Appendix 3/4 - Objective 3

Assessment of the potential for utilization of selected plant species and communities for phytoremediation of coalbed methane product water where such practices and approaches might be appropriate;

Objective 4: Assessment of 'beneficial use' opportunities for coalbed methane product water

MicroSoft Word Document - File title: Native Plant Sensitivity.doc

Title: Salinity, sodicity, and flooding tolerance of selected native and culturally significant plant species of the northern fringe of the Powder River Basin.

Author: Nikos Warrence and James W. Bauder, Montana State University

Content: comprehensive review of plant species identified as native and of cultural significance in the northern fringe of the Powder River Basin, with particular reference to culturally significant plants of the Northern Cheyenne tribe; a detailed listing and description of 31 species, including common and scientific name, rating and upper limit of tolerance to salinity, sodicity, flooding and inundation; known range in soil pH where species occur.

SALINITY, SODICITY AND FLOODING TOLERANCE OF SELECTED NATIVE AND CULTURALLY SIGNIFICANT PLANT SPECIES OF THE NORTHERN FRINGE OF THE POWDER RIVER BASIN

Preface

This document was prepared in response to numerous questions raised regarding the tolerance and/or sensitivity of native and culturally significant plants to salinity, sodicity, and flooding that might be a consequence of natural gas exploration and extraction in southeast Montana. Initially, a list of native and culturally significant plant species was obtained from the Department of Environmental Protection, Northern Cheyenne Tribe. A thorough search of references dealing with salinity, sodicity, flooding, and pH tolerances for the plants in question was then undertaken, with journals, reference books and Internet sources all providing pertinent information. The goal was to gain an accurate prediction as to how native and culturally significant plants would be likely to respond to increases in salinity, sodicity, flooding, and pH/ alkalinity, all possible consequences of proposed natural gas extraction in southeast Montana. Where no data were found for a specific plant tolerance, indicator species were used. Indicator species were either plants in the same genus or plants commonly found in the same habitats or communities as the plant in question. Some of the primary sources used were Ayers and Westcot's 1976 "Water Quality for Agriculture", E.V. Maas' 1993 "Testing crops for salinity tolerance", Frank F. Munshower's Forbs, Shrubs, and Trees for Revegetation of Disturbed Lands in the Northern Great Plains and Adjacent Areas with comments about some wetland species, James Small's 1946 pH and Plants: An Introduction for Beginners, K.K. Tanji's Agricultural Salinity Assessment and

Management. The United States Department of Agriculture website, Utah State University's Extension Service, and B. Wolf's The Fertile Triangle.

Scientific Basis

Salinity: A multitude of references have been published within the scientific literature assigning various ranges of soil solution salinity to categories of salt tolerant plants. Using these ratings systems, most plant species are assigned to categories such as degree of sensitivity or degree of tolerance to salinity. For purposes of reference, Table 1 presents two frequently cited salt tolerance rating systems (Miller and Donahue, 1995; Maas, 1993). Using the composite information from these two references, a general rating system was prepared for use in this report. Plant species identified in this report as "sensitive" were those determined to be adversely affected by EC_e values < 2 dS/m. At the other extreme, plant species reportedly tolerant and capable of reasonably normal growth under conditions of EC_e values > 6 dS/m were rated as tolerant. For further purposes of reference, a saline soil is generally considered to be one with an EC_e (saturated paste extract) greater than 3.0 dS/m (Miller and Donahue, 1995).

Table 1. Salinity Tolerance Ratings

Miller and Donahue, 1995	Maas, 1993	This report	Symbol-
	EC_e^{1} (dS/m)		
0-2 few plants affected	< 1.5 sensitive	< 2 sensitve	S
2-4 some sensitive plants affected	1.5 – 3.0 moderately sensitive	2-4 moderately sensitive	MS
4-8 many plants affected	3-6 moderately tolerant	4-6 moderately tolerant	MT
8-16 most crop plants affected	6-10 tolerant	>6 tolerant	T

>16 few plants tolerant	>10 very tolerant

[1]EC_e = salinity of saturated paste extract, dS/m

For purposes of this assessment, plant species determined to be adversely affected by salinity values < 2 dS/m were rated as sensitive; those adversely affected by salinity values between 2 and 4 dS/m were rated as moderately sensitive; those affected by salinity values between 4 and 6 dS/m were rated at moderately tolerant; plant species tolerant to EC > 6 dS/m were rated as tolerant.

Sodium Tolerance Ratings: The scientific literature contains few specific references to individual plant species' tolerances to sodicity, which may be expressed as SAR (sodium adsorption ration), ESP (exchangeable sodium percentage) or specific sodium concentration. Sodium is known to have an adverse effect on most plant tissue when in direct contact with leaves at high concentrations. Generally, however, effects of sodium on plant performance are indirect and a response to sodium-induced alterations in soil physical and chemical properties. For purposes of reporting herein, species exhibiting a high degree of sensitivity to sodium are listed as extremely sensitive (ES). Other species may be affected indirectly by sodium, through a change in soil physical structure. Species reportedly very tolerant of sodium (able to tolerate ESP of as much as 60%) are identified as VT. Where no ratings is presented, data were not available to justify a rating. Shainberg and Oster (1978) report that all deciduous fruits are extremely sensitive to sodium, with ESP 2 –10 % having a negative impact on plants and fruit production. Primary sodium toxicity symptoms are leaf burn and leaf wilting. In general, it is not uncommon for sodium toxicity to occur when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content > 70 mg/L or SAR >3.0 (DPI website, 2002).

Flooding Tolerance Ratings: (conventions used in this report)

Intolerant – unable to withstand flooding for more than a few days

Moderately Tolerant – able to withstand short-term flooding, approximately two weeks in duration, but not long term flooding

Tolerant – able to withstand relatively long flooding, up to a year or more, but may still be damaged by consecutive years of flooding

pH/Alkalinity Tolerance Ratings: (conventions used in this report) Ideal pH ranges are given. While plant species may be able to survive outside of the given ranges, they are likely to be negatively impacted, either through direct physical damage or through competition with species better adapted to the given pH.

Summary of Findings

The following table (Table 2) provides a summary of the primary information in the text, specifically plant tolerances to salinity, given as an overall sensitivity rating and threshold EC_e value (where salinity begins to have a negative impact), sodicity, flooding, and pH. The text itself provides a complete listing of all relevant data pertaining to the above criteria, as well as general habitat descriptions and other relevant information.

Table 2. Summary of sensitivity rating of thirty one native and culturally significant plant species of the Northern Cheyenne Reservation to soil solution salinity (EC_e), exchangeable sodium percentage, flooding, and changes in soil pH.

SPECIES

COMMON NAME	SCIENTIFIC NAME	SALINITY Rating	SALINITY Acceptable Upper Limit EC_e (sat) dS/m	SODIUM Tolerance Rating	FLOODING Rating	FLOODING Inundation Limits	pH Range
1. June/ Service Berry	*Amelanchier alnifolia*	S	2.0	ES; ESP 2-10 SAR 1.6-8.0	MT	short term, 2 weeks	no data
2. Red Osier Dogwood	*Cornus stolinifera*	S	2.0	no data available	MT	short term, 2 weeks	6.5-7.9
3. Common spikerush	*Eleocharis palustris*	MS	4.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.9
4. Horsetail, Field	*Equisetum arvense*	MS	4.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.2
5. Wild licorice/ American	*Glycyrrhiza lepidota*	MT	6.0	VT; ESP 60 SAR 48	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.2

Table 2 (continued). Summary of sensitivity rating of thirty one native and culturally significant plant species of the Northern Cheyenne Reservation to soil solution salinity (EC_e), exchangeable sodium percentage, flooding, and changes in soil pH.

SPECIES

COMMON NAME	SCIENTIFIC NAME	SALINITY Rating	SALINITY Acceptable Upper Limit EC_e (sat) dS/m	SODIUM Tolerance Rating	FLOODING Rating	FLOODING Inundation Limits	pH Range
6. Goose Berry, red shoot	*Ribes setosum*	S	2.0	ES: ESP: 2-10 SAR 1.6 - 8	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.9
7. Mint/ Field	*Mentha arvensis*	S/MS	2.0	ES: ESP 2-10 SAR 1.6-8	no data available		4.8-7.9
8. Horsemint/ W. Bergamot	*Monarda fistulosa*	MS	4.0	no data available	no data available		5.5-7.9
9. Water Plant/ Water Cress	*Nasturium officinale*	MS	4.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.2
10. Sweet Medicine	*Oxtropis lamnbertii*	MS	4.0	no data available		no data available	5.5-7.9
11. Chokecherry	*Prunus virginiana*	S	2.0	ES: ESP 2-10 SAR 1.6 – 8	I	very short term, < 2 weeks	4.8-7.9

Table 2 (continued). Summary of sensitivity rating of thirty one native and culturally significant plant species of the Northern Cheyenne Reservation to soil solution salinity (EC_e), exchangeable sodium percentage, flooding, and changes in soil pH.

SPECIES

COMMON NAME	SCIENTIFIC NAME	SALINITY Rating	SALINITY Acceptable Upper Limit EC_e (sat) dS/m	SODIUM Tolerance Rating	FLOODING Rating	FLOODING Inundation Limits	pH Range
12. Cottonwood, G. Plains	*Populus deltoides*	MS	4.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.9
13. Box elder	*Acer negundo*	MT	6.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.9
14. Green ash	*Fraxinus pennsylvania*	MT	6.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	6.5-7.9
15. Sand bar willow	*Salix exigua*	MS	4.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.9

Table 2 (continued). Summary of sensitivity rating of thirty one native and culturally significant plant species of the Northern Cheyenne Reservation to soil solution salinity (EC_e), exchangeable sodium percentage, flooding, and changes in soil pH.

SPECIES

COMMON NAME	SCIENTIFIC NAME	SALINITY Rating	SALINITY Acceptable Upper Limit EC_e (sat) dS/m	SODIUM Tolerance Rating	FLOODING Rating	FLOODING Inundation Limits	pH Range
16. Snow Berry	*Symphoricarpos occidentalis*	MS	4.0	ES: ESP 2-10 SAR 1.6 -1.8	I	long term, 1 year +; not tolerant to permanent flooding	4.8-7.9
17. Cattail	*Typha latifolia*	MS	4.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.9
18. Wild plum	*Prunus americana*	S	2.0	ES:ESP 2-10 SAR 1.6-8	T	long term, 1 year +; not tolerant to permanent flooding	no data
19. Sweet grass	*Hierochloe odorota*	MS	4.0	no data available		no data available	4.8-7.2
20. Quaking aspen	*Populus tremuloides*	S	2.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	no data

Table 2 (continued). Summary of sensitivity rating of thirty one native and culturally significant plant species of the Northern Cheyenne Reservation to soil solution salinity (EC_e), exchangeable sodium percentage, flooding, and changes in soil pH.

SPECIES

COMMON NAME	SCIENTIFIC NAME	SALINITY Rating	SALINITY Acceptable Upper Limit EC_e (sat) dS/m	SODIUM Tolerance Rating	FLOODING Rating	FLOODING Inundation Limits	pH Range
21. Saw beak sedge	*Carex stipata*	MS	4.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	5.0-7.9
22. Leafy aster	*Aster foliactus*	S	2.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.2
23. Stinging nettle	*Urtica dioica*	MS	4.0	no data available	I	very short term, < 2 weeks	4.8-7.2
24. Bulrush	*Scirpus nevadensis*	MT/T	6.0	no data available	T	long term, 1 year not tolerant to permanent flooding	4.8-7.9
25. Arrow leaf	*Sagittaria latifolia*	MS	4.0	no data available	T	long term, 1 year +; not tolerant to permanent flooding	4.8-7.9

Table 2 (continued). Summary of sensitivity rating of thirty one native and culturally significant plant species of the Northern Cheyenne Reservation to soil solution salinity (EC_e), exchangeable sodium percentage, flooding, and changes in soil pH.

SPECIES

COMMON NAME	SCIENTIFIC NAME	SALINITY Rating	SALINITY Acceptable Upper Limit EC_e (sat) dS/m	SODIUM Tolerance Rating	FLOODING Rating	FLOODING Inundation Limits	pH Range
26. Golden currant	*Ribes aureum*	MS	4.0	ES: ESP 2-10 SAR 1.6-8	no available data		4.8-7.9
27. Skunkbush sumac	*Rhus trixobata*	MT	6.0	no available data	MT	short term, 2 weeks	6.5-7.9
28. Milkweed, showy	*Asclepias speciosa*	MS	4.0	no avaible data	I	very short term, < 2 weeks	4.8-7.2
29. Western yarrow	*Achillea millelolium*	MS	4.0	no available data	I	very short term < 2 weeks	4.8-7.9
30. Raspberry, red	*Rubes idaue*	S	2.0	ES: ESP 2-10 SAR 1.6-8	no available data		4.8-7.9
31. Rose Bush	*Rosa arkansa*	MS	4.0	no available data	MT	short term, 2 week	4.8-7.9

Explanations and Descriptions of Plant Responses to Salinity, Sodicity, pH/Alkalinity, and Bicarbonates

Salinity: The quality of water plants are exposed to has a direct impact on their survival, growth, and overall health. This is particularly true in regard to salinity. Published research supports the premise that the salinity of water plants will actually have available to utilize, the soil EC, EC_e, or EC_{sat} (saturated paste extract), is on average as much as three times the salinity of applied irrigation water due to evapotranspiration (Ayers and Westcot, 1976). Schafer (1983b) reports an increase in EC_{sat} of as much as 5 dS/m for each dS/m of applied water. Hence it is important to distinguish the condition being referred to with regard to salt tolerance, i.e. salinity of applied water or salinity of the soil solution. Most salinity tolerance listings, including those outlined here, use soil saturated paste extract EC measurements, referred to as EC_e or EC_{sat}.

An extensive amount of research has been published regarding cultivated crop species' tolerances to salinity. Less data are available for plants normally considered non-agricultural. Figure 1 illustrates the relative crop yield of plants of varying sensitivity to soil water salinity, EC_e. Shainberg and Oster (1978) identified five categories of plants with respect to salinity tolerance. In their rating system, sensitive plants demonstrated reductions in performance at EC_e values as low as 1.5 dS/m and death occurred in the sensitive species at EC_e = 8.0 dS/m. At the other extreme, plants rated as tolerant did not demonstrate measurable yield reductions until EC_e exceeded 6 dS/m and 100 % reduction did not occur until EC_e reached 32 dS/m. This same rating system was subsequently reported by Maas (1993) and constitutes part of the report contained herein. Generally most agricultural plants demonstrate some degree of impairment when EC_e exceeds 8 dS/m (Schafer, 1983a).

The most likely effect of salinity on plants is a general stunting of growth. Increased salinity requires plants to expend more energy to obtain water from the soil, thereby reducing the amount of energy available for growth. **Moderately salt-stressed plants usually appear normal, although their leaves may be darker green, thicker and more succulent than non-stressed plants. Visual symptoms (leaf burn, necrosis, and defoliation) sometimes occur, particularly in woody species. At high levels, salinity can cause physical damage and mortality. Plant sensitivity to salinity changes throughout the growing season. While most crops are relatively tolerant to salinity during germination, young developing seedlings are particularly susceptible to salinity damage during emergence and early juvenile development.** After they are established, plants generally become increasingly tolerant to salinity in later growth stages (Maas, 1993).

A primary effect of salinity is that it delays germination and seedling development. This delay may prove fatal if the salt-stressed seedlings encounter additional stresses, such as water stress, extreme temperature fluctuations and/ or soil crusting. Additionally, because of evaporation at the soil surface, the salt concentration in the seedbed is often higher than deeper down in the soil profile. Hence, roots of emerging seedlings are exposed to a greater degree of stress than that indicated by usual salinity measurements which are generally derived from composite soil samples taken throughout the soil profile (Western Fertilizer Handbook, 1995). Plant loss during this seedling stage can reduce the plant population density to suboptimal levels and significantly reduce yields (Maas, 1993).

Sodium: Two potential risks of elevated sodium levels in the soil solution are well documented in the scientific literature. The first is the direct toxic effect of sodium, which can result in leaf burn, defoliation, or death (Western Fertilizer Handbook, 1995). The second is the effect that alteration of soil physical structure may have on plant growth. This second risk is an indirect one, due to sodium-induced disperson, but one which has potential to impact plant growth and development (Ayers and Westcot, 1976; Hansen et al., 1999; Miller and Donahue, 1995). If SAR of the soil solution or ESP values of the soil exchange complex (a measurement of the relative concentrations of sodium to calcium and magnesium) become sufficiently elevated, soils, particularly those high in clay content, may disperse. When this soil reforms, a concrete-like surface crust is generally formed. This causes a decline in hydraulic conductivity, reduced water infiltration, and the potential for increased runoff. This physical condition may also make seedling establishment very difficult, if not impossible (Shainberg and Letey, 1984).

These dispersed conditions, common to sodic soils, also make it difficult for plant roots to obtain water and nutrients. Sodic soils are likely to become and remain waterlogged. This reduces drainage, and may lead to anaerobic conditions. If anaerobic conditions persist for any length of time, generally more than a few days, roots are unable to gain sufficient oxygen, leading to reduced plant growth, plant injury and very likely eventual death (Western Fertilizer Handbook, 1995).

Additionally, a significant decline in drainage often leads to saline conditions. If water containing salts is not allowed to drain beneath the root zone, the salt concentration of the remaining water will continue to increase as plants take up water, by transpiration, and water is lost to the atmosphere by evaporation (Western Fertilizer Handbook, 1995). (For more information on sodic soils, see "Basics of EC/ SAR Effects on Soil Physical Properties on MSU- Bozeman's Water Quality Web Page: http:waterquality.montana.edu.)

Tisdale (1985) proposed that reductions in crop yield could be assigned to one of four categories of sodic soil, along with a corresponding ESP (%) and SAR (Table 3). As previously noted, plants are not generally evaluated with respect to sensitivity to either SAR or ESP, in as much as these two diagnostics are generally specific to soil physical responses

Table 3: Typical reductions in crop yields at various exchangeable sodium percentages (ESP) (Tisdale, 1985)

Type of Soil	*ESP (%*	*SAR Average*	*Decrease in Crop Yield (%)*
slightly sodic	7-15	<12	20 – 40
moderately sodic	15 – 20	12-16	40 – 60
very sodic	20 – 30	16-24	60 – 80
extremely sodic	> 30	> 24	> 80

pH/Alkalinity: The presence of carbonates and bicarbonates increases soil solution alkalinity. However, the direct effect of alkalinity on plant performance is not well known. It is well documented that most plant species demonstrate optimal performance within defined soil acidity/ alkalinity conditions. A sharp increase in alkalinity may cause a shift in the plant community, as plants more adapted to acidic conditions get outcompeted. Similarly, a shift toward acidic conditions will favor plants favorable to acid soils. However, it is more likely that salinity and sodicity will cause a shift in community structure and composition (Western Fertilizer Handbook, 1995). In general, most native plants and cultural plants in arid and semi-arid environments are adapted to slightly, moderately, or strongly alkaline conditions (Munshower, 1998).

Bicarbonates: Carbonates and bicarbonate salts are common in waters and soils of eastern Montana (Schafer, 1983a). The known effect of bicarbonates on plants is the potential for leaf burn when bicarbonate rich water at sufficiently elevated levels comes in direct contact with growing leaf tissue (ATTRA website, 2002). However, it is unlikely that bicarbonates will have a negative impact on native wetland plants. Only a few very sensitive crops are negatively affected by bicarbonates, and levels high enough to adversely affect plants are unlikely to occur under normal irrigation with good drainage. Under conditions of continuous flooding or frequent inundation, this situation could change (Western Fertilizer Handbook, 1995).

APPENDIX

Detailed description of tolerances, sensitivities and pecularities of selected native plant occurring on the Northern Cheyenne Reservation

1) June/Service Berry (*Amelanchier alnifolia*): June/ Service Berry is typically found in thickets in association with other shrubs (*Prunus* sp., *Cratuegus* sp.), in coulees, drainage bottoms and moist grasslands (Munshower, 1995).

Salinity Tolerance

Poor (Munshower, 1995) (Only qualatative ratings were given in Dr. Frank F. Munshower's ratings. Hence plants which occupy similar habitats and community types were used as indicator species in order to obtain quantitative

ratings.) (Ribus sp. was used as an indicator species because of similar habitat and general plant structure) (Maas, 1993).
threshold EC_e – 1.5 dS/m (yield reduction occurs at EC_e greater than this value)
% decrease in yield - 22 % for each 1 dS/m increase in EC_e
Rating – sensitive to salinity – see Figure 1 (Maas, 1993).

Sodium Tolerance (ESP)

extremely sensitive (all deciduous fruits) (ESP 2-10 has a negative impact) A reduction in growth response under field conditions. Sodium toxicity symptoms (leaf burn, leaf wilting) even at low ESP values (Shainberg and Oster, 1978). Very sensitive to sodium; may show its toxic effect when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content > 70 mg/L or SAR >3.0 (DPI website, 2002).

Flooding Tolerance

Poor – moderate (Munshower, 1995).

2) Red Osier Dogwood (*Cornus stolinifera*): Dogwood grows best in well-drained soils but is commonly found in riparian areas, moist woodlands, streambanks and other mesic sites. Essential requirement is well-drained rooting medium and abundance of oxygen in root zone (Munshower, 1995).

Salinity Tolerance

Sensitive >2dS/m soil EC (EC_e) will cause damage (yield reduction, injury) (Wolf, 1999).

Fair (Munshower, 1995)

Flooding Tolerance

Intolerant: (Flowering dogwood (*Cornus florida)* was used as an indicator species.) 4 – 10 inches of water for ten days leads to defoliation or death (U.S. Department of Agriculture Website). Red osier dogwood is considered moderately tolerant to periodic flooding in rapidly drained soils. Good (Munshower, 1995). The discrepancy in ratings indicates that dogwood will tolerate water but not continuous flooding/ anaerobic conditions.

pH/ Alkalinity Tolerance

Cornus sp.: alka-tolerant; will tolerate pH 6.5 – 7.9 (Small, 1946)

3) Common spike rush (*Eleocharis palustris*): Often found in fens and riparian areas, and in association with members of the *Salix* family. Because of their common association with *Salix*, similar habitat and responses, the genus *Salix* (willow) was used as an indicator where quantitative ratings are given (Munshower's ratings are for *Eleocharis palustris)* (USGS website, 2002).

Salinity Tolerance

Sensitive	(injury at > 2 dS/m EC_e) (arctic blue willow as indicator species)
Moderately Tolerant	(injury at 4- 6 dS/m EC_e) (golden willow as indicator species) (Wolf, 1999).
Good	(Munshower, 1995)

Flooding Tolerance

Tolerant (black willow (*Salix nigra*) used as an indicator species): able to survive deep, prolonged flooding for more than one year (Wolf, 1999). Very good (Munshower, 1998).

pH/alkalinity Tolerance

Spike rush is a calciphile (plants that prefer alkaline environments) (U.S. Department of Agriculture Website, 2002.); alka-tolerant (*Salix* sp. as indicator) (pH above 4.8/5.2 up to 7.5/9 or above) (Small, 1946).

4) Horsetail/ Field (*Equisetum arvense*): Horsetail is also commonly found with members of the *Salix* family, often in marshes or other mesic sites. Because of similar habitat and responses to flooding/salinity, S*alix* was used as an indicator (Wild Rivers Commission Webpage, 2002).

Salinity Tolerance

Sensitive/	(injury at > 2 dS/m EC_e) (arctic blue willow as indicator species)/
Moderately Tolerant	(injury at 4- 6 dS/m EC_e) (golden willow as indicator) species) (Wolf, 1999).

Flooding Tolerance

Tolerant (black willow (*Salix nigra)* used as an indicator species) able to survive deep, prolonged flooding for more than one year (U.S. Department of Agriculture Website, 2002).

pH/ alkalinity tolerance

Mesophilous (pH 4.8 up to pH 7.0/7.2) (*Equisetum* sp.) (Small, 1946). Not likely to tolerate extremely alkaline conditions.

5) Wild licorice/American (*Glycyrrhiza lepidota*): Wild licorice is often found associated with members of the wheat (*Agropyron)* family. Both are found in grasslands and open plains and do relatively well in mesic conditions (Wolf, 1999). Additionally, wild licorice is often found with green ash as part of the overstory, and ferns as part of the understory (National Park Service website, 2002).

Salinity Tolerance

Moderately tolerant to salinity – see Figure 1. (standard crested wheatgrass, *Agropyron sibiricum)* was used as an indicator) threshold EC_e – 3.5 dS/m % decrease in yield – 4 % for each 1 dS/m increase in EC_e above threshold (Maas, 1993).

Sodium (ESP) Tolerance

Most Tolerant (Agropyron sp. used as indicator) (ESP > 60 negatively impacts plant (stunted growth, usually due to adverse physical conditions of soil) (Shainberg and Oster, 1978).

Flooding Tolerance

Tolerant/ Green ash (*Fraxinus pennsylvania* as indicator) (able to survive deep flooding for one growing season, with significant mortality occurring if flooding is repeated the following year)

Very tolerant (able to survive deep, prolonged flooding for more than one year) (U.S. Department of Agriculture website, 2002). Good (Munshower, 1995).

pH/alkalinity Tolerance

Ferns in general: mesophilous (pH 4.8 up to 7.0/2) not likely to tolerate extreme alkaline conditions (Small, 1946).

6) **Goose berry, red shoot (*Ribes setosum*):** Gooseberry is either found in thickets or as individual plants, commonly on disturbed sites or along streambanks (Munshower, 1995).

Salinity Tolerance

Sensitive – see Figure 1 Ribes sp.: (Tanji, 1981).

Sodium Tolerance (ESP)

Extremely sensitive (ESP 2-10 will cause damage) (Shainberg and Oster, 1978). Very sensitive to sodium; may show its toxic affect when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content > 70 mg/L or SAR >3.0 (DPI website, 2002).

pH/ Alkalinity Tolerance

Ribes sp.: alka-tolerant (above pH 4.8/ 5.2 up to 7.5/9 pH or above) (Small, 1946).

7) **Mint/ Field (*Mentha arvensis*):** Mint is commonly found in wetlands, floodplains or other relatively moist environments. For this reason, *Salix* sp. was used as an indicator (U.S. Department of Agriculture website, 2002).

Salinity Tolerance

Sensitive/ (injury at > 2 dS/m EC_e) (arctic blue willow as indicator species)

Moderately tolerant (injury at 4-6 dS/m EC_e) (Golden willow as indicator species) (Wolf, 1999).

Flooding Tolerance

Tolerant able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra*) as indicator species) (U.S. Department of Agriculture website, 2002).

pH/ Alkalinity Tolerance

alka-tolerant (above pH 4.8/ 5.2 up to 7.5/9) *Salix* sp. (Small, 1946).

8) Horsemint/W. Bergamot (*Monarda fistulosa*): Horsemint is often found in grasslands environments. Commonly associated species are aster, festuca, bromus and Elymus (Interactive Biodiversity Information System website, 2002).

Salinity Tolerance

Moderately sensitive tall Fescue (*Festuca elatior)* used as indicator species.

threshold EC_e	10% yield loss	25% yield loss	0% survival
3.9	5.8	9.0	46.0

(Shainberg and Oster, 1978).

pH/ alkalinity Tolerance

alka-tolerant (5.5/9 - 7.5/9 pH) (tall Fescue as indicator species) (Small, 1946).

9) Water Plant/ WaterCress (*Nasturium officinale*): Both *Carex* and *Salix* were used as indicator species, as all three species typically grow in moist environments such as riparian areas, floodplains, and wetlands (Centreconnect website, 2002).

Salinity Tolerance

Sensitive/ (injury at > 2 dS/m EC_e) (arctic blue willow as indicator species)
Moderately tolerant) (injury at 4-6 dS/m EC_e) (Golden willow as indicator species) (Wolf, 1999).

Flooding Tolerance

Tolerant able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra)* as indicator species) (U.S. Department of Agriculture website, 2002).

pH/ alkalinity Tolerance

mesophilous (pH 4.8 up to pH 7.0/2) *(Carex* sp. used as indicator) (Small, 1946).

10) Sweet Medicine (*Oxtropis lamnbertii*): Sweet medicine is often found in association with *Festuca* sp., and therefore tall Fescue was used as an indicator species (U.S. Department of Agriculture website, 2002).

Salinity Tolerance

Moderately sensitive	Threshold EC_e	10% yield loss	25% yield loss	50% yield loss
	3.9	5.8	8.6	13.3

(Shainberg and Oster, 1978)

pH/ alkalinity Tolerance
alka-tolerant (5.5/9 - 7.5/9 pH) (Small, 1946)

11) Choke Cherry (*Prunus virgiana*): Choke cherry is found in coulees and other damp areas in association with cottonwoods, willows, maples, aspen, service berry and snowberry (Munshower, 1995).

Salinity Tolerance
Sensitive/ (see graph) (Tanji, 1981).
moderately sensitive (injury at 2- 4 dS/m EC_e) (Wolf, 1999).

Threshold value (EC_e in dS/m)	10% yield loss	25% yield loss	50% yield loss
.9	1.9	2.2	3.1

(Utah State University Extension website, 2002)

Sodium Tolerance (ESP)
extremely sensitive (ESP of 2-10 will cause injury) very sensitive to sodium; may show its toxic affect when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content >70 mg/L or SAR >3.0 (DPI website, 2002).

Flooding Tolerance
Intolerant (black cherry (*prunus serotina)* was used as an indicator species): (4-10 inches of water for 10 days will cause defoliation or death) (U.S. Department of Agriculture website, 2002). Poor to prolonged flooding but performs well on briefly flooded sites (Munshower, 1995).

pH/ alkalinity Tolerance
Prunus sp.: alka-tolerant (above pH 4.8/5.2 up to or above 7.5/9) (Small, 1946)

12) Cottonwood (*Populus deltoides*): Cottonwood is frequently a pioneer on wet, disturbed sites and is the most common Plains riparian tree species. Cottonwood is commonly found on alluvial terraces of streams/ rivers, around lakes and ponds, or in almost any moist subirrigated area (Munshower, 1995).

Salinity Tolerance
Moderately sensitive (2-4 dS/m EC_e will cause damage) (Wolf, 1999).
Fair (Munshower, 1995).

Flooding tolerance

Tolerant: able to survive deep flooding for one growing season, with significant mortality occurring if flooding is repeated the following year (U.S. Department of Agriculture website, 2002).

pH/Alkalinity Tolerance

alka-tolerant (above pH 4.8/5.2 up to 7.5/9 or above) (*Salix* sp. (willow) was used as an indicator species because of similar habitat and growth strategies) (U.S. Department of Agriculture website, 2002; Small, 1946). Very good (Munshower, 1995).

13) Box Elder (*Acer negundo*): Box elder is commonly found in coulee bottoms, along streams, or in riparian habitats (Munshower, 1995).

Salinity Tolerance

moderately tolerant: 4-6 dS/m EC_e will cause injury (Wolf, 1999)

Flooding Tolerance

Tolerant able to survive deep flooding for one growing season, with significant mortality occurring if flooding is repeated the following year (U.S. Department of Agriculture website, 2002).

pH/ Alkalinity Tolerance

mesophilous (pH 4.8 - 7.0.2)/ alka-tolerant (above pH 4.8/5.2 up to 7.5/9) (Small, 1946)

14) Green Ash (*Fraxinus pennsylvania*)

Salinity Tolerance

Moderately tolerant injury at 4– 6 dS/m EC_e (Wolf, 1999)

Flooding Tolerance

Tolerant/ (able to survive deep flooding for one growing season, with significant mortality occurring if flooding is repeated the following year)

Very tolerant (able to survive deep, prolonged flooding for more than one year) (U.S. Department of Agriculture website, 2002).

pH/ Alkalinity Tolerance

Alka-tolerant (6.5/9 – 7.5/9) – *Fraxinus* sp. (Small, 1946).

15) Sand bar Willow (*Salix exigua*): Willow readily invades disturbed wet sites if adjacent area has parent stock. Commonly used for rehabilitation along waterways, willow is a common riparian and floodplain Plains species (Munshower, 1995).

Salinity Tolerance

Sensitive/ (injury at > 2 dS/m EC_e) (arctic blue willow as indicator species)

Moderately tolerant (injury at 4-6 dS/m EC) (Golden willow as indicator species) (Wolf, 1999). Usually moderate but some species reveal fair – good tolerance (Munshower, 1995).

Flooding Tolerance

Tolerant able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra)* as indicator species) (U.S. Department of Agriculture website, 2002). Very good (Munshower, 1995).

pH/ Alkalinity Tolerance
alka-tolerant (above pH 4.8/ 5.2 up to 7.5/9) *Salix* sp. (Small, 1946).

16) Snow berry (*Symphoricarpos occidentalis*): Snowberry is commonly found in moist environments, often in association with *Salix* sp. (U.S. Department of Agriculture website, 2002). Often found in riparian areas and floodplians as well as run-in areas where water collects and in soils with above average water holding capacity (Munshower, 1995).

Salinity Tolerance

Sensitive	(Munshower, 1995)
Moderate – fair	(injury at > 2 dS/m EC_e) (arctic blue willow as indicator speciies)
Moderately tolerant	(injury at 4-6 dS/m EC_e) (Golden willow as indicator species) (Wolf, 1999).

Sodium Tolerance (ESP)

Extremely sensitive (ESP 2-10 will cause injury) (Shainberg and Oster, 1978). very sensitive to sodium; may show its toxic affect when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content > 70 mg/L or SAR >3.0 (DPI website, 2002).

Flooding Tolerance

Tolerant able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra* as indicator species) (U.S. Department of Agriculture website, 2002). Fair – good. Can tolerate imperfectly drained soils and some flooding but not prolonged flooding (Munshower, 1995).

pH/ Alkalinity Tolerance
alka-tolerant (above pH 4.8/ 5.2 up to 7.5/9) *Salix* sp. (Small, 1946)

17) Cattail (*Typha latifolia*): Cattail is typically found in moist areas such as riparian areas, floodplains, and surrounding lakes. Because of a shared habitat, *Salix* sp. was used as an indicator (U.S. Department of Agriculture website, 2002).

Salinity Tolerance

Sensitive/	(injury at > 2 dS/m EC_e) (arctic blue willow as indicator species)/
Moderately tolerant	(injury at 4-6 dS/m EC_e) (Golden willow as indicator species) (Wolf, 1999).

Flooding Tolerance

Tolerant able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra)* as indicator species) (U.S. Department of Agriculture website, 2002).

pH/ Alkalinity Tolerance
alka-tolerant (above pH 4.8/ 5.2 up to 7.5/9) *Salix* sp. (Small, 1946).

18) Wild Plum (*Prunus americana)*: Wild plum is found in association with willow, alder, aspen and dogwood in riparian habitats, wooded draws and thickets (Munshower, 1995).

Salinity Tolerance

Sensitive	Threshold EC_e	10 % reduction	25% reduction	50% reduction	maxEC_e
	1.5 , 7% LR	2.1, 10% LR	2.9, 14% LR	4.3, 20% LR	7.0

(all values in dS/m; LR = leaching requirement) (Ayers and Westcot, 1976; Maas, 1993, Western Fertilizer Handbook, 1995).

Moderate – fair (Munshower, 1995).

Sodium Tolerance (ESP and sodium concentration)
ESP – extremely sensitive (2-10 ESP will cause injury) (Shainberg and Oster, 1978). Sodium concentration < 5 mol/m^3 may cause foliar injury (susceptibility based on direct accumulation of salts through leaves) (Shainberg and Oster, 1978). Very sensitive to sodium; may show its toxic affect when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content >7.0 mg/L or SAR >3.0 (DPI website, 2002).

Flooding Tolerance
Fair, poor to prolonged flooding (Munshower, 1995).

19) Sweet grass (*Hierochloe odorata)*: Sweet grass is commonly found in low, moist areas, often in association with *Agropyron* and *Carex,* both of which were used as indicator species (U.S. Department of Agriculture website, 2002).

Salinity Tolerance
Moderately sensitive (Standard crested wheat grass (*Agropyron trachycaulum)* used as indicator species)

threshold EC_e	slope %/dS/m	Rating
3.5	4.0	moderately tolerant (see graph)

(U.S. Department of Agriculture website, 2002).

pH/ alkalinity Tolerance
mesophilous *(Carex* sp. used as indicator) (pH 4.8 up to pH 7.0/2) (Small, 1946)

20) Quaking aspen (*Populus tremuloides)*: Quaking aspen is a shallow rooted species, with strong lateral roots forming in the top 18 inches of the soil profile. Stands indicate water within five feet. Quaking aspen is found in damp and wet sites, primarily in foothills and mountains (Munshower, 1995).

Salinity Tolerance
Poor (Munshower, 1995).

Flooding Tolerance
Very good to high water table and good to flooding (Munshower, 1995).

21) Saw beak sedge (*Carex stipata*): Saw beak sedge is common in moist riparian, floodplain, and wetland areas, and is often found growing in association with Kentucky bluegrass (*Poa pratensis*), which was used as an indicator species. (Watershed.org website, 2002). *Salix* sp. was also used as an indicator.

Salinity Tolerance
Sensitive Low Tolerance (EC_e > 3 dS/m will cause damage (Kentucky bluegrass *(Poa pratensis)* used as indicator species (Utah State University Extension website, 2002). (Nebraska Fair Sedge (*Carex nebraskensis)* used as indicator) (Munshower, 1995).

Flooding Tolerance
Tolerant able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra)* as indicator species) (U.S. Department of Agriculture website, 2002). Very good to both flooding and high water table (Munshower, 1995).

pH/ alkalinity Tolerance
alka- tolerant (5.0/4 pH - 7.5/9) (Kentucky bluegrass *(Poa pratensis)* used as indicator species) (Small, 1946).

22) Leafy aster (*Aster foliactus*): Leafy aster is commonly found in mesic meadows, often in association with *Carex* and *Salix* sp., both of which were used as an indicators (EPA website, 2002).

Salinity Tolerance
Low tolerance (EC_e > 2.0 dS/m will cause damage) (China aster used as indicator species) (Utah State University Extension Service website, 2002).

Flooding Tolerance
Tolerant able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra* as indicator species) (U.S. Department of Agriculture website, 2002).

pH/ alkalinity Tolerance
mesophilous (pH 4.8 up to pH 7.0/2) (*Carex* sp. used as indicator) (Small, 1946).

23) Stinging nettle (*Urtica dioica*): Stinging nettle is often found in oak- savanah environments, often in association with cottonwood, oak, and pine (U.S. Department of Agriculture website, 2002).

Salinity Tolerance

Moderately sensitive (2-3 dS/m) when oaks (Bur, Gambel, Shingle used as indicators)(3-4 dS/m) when cottonwoods used as indicator (Utah State Extension webpage, 2002).

Flooding Tolerance

Intolerant (Red oak as indicator) (4 to 10 inches of water for 10 days results in defoliation or death) U.S. Department of Agriculture website, 2002).

pH/Alkalinity Tolerance

mesophilous (pH 4.8 up to PH 7.0/2) (both oaks and pines used as indicators) (Small, 1946).

24) Bulrush (*Scirpus nevadensis*): Bulrush is often found in riparian areas, floodplains, and wetlands, often in association with *Carex* and *Salix* sp. (U.S. Department of Agriculture website, 2002). Bulrush is tolerant of brackish, saline, and alkaline sites and is always found in standing water, often around the periphery of lakes/ponds and on muddy shores (Munshower, 1995).

Salinity Tolerance

Moderately tolerant (injury at 4-6 dS/m EC_e) (Golden willow as indicator species) (U.S. Department of Agriculture website, 2002).

Very good (Munshower, 1995).

Flooding Tolerance

Tolerant able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra*) as indicator species) (U.S. Department of Agriculture website, 2002). Very good (Munshower, 1995).

pH/ Alkalinity Tolerance

Mesophilous/ (pH 4.8/5.2 up to 7.0/2), (*Scirpus trichophorus* as indicator)

Alka-tolerant (6.5/9 – 7.5/9 pH), (*Scirpus silvatica* as indicator species) (Small, 1946).

25) Arrow leaf (*sagittaria latifolia*): Arrow leaf is generally found in saturated riparian, floodplain, and wetland environments, often in association with *Salix* sp., which was used as an indicator (U.S. Department of Agriculture website, 2002).

Salinity Tolerance

Sensitive/ (injury at > 2 dS/m EC_e) (arctic blue willow as indicator species)

Moderately tolerant (injury at 4-6 dS/m EC_e) (Golden willow as indicator species) (Wolf, 1999).

Flooding Tolerance

Tolerant — able to survive deep, prolonged flooding for more than one year (black willow (*Salix nigra)* as indicator species) (U.S. Department of Agriculture website, 2002).

pH/ Alkalinity Tolerance

alka-tolerant (above pH 4.8/ 5.2 up to 7.5/9) *Salix* sp. (Small, 1946).

26) Golden currant (*Ribes aureum*): Golden currant is commonly found on disturbed soils and along streamsides and streambanks (Munshower, 1995).

Salinity Tolerance

Sensitive — Probabably poor (Munshower, 1995)

Moderately tolerant (injury at 4 –6 dS/m) Black and European currant used as indicator species (Maas, 1993).

Ribes sp.: threshold EC_e = 1.5 dS/m, slope %/dS/m = 22.0 (Maas, 1993)

Sodium Tolerance (ESP)

Extremely sensitive — (2 –10 ESP will cause damage) (Shainberg and Oster, 1978). Very sensitive to sodium; may show its toxic affect when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content > 70 mg/L or SAR >3.0 (DPI website, 2002).

Flooding Tolerance

Poor – moderate (Munshower, 1995)

pH/Alkalinity Tolerance

Alka-tolerant (above pH 4.8/ 5.2 up to 7.5/9 or above) (Small, 1946). Slightly acidic – slightly basic (Munshower, 1995).

27) Skunkbush Sumac (*Rhus Trixobata*): Skunkbush is usually found growing in coarse-textured soils from prairies to foothills (Munshower, 1995). Skunkbush sumac is often found in association with mountain ash, snowberry, and elderberry, often in relatively moist environments. Green ash was used as an indicator species (Wildlife Habitat Management Institute Webpage, 2002).

Salinity Tolerance

Moderately tolerant — Injury at 4– 6 dS/m EC_e (Wolf, 1999). Fair – good (Munshower, 1995).

Sodium Tolerance

extremely sensitive — (2-10 ESP will cause damage)/ very sensitive to sodium; may show its toxic affect when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content > 70 mg/L or SAR >3.0 (DPI website, 2002).

Flooding Tolerance

Tolerant/ (able to survive deep flooding for one growing season, with significant mortality occurring if flooding is repeated the following year)

Very tolerant (able to survive deep, prolonged flooding for more than one year) U.S. Department of Agriculture website, 2002). Poor (Munshower, 1995).

pH/ Alkalinity Tolerance

Alka-tolerant (*Fraxinus* sp.) (6.5/9 – 7.5/9 pH) (Small, 1946)

28) Milkweed, showy (*Asclepias speciosa)*: Showy milkweed is often found in association with oak, which was used as an indicator species (U.S. Department of Agriculture website, 2002).

Salinity Tolerance

Moderately tolerant (Oaks (Bur, Gambel, Shingle) used as indicators) (2-3 EC_e dS/m threshold) (Utah State University Extension webpage, 2002).

Flooding Tolerance

Intolerant (Red oak (*Quercus rubra* used as indicator*)* (4 - 10 inches of water for 10 days results in defoliation or death) (U.S. Department of Agriculture website, 2002).

pH/alkalinity

mesophilous (*Quercus* sp. used as indicator) (pH 4.8 up to pH 7.0/2) (Small, 1946).

29) Western yarrow (*Achilliea millelolium*): Western yarrow is found on disturbed/ overgrazed sites, as well as dry, sunny range sites from prairie to alpine environments (Munshower, 1995). Yarrow is commonly found in association with Rocky mountain maple (*Acer rubra),* hence *Acer* sp. was used as an indicator (U.S. Department of Agriculture website, 2002).

Salinity Tolerance

Moderately sensitive Good (Munshower, 1995.); (3-4 dS/m threshold) (Maples (Norway, Hedge) used as indicators (Utah State University Extension webpage, 2002).

Flooding Tolerance

Intolerant (4 - 10 inches of water for 10 days results in defoliation or death) (Red oak (*Quercus rubra)* used as indicator*)* (U.S. Department of Agriculture website, 2002). Moderate – fair (Munshower, 1995).

pH/alkalinity

Mesophilous (pH 4.8 up to pH 7.0/2)/ alka-tolerant (pH 4.8/5.2 up to 7.5/9 or above) (*Acer* sp. used as indicator (Small, 1946).

30) Raspberry, red (*Rubes idaue)*
Salinity Tolerance

Sensitive	0% reduction	10% reduction	25% reduction	50% reduction	max EC_e
	1.0, 6% LR	1.4, 9% LR	2.1, 13% L	3.2, 19% LR	5.5

(Ayers and Westcot, 1976; Western Fertilizer Handbook, 1995).

Sodium Tolerance (ESP)
Extremely sensitive (2-10 ESP will cause damage) (Shainberg and Oster, 1978); Very sensitive to sodium; may show its toxic affect when flood irrigation water has an SAR as low as 4.5 and/or spray irrigation water that wets the foliage has a sodium content > 70 mg/L or SAR >3.0 (DPI website, 2002).

pH/alkalinity
alka-tolerant (above pH 4.8/5.2 up to 7.5/9 or above) Ribes sp. (Small, 1946).

31) Rose bush (*Rosa arkansa*) Rose bush is generally found on more mesic sites, but will persist in disturbed or open rangeland habitats (Munshower, 1995).
Salinity Tolerance
Moderate – fair (Rose, common used as indicator species) (Munshower, 1995).
Moderately sensitive (injury at 2 – 4 dS/m) (Wolf, 1999). Maximum permissible EC_e = 2 – 3 dS/m (Tanji, 1981; Chabbra, 1996).

Flooding Tolerance
Some varieties will tolerate high water tables (Munshower, 1995).

pH/Alkalinity Tolerance
Alka-tolerant (above pH 4.8/5.2 up to 7.5/9 or above) (Small, 1946).

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Power Point Presentation - File title: Phelps - Part 1 - Phytoremediation

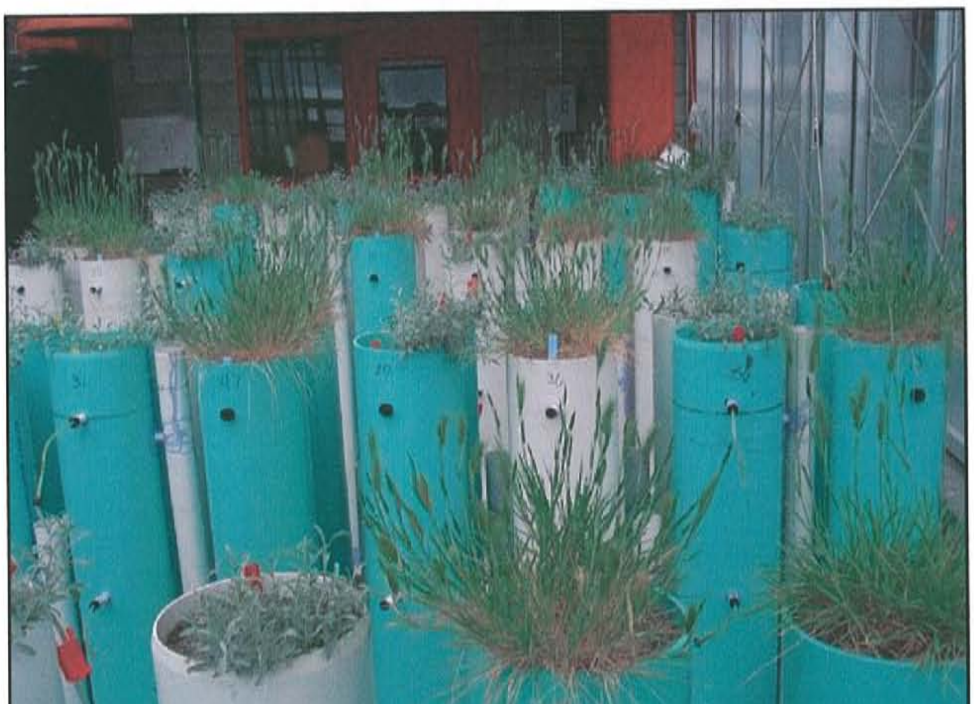
Title: Effects of surface irrigation water quality and water table position on the ability of selected plant species to remove salts and sodium.

Author: Shannon Dale Phelps, Montana State University

Content: 6-frame power point presentation summarizing results of controlled greenhouse study consisting of evaluation of phytoremediation capabilities of *Atriplex lentiformis, Atriplex Wytana*, and *Hordeum marinum* under conditions of varying water table position and low salinity x low sodicity and high salinity x high sodicity water supplies. Data presented include comparisons of biomass production as a function of source water quality and water table position, cumulative salt (base cation) uptake. Complete details provided in appendix document of same title, Appendix 6 - Completed Thesis.

Effects of surface irrigation water quality and water table position on the ability of selected plant species to remove salts and sodium

Shannon D. Phelps, Department of Land Resources and Environmental Sciences.
Montana State University, Bozeman.
Dec. 2002



Species selection

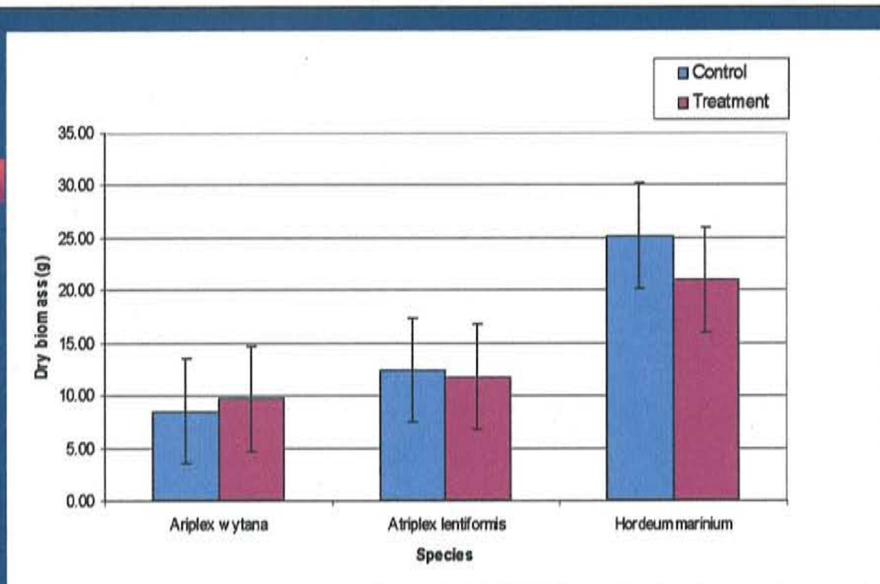
- **Selection criteria**
  - Documented capability as a perennial source of livestock forage
  - Documented halophytic characteristics
- **Species**

  Wytana saltbush (*Atriplex wytana.*), extremely salt tolerant shrub naturally occurring in Montana, Washington, and Wyoming (Mackie *et al.*, 2001)

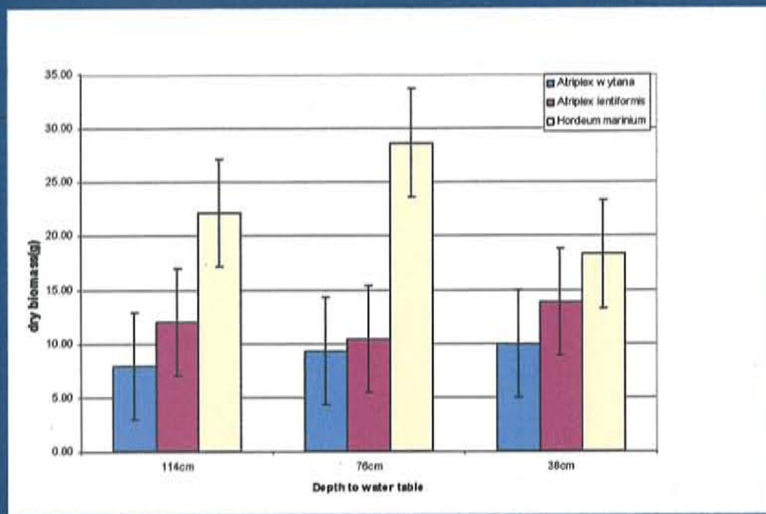
  Big saltbrush (*Atriplex lentiformis*), moderately salt tolerant, native shrub known for high productivity and quality forage potential (Watson *et al.*, 1987)

  Maritime Barley (*Hordeum marinium*), salt tolerant, flood tolerant species found in coastal environments reported to provide high nutritional value (Redman and Fedec, 1987)

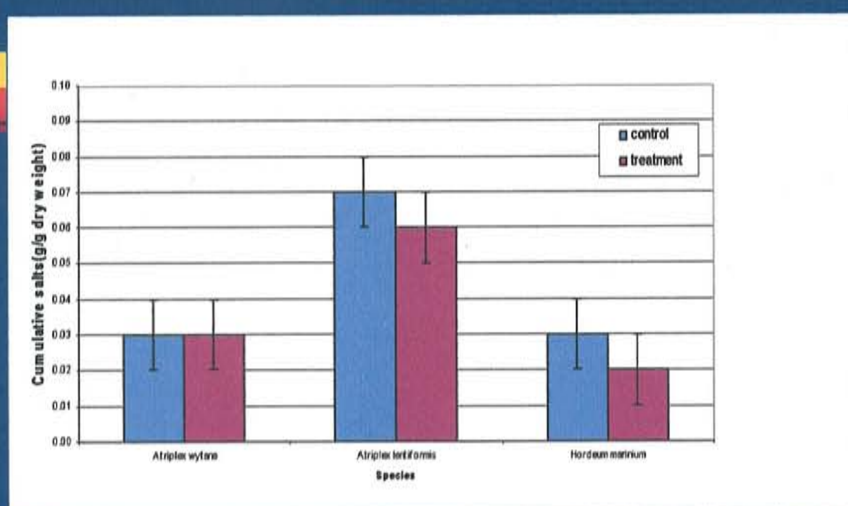
- **Planting**
  - Direct seed 30 per column



Average dry biomass of *Atriplex wytana,Atriplex lentiformis*, and *Hordeum marinium* over three harvests irrigated with control and treatment water quality (average across all water table positions; no drainage)



Average biomass production over three successive harvests for columns maintained at three separate water table positions. Water table positions are maintained at 114, 76, and 38cm below soil surface



Cumulative salt content reported as grams of total salts (Ca, Mg, Na) per gram of dry matter irrigated with treatment and control water averaged over three water table positions and three harvests for *Atriplex wytana, Atriplex lentiformis,* and *Hordeum marinium.*

Word Perfect Document - File title: Humic Substance Mitigation

Title: Report of Assault DG and Liquid Assault Experiments with coalbed methane product water

Author: Linzy Browning and James W. Bauder, Montana State University

Content: The report summarizes results of two experiments focused on the potential use of coalbed methane product water for agricultural crop production and the effects of Assault DG and liquid Assault on seedling emergence, biomass production, and nutrient uptake in pinto beans, sugar beets, and barley when these crops were irrigated with coalbed methane product water. Word Perfect document.

Report of Assault DG and Liquid Assault Experiments Conducted at Montana State University-Bozeman, Spring 2004

by Linzy Browning and Jim Bauder, Research Assistant and Professor, respectively
Montana State University-Bozeman

The following report summarizes the results of two experiments focused on the potential use of coalbed methane product water for agricultural crop production and the effects of Assault DG and liquid Assault on seedling emergence, biomass production, and nutrient uptake in pinto beans, sugar beets, and barley when these crops were irrigated with coalbed methane product water.

Experiment 2. Effects of Assault DG on Seedling Emergence
Hypothesis: The humic substances in Assault DG will improve the rate and percentage of emergence of seedlings grown in saline-sodic soil using simulated CBM irrigation water.

Experiment 3a. Effect of Assault DG on Sugar Beets, Beans, and Barley Grown Under Heat and Moisture Stress Conditions With Simulated CBM Water
Hypothesis #1: Humic substances contained in Assault DG will assist sugar beets, beans, and barley in dealing with heat and moisture stress while being irrigated with simulated CBM water.

Experiment 3b. Effect of Assault DG on Calcium, Potassium, and Sodium Uptake by Barley, Sugar Beets, and Beans
Hypothesis #2: Assault DG has the ability to increase the uptake of potassium and calcium and restrict the uptake of sodium in plants grown in saline-sodic soil with simulated CBM water.

The following report is divided into three sections, one each for Experiment 2, 3a, and 3b. Each section's pages and figures are numbered separately.

Experiment 2. Effects of Assault on Seedling Emergence

Introduction

Humic substances are known to increase emergence rates and seedling viability under normal salinity and sodicity conditions. However, emergence studies focused on interactions between humic substances and salts have not previously been conducted. This 18-day study examined emergence rates of sugar beets, pinto beans, and barley germinated either in soil or sand with either tap water or simulated CBM water (EC=3.4 dS/m, SAR=28).

The experimental soil consisted of a clay soil mixed with 25% sand and amended with sodium sulfate and sodium bicarbonate at rates necessary to achieve SAR=5.1 and EC=2.8 dS/m. Unamended sand was chosen as a growth medium for half the seeds in order to isolate seed-soil interactions.

Each of 3 replications consisted of 16 randomly placed 8"x12"x2 ½" pans filled with 2" of soil or sand amended with Assault DG at rates of 0, 50, 100, or 200#/acre. One row each of 20 beet, 20 barley, and 15 bean seeds was planted lengthwise in each pan. The pans were watered according to greenhouse evaporation. Pans amended with Assault DG received water containing 15 ppm liquid Assault. Control pans received no liquid Assault. Numbers of seedlings emerged were counted every other day following planting.

Results - Beans

Beans in Soil

Beans germinated in soil with tap water exhibited a pattern supporting previous research findings of increased emergence rates with humic substances. Assault clearly gave the seedlings an early advantage, indicated by greater numbers of emerged seedlings in the amended groups on day 8 (Figure 1). This pattern was generally exhibited throughout the germination period. Beans amended with Assualt DG at 50#/acre performed the best, with an average of 14.7 emerged seedlings per pan out of a possible 15 seeds (Figure 2). With each geometric increase in Assault DG rates, seedling emergence dropped by 1 seedling per pan, indicating peak performance of Assault at relatively low rates in this situation.

Beans germinated in soil with CBM water displayed a very different pattern than those germinated with tap water. Of greatest interest is the fact that unamended control seeds emerged in greater numbers than their amended counterparts, averaging 12.7 seedlings per pan (Figure 2). Of the amended groups, those receiving 50#/acre performed poorest, with only 10.3 emerged seedlings per pan. Increasing the Assault rate to 100#/acre increased emergence to 12 seedlings per pan, and 200#/acre treatment led to 12.3 emerged seedlings per pan. In this case, the 200#/acre Assault rate gave seedlings an advantage from day 8 to day 10, but showed no final advantage (Figure 1). The 50#/acre treatment group clearly lagged behind the rest throughout the germination period.

Beans in Sand

Beans germinated in sand with tap water emerged in the greatest numbers with no Assault treatment, averaging 14.7 seedlings per pan. Aside from that, increasing Assault rates led to a negative emergence response. The 50#/acre treatment group performed slightly better in this situation than the higher rates, resulting in 13 emerged seedlings per pan, in comparison to 12.3 seedlings per pan in the 100 and 200#/acre treatment groups (Figure 2). Overall, the 50, 100, and 200#/acre treatment groups performed very similarly throughout the emergence period (Figure 1).

Once again, beans germinated in sand with CBM water had greatest emergence with no Assault treatment, averaging 13.7 seedlings per pan. Of the Assault treatment groups, the 200#/acre group performed the best, averaging 11.7 emerged seedlings per pan, while the 50 and 100#/acre groups averaged only 9 (Figure 2). The 200#/acre treatment gave the seedlings a consistent advantage over the 50 and 100#/acre groups throughout the germination period (Figure 1).

Average emergence of all beans germinated in both soil and sand with tap water was 87%, indicating that growth media had little effect on emergence under irrigation with tap water. Irrigation with CBM water decreased emergence rates in soil to 79% and in sand to 72% (Figure 3). This response is consistent with the tendency of sand to have greater osmotic and matric potentials. Because the pans were kept moist, matric potential was approximately the same in both sand and soil, and in those pans irrigated with tap water, osmotic potential would also have been similar. Consequently, tap water treatment groups performed similarly overall. Addition of salts in CBM water increased osmotic potential in both the sand and soil treatment groups. However, because of its greater pore space and ability to buffer some sodium ions, soil was more capable of reducing osmotic potential than sand. This explains the greater decrease in emergence in sand irrigated with CBM water compared to soil.

Results - Sugar Beets

Beets in Soil

In comparison to controls, beets germinated in soil with tap water exhibited positive emergence responses to 50 and 100#/acre treatments and a negative response to 200#/acre treatments (Figure 5). The 100#/acre treatment group performed best, averaging 16.7 seedlings per pan, a 17% increase over 14.3 seedlings per control pan. While 50#/acre treatment offered an advantage over other groups from day 6-8 (Figure 4), total emergence averaged only slightly more than the control group with 14.7 seedlings per pan. The 200#/acre treatment prompted a significant negative response, reducing emergence to 10.3 seedlings per pan, a 28% decrease compared to controls.

Beets germinated in soil with CBM water exhibited a similar trend in that the 100#/acre treatment caused a positive response, increasing emergence to 16 seedlings per pan, a 5% increase over 15.3 seedlings per pan in the control group. The 50#/acre treatment led to a slight negative response, reducing emergence to 15 seedlings per pan. Of particular interest is the poor performance of the 200#/acre groups with both tap and CBM water (see Figure 4). In this situation, high treatment rates appear to have a significant detrimental affect on seedling emergence.

Note that beets emerged in soil with CBM water averaged 73% emergence, with 14.6 seedlings per pan, while their counterparts in tap water averaged 70% emergence, with 14 seedlings per pan (Figure 6). Sugar beets have relatively high salt tolerance, so their increased emergence in saline-sodic conditions may have reflected their ability to deal with moderate amounts of salts.

Beets in Sand

Beets germinated in sand with tap water showed a slight positive response to 50 and 100#/acre treatments, resulting in 5% increased emergence over controls, from 12.7 to 13.3 seedlings per pan (Figure 5). Although the 200 #/acre treatment had a clear advantage from day 8-10, it showed no advantage in comparison to controls after day 14 (Figure 4).

Beans germinated in sand with CBM water responded very differently to Assault treatments than those germinated with tap water. In this case, 200#/acre treatment gave seedlings an advantage throughout the germination period and led to an average of 9.7 emerged seedlings per pan, an 11% increase over 8.7 seedlings per control pan (Figures 4 and 5). Dramatic decreases in emergence in the 50 and 100#/acre treatment groups indicate that in this situation, lower treatment rates actually had a negative impact on emergence.

Overall, beets emerged at a rate of 65% (13 seedlings per pan) in sand with tap water, only 5% less than their counterparts grown in soil. Because of sand's reduced ability to buffer sodium ions, beets germinated in sand with CBM water faced greater osmotic potentials than those in tap water. While addition of salts to beets germinated in soil led to increased emergence, addition of the same amounts of salts to those grown in sand appears to have exceeded their salt tolerance threshold, reducing emergence in these groups to only 39% (7.7 seedlings per pan).

Results - Barley

Barley in Soil

Barley germinated in soil with tap water experienced a positive response to both 50 and 100#/acre Assault DG treatments, increasing from 19.5 seedlings per pan in the control to 20, a 3% increase (Figure 7). (Note that the 100#/acre treatment shows emergence of 20.3 seedlings per pan. This was caused by overplanting in one of the replications. For analysis purposes, the additional seedling will be disregarded.) The 50#/acre treatment also gave the seedlings a clear advantage from days 4-6. The 200#/acre treatment resulted in a slight negative response, decreasing emerged by 3% to 19 seedlings per pan.

Fifty, 100, and 200#/acre Assault DG treatments of barley germinated in soil with CBM water all had an average emergence of 19.7 seedlings per pan, in comparison to 19.3 in the control groups (Figure 8). The 200#/acre treatment offered a slight early advantage on day 4, but no final advantage (Figure 7). Identical positive responses to each Assault treatment group indicate that increased rates have no agronomic or economic benefit, leading to the logical conclusion that 50#/acre treatment provides the greatest advantage in this situation.

Overall, barley germinated in soil with tap water emerged at a rate of 99%, while barley germinated with CBM water emerged at a rate of 98%. The minor impact of CBM water results from barley's halophytic nature, which allows it to thrive in high salinity conditions.

Barley in Sand

Barley germinated in sand with tap water showed a positive response to 100#/acre amendment with Assault DG, increasing emergence by 2% over the control (Figure 8). Fifty and 100#/acre treatments had no affect on emergence. Other than minor advantages offered by the 100#/acre treatment, all groups performed similarly throughout the emergence period.

Addition of CBM water to barley germinated in sand created a very different response than tap water treatment in that 50#/acre treatment groups exhibited a negative response. Emergence dropped from 19 seedlings per pan in the control to 17.7, a 7% decrease. The 100#/acre treatment increased emergence by 4% to 19.7 seedlings per pan, and the 200#/acre treatment led to no response.

Overall, emergence of barley in sand irrigated with tap water averaged 99%, while barley in sand irrigated with CBM water averaged 95% emergence. The decrease in barley emergence under irrigation with CBM water was probably the result of increased osmotic potential above the threshold for maximum performance.

Conclusion

In general, beans exhibited a negative response to Assault treatments. The only group with a positive response was beans germinated in soil with tap water. Beets in each media-water quality group responded favorably to at least one of the Assault rates, indicating variable levels of salinity and sodicity require varying Assault rates. Because of its hardy, halophytic nature, barley did not respond dramatically to Assault treatments. However, like beets, barley exhibited positive responses to at least one Assault treatment rate in each media-water quality group. Results from Experiment 3, an 8-week grow out of sugar beets, pinto beans, and barley under the same Assault treatments as Experiment 2, will shed more light on longer term effects of Assault on plant performance.

Pinto Beans

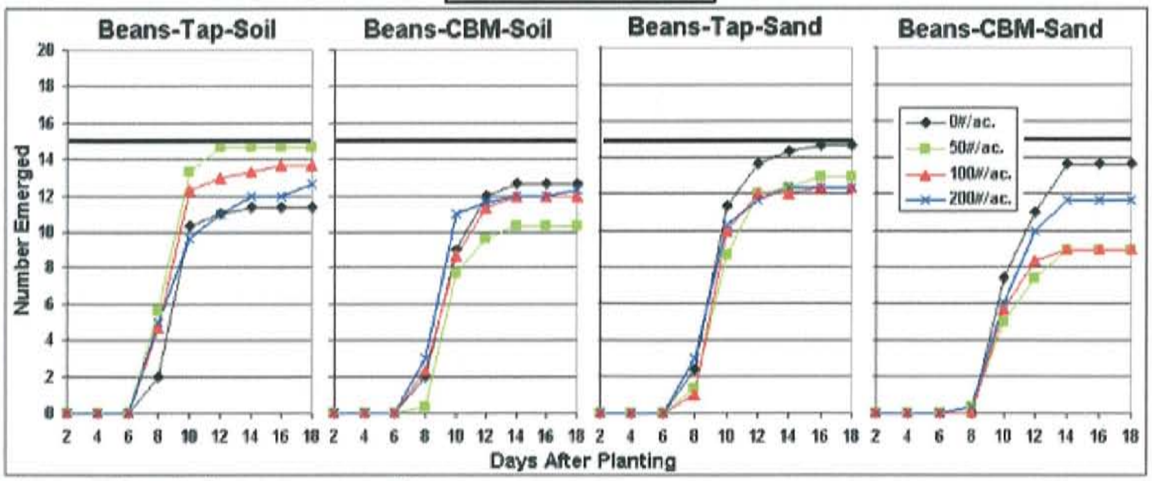


Figure 1. Cumulative emergence of beans.

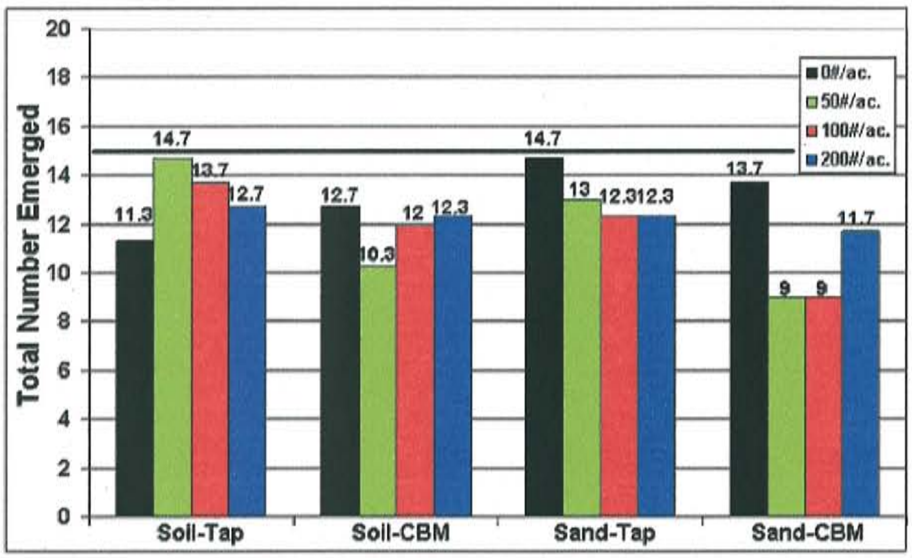


Figure 2. Average number of beans emerged in each treatment group.

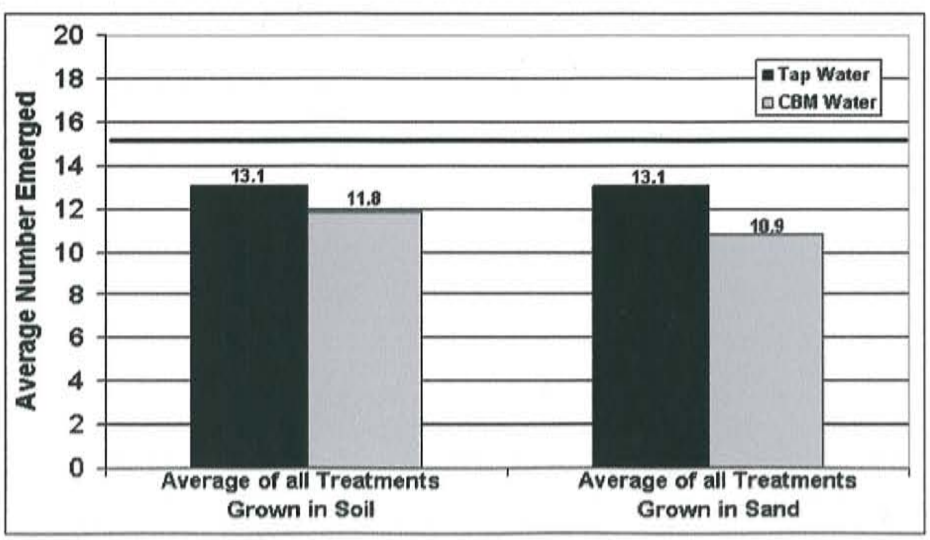


Figure 3. Average emergence of beans in sand and soil.

Sugar Beets

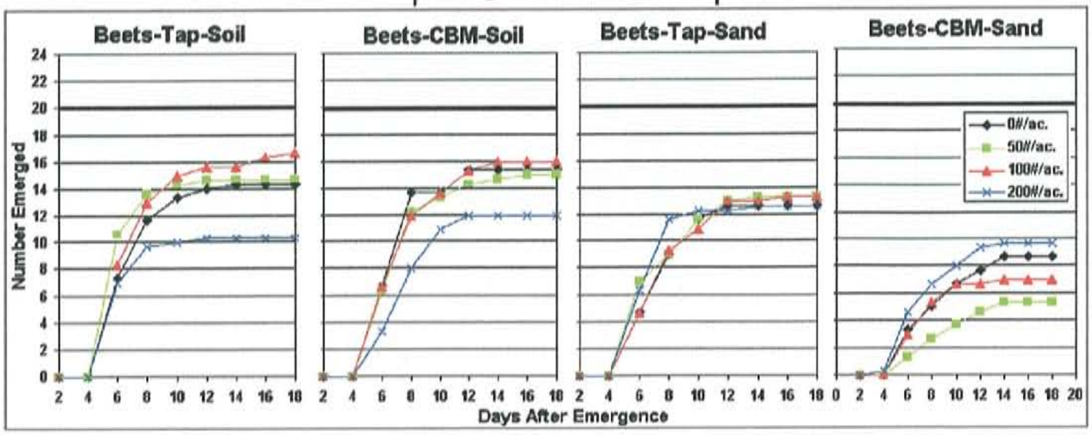


Figure 4. Cumulative emergence of beets.

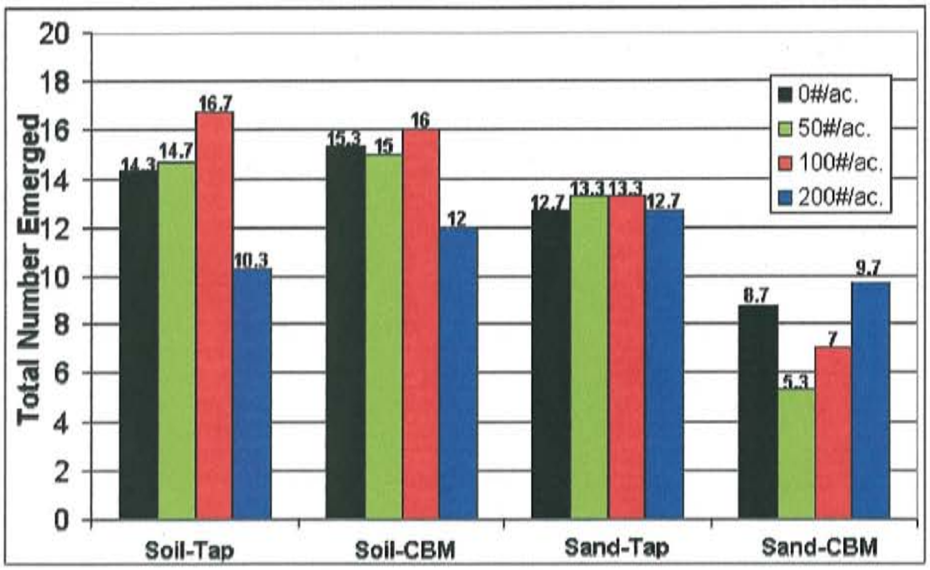


Figure 5. Average number of beets emerged in each treatment group.

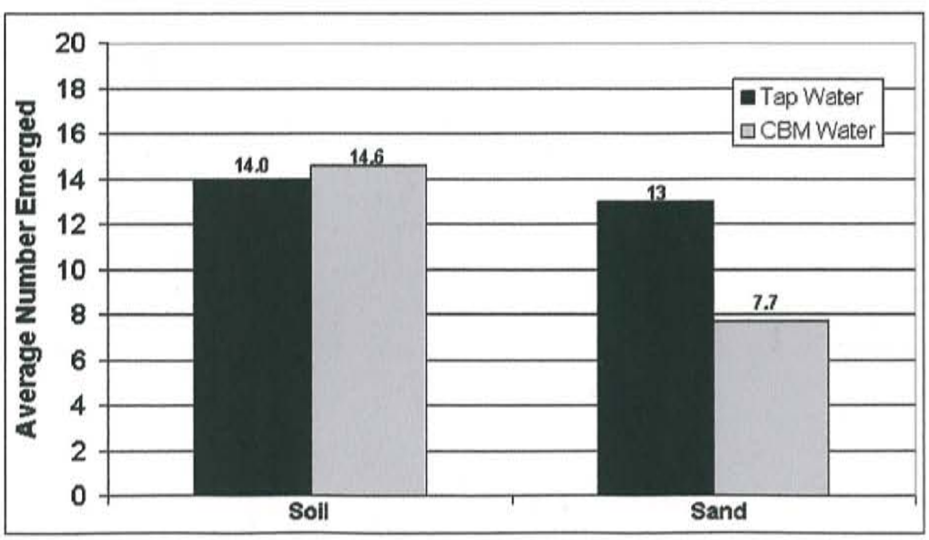


Figure 6. Average emergence of beets in sand and soil.

Barley

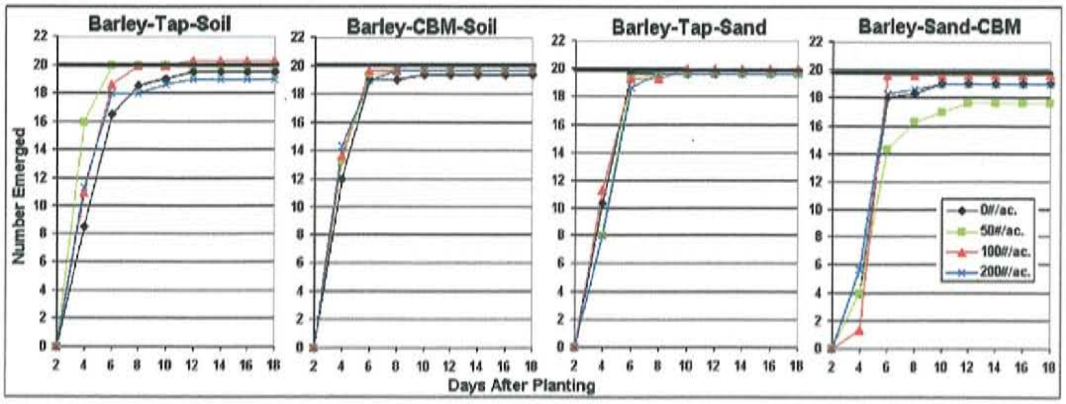


Figure 7. Cumulative emergence of barley.

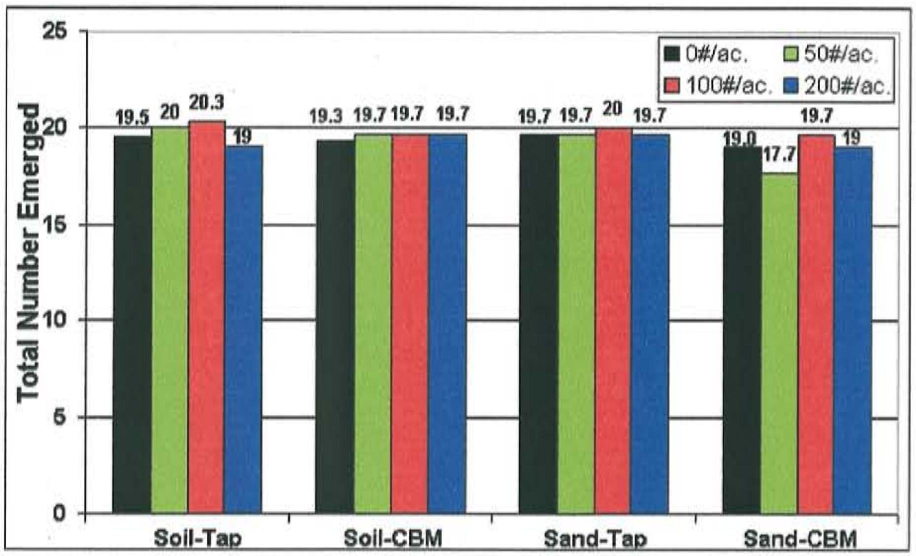


Figure 8. Average number of barley seedlings emerged in each treatment group.

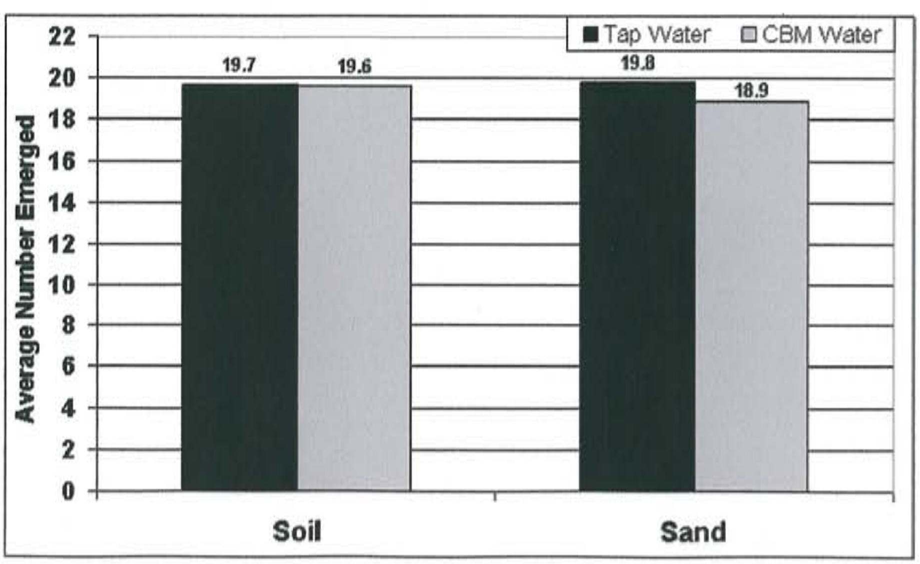


Figure 9. Average emergence of barley in sand and soil.

Experiment 3a. Sugar Beet, Pinto Bean, and Barley Biomass Production Responses to Assault Treatment under Irrigation with Simulated CBM Water and Heat and Moisture Stress

Introduction

One proposed mode of action of Assault DG and Assault liquid is to enhance plants' abilities to deal with heat and moisture stress. This 8-week experiment examined the responses of sugar beets, pinto beans, and barley to Assault DG treatments of 0, 50, 100, and 200#/acre under heat and moisture stress conditions and irrigation with simulated CBM water (EC=3.4 mmhos/cm, SAR=28).

The experimental soil consisted of a clay soil mixed with 25% sand and amended with sodium sulfate and sodium bicarbonate. Eight inch pots were filled with this media and soaked with either tap water or simulated CBM water to dissolve added salts and settle the soil. Soil samples were gathered after soaking to establish baseline soil chemistry values of EC=2.8 mmhos/cm and SAR=5.08 for tap water-treated soil and EC=3.8 mmhos/cm and SAR=7.86 for CBM-treated soil. Seventy-two hours later, those pots receiving Assault DG were amended in quantities necessary to achieve application rates of 50, 100, or 200#/acre. The Assault was incorporated, and 2-3 days later, HH88 sugar beets, Maverick pinto beans, and Valier barley were planted in four randomized replications. After 3 weeks, beets and beans were thinned to 3 plants per pot and barley to 10 plants per pot.

Simulated heat and moisture stress conditions were applied to half the pots using heating mats and reduced irrigation volumes. Heating mat temperatures were originally set at 90 °F and then reduced to 70 °F after one week. Soil temperature was monitored with a Hansen AM400 monitor. Average soil temperature in pots subjected to heat and moisture stress was 74 °F (23.5 C). Because of an equipment malfunction, average temperature data was only available for weeks 1-3 for the normal temperature and moisture treatment. During this time, average soil temperature was 65 °F (18 C).

Seedlings were kept moist with either tap or CBM water during a three week germination period, after which the watering regime was changed to reflect greenhouse evaporation. Pots were watered twice weekly, normal pots with 400 mL and hot pots with 240 mL, 60% of greenhouse evaporation. Based on plant appearance, the hot treatment watering regime was increased to 80% of greenhouse evaporation during week 5, and during week 8, plants were watered three times, rather than twice, to accommodate for seasonal increases in evapotranspiration. Tap and CBM water applied to pots treated with Assault DG was amended with liquid Assault at 15 ppm. Control pots received either tap or CBM water with no liquid Assault. At the end of 8 weeks, aboveground biomass was harvested, dried, and weighed.

Results - Beans

Beans in normal temperature and moisture conditions watered with tap water responded positively to all Assault treatment rates (Figure 1). Greatest positive responses occurred with 200#/acre Assault application, increasing average biomass per pot to 9.54 g, an 8% increase over controls. Fifty and 100#/acre Assault treatments resulted in 5% and 3% increases in biomass, respectively. Figure 2 also displays this generally positive trend, indicating that under conditions such as these, increasing Assault rates lead to increased biomass production.

Beans grown in tap water under heat and moisture stress display virtually no response to Assault treatment (Figure 1). Under such conditions, heat and moisture stress, rather than Assault treatment, appear to be controlling factors in biomass production.

Beans grown in normal temperature and moisture conditions with CBM water show significant positive responses to 50 and 200#/acre Assault treatments and a slight negative response to 100#/acre treatment. Although data for this treatment was somewhat scattered across replications (Figure 3), it is clear that under normal conditions and irrigation with CBM water, Assault treatment prompted positive responses in biomass production.

Like their counterparts grown in tap water, beans grown in CBM water under heat and moisture stress exhibited no response to Assault treatment (Figure 1). Biomass was generally less in this group than in the tap water group, indicating that in addition to heat and moisture stress, CBM water also played a role in limiting biomass production.

Overall, pinto bean responses to heat and moisture stress, varying water qualities, and Assault treatment indicate that under normal temperature and moisture conditions, Assault effects biomass production positively. Under heat and moisture stress, biomass production appears to be limited primarily by those environmental conditions and largely unaffected by Assault treatment.

Results - Sugar Beets

Beets under normal temperature and moisture conditions irrigated with tap water generally responded positively to Assault treatment (Figure 4). Fifty pound/acre treatment increased average biomass production to 7.19 g/pot, a 9% increase over controls. One hundred and 200#/acre treatments both resulted in 6% increases in biomass production. Figure 5 also displays this positive trend.

Beets grown in tap water under heat and moisture stress display slight negative responses to all Assault treatments. Fifty, 100, and 200#/acre treatments result in 5%, 2%, and 1% decreases in average biomass production, respectively (Figure 4).

Beets grown under normal conditions with CBM water actually outperformed those grown with tap water, confirming their moderate halophytic nature (Figure 4). Under these conditions, 100 and 200#/acre Assault treatments performed similarly, resulting in 2-3% increases in biomass production over average control biomass production of 7.51 g/pot. Fifty pound/acre treatment reduced production to7.27 g/pot, a 3% decrease.

Beets grown with CBM water under heat and moisture stress conditions performed similarly to those grown in tap water in that each Assault treatment rate prompted a negative biomass production response. All Assault treatments resulted in 7-8% production declines compared to controls, which averaged 4.0 g biomass per pot.

Beets responded very similarly to beans in their overall responses to heat and moisture stress, saline-sodic water, and varying Assault treatments. Beets grown under normal heat and moisture conditions generally responded positively to Assault treatment, indicating that in the absence of these stresses, Assault treatment enhanced biomass production. However, under drought conditions, Assault actually had a detrimental effect on biomass production regardless of water quality or Assault treatment (Figures 5, 6).

Results - Barley

Barley under normal heat and moisture conditions irrigated with tap water responded negatively to Assault treatment, with treatments of 50, 100, and 200#/acre resulting in reductions in average biomass production of 5%, 19%, and 13%, respectively (Figure 7). Figure 8 displays this decrease in biomass with increasing Assault rates.

Barley subjected to heat and moisture stress and irrigated with tap water performed poorest of all treatment groups (Figure 7). Although it responded negatively to 50 and 200#/acre Assault treatments, 100#/acre treatment increased average biomass production from 2.98 g/pot in controls to 3.46 g/pot, a 16% increase.

Because of its halophytic nature, barley grown in CBM water under normal conditions far outperformed all other groups. Once again, Assault treatments negatively impacted biomass production, reducing production 4-6% compared to controls (Figure 7).

Barley grown with CBM water under heat and moisture stress conditions produced approximately 4% more biomass than controls when treated with Assault at 50 and 100#/acre. There was no response to 200#/acre treatment.

Trend lines in Figures 8 and 9 show that for barley grown under normal conditions, increasing Assault treatment reduced biomass production. Under heat and moisture stress conditions, increasing Assault rates had no net effect on biomass production.

Conclusion

In general, sugar beets and pinto beans grown under normal temperature and moisture conditions showed slight positive responses to Assault treatment. In the case of pinto beans, Assault treatments had virtually no effect on biomass production under heat and moisture stress conditions. However, Assault treatments actually had a negative impact on biomass production in beets subjected to these stresses. Barley showed virtually no positive responses to Assault in any treatment group.

Differences in biomass production in this study appeared to primarily result from differences in water quality and environmental stress, not Assault treatment. Because some positive responses to Assault treatment were seen under normal heat and moisture conditions, one can conclude that the product enhances biomass production only under environmental conditions more ideal than those in this experiment.

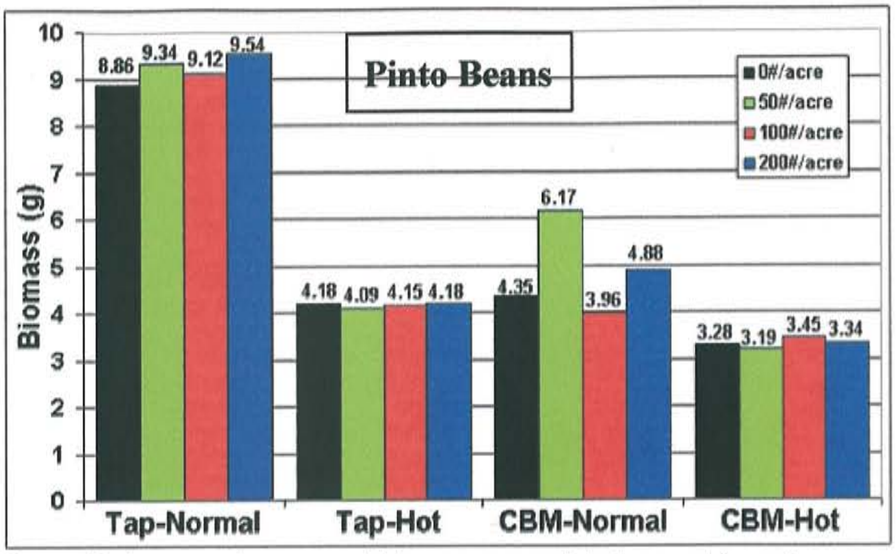


Figure 10. Average aboveground biomass accumulated per pot in each treatment group.

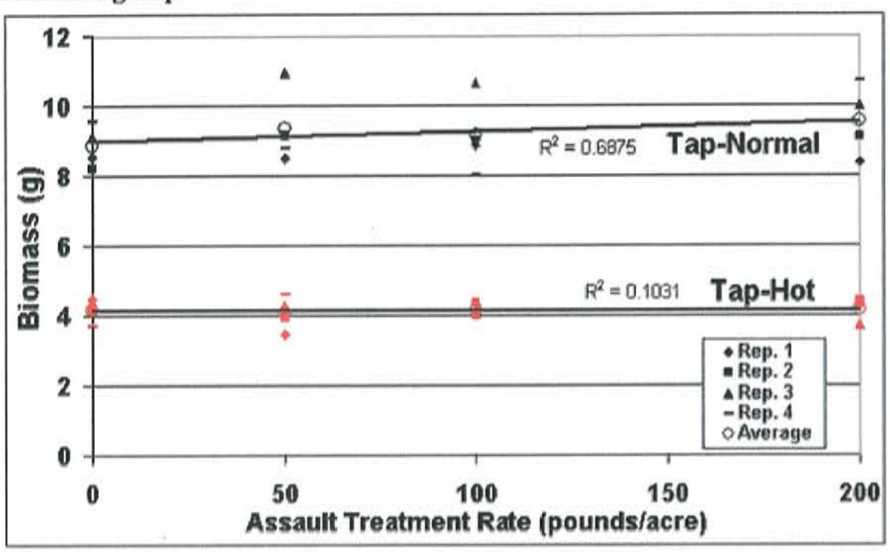


Figure 11. Assault treatment rate versus aboveground biomass for each tap water treatment. Includes data from all four replications.

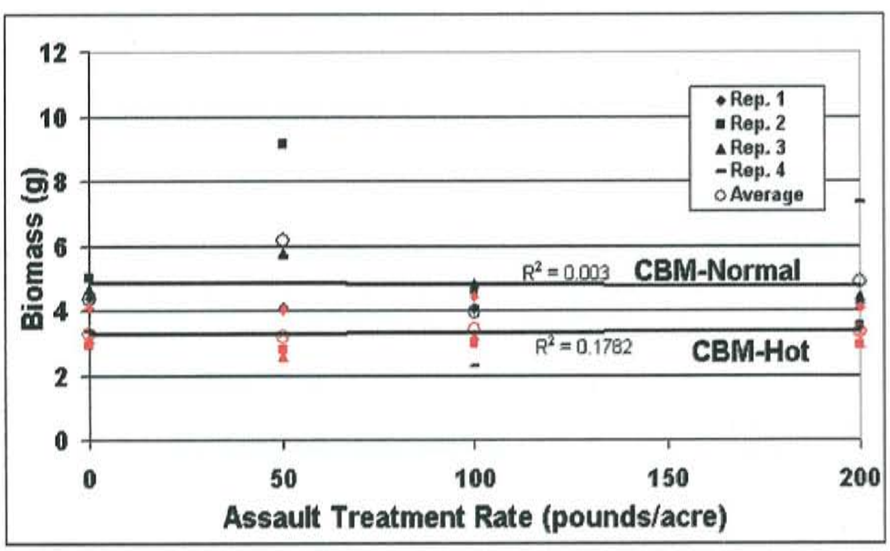


Figure 12. Assault treatment rate versus aboveground biomass for each CBM water treatment. Includes data from all four replications.

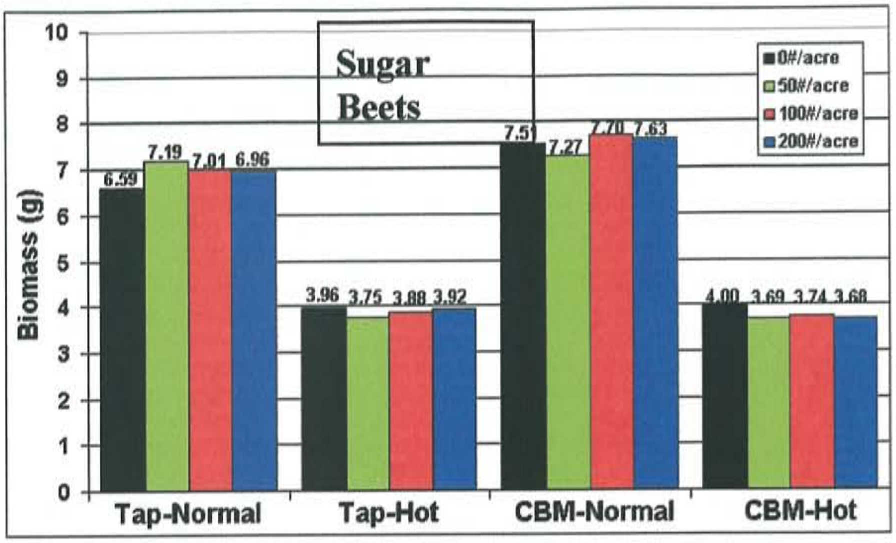


Figure 13. Average aboveground biomass accumulated per pot for each treatment group.

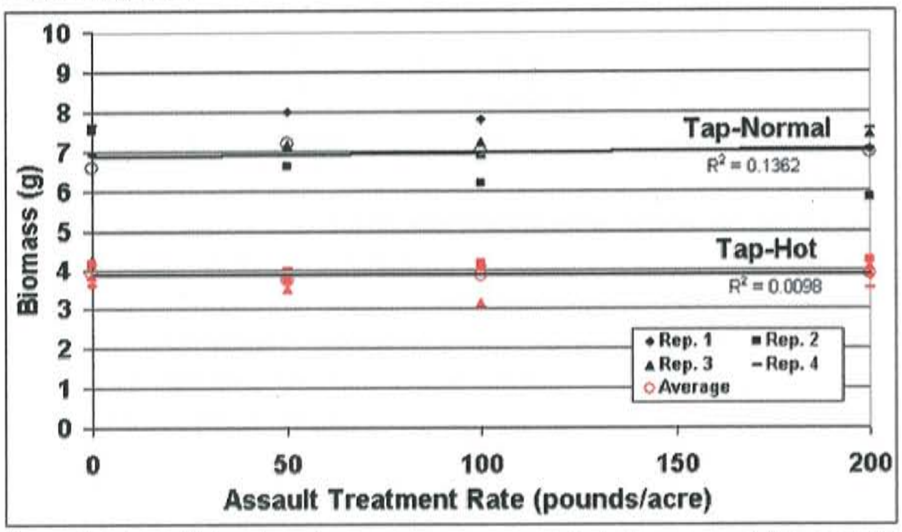


Figure 14. Assault treatment rate versus accumulated aboveground biomass for each tap water treatment group. Includes data from all four replications.

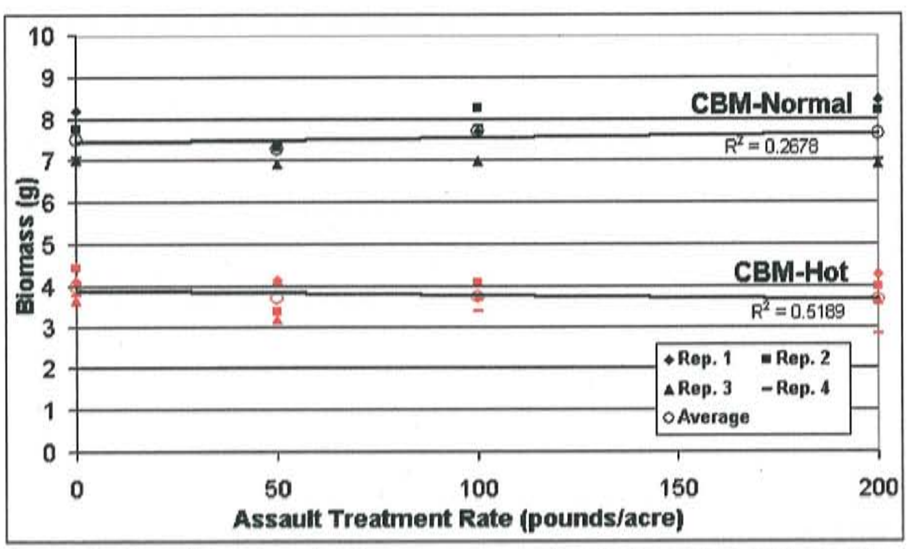


Figure 15. Assault treatment rate versus accumulated aboveground biomass for each CBM water treatment group. Includes data from all four replications.

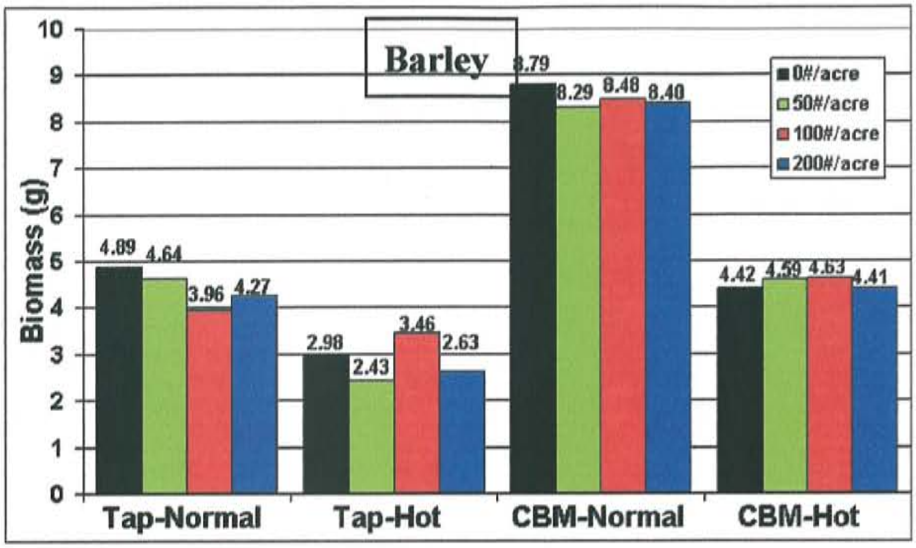


Figure 16. Average aboveground biomass accumulated per pot for each treatment group.

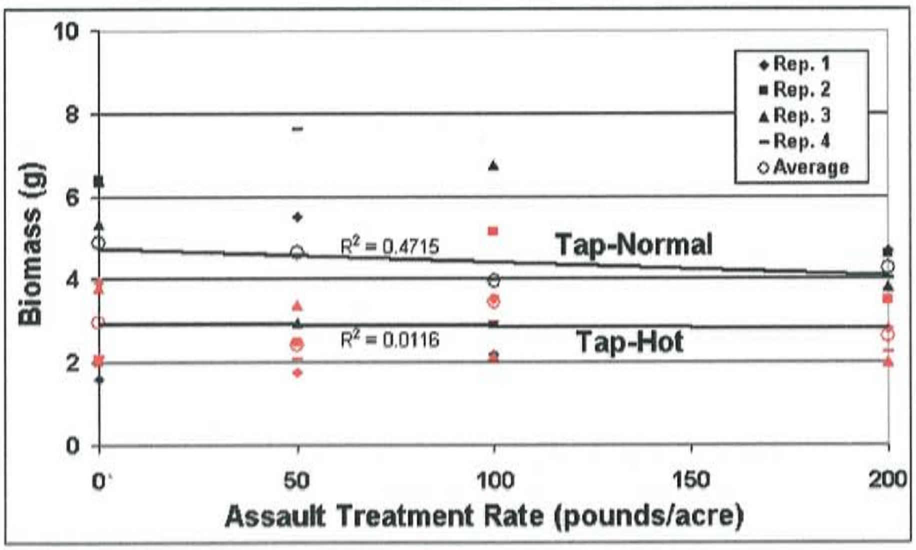


Figure 17. Assault treatment rate versus accumulated aboveground biomass for tap water treatments. Includes data from all four replications.

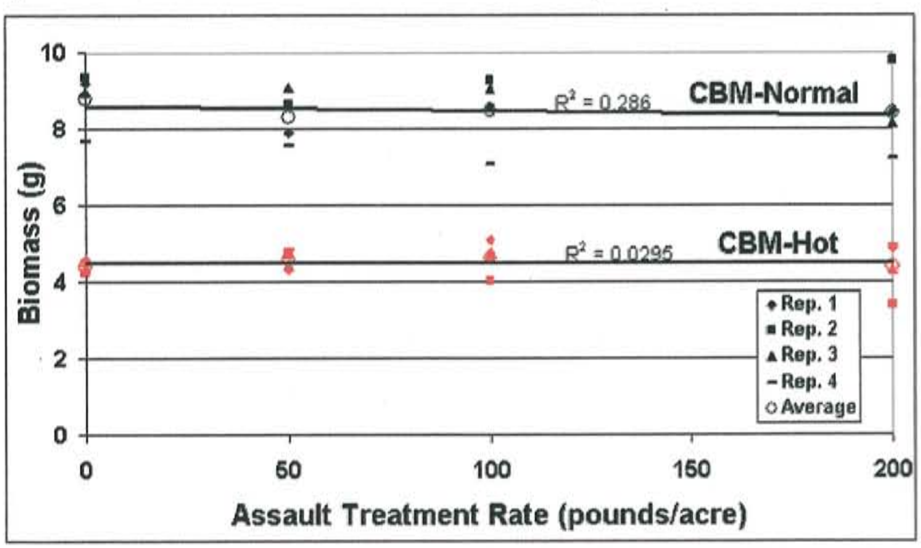


Figure 18. Assault treatment rate versus accumulated aboveground biomass for CBM water treatments. Includes data from all four replications.

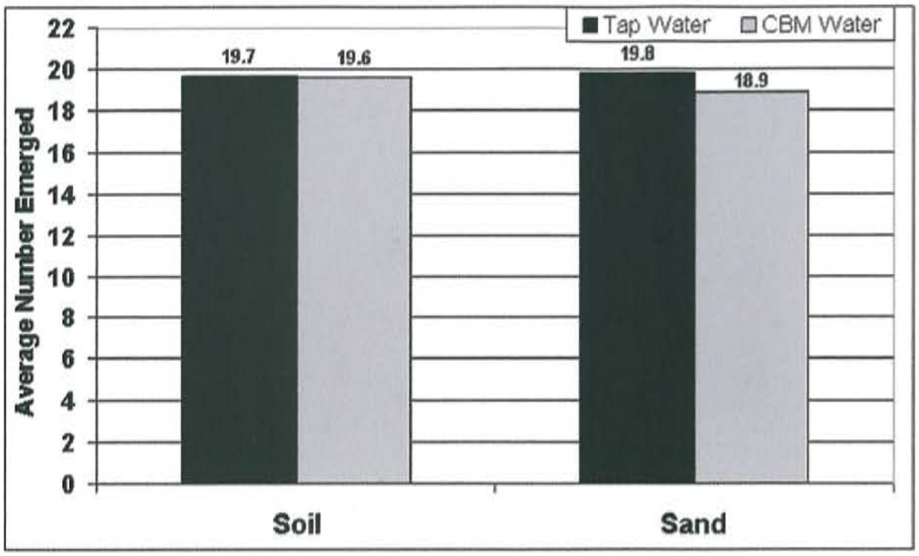


Figure 19. Average emergence of barley in sand and soil.

Experiment 3b. Effects of Assault on Plant Uptake of Sodium, Calcium, Magnesium, and Potassium

Introduction

Another proposed mode of action of Assault DG and liquid Assault is to encourage plant uptake of potassium and calcium, while inhibiting sodium uptake. This part of Experiment 3 examined the effects of Assault on levels of extractable sodium, calcium, magnesium, and potassium in plant tissues and soil of members of each treatment group. Soil electrical conductivity (EC) and sodium adsorption ratio were also measured. Following harvest of biomass, composite soil samples were made from the four replications of each treatment, dried, ground, and sent to MDS Harris labs in Lincoln, NE for analysis. Biomass was dried, weighed, and combined into composite samples, then ground and sent to Midwest Laboratories in Omaha, NE for analysis.

Results - Electrical Conductivity

In order to look at general trends in electrical conductivity, Figure 1 displays baseline soil EC (measured after pots received 1 pore volume of either tap or CBM water prior to planting) as well as average EC of each treatment group for all three crops. Generally, Assault treatment led to lower EC values compared to controls. Soils irrigated with tap water under normal temperature and moisture conditions experienced the greatest drop in EC with Assault treatment, with decreases ranging from 13% in 50 and 200#/acre groups to 25% in 100#/acre groups. Soils irrigated with tap water under increased heat and drought conditions showed little change in EC in 100 and 200#/acre treatment groups and an increase in 50#/acre groups. This increase in EC probably reflects the anomalous increase in EC at 50#/acre in the barley group (Figure 4). Soils irrigated with CBM water under both hot and normal conditions generally experienced decreased

EC values with Assault treatment. Figures 2, 3, and 4 display baseline soil EC values and EC for each Assault treatment group by crop.

Results - Soil Sodium Adsorption Ratio

Figure 5 displays baseline SAR for soils irrigated with tap and CBM water and average SAR of each treatment group for the three crops. Soils irrigated with tap water under normal temperature and moisture conditions saw the greatest decreases compared to controls, with SAR in 50, 100, and 200#/acre Assault treatment groups decreasing by 12, 22, and 8%, respectively. Those soils irrigated with tap water under heat and moisture stress also had decreased SAR values compared to controls, ranging from 7% in 50 and 100#/acre groups to 15% in 200#/acre groups.

SAR values for soils irrigated with CBM water were erratic. Under normal temperature and moisture condition, 50#/acre Assault treatment led to a 6% decrease in SAR, while 200#/acre treatment led to a 5% increase compared to controls. One hundred pound per acre treatment made virtually not difference in overall SAR. Under heat and moisture stress, 50#/acre treatment increased SAR by 14% compared to controls, while 200#/acre treatment led to an 8% increase. Again, 100#/acre treatment made no difference. Figures 6, 7, and 8 display SAR values for individual crops.

Results - Average Sodium, Calcium, Magnesium, and Potassium Levels in Soil and Plant Tissue

Figures 9-16 display average sodium, calcium, magnesium, and potassium content in soil and plant tissues of each treatment group for all three crops. Although sugar beets, pinto beans, and barley respond differently to minerals, these average values give a representative idea of soil and plant tissue level responses in the presence of Assault.

Figures 9 and 10 represent average soil and plant tissue sodium levels for all treatment groups. In general, under normal heat and moisture conditions, Assault led to slightly decreased soil sodium levels and slightly increased plant tissue sodium levels compared to controls. Under heat and moisture stress, both soil and plant tissue sodium levels were elevated with Assault treatment.

Figures 11 and 12 show that under irrigation with tap water and normal heat and moisture condition, Assault treatment clearly reduced soil calcium levels, yet had no significant impact on plant tissue levels compared to controls. Under normal conditions and irrigation with CBM water, calcium levels in plant tissues were generally lower with Assault treatment compared to controls. Under these conditions, soil calcium levels decreased with 50 and 200#/acre treatments and increased with 100#/acre treatment. Under heat and moisture stress conditions, soil calcium levels generally rose with Assault treatment, compared to controls. Plant tissue calcium levels were slightly lower than controls under irrigation with tap water and heat and moisture stress. Under heat and moisture stress and CBM irrigation, Assault treatment led to slightly higher calcium levels in tissues.

Trends in average soil magnesium levels closely mimic those of average soil calcium levels (Figure 13). All treatment groups show a slight rise in average plant tissue magnesium levels with Assault treatment (Figure 14).

Soil potassium levels generally decreased with Assault treatment under normal temperature and moisture conditions and generally increased with elevated temperature and drought (Figure 15). Figure 16 indicates that plant tissue potassium levels showed no significant responses to Assault treatment compared to controls.

Results - Pinto Beans

Bean tissue sodium levels showed significant responses to Assault treatment under irrigation with tap water, with levels decreasing 74-84% compared to controls (Figure 18). Under irrigation with CBM water, Assault treatment either increased tissue sodium levels or had no significant effect. Assault treatment either inhibited or had no effect on calcium and magnesium levels under all conditions except irrigation with CBM water and heat and moisture stress (Figures 20 and 22). Overall, Assault either reduced or did not affect plant tissue potassium levels compared to controls (Figure 24). There were no identifiable correlations between tissue nutrient levels and overall biomass production (Experiment 3a Report, Figure 1).

Results - Sugar Beets

Assault treatment led to increased levels of plant tissue sodium, magnesium, and potassium under nearly all conditions compared to controls (Figure 26, 30 and 32). Calcium levels rose with Assault treatment under irrigation with tap water and decreased under irrigation with CBM water (Figure28). In terms of biomass production, the only Assault treatment groups showing consistent, significant increases were those receiving tap water irrigation and no heat and moisture stress (Experiment 3a Report, Figure 4). In this case, soil levels of calcium, magnesium, and potassium in Assault treatment groups were all lower than controls (Figures 27, 29, and 31), indicating that Assault may have made those nutrients more available for plant uptake. However, despite this observation, there appear to be no obvious correlations between tissue nutrient levels and biomass production.

Results - Barley

Barley tissue levels of sodium were generally slightly higher or unchanged with Assault treatment under heat and moisture stress, compared to controls (Figure 34). Under normal heat and moisture conditions, barley irrigated with tap water had slightly less sodium in its tissues with Assault treatment. Under irrigation with CBM water and otherwise normal conditions, Assault reduced tissue sodium levels 16-20%, compared to controls. Plant tissue calcium and magnesium levels were unaffected or slightly higher than controls under all conditions except irrigation with CBM water and normal temperature and moisture conditions (Figures 36 and 38). In this situation, calcium and magnesium levels dropped 8-17% in Assault treatment groups compared to controls. Tissue levels of potassium were lower or unchanged with Assault treatment under normal temperature and moisture conditions (Figure 40). Heat and moisture stress led to generally increased potassium levels with Assault treatment.

In terms of biomass production, positive responses to Assault treatment occurred under irrigation with CBM water and heat and moisture stress (Experiment 3a Report, Figure 7). This positive biomass response correlates to increases in plant tissue calcium, magnesium, and potassium with Assault treatment. Aside from this observation, there were no other obvious correlations between tissue nutrient levels and biomass production.

Conclusion

Under all conditions, Assault treatment generally led to decreased soil EC. Under irrigation with tap water, SAR values were decreased with Assault treatment. However, under irrigation with CBM water, SAR responded erratically to Assault treatment.

Regardless of temperature, moisture, and water quality, Assault treatment led to slightly higher sodium levels in plant tissues. Assault treatment lowered tissue calcium levels under normal conditions with CBM irrigation water. Calcium levels were unchanged or slightly higher in all other treatment groups. Tissue magnesium and potassium levels consistently rose with Assault treatment. There was little correlation between plant tissue nutrient levels and biomass production for all three plant species.

Power Point Presentation - File title: Phytoremediation Potential

Title: Effects of surface irrigation water quality and water table position on the ability of selected plant species to remove salts and sodium from coalbed methane product water.

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Content: 39-frame power point presentation summarizing results of controlled greenhouse study consisting of evaluation of phytoremediation capabilities of *Atriplex lentiformis, Atriplex Wytana*, and *Hordeum marinum* under conditions of varying water table position and low salinity x low sodicity and high salinity x high sodicity water supplies. Data presented include changes in shallow alluvial water chemistry (salinity, sodicity), base cation uptake. Complete details provided in appendix document of same title, Appendix 6 - Completed Thesis.

Effects of surface irrigation water quality and water table position on the ability of selected plant species to remove salts and sodium

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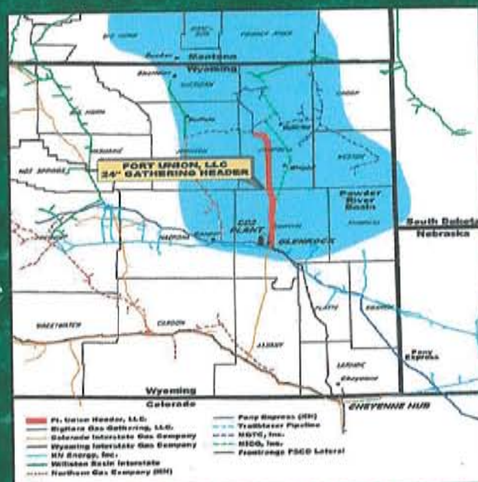
Need for research

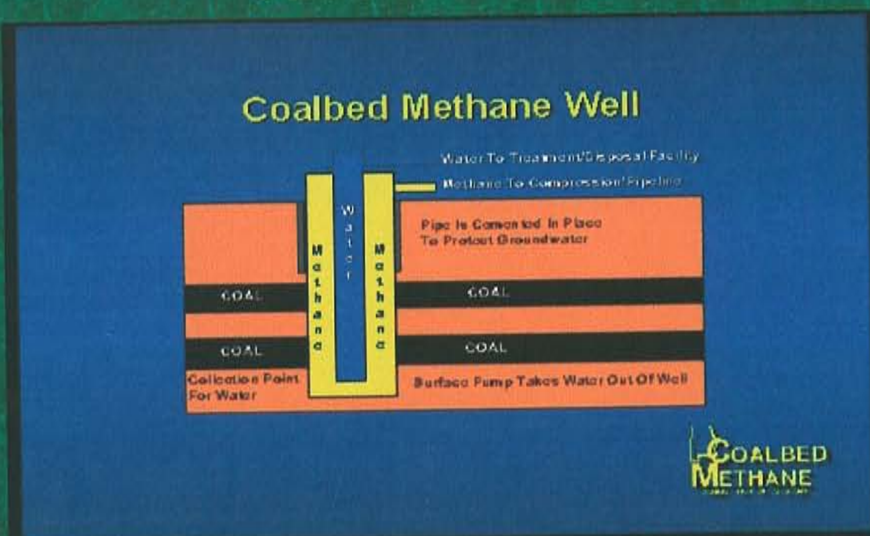
- 1997-Rapid development begins in the Powder River Basin (PRB)
- Impact to landscape, vegetation, and soil structure unknown
- Moratorium on exploratory well permits in Montana
- 2000-EIS process begins in the PRB

Powder River Basin

- Approximately 34,700 square kilometers
- Principle watershed for the Powder River
- Approximately 70% of the U.S. proposed CBM development scheduled here
- 7.5% of all U.S. natural gas production



CBM extraction



Water quality and quantity

- Quality
  - Elevated salinity
  - Elevated sodicity

- Quantity
  - Currently 5,000 production wells in the Powder River Basin of Wyoming and Montana
  - A typical CBM well produces about 13 gpm of production water
  - By 2010 well numbers are expected to increase to 30,000 wells
  - Production water volume is expected to increase to 400,000 gpm

Management options

- Disposal
  - Reinjection
  - Surface discharge
  - Impoundment

- Beneficial Reuse
  - Stock ponds
  - Irrigation
  - Wetlands

Water quality treatment chemistry

- Reagent combination data gathered from MINTEQ2 run

	SAR	EC(dS/m)	pH
Water quality			
Powder River (control)	3.5	1.9	7.9
CBM (treatment)	10.5	3.5	8.0

Water quality guidelines

- Majority of CBM discharge water meets livestock standards
- Majority of CBM discharge water meets human consumption standards
- Much of CBM discharge water fails to meet irrigation water guidelines
  - TDS(mg/L) < 1000
  - SAR < 3

(Proposed BLM limits)

Experimental design

- Experiment 1: The experiment consisted of a replicated, randomized block, complete factorial of three species x two water quality treatments x three water table positions with four replications of all 18-treatment combinations
  - Data collected from three treated harvest over a 32-week period of irrigation
  - Variables are plant species, water quality, and water table position
  - Response variables are biomass production, crude protein, and salt uptake by individual species

Experimental design

- Experiment 2: The experiment consisted of a replicated, randomized block, complete factorial of two water quality treatments x three water table positions with four replications of all treatment combinations for three perennial forage species
  - Water samples were taken weekly (*) for a 32-week period of irrigation
  - Variables are water quality and water table position
  - Response variables are SAR and EC

Study objectives

- Objective of Experiment 1:Determine selected plant species ability to perform and uptake salt over a 32-week period of irrigation with CBM product water

- Objective of Experiment 2: Evaluate shallow groundwater response to a 32-week period of repeated irrigation with CBM product water

Specific objectives

1. evaluate plant biomass production, crude protein, and salt uptake of three perennial forage species
2. determine the effect of three imposed water table positions
3. evaluate the effect of repeated irrigation on shallow groundwater SAR and EC

Greenhouse design

- Column construction
  - 20cm diameter x 100cm tall(72)
  - External manometers
  - Sampling ports at 114, 76, and 38cm from top of column
- Column preparation
  - Fill with river washed sand
  - 24 hour saturation period
  - Drain and fill to 114, 76, and 38cm water table positions
  - Baseline sample analysis

Species selection

- **Selection criteria**
  - Documented capability as a perennial source of livestock forage
  - Documented halophytic characteristics
- **Species**
  - **Wytana saltbush** (*Atriplex wytana*), extremely salt tolerant shrub naturally occurring in Montana, Washington, and Wyoming (Mackie *et al.*, 2001)
  - **Big saltbrush** (*Atriplex lentiformus*), moderately salt tolerant, native shrub known for high productivity and quality forage potential (Watson *et al.*, 1987)
  - **Maritime Barley** (*Hordeum marinum*), salt tolerant, flood tolerant species found in coastal environments reported to provide high nutritional value (Redman and Fedec, 1987)
- **Planting**
  - Direct seed 30 per column

Methods for building and sampling water

- Building water
  - Build dry recipes (control and treatment) once per week for 32 weeks
  - Mixed in 200L barrels (1 horsepower circulation pumps)
  - Equilibration period (two hours)
  - Irrigation with plastic bottles once per week for 32 weeks
- Sampling
  - 100ml samples taken from each column once per week for 32 weeks from three different water table sampling ports (114, 76, and 38cm)
  - Samples were analyzed for SAR and EC
- Repeat process for 32 weeks

Greenhouse study

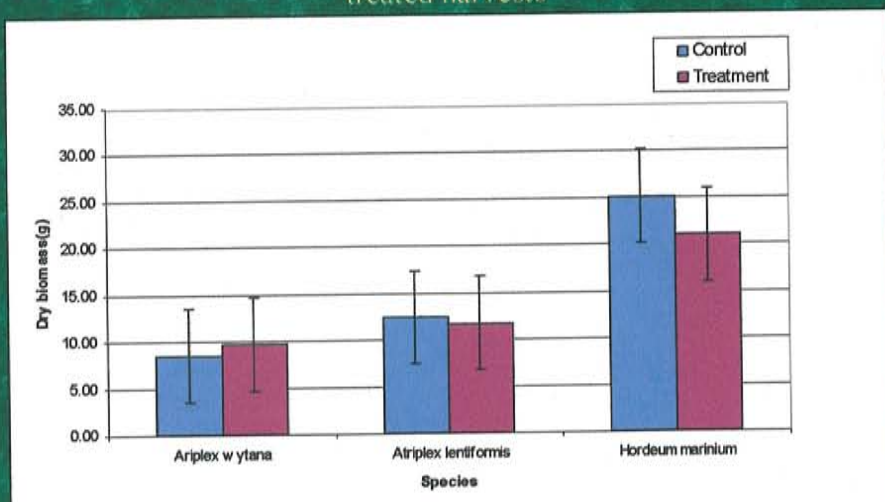
- Experiment 1

Effects of irrigation water quality and water table position on biomass, crude protein, and uptake of salts by three perennial forage species over a 32-week irrigation period and three successive harvests

Experiment 1: statistical analysis

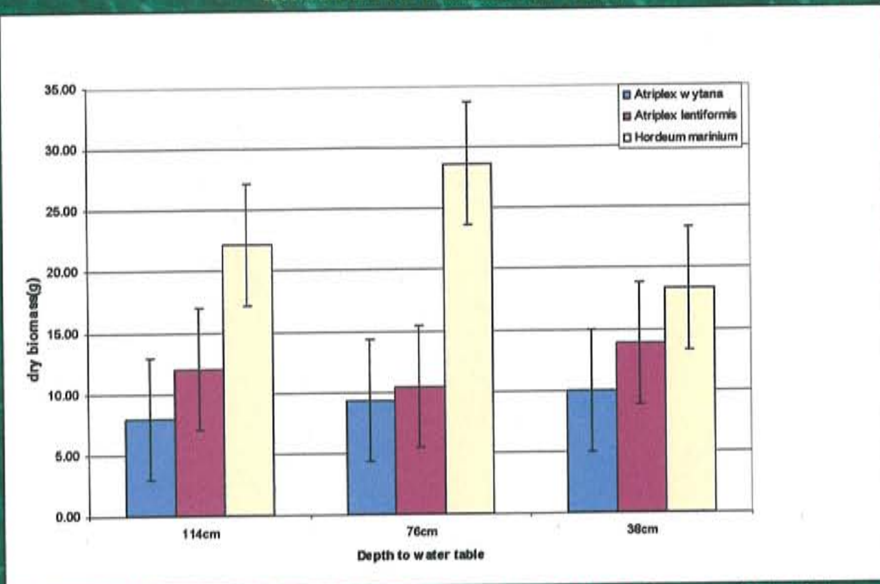
- Statistical analysis of biomass production, crude proteins, and salt uptake were accomplished using SPSS general linear repeated measures in time procedures using successive repeated harvests as an independent variable
- Analyses were completed as a three-way ANOVA of species, water quality, and water table depth for three harvests

Species effect to biomass production averaged across three treated harvests



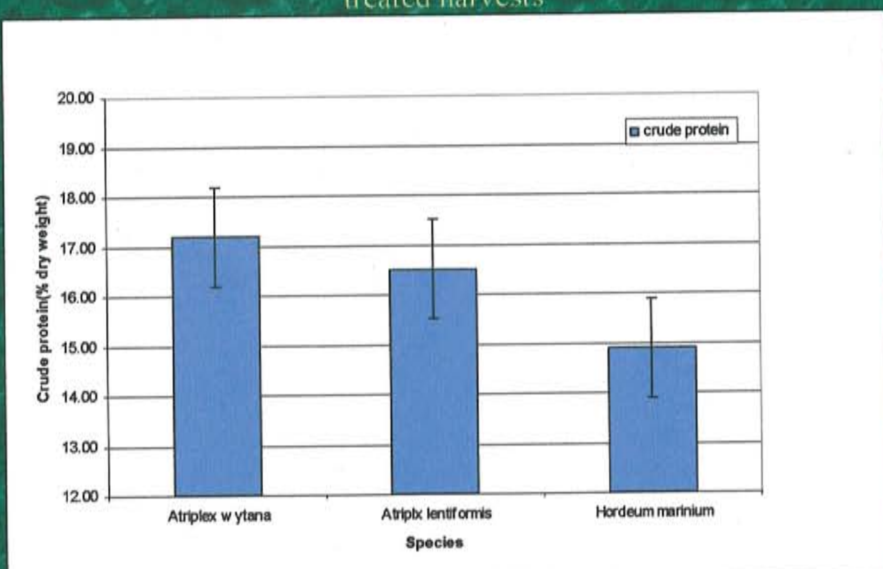
Average dry biomass of *Atriplex wytana*, *Atriplex lentiformis*, and *Hordeum marinium* over three harvests irrigated with control and treatment water quality (average across all water table positions; no drainage)

Water table position effects to biomass production averaged across three treated harvests



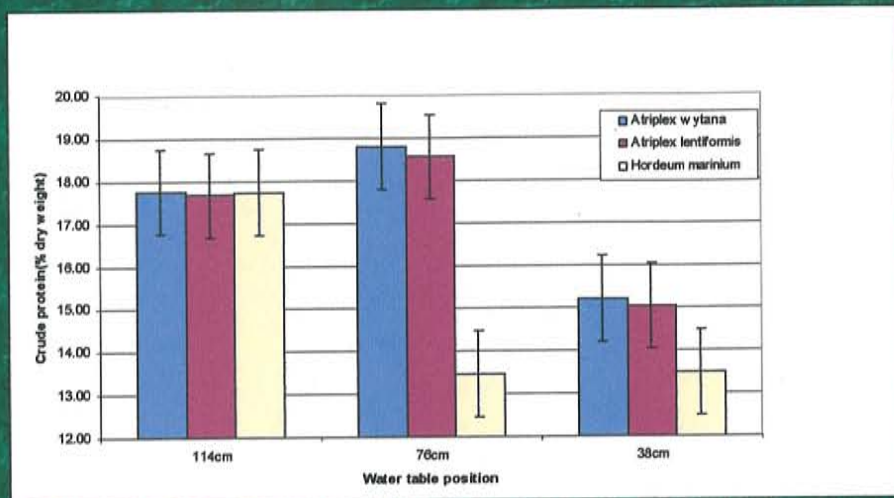
Average biomass production over three successive harvests for columns maintained at three separate water table positions. Water table positions are maintained at 114, 76, and 38cm below soil surface

Species effect to crude protein content averaged over three treated harvests



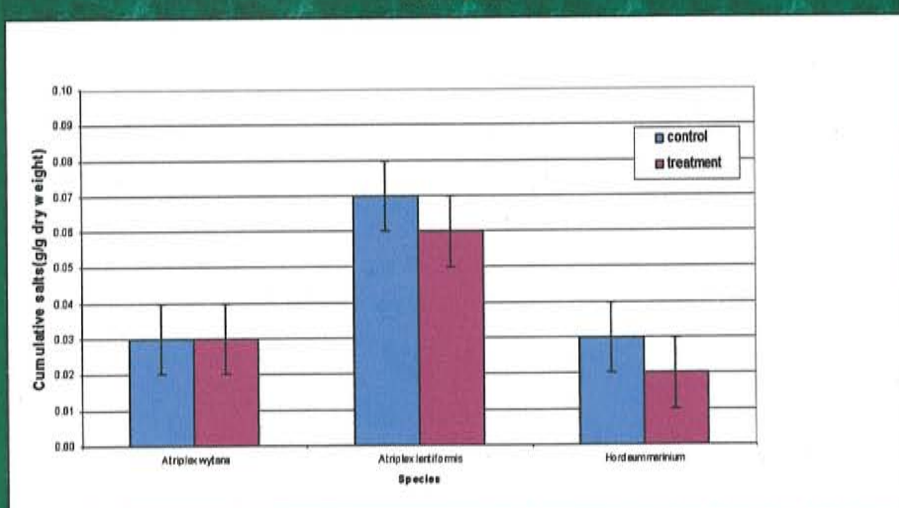
Dry plant material crude proteins of three perennial species averaged across three consecutive harvests, two water treatments, and three water table positions(value range from 12-20%)

Water table position effects to crude protein averaged over three treated harvests



Crude protein reported as percent dry weight (12%-20%) across each water table position averaged over three harvests and two water treatments for *Atriplex wytana*, *Atriplex lentiformis*, and *Hordeum marinium*

Species effect to salt uptake averaged across three treated harvests



Cumulative salt content reported as grams of total salts (Ca, Mg, Na) per gram of dry matter irrigated with treatment and control water averaged over three water table positions and three harvests for *Atriplex wytana*, *Atriplex lentiformis*, and *Hordeum marinium*

Experiment 1: conclusions

- Plant biomass production, crude protein, and salt uptake where less effected by irrigation quality and more a result of column species
- Significantly greater biomass production by *Hordeum marinium* as compared to the other two species (7,000 kg/hectare)
- Trends indicate that biomass production of *Atriplex*, an upland species, was not effected by elevated water table

Experiment 1: conclusions

- Average crude proteins were greatest in the *Atriplex wytana* species
- Average crude protein values were significantly less in columns maintained to the 38cm (shallowest) water table position
- Significantly greater salt uptake by *Atriplex lentiformis* as compared to the other two species

Greenhouse study

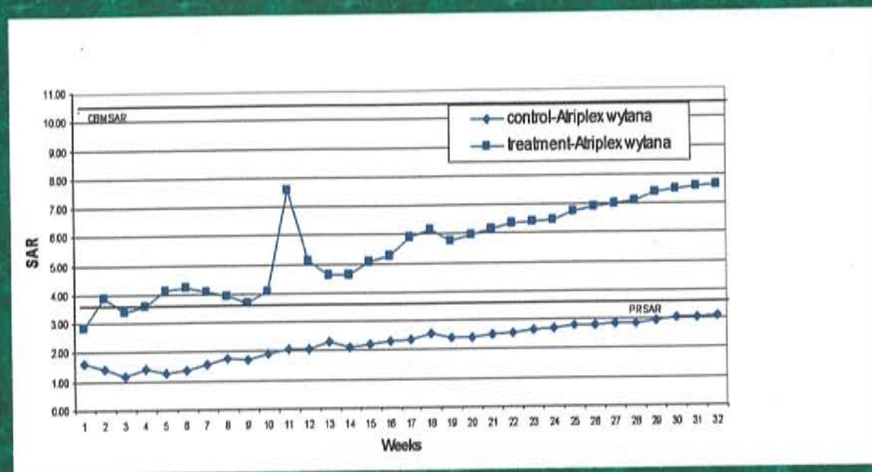
- Experiment 2

Effects of irrigation water quality x water table depth on saturated zone solution chemistry(SAR and EC) over a 32-week period of irrigation

Experiment 2:statistical analysis

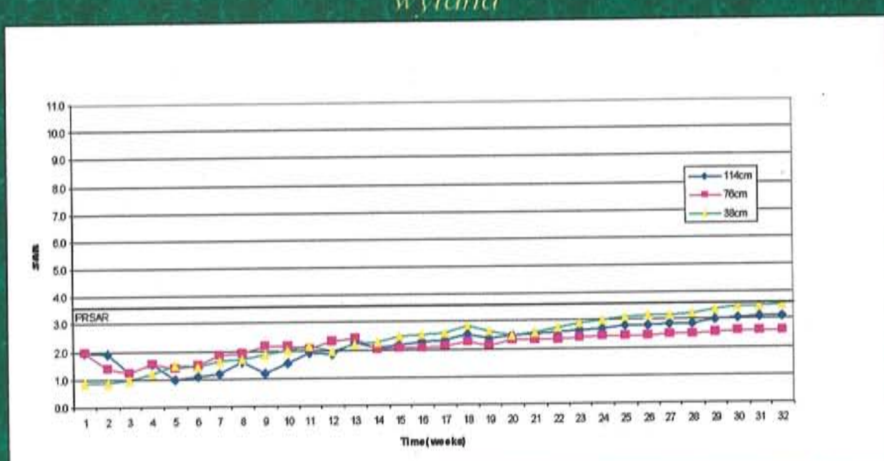
- Statistical analysis of shallow groundwater SAR and EC were accomplished using SPSS general linear repeated measures in time procedures over a 32-week period of irrigation
- Analyses were completed as a two-way ANOVA of water quality and water table depth for three individual plant species

Water quality effects to SAR for *Atriplex wytana*



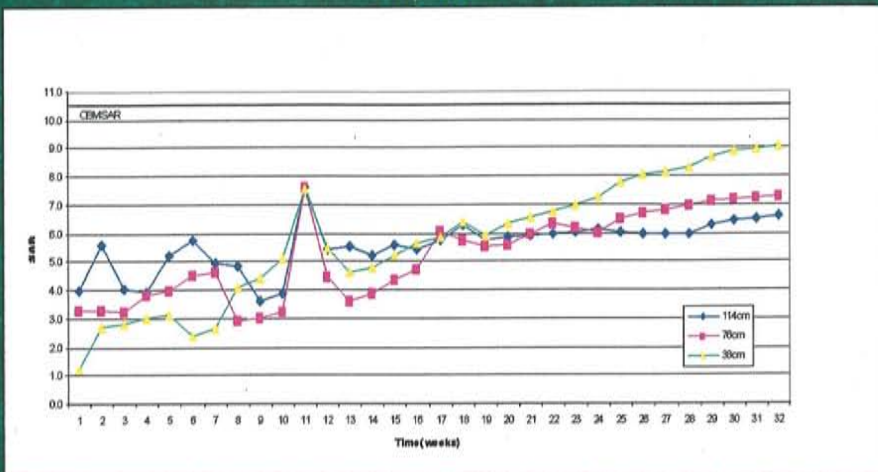
SAR of shallow groundwater over a 32-week period of irrigation of *Atriplex wytana*(no drainage, average of all water table positions) Bold horizontal lines at SAR=3.5 and SAR=10.5 correspond to applied water SAR

Effects of irrigation control water and water table position on shallow groundwater SAR for *Atriplex wytana*



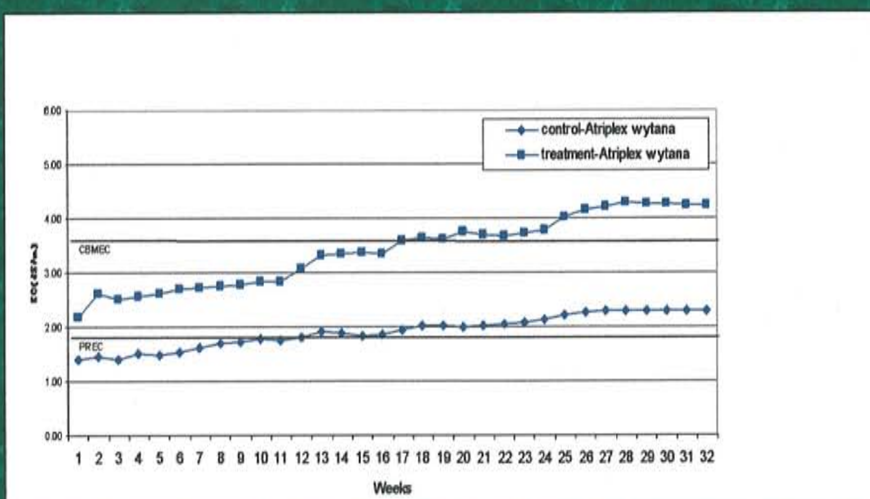
SAR of groundwater over a 32-week period for columns planted to *Atriplex wytana* and irrigated with control product water. Water table positions are maintained at 114, 76, or 38cm below soil surface

Effects of irrigation treatment water and water table position on shallow groundwater SAR for *Atriplex wytana*



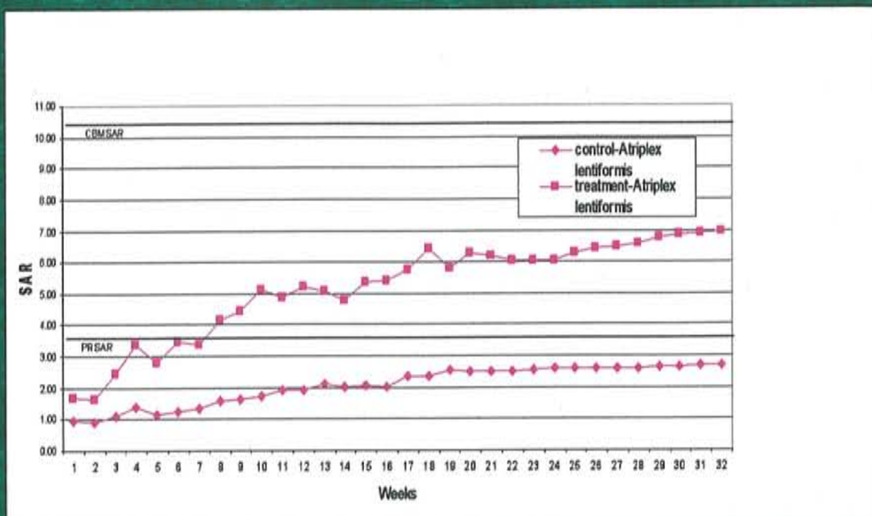
SAR of groundwater over a 32-week period for columns planted to *Atriplex wytana* and irrigated with treatment product water. Water table positions are maintained at 114, 76, or 38cm below soil surface

Water quality effects to EC for *Atriplex wytana*



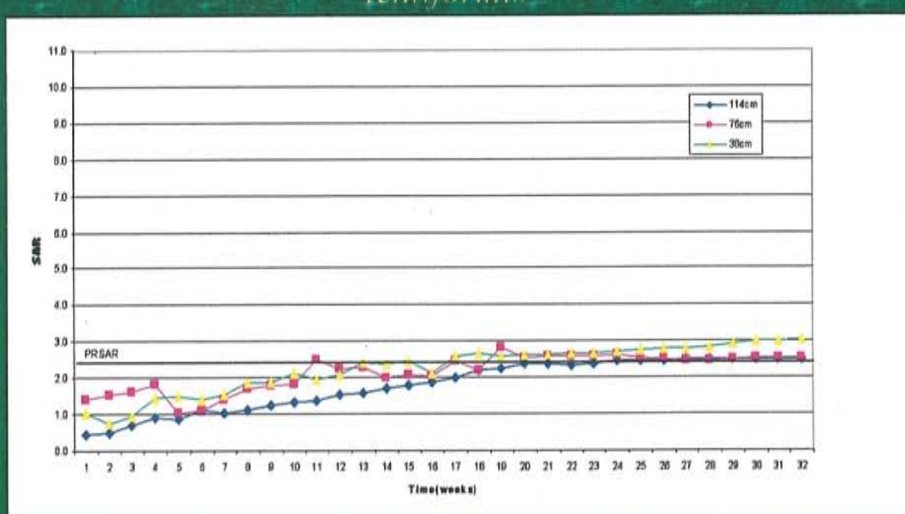
EC of shallow groundwater over a 32-week period of irrigation of *Atriplex wytana*(no drainage, average of all water table positions) Bold horizontal lines at EC=1.9dS/m and EC=3.5dS/m correspond to applied water EC.

Water quality effects to SAR for *Atriplex lentiformis*



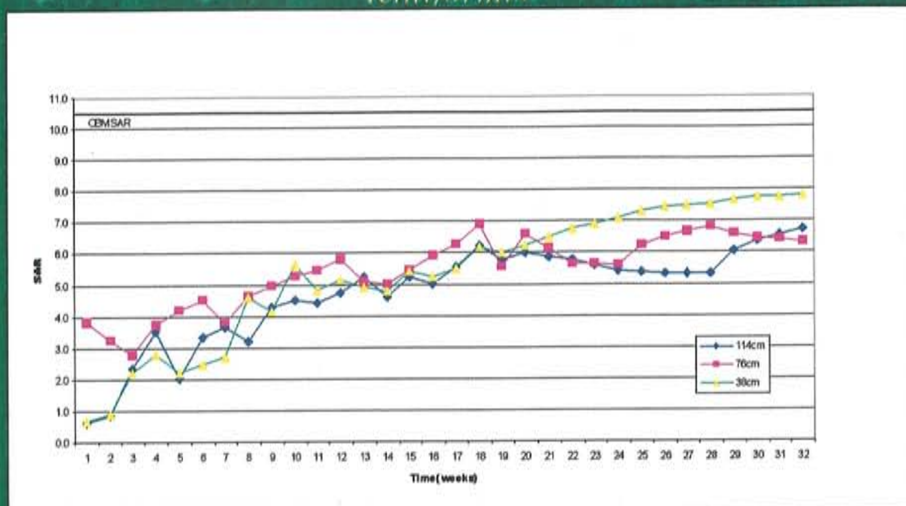
SAR of shallow groundwater over a 32-week period of irrigation of *Atriplex lentiformis*(no drainage, average of all water table positions) Bold horizontal lines at SAR=3.5 and SAR=10.5 correspond to applied water SAR

Effects of irrigation control water and water table position on shallow groundwater SAR for *Atriplex lentiformis*



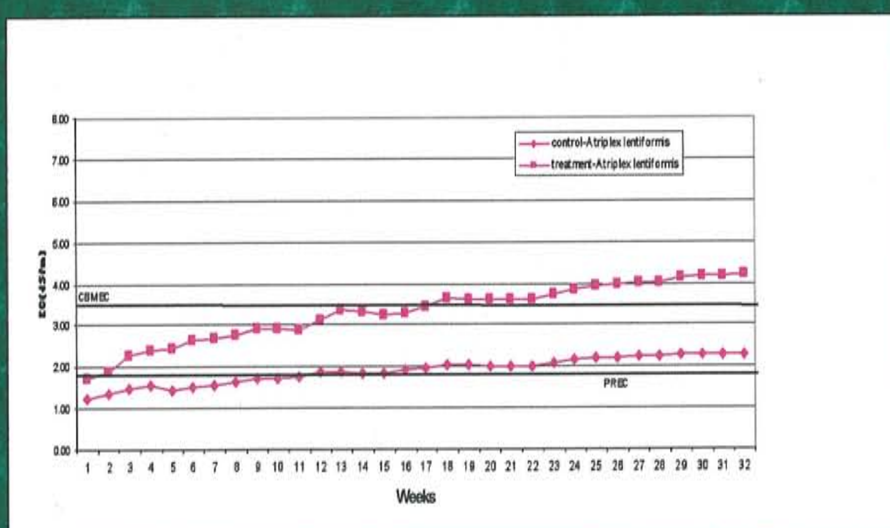
SAR of groundwater over a 32-week period for columns planted to *Atriplex lentiformis* and irrigated with treatment product water. Water table positions are maintained at 114, 76, or 38cm below soil surface.

Effects of irrigation treatment water and water table position on shallow groundwater SAR for *Atriplex lentiformis*



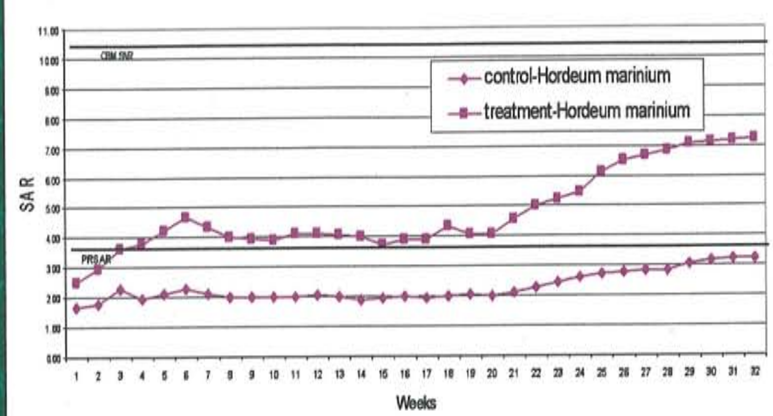
SAR of groundwater over a 32-week period for columns planted to *Atriplex lentiformis* and irrigated with treatment product water. Water table positions are maintained at 114, 76, or 38cm below soil surface.

Water quality effects to EC for *Atriplex lentiformis*



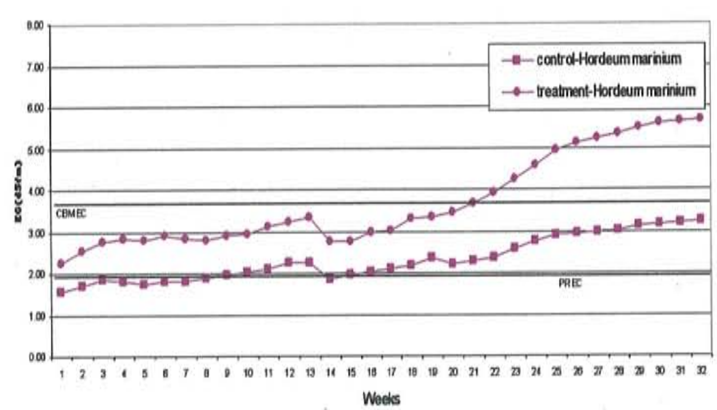
EC of shallow groundwater over a 32-week period of irrigation of *Atriplex lentiformis*(no drainage, average of all water table positions)

Water quality effects to SAR for *Hordeum marinium*



SAR of shallow groundwater over a 32-week period of irrigation of *Hordeum marinium*(no drainage, average of all water table positions) Bold horizontal lines at SAR=3.5and SAR=10.5 correspond to applied water SAR

Water quality effects to EC for *Hordeum marinium*



EC of shallow groundwater over a 32-week period of irrigation of *Hordeum marinium*(no drainage, average of all water table positions) Bold horizontal lines at EC=1.9dS/m and EC=3.5dS/m correspond to applied water EC

Experiment 2: conclusions

- Over a 32-week period of irrigation with simulated CBM(treatment) and Powder River(control) water SAR and EC of shallow groundwater increased
- During irrigation period columns irrigated with treatment water chemistry SAR and EC nearly doubled the SAR and EC values of columns irrigated with the control
- Given enough time and with restriction of infiltration SAR and EC will equilibrate with applied irrigation water chemistry

Study objective summary

- All perennial forage species were able to produce biomass, crude proteins, and uptake salt over a 32-week period of irrigation
- Continued irrigation with saline-sodic water, within a closed environment, will elevate SAR and EC if given enough time

Recommendations

- Salt accumulating species are not the "silver bullet"
- Salt tolerant halophyte use is a "best case" scenario for the beneficial use of CBM production water
- Use of selected species in combination with well-defined water management strategy could provide a cost-effective approach to dealing with high volumes of excessive saline-sodic irrigation water