075	1.000	0.353

Source of Variation	DF	SS	MS	F	P
Between Groups	2	213.681	106.840	66.580	<0.001
Residual	21	33.699	1.605		
Total	23	247.380			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
G vs. I	6.913	3	15.434	<0.001	Yes
G vs. H	5.512	3	12.308	<0.001	Yes
H vs. I	1.400	3	3.126	0.093	No

ANOVA Results for *Hesperostipa* Height Under High Soil Moisture

One Way Analysis of Variance

Data source: NT Height Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.238)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	20.438	3.885	1.373
D	8	0	17.800	3.568	1.262
G	8	0	14.988	1.788	0.632

Source of Variation	DF	SS	MS	F	P
Between Groups	2	118.851	59.425	5.747	0.010
Residual	21	217.148	10.340		
Total	23	335.998			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.010).

Power of performed test with alpha = 0.050: 0.733

The power of the performed test (0.733) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. G	5.450	3	4.794	0.008	Yes
A vs. D	2.638	3	2.320	0.251	No
D vs. G	2.812	3	2.474	0.211	No

ANOVA Results for *Hesperostipa* Height Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: NT Height Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.887)

Group Name	N	Missing	Mean	Std Dev	SEM
B	8	0	11.612	0.589	0.208
E	8	0	9.838	0.977	0.345
H	8	0	9.475	0.785	0.278

Source of Variation	DF	SS	MS	F	P
Between Groups	2	20.936	10.468	16.377	<0.001
Residual	21	13.423	0.639		
Total	23	34.358			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.999

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
B vs. H	2.137	3	7.562	<0.001	Yes
B vs. E	1.775	3	6.280	<0.001	Yes
E vs. H	0.362	3	1.282	0.642	No

ANOVA Results for *Hesperostipa* Height Under Low Soil Moisture

One Way Analysis of Variance

Data source: NT Height Data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.810)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	9.125	1.085	0.383
F	8	0	8.188	1.082	0.382
I	8	0	8.075	1.000	0.353

Source of Variation	DF	SS	MS	F	P
Between Groups	2	5.317	2.659	2.384	0.117
Residual	21	23.419	1.115		
Total	23	28.736			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.117).

Power of performed test with alpha = 0.050: 0.255

The power of the performed test (0.255) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

Spearman Rank Order Correlation for *Hesperostipaa* Plant Height

Spearman Rank Order Correlation
Data source: NT Height Data in NTpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
Avg height (cm)	-0.263
	0.0259
	72

	Water Treatment
Avg height (cm)	-0.866
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 26. Plant height data (cm) for *Pascopyrum*

	Treatment								
Replication	A	B	C	D	E	F	G	H	I
1	45	27.7	14.2	42.4	13.6	11.9	42.1	16.8	10.4
2	42.2	29.4	11.1	36	29	11.3	41.1	17.4	10.5
3	45.8	28.5	16	44.9	21.5	11.1	39.5	19.6	11.2
4	51.2	35.3	12	39.6	19.4	14.9	39.8	16.2	11.2
5	41	18.9	14.4	42.5	25.1	13.5	41.5	16.7	12.1
6	43.3	21.2	17	46.6	20.7	9.8	39.1	17	9.2
7	38.3	27.4	11.9	41.4	21.7	10.6	40.2	15.5	13
8	46.7	26.1	13.9	41.5	23.6	12.3	41.8	11.2	13.4

Table 27. Means and standard error for *Pascopyrum* plant height.

Treatment	Plant Height (cm)	Standard Error
A	44.1875	1.390714
B	26.8125	1.77949
C	13.8125	0.728854
D	41.8625	1.135457
E	21.825	1.582691
F	11.925	0.57964
G	40.6375	0.400864
H	16.3	0.841555
I	11.375	0.495966

ANOVA Results for *Pascopyrum* Height Under Low Salinity

One Way Analysis of Variance

Data source: Height data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.342)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	44.188	3.934	1.391
B	8	0	26.812	5.033	1.779
C	8	0	13.813	2.062	0.729

Source of Variation	DF	SS	MS	F	P
Between Groups	2	3716.083	1858.042	123.718	<0.001
Residual	21	315.386	15.018		
Total	23	4031.470			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. C	30.375	3	22.169	<0.001	Yes
A vs. B	17.375	3	12.681	<0.001	Yes
B vs. C	13.000	3	9.488	<0.001	Yes

ANOVA Results for *Pascopyrum* Height Under Moderate Salinity

One Way Analysis of Variance

Data source: Height data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.300)

Group Name	N	Missing	Mean	Std Dev	SEM
D	8	0	41.862	3.212	1.135
E	8	0	21.825	4.477	1.583
F	8	0	11.925	1.639	0.580

Source of Variation	DF	SS	MS	F	P
Between Groups	2	3722.041	1861.020	168.972	<0.001
Residual	21	231.289	11.014		
Total	23	3953.330			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
D vs. F	29.938	3	25.515	<0.001	Yes
D vs. E	20.038	3	17.077	<0.001	Yes
E vs. F	9.900	3	8.437	<0.001	Yes

ANOVA Results for *Pascopyrum* Height Under High Salinity

One Way Analysis of Variance

Data source: Height data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.774)

Group Name	N	Missing	Mean	Std Dev	SEM
G	8	0	40.638	1.134	0.401
H	8	0	16.300	2.380	0.842
I	8	0	11.375	1.403	0.496

Source of Variation	DF	SS	MS	F	P
Between Groups	2	3927.636	1963.818	660.543	<0.001
Residual	21	62.434	2.973		
Total	23	3990.070			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
G vs. I	29.263	3	48.002	<0.001	Yes
G vs. H	24.338	3	39.923	<0.001	Yes
H vs. I	4.925	3	8.079	<0.001	Yes

ANOVA Results for *Pascopyrum* Height Under High Soil Moisture

One Way Analysis of Variance

Data source: Height data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.112)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	44.188	3.934	1.391
D	8	0	41.862	3.212	1.135
G	8	0	40.638	1.134	0.401

Source of Variation	DF	SS	MS	F	P
Between Groups	2	52.023	26.012	2.882	0.078
Residual	21	189.506	9.024		
Total	23	241.530			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.078).

Power of performed test with alpha = 0.050: 0.337

The power of the performed test (0.337) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

ANOVA Results for *Pascopyrum* Height Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: Height data in WWpots_2004stats.SNB

Normality Test: Failed (P = 0.034)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Height data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
B	8	0	27.550	23.650	28.950
E	8	0	21.600	20.050	24.350
H	8	0	16.750	15.850	17.200

H = 13.245 with 2 degrees of freedom. (P = 0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
B vs H	102.000	5.100	Yes
B vs E	39.000	1.950	No
E vs H	63.000	3.150	No

ANOVA Results for *Pascopyrum* Height Under Low Soil Moisture

One Way Analysis of Variance

Data source: Height data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.584)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	13.813	2.062	0.729
F	8	0	11.925	1.639	0.580
I	8	0	11.375	1.403	0.496

Source of Variation	DF	SS	MS	F	P
Between Groups	2	26.151	13.075	4.405	0.025
Residual	21	62.339	2.969		
Total	23	88.490			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.025).

Power of performed test with alpha = 0.050: 0.571

The power of the performed test (0.571) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
C vs. I	2.438	3	4.001	0.026	Yes
C vs. F	1.888	3	3.099	0.096	No
F vs. I	0.550	3	0.903	0.801	No

Spearman Rank Order Correlation for *Pascopyrum* Plant Height

Spearman Rank Order Correlation

Data source: Height data in WWpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
Avg. Height (cm)	-0.218
	0.0656
	72
	Water Treatment
Avg. Height (cm)	0.920
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 28. Aboveground mass (g/plant) data for *Pseudoroegneria*.

	Treatment								
Replication	A	B	C	D	E	F	G	H	I
1	0.32	0.0333	0.0375	0.2475	0.03	0.0115	0.2075	0.0123	0.0135
2	0.34	0.0867	0.04	0.2125	0.0375	0.013	0.1875	0.035	0.008
3	0.325	0.07	0.0375	0.265	0.0225	0.0098	0.16	0.0198	0.0078
4	0.2725	0.11	0.05	0.2475	0.0225	0.0135	0.1533	0.0163	0.013
5	0.3325	0.1075	0.03	0.2225	0.04	0.0108	0.135	0.0083	0.0078
6	0.29	0.095	0.045	0.2025	0.0325	0.009	0.1033	0.0225	0.0113
7	0.4275	0.125	0.0325	0.2125	0.04	0.01	0.205	0.015	0.008
8	0.35	0.0925	0.0325	0.23	0.0225	0.014	0.1125	0.0375	0.0088

Table 29. Means and standard error for *Pseudoroegneria* aboveground mass.

Treatment	Aboveground mass (g/plant)	Standard Error
A	0.332188	0.016369
B	0.09	0.00999
C	0.038125	0.002397
D	0.23	0.007633
E	0.030938	0.002752
F	0.01145	0.00066
G	0.158013	0.014109
H	0.020838	0.0037
I	0.009775	0.000862

ANOVA Results for *Pseudoroegneria* Aboveground Mass Under Low Salinity

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Aboveground mass data in BBWpots_2004stats.SNB

Normality Test: Failed (P = 0.025)

Group	N	Missing	Median	25%	75%
A	8	0	0.329	0.305	0.345
B	8	0	0.0938	0.0784	0.109
C	8	0	0.0375	0.0325	0.0425

H = 19.022 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
A vs C	123.000	6.150	Yes
A vs B	69.000	3.450	Yes
B vs C	54.000	2.700	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pseudoroegneria* Aboveground Mass Under Moderate Salinity

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Aboveground mass data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
D	8	0	0.226	0.212	0.248
E	8	0	0.0313	0.0225	0.0388
F	8	0	0.0112	0.00990	0.0133

H = 20.543 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
D vs F	128.000	6.400	Yes
D vs E	64.000	3.200	No
E vs F	64.000	3.200	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pseudoroegneria* Aboveground Mass Under High Salinity

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Aboveground mass data in BBWpots_2004stats.SNB

Normality Test: Failed (P = 0.002)

Group	**N**	**Missing**	**Median**	**25%**	**75%**
G	8	0	0.157	0.124	0.196
H	8	0	0.0181	0.0136	0.0288
I	8	0	0.00840	0.00790	0.0121

H = 18.756 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	**Diff of Ranks**	**q**	**P<0.05**
G vs I	122.000	6.100	Yes
G vs H	70.000	3.500	Yes
H vs I	52.000	2.600	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pseudoroegneria* Aboveground Mass Under High Soil Moisture

One Way Analysis of Variance

Data source: BBWpots Aboveground mass data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.419)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	0.332	0.0463	0.0164
D	8	0	0.230	0.0216	0.00763
G	8	0	0.158	0.0399	0.0141

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.123	0.0613	43.751	<0.001
Residual	21	0.0294	0.00140		
Total	23	0.152			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. G	0.174	3	13.163	<0.001	Yes
A vs. D	0.102	3	7.723	<0.001	Yes
D vs. G	0.0720	3	5.440	0.003	Yes

ANOVA Results for *Pseudoroegneria* Aboveground Mass Under Moderate Soil Moisture

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Aboveground mass data in BBWpots_2004stats.SNB

Normality Test: Failed (P = 0.022)

Group	N	Missing	Median	25%	75%
B	8	0	0.0938	0.0784	0.109
E	8	0	0.0313	0.0225	0.0388
H	8	0	0.0181	0.0136	0.0288

H = 15.234 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
B vs H	109.000	5.450	Yes
B vs E	68.000	3.400	Yes
E vs H	41.000	2.050	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pseudoroegneria* Aboveground Mass Under Low Soil Moisture

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Aboveground mass data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Failed (P = 0.038)

Group	N	Missing	Median	25%	75%
C	8	0	0.0375	0.0325	0.0425
F	8	0	0.0112	0.00990	0.0133
I	8	0	0.00840	0.00790	0.0121

H = 16.684 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
C vs I	112.000	5.600	Yes
C vs F	80.000	4.000	Yes
F vs I	32.000	1.600	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

Spearman Rank Order Correlation for *Pseudoroegneria* Aboveground Mass

Spearman Rank Order Correlation

Data source: BBWpots Aboveground mass data in BBWpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
Aboveground biomass (g)	-0.431
	0.000
	72
	Water Treatment
Aboveground biomass (g)	0.837
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 30. Aboveground mass (g/plant) data for *Hesperostipa*.

	Treatment								
Replicatio n	A	B	C	D	E	F	G	H	I
1	0.1465	0.0247	0.0102	0.1194	0.0144	0.0088	0.0667	0.0136	0.0094
2	0.1483	0.0339	0.0134	0.099	0.0154	0.0081	0.068	0.0103	0.0066
3	0.0925	0.018	0.0091	0.0387	0.0134	0.0096	0.0737	0.0143	0.0091
4	0.2463	0.0164	0.0101	0.1017	0.0087	0.0112	0.1012	0.0097	0.0109
5	0.1371	0.0233	0.0123	0.0751	0.0142	0.0116	0.0691	0.0116	0.0109
6	0.2621	0.0204	0.0106	0.0543	0.0189	0.0067	0.0756	0.0161	0.0112
7	0.159	0.0583	0.0067	0.1239	0.0118	0.0099	0.0291	0.0112	0.0101
8	0.1724	0.0175	0.0083	0.0773	0.0156	0.0092	0.1232	0.0142	0.009

Table 31. Means and standard error for *Hesperostipa* aboveground mass.

Treatmen t	Aboveground mass (g/plant)	Standard Error
A	0.170525	0.020063
B	0.026563	0.00495
C	0.010088	0.000753
D	0.086175	0.010694
E	0.01405	0.001052
F	0.009388	0.000563
G	0.075825	0.009697
H	0.012625	0.000795
I	0.00965	0.000532

ANOVA Results for *Hesperostipa* Aboveground Mass Under Low Salinity

One Way Analysis of Variance

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
A	8	0	0.154	0.142	0.209
B	8	0	0.0219	0.0178	0.0293
C	8	0	0.0101	0.00870	0.0115

H = 20.480 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
A vs C	128.000	6.400	Yes
A vs B	64.000	3.200	No
B vs C	64.000	3.200	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Hesperostipa* Aboveground Mass Under Moderate Salinity

One Way Analysis of Variance

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
D	8	0	0.0882	0.0647	0.111
E	8	0	0.0143	0.0126	0.0155
F	8	0	0.00940	0.00845	0.0106

H = 18.740 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
D vs F	122.000	6.100	Yes
D vs E	70.000	3.500	Yes
E vs F	52.000	2.600	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Hesperostipa* Aboveground Mass Under High Salinity

One Way Analysis of Variance

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
G	8	0	0.0714	0.0673	0.0884
H	8	0	0.0126	0.0107	0.0143
I	8	0	0.00975	0.00905	0.0109

H = 18.377 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
G vs I	120.500	6.025	Yes
G vs H	71.500	3.575	Yes
H vs I	49.000	2.450	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Hesperostipa* Aboveground Mass Under High Soil Moisture

One Way Analysis of Variance

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.311)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	0.171	0.0567	0.0201
D	8	0	0.0862	0.0302	0.0107
G	8	0	0.0758	0.0274	0.00970

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.0432	0.0216	13.251	<0.001
Residual	21	0.0342	0.00163		
Total	23	0.0774			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.993

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. G	0.0947	3	6.636	<0.001	Yes
A vs. D	0.0843	3	5.911	0.001	Yes
D vs. G	0.0103	3	0.725	0.866	No

ANOVA Results for *Hesperostipa* Aboveground Mass Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
B	8	0	0.0219	0.0178	0.0293
E	8	0	0.0143	0.0126	0.0155
H	8	0	0.0126	0.0107	0.0143

H = 14.680 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
B vs H	103.500	5.175	Yes
B vs E	79.500	3.975	Yes
E vs H	24.000	1.200	No

ANOVA Results for *Hesperostipa* Aboveground Mass Under Low Soil Moisture

One Way Analysis of Variance

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.722)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	0.0101	0.00213	0.000753
F	8	0	0.00939	0.00159	0.000563
I	8	0	0.00965	0.00150	0.000532

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.00000200	0.00000100	0.321	0.729
Residual	21	0.0000654	0.00000311		
Total	23	0.0000674			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.729).

Power of performed test with alpha = 0.050: 0.049

The power of the performed test (0.049) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

Spearman Rank Order Correlation for *Hesperostipa* Aboveground Mass

Spearman Rank Order Correlation

Data source: NT Aboveground mass data in NTpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
Aboveground biomass (g)	-0.205
	0.0845
	72
	Water Treatment
Aboveground biomass (g)	0.900
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 32. Aboveground mass (g/plant) data for *Pascopyrum*.

	Treatment								
Replication	A	B	C	D	E	F	G	H	I
1	0.8714	0.1718	0.0308	0.5481	0.0335	0.0149	0.6184	0.0481	0.0083
2	0.6724	0.165	0.0221	0.627	0.2385	0.0137	0.5457	0.0427	0.0095
3	1.042	0.1657	0.0313	0.7036	0.1074	0.0168	0.4821	0.061	0.0092
4	0.8483	0.3389	0.0265	0.5432	0.0641	0.0288	0.5834	0.0416	0.0098
5	0.7265	0.0625	0.0317	0.4105	0.1069	0.0173	0.6216	0.0357	0.0205
6	0.5817	0.0862	0.0434	0.7466	0.0714	0.0081	0.4968	0.0359	0.0103
7	0.641	0.158	0.0171	0.6536	0.0748	0.011	0.5643	0.0254	0.0117
8	0.8474	0.1027	0.0221	0.5724	0.0818	0.017	0.6185	0.024	0.0157

Table 33. Means and standard error for *Pascopyrum* aboveground mass.

Treatment	Aboveground mass (g/plant)	Standard Error
A	0.778838	0.053332
B	0.15635	0.029981
C	0.028125	0.002866
D	0.600625	0.03742
E	0.0973	0.021844
F	0.01595	0.002159
G	0.56635	0.019428
H	0.0393	0.004262
I	0.011875	0.001472

ANOVA Results for *Pascopyrum* Aboveground Mass Under Low Salinity

One Way Analysis of Variance

Data source: aboveground data in WWpots_2004stats.SNB

Normality Test: Failed (P = 0.002)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: aboveground data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
A	8	0	0.787	0.657	0.860
B	8	0	0.162	0.0945	0.169
C	8	0	0.0287	0.0221	0.0315

H = 20.489 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
A vs C	128.000	6.400	Yes
A vs B	64.000	3.200	No
B vs C	64.000	3.200	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Aboveground Mass Under Moderate Salinity

One Way Analysis of Variance

Data source: aboveground data in WWpots_2004stats.SNB

Normality Test: Failed (P = 0.004)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: aboveground data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
D	8	0	0.600	0.546	0.679
E	8	0	0.0783	0.0678	0.107
F	8	0	0.0159	0.0124	0.0171

H = 20.480 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
D vs F	128.000	6.400	Yes
D vs E	64.000	3.200	No
E vs F	64.000	3.200	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Aboveground Mass Under High Salinity

One Way Analysis of Variance

Data source: aboveground data in WWpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: aboveground data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
G	8	0	0.574	0.521	0.618
H	8	0	0.0388	0.0306	0.0454
I	8	0	0.0101	0.00935	0.0137

H = 20.480 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
G vs I	128.000	6.400	Yes
G vs H	64.000	3.200	No
H vs I	64.000	3.200	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Aboveground Mass Under High Soil Moisture

One Way Analysis of Variance

Data source: aboveground data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Failed (P = 0.037)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: aboveground data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
A	8	0	0.787	0.657	0.860
D	8	0	0.600	0.546	0.679
G	8	0	0.574	0.521	0.618

H = 10.095 with 2 degrees of freedom. (P = 0.006)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.006)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
A vs G	87.000	4.350	Yes
A vs D	63.000	3.150	No
D vs G	24.000	1.200	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Aboveground Mass Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: aboveground data in WWpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: aboveground data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
B	8	0	0.162	0.0945	0.169
E	8	0	0.0783	0.0678	0.107
H	8	0	0.0388	0.0306	0.0454

H = 14.235 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
B vs H	105.000	5.250	Yes
B vs E	36.000	1.800	No
E vs H	69.000	3.450	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Aboveground Mass Under Low Soil Moisture

One Way Analysis of Variance

Data source: aboveground data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.274)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	0.0281	0.00811	0.00287
F	8	0	0.0159	0.00611	0.00216
I	8	0	0.0119	0.00416	0.00147

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.00114	0.000572	14.252	<0.001
Residual	21	0.000843	0.0000401		
Total	23	0.00199			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.996

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
C vs. I	0.0163	3	7.256	<0.001	Yes
C vs. F	0.0122	3	5.436	0.003	Yes
F vs. I	0.00407	3	1.820	0.418	No

Spearman Rank Order Correlation for *Pascopyrum* Aboveground Mass

Spearman Rank Order Correlation

Data source: aboveground data in WWpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
bveground biomass (g)	-0.267
	0.0237
	72
	Water Treatment
bveground biomass (g)	0.929
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 34. Belowground mass (g/plant) data for *Pseudoroegneria*.

	Treatment								
Replicatio n	A	B	C	D	E	F	G	H	I
1	0.35	0.0533	0.04	0.2775	0.025	0.01	0.1525	0.0075	0.0075
2	0.3333	0.09	0.0525	0.26	0.02	0.0125	0.1405	0.0238	0.0085
3	0.315	0.0625	0.06	0.1575	0.025	0.0085	0.09	0.012	0.008
4	0.2925	0.1	0.09	0.0825	0.0168	0.0225	0.1233	0.0095	0.0075
5	0.31	0.1673	0.055	0.2475	0.0185	0.0088	0.085	0.0075	0.01
6	0.275	0.1415	0.0925	0.1725	0.017	0.0093	0.0767	0.0223	0.0075
7	0.475	0.1575	0.0638	0.12	0.035	0.01	0.18	0.0088	0.01
8	0.34	0.1375	0.065	0.1625	0.0175	0.015	0.07	0.04	0.0048

Table 35. Means and standard error for *Pseudoroegneria* belowground mass.

Treatmen t	Belowground mass (g/plant)	Standard Error
A	0.33635	0.021659
B	0.1137	0.015324
C	0.06485	0.006393
D	0.185	0.024726
E	0.02185	0.002217
F	0.012075	0.001676
G	0.11475	0.014247
H	0.016425	0.004074
I	0.007975	0.000586

ANOVA Results for *Pseudoroegneria* Belowground Mass Under Low Salinity

One Way Analysis of Variance

Data source: BBWpots Belowground mass data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.189)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	0.336	0.0613	0.0217
B	8	0	0.114	0.0433	0.0153
C	8	0	0.0648	0.0181	0.00639

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.335	0.168	84.368	<0.001
Residual	21	0.0417	0.00199		
Total	23	0.377			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. C	0.271	3	17.231	<0.001	Yes
A vs. B	0.223	3	14.131	<0.001	Yes
B vs. C	0.0489	3	3.100	0.096	No

ANOVA Results for *Pseudoroegneria* Belowground Mass Under Moderate Salinity

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Belowground mass data in BBWpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
D	8	0	0.167	0.139	0.254
E	8	0	0.0193	0.0173	0.0250
F	8	0	0.01000	0.00905	0.0138

H = 19.022 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
D vs F	123.000	6.150	Yes
D vs E	69.000	3.450	Yes
E vs F	54.000	2.700	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pseudoroegneria* Belowground Mass Under High Salinity

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Belowground mass data in BBWpots_2004stats.SNB

Normality Test: Failed (P = 0.018)

Group	**N**	**Missing**	**Median**	**25%**	**75%**
G	8	0	0.107	0.0809	0.147
H	8	0	0.0107	0.00815	0.0231
I	8	0	0.00775	0.00750	0.00925

H = 16.960 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	**Diff of Ranks**	**q**	**P<0.05**
G vs I	113.000	5.650	Yes
G vs H	79.000	3.950	Yes
H vs I	34.000	1.700	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pseudoroegneria* Belowground Mass Under High Soil Moisture

One Way Analysis of Variance

Data source: BBWpots Belowground mass data in BBWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.554)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	0.336	0.0613	0.0217
D	8	0	0.185	0.0699	0.0247
G	8	0	0.115	0.0403	0.0142

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.205	0.103	29.977	<0.001
Residual	21	0.0719	0.00342		
Total	23	0.277			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. G	0.222	3	10.714	<0.001	Yes
A vs. D	0.151	3	7.317	<0.001	Yes
D vs. G	0.0703	3	3.396	0.064	No

ANOVA Results for *Pseudoroegneria* Belowground Mass Under Moderate Soil Moisture

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Belowground mass data in BBWpots_2004stats.SNB

Normality Test: Failed (P = 0.014)

Group	N	Missing	Median	25%	75%
B	8	0	0.119	0.0762	0.149
E	8	0	0.0193	0.0173	0.0250
H	8	0	0.0107	0.00815	0.0231

H = 16.354 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
B vs H	110.000	5.500	Yes
B vs E	82.000	4.100	Yes
E vs H	28.000	1.400	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pseudoroegneria* Belowground Mass Under Low Soil Moisture

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: BBWpots Belowground mass data in BBWpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
C	8	0	0.0619	0.0537	0.0775
F	8	0	0.01000	0.00905	0.0138
I	8	0	0.00775	0.00750	0.00925

H = 18.240 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
C vs I	119.500	5.975	Yes
C vs F	72.500	3.625	Yes
F vs I	47.000	2.350	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

Spearman Rank Order Correlation for *Pseudoroegneria* Belowground Mass

Spearman Rank Order Correlation

Data source: BBWpots Belowground mass data in BBWpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
Belowground biomass (g)	-0.541
	0.000
	72
	Water Treatment
Belowground biomass (g)	0.735
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 36. Belowground mass (g/plant) data for *Hesperostipa*.

	Treatment								
Replicatio n	A	B	C	D	E	F	G	H	I
1	0.2823	0.0457	0.009	0.1847	0.0161	0.0076	0.1276	0.0127	0.0075
2	0.1302	0.048	0.0284	0.1628	0.0166	0.0135	0.149	0.01	0.0137
3	0.0731	0.0245	0.0159	0.0597	0.023	0.0166	0.0863	0.0314	0.0171
4	0.2802	0.039	0.0253	0.1718	0.0158	0.0239	0.2509	0.0201	0.0225
5	0.1946	0.0616	0.0324	0.0959	0.0247	0.0251	0.1053	0.0182	0.02
6	0.355	0.0407	0.0215	0.0422	0.016	0.0088	0.1278	0.02	0.0177
7	0.1802	0.0607	0.015	0.0854	0.0163	0.0208	0.0344	0.0113	0.0104
8	0.3651	0.0252	0.018	0.0921	0.0293	0.0167	0.1701	0.0103	0.0084

Table 37. Means and standard error for *Hesperostipa* belowground mass.

Treatment	Belowground mass (g/plant)	Standard Error
A	0.232588	0.037175
B	0.043175	0.004949
C	0.020688	0.002731
D	0.111825	0.019092
E	0.019725	0.001847
F	0.016625	0.002294
G	0.131425	0.022456
H	0.01675	0.002577
I	0.014663	0.001958

ANOVA Results for *Hesperostipa* Belowground Mass Under Low Salinity

One Way Analysis of Variance

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Normality Test: Failed (P = 0.005)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
A	8	0	0.237	0.155	0.319
B	8	0	0.0432	0.0321	0.0543
C	8	0	0.0197	0.0155	0.0268

H = 18.740 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
A vs C	122.000	6.100	Yes
A vs B	70.000	3.500	Yes
B vs C	52.000	2.600	No

ANOVA Results for *Hesperostipa* Belowground Mass Under Moderate Salinity

One Way Analysis of Variance

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
D	8	0	0.0940	0.0726	0.167
E	8	0	0.0164	0.0161	0.0239
F	8	0	0.0166	0.0112	0.0224

H = 15.468 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
D vs F	100.500	5.025	Yes
D vs E	91.500	4.575	Yes
E vs F	9.000	0.450	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Hesperostipa* Belowground Mass Under High Salinity

One Way Analysis of Variance

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
G	8	0	0.128	0.0958	0.160
H	8	0	0.0155	0.0108	0.0200
I	8	0	0.0154	0.00940	0.0188

H = 15.518 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
G vs I	101.500	5.075	Yes
G vs H	90.500	4.525	Yes
H vs I	11.000	0.550	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Hesperostipa* Belowground Mass Under High Soil Moisture

One Way Analysis of Variance

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.068)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	0.233	0.105	0.0372
D	8	0	0.112	0.0540	0.0191
G	8	0	0.131	0.0635	0.0225

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.0672	0.0336	5.599	0.011
Residual	21	0.126	0.00600		
Total	23	0.193			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.011).

Power of performed test with alpha = 0.050: 0.718

The power of the performed test (0.718) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. D	0.121	3	4.409	0.014	Yes
A vs. G	0.101	3	3.693	0.042	Yes
G vs. D	0.0196	3	0.716	0.869	No

ANOVA Results for *Hesperostipa* Belowground Mass Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.065)

Group Name	N	Missing	Mean	Std Dev	SEM
B	8	0	0.0432	0.0140	0.00495
E	8	0	0.0197	0.00522	0.00185
H	8	0	0.0167	0.00729	0.00258

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.00335	0.00168	18.194	<0.001
Residual	21	0.00193	0.0000921		
Total	23	0.00529			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
B vs. H	0.0264	3	7.787	<0.001	Yes
B vs. E	0.0234	3	6.911	<0.001	Yes
E vs. H	0.00298	3	0.877	0.811	No

ANOVA Results for *Hesperostipa* Belowground Mass Under Low Soil Moisture

One Way Analysis of Variance

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.652)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	0.0207	0.00772	0.00273
F	8	0	0.0166	0.00649	0.00229
I	8	0	0.0147	0.00554	0.00196

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.000151	0.0000755	1.711	0.205
Residual	21	0.000927	0.0000441		
Total	23	0.00108			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.205).

Power of performed test with alpha = 0.050: 0.149

The power of the performed test (0.149) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

Spearman Rank Order Correlation for *Hesperostipa* Belowground Mass

Spearman Rank Order Correlation

Data source: NT Belowground mass data in NTpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
Belowground biomass (g)	-0.283
	0.0161
	72
	Water Treatment
Belowground biomass (g)	0.779
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 38. Belowground mass (g/plant) data for *Pascopyrum*.

	Treatment								
Replication	A	B	C	D	E	F	G	H	I
1	0.5129	0.1361	0.0255	0.3101	0.024	0.0163	0.2687	0.0236	0.008
2	0.4423	0.0838	0.0202	0.5575	0.2166	0.0086	0.3315	0.0252	0.0058
3	0.5449	0.0911	0.016	0.4688	0.0488	0.0053	0.433	0.0443	0.0098
4	0.5217	0.4291	0.0215	0.2283	0.0262	0.019	0.2546	0.023	0.0179
5	0.4126	0.0383	0.0342	0.2167	0.0475	0.0165	0.2268	0.0187	0.0197
6	0.3648	0.0474	0.0277	0.4933	0.0348	0.0099	0.3764	0.0108	0.008
7	0.3253	0.1182	0.0204	0.4263	0.066	0.0179	0.3144	0.0122	0.0116
8	0.4189	0.0544	0.0179	0.5323	0.0316	0.013	0.3033	0.0125	0.0114

Table 39. Means and standard error for *Pascopyrum* belowground mass.

Treatment	Belowground mass (g/plant)	Standard Error
A	0.442925	0.02769
B	0.1248	0.045122
C	0.022925	0.002094
D	0.404163	0.047709
E	0.061938	0.022635
F	0.013313	0.001746
G	0.313588	0.023777
H	0.021288	0.003849
I	0.011525	0.001733

ANOVA Results for *Pascopyrum* Belowground Mass Under Low Salinity

One Way Analysis of Variance

Data source: belowground mass data in WWpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: belowground mass data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
A	8	0	0.431	0.389	0.517
B	8	0	0.0875	0.0509	0.127
C	8	0	0.0210	0.0190	0.0266

H = 19.280 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
A vs C	124.000	6.200	Yes
A vs B	56.000	2.800	No
B vs C	68.000	3.400	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Belowground Mass Under Moderate Salinity

One Way Analysis of Variance

Data source: belowground mass data in WWpots_2004stats.SNB

Normality Test: Failed (P = 0.003)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: belowground mass data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
D	8	0	0.448	0.269	0.513
E	8	0	0.0411	0.0289	0.0574
F	8	0	0.0147	0.00925	0.0172

H = 20.480 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
D vs F	128.000	6.400	Yes
D vs E	64.000	3.200	No
E vs F	64.000	3.200	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Belowground Mass Under High Salinity

One Way Analysis of Variance

Data source: belowground mass data in WWpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: belowground mass data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
G	8	0	0.309	0.262	0.354
H	8	0	0.0209	0.0124	0.0244
I	8	0	0.0106	0.00800	0.0147

H = 18.013 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
G vs I	119.000	5.950	Yes
G vs H	73.000	3.650	Yes
H vs I	46.000	2.300	No

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Belowground Mass Under High Soil Moisture

One Way Analysis of Variance

Data source: belowground mass data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.134)

Group Name	N	Missing	Mean	Std Dev	SEM
A	8	0	0.443	0.0783	0.0277
D	8	0	0.404	0.135	0.0477
G	8	0	0.314	0.0673	0.0238

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.0705	0.0352	3.663	0.043
Residual	21	0.202	0.00962		
Total	23	0.273			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.043).

Power of performed test with alpha = 0.050: 0.462

The power of the performed test (0.462) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
A vs. G	0.129	3	3.729	0.039	Yes
A vs. D	0.0388	3	1.118	0.713	No
D vs. G	0.0906	3	2.612	0.179	No

ANOVA Results for *Pascopyrum* Belowground Mass Under Moderate Soil Moisture

One Way Analysis of Variance

Data source: belowground mass data in WWpots_2004stats.SNB

Normality Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: belowground mass data in WWpots_2004stats.SNB

Group	N	Missing	Median	25%	75%
B	8	0	0.0875	0.0509	0.127
E	8	0	0.0411	0.0289	0.0574
H	8	0	0.0209	0.0124	0.0244

H = 14.615 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
B vs H	107.000	5.350	Yes
B vs E	40.000	2.000	No
E vs H	67.000	3.350	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

ANOVA Results for *Pascopyrum* Belowground Mass Under Low Soil Moisture

One Way Analysis of Variance

Data source: belowground mass data in WWpots_2004stats.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.921)

Group Name	N	Missing	Mean	Std Dev	SEM
C	8	0	0.0229	0.00592	0.00209
F	8	0	0.0133	0.00494	0.00175
I	8	0	0.0115	0.00490	0.00173

Source of Variation	DF	SS	MS	F	P
Between Groups	2	0.000601	0.000301	10.808	<0.001
Residual	21	0.000584	0.0000278		
Total	23	0.00119			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.973

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
C vs. I	0.0114	3	6.113	<0.001	Yes
C vs. F	0.00961	3	5.154	0.004	Yes
F vs. I	0.00179	3	0.958	0.779	No

Spearman Rank Order Correlation for *Pascopyrum* Belowground Mass

Spearman Rank Order Correlation

Data source: belowground mass data in WWpots_2004stats.SNB

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	EC Treatment
Belowground biomass (g)	-0.311
	0.00800
	72
	Water Treatment
Belowground biomass (g)	0.873
	0.000
	72

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

APPENDIX B

STUDY NO. 2: DATA AND STATISTICAL OUTPUT

Table 40. Data for *Pseudoroegneria* percent emergence.

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	30	30	10	30	30	30
2	0	10	20	20	20	30
3	0	50	20	20	20	40
4	10	30	30	20	30	20
5	30	20	20	40	40	40
6	30	20	40	40	40	20
7	30	30	60	30	10	30
8	20	10	20	20	30	20

Table 41. Means and standard error for *Pseudoroegneria* emergence.

Coversoil (cm)	% Emergence	Standard Error
0	18.75	4.794901
5	25	4.6291
10	27.5	5.59017
15	27.5	3.133916
30	27.5	3.659625
45	28.75	2.950484

ANOVA Results for *Pseudoroegneria* Emergence

One Way Analysis of Variance

Data source: Copy of Data 1 in BBWtubes2004.SNB

Normality Test: Failed (P = 0.008)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Copy of Data 1 in BBWtubes2004.SNB

Group	N	Missing	Median	25%	75%
0cm	8	0	25.000	5.000	30.000
5cm	8	0	25.000	15.000	30.000
10cm	8	0	20.000	20.000	35.000
15cm	8	0	25.000	20.000	35.000
30cm	8	0	30.000	20.000	35.000
45cm	8	0	30.000	20.000	35.000

H = 2.762 with 5 degrees of freedom. (P = 0.737)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.737)

Table 42. Data for *Hesperostipa* percent emergence.

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	20	60	40	30	10	10
2	20	50	40	40	40	40
3	40	30	30	50	20	30
4	50	10	20	30	50	60
5	30	60	30	60	50	40
6	50	40	40	40	40	30
7	70	10	40	20	20	20
8	40	60	40	50	0	30

Table 43. Means and standard error for *Hesperostipa* emergence.

Coversoil depth (cm)	% Emerged	Standard Error
0	40	5.976143
5	40	7.559289
10	35	2.672612
15	40	4.6291
30	28.75	6.664806
45	32.5	5.261043

ANOVA Results for *Hesperostipa* Emergence

One Way Analysis of Variance

Data source: % emergence data in NTtubes2004.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.111)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	40.000	16.903	5.976
5cm	8	0	40.000	21.381	7.559
10cm	8	0	35.000	7.559	2.673
15cm	8	0	40.000	13.093	4.629
30cm	8	0	28.750	18.851	6.665
45cm	8	0	32.500	14.880	5.261

Source of Variation	DF	SS	MS	F	P
Between Groups	5	910.417	182.083	0.706	0.622
Residual	42	10837.500	258.036		
Total	47	11747.917			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.622).

Power of performed test with alpha = 0.050: 0.050

The power of the performed test (0.050) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

Table 44. Data for *Pascopyrum* percent emergence.

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	50	80	70	60	80	80
2	80	90	60	70	80	80
3	60	50	70	60	30	50
4	60	60	50	60	60	80
5	70	50	90	70	80	90
6	100	70	60	90	70	60
7	40	50	80	80	50	70
8	70	70	50	90	90	10

Table 45. Means and standard error for *Pascopyrum* emergence.

Coversoil depth (cm)	% Emerged	Standard Error
0	66.25	6.529466
5	65	5.345225
10	66.25	4.977629
15	72.5	4.531635
30	67.5	7.007649
45	65	9.06327

ANOVA Results for *Pascopyrum* Emergence

One Way Analysis of Variance

Data source: emergence data in WWtubes2005.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.857)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	66.250	18.468	6.529
5cm	8	0	65.000	15.119	5.345
10cm	8	0	66.250	14.079	4.978
15cm	8	0	72.500	12.817	4.532
30cm	8	0	67.500	19.821	7.008
45cm	8	0	65.000	25.635	9.063

Source of Variation	DF	SS	MS	F	P
Between Groups	5	316.667	63.333	0.192	0.964
Residual	42	13875.000	330.357		
Total	47	14191.667			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.964).

Power of performed test with alpha = 0.050: 0.050

The power of the performed test (0.050) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

Table 46. Data for *Pseudoroegneria* plant height (cm).

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	42.7	35.3	34.4	51.8	59.7	37.5
2	38.1	46.8	55.1	41.5	40.7	40.8
3	40.1	42.7	42.1	42	40.4	43.2
4	39	43.7	44.7	46.3	46.2	53.8
5	46	39.1	48.4	37.9	35.1	59.6
6	40.1	35.7	39	44.2	46.3	48
7	55	45.4	48.7	37.5	50.1	43.1
8	38.2	38.3	47.7	34.5	39.4	44.5

Table 47. Means and standard error for *Pseudoroegneria* plant height.

Coversoil Depth (cm)	Height (cm)	Standard Error
0	42.4	2.026961
5	40.875	1.549971
10	45.0125	2.281168
15	41.9625	1.949903
30	44.7375	2.717991
45	46.3125	2.559327

ANOVA Results for *Pseudoroegneria* Plant Height

One Way Analysis of Variance

Data source: Copy (2) ofData 1 in BBWtubes2004.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.869)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	42.400	5.733	2.027
5cm	8	0	40.875	4.384	1.550
10cm	8	0	45.013	6.452	2.281
15cm	8	0	41.963	5.515	1.950
30cm	8	0	44.737	7.688	2.718
45cm	8	0	46.313	7.239	2.559

Source of Variation	DF	SS	MS	F	P
Between Groups	5	177.430	35.486	0.904	0.488
Residual	42	1649.450	39.273		
Total	47	1826.880			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.488).

Power of performed test with alpha = 0.050: 0.050

The power of the performed test (0.050) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

Table 48. Data for *Hesperostipa* plant height (cm).

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	23.5	17.4	21.6	18.5	21.2	29.2
2	15.7	18.9	23	13.8	28.2	27.5
3	18.8	15.8	16.6	22.2	25.5	24.7
4	16.2	12.9	18.1	21.6	27.1	26.7
5	16.5	21.5	22.1	21.3	24.2	23.7
6	16.5	21.5	20.7	26.2	28.1	30.3
7	17.1	16.5	22.2	11.4	19	23
8	17.3	20.4	19.1	19.9	17.3	21.9

Table 49. Means and standard error for *Hesperostipa* plant height.

Coversoil depth (cm)	Plant Height (cm)	Standard Error
0	17.7	0.891427
5	18.1125	1.07262
10	20.425	0.799944
15	19.3625	1.684693
30	23.825	1.487057
45	25.875	1.070172

ANOVA Results for *Hesperostipa* Plant Height

One Way Analysis of Variance
Data source: plant height data in NTtubes2004.SNB

Normality Test: Passed (P > 0.050)
Equal Variance Test: Passed (P = 0.348)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	17.700	2.521	0.891
5cm	8	0	18.113	3.034	1.073
10cm	8	0	20.425	2.263	0.800
15cm	8	0	19.363	4.765	1.685
30cm	8	0	23.825	4.206	1.487
45cm	8	0	25.875	3.027	1.070

Source of Variation	DF	SS	MS	F	P
Between Groups	5	431.234	86.247	7.367	<0.001
Residual	42	491.672	11.706		
Total	47	922.907			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.995

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
45cm vs. 0cm	8.175	6	6.758	<0.001	Yes
45cm vs. 5cm	7.763	6	6.417	<0.001	Yes
45cm vs. 15cm	6.513	6	5.384	0.006	Yes
45cm vs. 10cm	5.450	6	4.505	0.031	Yes
45cm vs. 30cm	2.050	6	1.695	0.835	No
30cm vs. 0cm	6.125	6	5.063	0.011	Yes
30cm vs. 5cm	5.713	6	4.722	0.021	Yes
30cm vs. 15cm	4.463	6	3.689	0.118	No
30cm vs. 10cm	3.400	6	2.811	0.367	Do Not Test
10cm vs. 0cm	2.725	6	2.253	0.608	No
10cm vs. 5cm	2.313	6	1.912	0.755	Do Not Test
10cm vs. 15cm	1.063	6	0.878	0.989	Do Not Test
15cm vs. 0cm	1.662	6	1.374	0.924	Do Not Test
15cm vs. 5cm	1.250	6	1.033	0.977	Do Not Test
5cm vs. 0cm	0.412	6	0.341	1.000	Do Not Test

A result of "Do Not Test" occurs for a comparison when no significant difference is found between two means that enclose that comparison. For example, if you had four means sorted in order, and found no difference between means 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed means is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the means, even though one may appear to exist.

Table 50. Data for *Pascopyrum* plant height (cm).

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	55.8	55.6	61.3	57.4	50.9	56.6
2	51.5	57.9	55.4	61.3	48	49
3	57.8	48.5	62.7	54.7	58.2	55.7
4	60.9	51.6	62.1	67.3	55.4	51.3
5	49.8	60.3	57.1	52.2	54.1	56.7
6	59.9	51	58.1	49.2	49.3	44
7	55	61.4	62.6	56.1	49.6	50.3
8	60.9	57.8	58	54.6	45.5	48.1

Table 51. Means and standard error for *Pascopyrum* plant height.

Coversoil depth (cm)	Plant height (cm)	Standard Error
0	56.45	1.491524
5	55.5125	1.65491
10	59.6625	1.003732
15	56.6	1.978455
30	51.375	1.486817
45	51.4625	1.615874

ANOVA Results for *Pascopyrum* Plant Height

One Way Analysis of Variance
Data source: plant height data in WWtubes2005.SNB

Normality Test: Passed (P > 0.050)
Equal Variance Test: Passed (P = 0.905)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	56.450	4.219	1.492
5cm	8	0	55.512	4.681	1.655
10cm	8	0	59.663	2.839	1.004
15cm	8	0	56.600	5.596	1.978
30cm	8	0	51.375	4.205	1.487
45cm	8	0	51.463	4.570	1.616

Source of Variation	DF	SS	MS	F	P
Between Groups	5	417.044	83.409	4.254	0.003
Residual	42	823.581	19.609		
Total	47	1240.625			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.003).

Power of performed test with alpha = 0.050: 0.852
All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
10cm vs. 30cm	8.287	6	5.293	0.007	Yes
10cm vs. 45cm	8.200	6	5.238	0.008	Yes
10cm vs. 5cm	4.150	6	2.651	0.432	No
10cm vs. 0cm	3.213	6	2.052	0.696	Do Not Test
10cm vs. 15cm	3.063	6	1.956	0.737	Do Not Test
15cm vs. 30cm	5.225	6	3.337	0.194	No
15cm vs. 45cm	5.137	6	3.281	0.209	Do Not Test
15cm vs. 5cm	1.088	6	0.695	0.996	Do Not Test
15cm vs. 0cm	0.150	6	0.0958	1.000	Do Not Test
0cm vs. 30cm	5.075	6	3.242	0.220	Do Not Test
0cm vs. 45cm	4.987	6	3.186	0.236	Do Not Test
0cm vs. 5cm	0.938	6	0.599	0.998	Do Not Test
5cm vs. 30cm	4.137	6	2.643	0.435	Do Not Test
5cm vs. 45cm	4.050	6	2.587	0.459	Do Not Test
45cm vs. 30cm	0.0875	6	0.0559	1.000	Do Not Test

A result of "Do Not Test" occurs for a comparison when no significant difference is found between two means that enclose that comparison. For example, if you had four means sorted in order, and found no difference between means 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed means is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the means, even though one may appear to exist.

Table 52. Data for *Pseudoroegneria* aboveground mass (g/plant).

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	1.0117	0.7431	0.1675	2.1277	1.9335	1.2582
2	0.222	0.711	1.4429	1.3451	1.404	1.1232
3	0.4584	0.6916	1.2403	1.0652	1.8605	1.6597
4	0.2294	0.8103	1.2562	0.4574	0.9783	2.0061
5	0.4969	0.8481	1.102	1.5011	1.5116	1.4368
6	0.7123	0.9931	1.3944	0.9181	1.7858	1.6264
7	0.6951	0.8077	1.0447	1.1999	1.4229	1.1732
8	0.5747	0.6739	1.1286	1.1326	1.3262	1.706

Table 53. Means and standard error for *Pseudoroegneria* aboveground mass.

Coversoil (cm)	Aboveground mass (g/plant)	Standard Error
0	0.550063	0.092847
5	0.78485	0.037019
10	1.097075	0.141529
15	1.218388	0.170256
30	1.52785	0.112681
45	1.4987	0.107842

ANOVA Results for *Pseudoroegneria* Aboveground Mass

One Way Analysis of Variance
Data source: Aboveground biomass data in BBWtubes2004.SNB

Normality Test: Passed (P > 0.050)
Equal Variance Test: Passed (P = 0.413)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	0.550	0.263	0.0928
5cm	8	0	0.785	0.105	0.0370
10cm	8	0	1.097	0.400	0.142
15cm	8	0	1.218	0.482	0.170
30cm	8	0	1.528	0.319	0.113
45cm	8	0	1.499	0.305	0.108

Source of Variation	DF	SS	MS	F	P
Between Groups	5	6.054	1.211	10.898	<0.001
Residual	42	4.667	0.111		
Total	47	10.721			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000
All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
30cm vs. 0cm	0.978	6	8.297	<0.001	Yes
30cm vs. 5cm	0.743	6	6.304	<0.001	Yes
30cm vs. 10cm	0.431	6	3.655	0.124	No
30cm vs. 15cm	0.309	6	2.626	0.442	Do Not Test
30cm vs. 45cm	0.0292	6	0.247	1.000	Do Not Test
45cm vs. 0cm	0.949	6	8.049	<0.001	Yes
45cm vs. 5cm	0.714	6	6.057	0.001	Yes
45cm vs. 10cm	0.402	6	3.408	0.176	Do Not Test
45cm vs. 15cm	0.280	6	2.379	0.551	Do Not Test
15cm vs. 0cm	0.668	6	5.671	0.003	Yes
15cm vs. 5cm	0.434	6	3.679	0.120	No
15cm vs. 10cm	0.121	6	1.029	0.977	Do Not Test
10cm vs. 0cm	0.547	6	4.641	0.024	Yes
10cm vs. 5cm	0.312	6	2.649	0.432	Do Not Test
5cm vs. 0cm	0.235	6	1.992	0.722	No

A result of "Do Not Test" occurs for a comparison when no significant difference is found between two means that enclose that comparison. For example, if you had four means sorted in order, and found no difference between means 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed means is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the means, even though one may appear to exist.

Table 54. Data for *Hesperostipa* aboveground mass (g/plant).

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	0.1221	0.1588	0.1099	0.1575	0.1148	0.1326
2	0.0414	0.1214	0.1654	0.125	0.2472	0.4147
3	0.0531	0.1314	0.1207	0.2252	0.167	0.4117
4	0.051	0.0659	0.1025	0.2205	0.3256	0.2689
5	0.0492	0.192	0.1748	0.183	0.2033	0.1888
6	0.0986	0.0997	0.171	0.1654	0.3469	0.3066
7	0.1004	0.0378	0.1381	0.0515	0.0527	0.1875
8	0.0922	0.17	0.1165	0.1515	0.0474	0.2049

Table 55. Means and standard error for *Hesperostipa* aboveground mass.

Coversoil depth (cm)	Aboveground mass (g/plant)	Standard Error
0	0.076	0.010822
5	0.122125	0.018603
10	0.137363	0.010353
15	0.15995	0.019615
30	0.188113	0.040487
45	0.264463	0.037471

ANOVA Results for *Hesperostipa* Aboveground Mass

One Way Analysis of Variance

Data source: aboveground mass data in NTtubes2004.SNB

Normality Test: Passed (P > 0.050)
Equal Variance Test: Failed (P = 0.002)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, February 18, 2005, 9:39:40 AM

Data source: aboveground mass data in NTtubes2004.SNB

Group	N	Missing	Median	25%	75%
0cm	8	0	0.0727	0.0501	0.0995
5cm	8	0	0.126	0.0828	0.164
10cm	8	0	0.129	0.113	0.168
15cm	8	0	0.161	0.138	0.202
30cm	8	0	0.185	0.0837	0.286
45cm	8	0	0.237	0.188	0.359

H = 20.764 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
45cm vs 0cm	242.000	6.111	Yes
45cm vs 5cm	157.000	3.965	No
45cm vs 10cm	133.500	3.371	Do Not Test
45cm vs 15cm	93.500	2.361	Do Not Test
45cm vs 30cm	88.000	2.222	Do Not Test
30cm vs 0cm	154.000	3.889	No
30cm vs 5cm	69.000	1.743	Do Not Test
30cm vs 10cm	45.500	1.149	Do Not Test
30cm vs 15cm	5.500	0.139	Do Not Test
15cm vs 0cm	148.500	3.750	Do Not Test
15cm vs 5cm	63.500	1.604	Do Not Test
15cm vs 10cm	40.000	1.010	Do Not Test
10cm vs 0cm	108.500	2.740	Do Not Test
10cm vs 5cm	23.500	0.593	Do Not Test
5cm vs 0cm	85.000	2.147	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

Table 56. Data for *Pascopyrum* aboveground mass (g/plant).

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	0.5358	0.8829	0.8866	0.7791	0.8788	1.2312
2	0.3451	0.852	0.8339	0.7552	0.8411	1.1264
3	0.7239	0.4607	0.951	1.1448	0.8215	1.2391
4	0.5028	0.7245	0.8866	0.9387	1.1749	0.9716
5	0.6065	0.8701	0.6296	0.7354	0.9357	1.1417
6	0.7097	0.6827	0.879	0.7253	0.8864	0.7511
7	0.667	0.7818	0.8406	1.0368	1.164	1.0086
8	0.5684	0.6385	0.7166	0.6795	0.838	0.9144

Table 57. Means and standard error for *Pascopyrum* aboveground mass.

Coversoil depth (cm)	Aboveground mass (g/plant)	Standard Error
0	0.5824	0.044114
5	0.73665	0.0506
10	0.827988	0.036976
15	0.84935	0.059975
30	0.94255	0.051089
45	1.048013	0.059521

ANOVA Results for *Pascopyrum* Aboveground Mass

One Way Analysis of Variance
Data source: aboveground mass data in WWtubes2005.SNB

Normality Test: Passed (P > 0.050)
Equal Variance Test: Passed (P = 0.823)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	0.582	0.125	0.0441
5cm	8	0	0.737	0.143	0.0506
10cm	8	0	0.828	0.105	0.0370
15cm	8	0	0.849	0.170	0.0600
30cm	8	0	0.943	0.145	0.0511
45cm	8	0	1.048	0.168	0.0595

Source of Variation	DF	SS	MS	F	P
Between Groups	5	1.045	0.209	10.030	<0.001
Residual	42	0.875	0.0208		
Total	47	1.920			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
45cm vs. 0cm	0.466	6	9.125	<0.001	Yes
45cm vs. 5cm	0.311	6	6.102	0.001	Yes
45cm vs. 10cm	0.220	6	4.312	0.043	Yes
45cm vs. 15cm	0.199	6	3.893	0.086	No
45cm vs. 30cm	0.105	6	2.067	0.690	Do Not Test
30cm vs. 0cm	0.360	6	7.058	<0.001	Yes
30cm vs. 5cm	0.206	6	4.035	0.068	No
30cm vs. 10cm	0.115	6	2.245	0.611	Do Not Test
30cm vs. 15cm	0.0932	6	1.826	0.788	Do Not Test
15cm vs. 0cm	0.267	6	5.231	0.008	Yes
15cm vs. 5cm	0.113	6	2.209	0.627	Do Not Test
15cm vs. 10cm	0.0214	6	0.419	1.000	Do Not Test
10cm vs. 0cm	0.246	6	4.813	0.017	Yes
10cm vs. 5cm	0.0913	6	1.790	0.802	Do Not Test
5cm vs. 0cm	0.154	6	3.023	0.289	No

A result of "Do Not Test" occurs for a comparison when no significant difference is found between two means that enclose that comparison. For example, if you had four means sorted in order, and found no difference between means 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed means is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the means, even though one may appear to exist.

Table 58. Data for *Pseudoroegneria* belowground mass (g/plant).

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	0.7093	0.4925	0.154	1.4192	1.2399	1.1248
2	0.16	0.6252	0.6902	1.3197	1.3431	1.17
3	0.1888	0.5229	0.8922	0.7349	1.2735	1.5156
4	0.162	0.6479	1.0739	0.1748	0.8268	0.967
5	0.5102	0.8226	1.0109	1.1652	1.3679	0.8282
6	0.7596	0.8534	1.1393	0.7562	1.3029	0.9402
7	0.5305	0.835	0.9133	0.9954	1.025	0.9017
8	0.4927	0.4152	0.5223	0.7015	1.3047	1.2473

Table 59. Means and standard error for *Pseudoroegneria* belowground mass.

Coversoil (cm)	Belowground mass (g/plant)	Standard Error
0	0.439138	0.085497
5	0.651838	0.06007
10	0.799513	0.116684
15	0.908363	0.142543
30	1.210475	0.066311
45	1.08685	0.079617

ANOVA Results for *Pseudoroegneria* Belowground Mass

One Way Analysis of Variance
Data source: Copy (4) of Data 1 in BBWtubes2004.SNB

Normality Test: Passed (P > 0.050)
Equal Variance Test: Passed (P = 0.253)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	0.439	0.242	0.0855
5cm	8	0	0.652	0.170	0.0601
10cm	8	0	0.800	0.330	0.117
15cm	8	0	0.908	0.403	0.143
30cm	8	0	1.210	0.188	0.0663
45cm	8	0	1.087	0.225	0.0796

Source of Variation	DF	SS	MS	F	P
Between Groups	5	3.201	0.640	8.636	<0.001
Residual	42	3.113	0.0741		
Total	47	6.313			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.999

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
30cm vs. 0cm	0.771	6	8.014	<0.001	Yes
30cm vs. 5cm	0.559	6	5.804	0.002	Yes
30cm vs. 10cm	0.411	6	4.270	0.046	Yes
30cm vs. 15cm	0.302	6	3.139	0.251	No
30cm vs. 45cm	0.124	6	1.284	0.942	Do Not Test
45cm vs. 0cm	0.648	6	6.729	<0.001	Yes
45cm vs. 5cm	0.435	6	4.519	0.030	Yes
45cm vs. 10cm	0.287	6	2.985	0.302	No
45cm vs. 15cm	0.178	6	1.854	0.777	Do Not Test
15cm vs. 0cm	0.469	6	4.875	0.015	Yes
15cm vs. 5cm	0.257	6	2.665	0.426	No
15cm vs. 10cm	0.109	6	1.131	0.966	Do Not Test
10cm vs. 0cm	0.360	6	3.744	0.108	No
10cm vs. 5cm	0.148	6	1.534	0.885	Do Not Test
5cm vs. 0cm	0.213	6	2.210	0.627	Do Not Test

A result of "Do Not Test" occurs for a comparison when no significant difference is found between two means that enclose that comparison. For example, if you had four means sorted in order, and found no difference between means 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed means is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the means, even though one may appear to exist.

Table 60. Data for *Hesperostipa* belowground mass (g/plant).

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	0.1588	0.1061	0.104	0.0994	0.098	0.0829
2	0.0351	0.0814	0.1114	0.1203	0.1943	0.289
3	0.0469	0.2609	0.157	0.1782	0.1469	0.1656
4	0.0655	0.0583	0.1173	0.1233	0.2437	0.098
5	0.0714	0.1653	0.1307	0.1479	0.0965	0.1508
6	0.1653	0.1609	0.1528	0.1827	0.2	0.1076
7	0.0999	0.0376	0.0978	0.0554	0.0277	0.1328
8	0.0905	0.1658	0.1252	0.0885	0.0422	0.1321

Table 61. Means and standard error for *Hesperostipa* belowground mass.

Coversoil depth (cm)	Belowground mass (g/plant)	Standard Error
0	0.091675	0.017059
5	0.129538	0.025783
10	0.124525	0.007621
15	0.124463	0.015549
30	0.131163	0.027567
45	0.14485	0.022746

ANOVA Results for *Hesperostipa* Belowground Mass

One Way Analysis of Variance

Data source: belowground mass data in NTtubes2004.SNB

Normality Test: Passed (P > 0.050)

Equal Variance Test: Passed (P = 0.080)

Group Name	N	Missing	Mean	Std Dev	SEM
0cm	8	0	0.0917	0.0483	0.0171
5cm	8	0	0.130	0.0729	0.0258
10cm	8	0	0.125	0.0216	0.00762
15cm	8	0	0.124	0.0440	0.0155
30cm	8	0	0.131	0.0780	0.0276
45cm	8	0	0.145	0.0643	0.0227

Source of Variation	DF	SS	MS	F	P
Between Groups	5	0.0125	0.00250	0.740	0.598
Residual	42	0.142	0.00338		
Total	47	0.154			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.598).

Power of performed test with alpha = 0.050: 0.050

The power of the performed test (0.050) is below the desired power of 0.800.
You should interpret the negative findings cautiously.

Table 62. Data for *Pascopyrum* belowground mass (g/plant)

	Coversoil Depth (cm)					
Replication	0	5	10	15	30	45
1	0.253	0.3515	0.1958	0.3136	0.3539	0.4139
2	0.0809	0.2523	0.3011	0.5587	0.35	0.3931
3	0.2378	0.2882	0.3797	0.4506	0.3319	0.5173
4	0.1858	0.4399	0.388	0.3295	0.5922	0.3522
5	0.2713	0.3988	0.2746	0.245	0.6276	0.4396
6	0.1665	0.2559	0.2905	0.3518	0.3442	0.3649
7	0.2633	0.1588	0.267	0.6119	0.3649	0.3868
8	0.1377	0.264	0.2588	0.3762	0.3064	0.4465

Table 63. Means and standard error for *Pascopyrum* belowground mass.

Coversoil Depth (cm)	Belowground Mass (g/plant)	Standard Error
0	0.199538	0.024171
5	0.301175	0.032062
10	0.294438	0.022452
15	0.404663	0.044686
30	0.408888	0.044417
45	0.414288	0.018798

ANOVA Results for *Pascopyrum* Belowground Mass

One Way Analysis of Variance

Data source: belowground mass data in WWtubes2005.SNB

Normality Test: Failed (P = 0.021)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: belowground mass data in WWtubes2005.SNB

Group	N	Missing	Median	25%	75%
0cm	8	0	0.212	0.152	0.258
5cm	8	0	0.276	0.254	0.375
10cm	8	0	0.283	0.263	0.340
15cm	8	0	0.364	0.322	0.505
30cm	8	0	0.352	0.338	0.479
45cm	8	0	0.403	0.376	0.443

H = 24.127 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
45cm vs 0cm	239.500	6.048	Yes
45cm vs 10cm	138.500	3.498	No
45cm vs 5cm	136.500	3.447	Do Not Test
45cm vs 15cm	48.500	1.225	Do Not Test
45cm vs 30cm	46.000	1.162	Do Not Test
30cm vs 0cm	193.500	4.887	Yes
30cm vs 10cm	92.500	2.336	Do Not Test
30cm vs 5cm	90.500	2.285	Do Not Test
30cm vs 15cm	2.500	0.0631	Do Not Test
15cm vs 0cm	191.000	4.823	Yes
15cm vs 10cm	90.000	2.273	Do Not Test
15cm vs 5cm	88.000	2.222	Do Not Test
5cm vs 0cm	103.000	2.601	No
5cm vs 10cm	2.000	0.0505	Do Not Test
10cm vs 0cm	101.000	2.551	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.