EFFECTS OF SURFACE IRRIGATION WATER QUALITY AND WATER TABLE POSITION ON THE ABILITY OF SELECTED PLANT SPECIES TO PRODUCE BIOMASS, CRUDE PROTEIN, AND REMOVE SODIUM, CALCIUM AND MAGNESIUM FROM SHALLOW GROUNDWATER[1]

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Abstract. Coalbed methane (CBM) exploration and development has increased substantially over the past ten years in the United States. The Powder River basin in Wyoming and Montana has emerged as one of the most active new locations for exploration. Today, almost 7.5% of United States natural gas production occurs in this area. CBM extraction wells co-produce water that is typically characterized as both saline and sodic. This water has the potential to elevate the saline-sodic conditions within soil or water systems it contacts.

This research was undertaken to examine the effects of surface irrigation water quality and water table position on the ability of selected plant species to produce biomass, crude protein, and to remove the base cations sodium (Na^{+1}), calcium (Ca^{+2}), and magnesium (Mg^{+2}) from shallow groundwater. It was hypothesized that selected species could effectively produce biomass, crude protein, and potentially phytoremediate saline-sodic irrigation water by reducing the sodicity and salinity of that water.

A column experiment was conducted in the greenhouse. Columns were arranged as a two water qualities x three water table positions x three species randomized block design with four replications of all 18-treatment combinations. A simulated CBM water treatment and a simulated Powder River water control serve as irrigation treatments. Three water table positions at 114, 76, and 38 centimeters were imposed to the columns. Species Wytana saltbush (*Atriplex wytana),* Big saltbrush (*Atriplex lentiformis*) and Maritime barley (*Hordeum marinium*) were selected for their livestock forage and salt tolerant (halophytic) characteristics.

Harvest analyses evaluated selected plant species ability to produce biomass, crude proteins, and uptake base cations from shallow groundwater. It can be concluded that plant biomass, crude protein, and base cation uptake were less affected by irrigation quality and more a result of column species and water table position.

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It is recommended that halophytes or salt tolerant crops be used as a "best case" scenario for the beneficial use of low quality irrigation water. If EC-SAR relationships could be modeled over time and plants could be used, having both marketable qualities and the ability to actively remove base cations from the shallow groundwater, the producer may benefit economically through irrigating with this water.

Introduction

Exploration, development, and production within the coalbed methane (CBM) gas industry have increased dramatically over the past ten years. Since 1997, the Powder River Basin in Wyoming and Montana has emerged as one of the most active new areas of CBM production in the U.S., comprising nearly 7.5% of U.S. total natural gas production (Rice *et al.*, 2001). The Powder River Basin is the primary watershed for the Powder River. The Powder River and its tributaries drain an area of approximately 34,700 square kilometers and run north from northeastern Wyoming to southeastern Montana (Hembree *et al.*, 1952) (Figure 1).

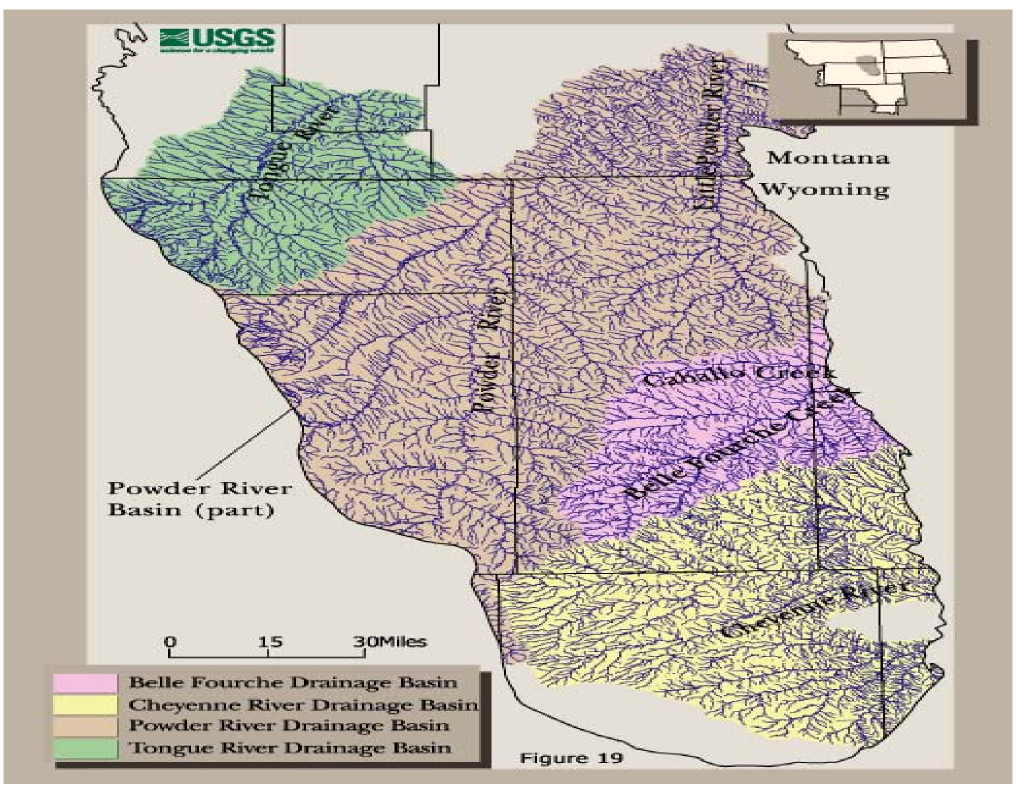

Figure 1. Map of drainage basins in Montana and Wyoming (map provided by U.S. Geological Survey, 2001).

This research was undertaken to examine the effects of surface irrigation water quality and water table position on the ability of selected plant species to produce biomass, crude protein, and to remove the base cations sodium (Na^{+1}), calcium (Ca^{+2}), and magnesium (Mg^{+2}) from shallow groundwater. It was hypothesized that selected species could effectively produce biomass, crude protein, and potentially phytoremediate saline-sodic irrigation water by reducing the sodicity and salinity of that water.

The objectives of this study were:

1. to compare the effect of water quality and water table position on plant production;
2. to evaluate selected plant species' ability to produce biomass and crude protein, and uptake sodium, calcium, and magnesium from shallow groundwater.

Methods and Materials

A greenhouse experiment was selected to best facilitate the objectives of this study. The experiment took place at Montana State University in the Plant Growth Center beginning March 2001.

Experimental design and treatment

The plant performance design 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 from three consecutive harvests were accumulated to provide a single cumulative data set spanning the entire 32-week period of study. Providing the harvest data as a cumulative sum over 32- weeks reduced the effects from between harvest results attributable to species establishment over time (i.e. harvest 1 mean biomass (g) was 1/3 the yields of harvest 2 or harvest 3).

Data were collected from three treated harvests over a 32-week period of irrigation. Variables are plant species, water quality, and water table position. Response variables are biomass, crude protein, and salt uptake by individual species.

Planting method

Prior to imposing any water quality treatment, a permanent monoculture plant population was established in each column. All subsequent plant performance data (yield, forage quality) was determine from successive harvests from each column. The criteria for species selection were: 1) that the species had documented capability as a perennial source of livestock or wildlife forage; and 2) that the species display documented salt tolerant (halophytic) characteristics.

Selected species included:

1. Wytana saltbush (*Atriplex wytana*.), extremely salt tolerant shrub naturally occurring in Montana, Washington, and Wyoming (Mackie *et al*., 2001).
2. Big saltbrush (*Atriplex lentiformis*), moderately salt tolerant, native shrub known for high productivity and quality forage potential (Watson *et al*., 1987).
3. Maritime Barley (*Hordeum marinium*), salt tolerant glycophyte, flood tolerant species found in coastal environments reported to provide high nutritional value (Redman and Fedec, 1987).

Each species was direct seeded by hand to each column at 30 seeds per column with the expectation of attaining 90-100 % cover. Seeds were planted 2 cm deep and lightly watered daily for four days to facilitate germination. Six days from seeding, seed emergence was documented by hand counting column seedlings. Percent emergence varied among the species. To attain the cover criteria, a second 30 seed planting was administered to all columns seeded to *Atriplex wytana*.

Water quality treatments

Water quality treatments were designed to simulate water of the Powder River during the month of June and simulated CBM product water. Irrigation waters simulating the composition of the Powder River representing the control, and coalbed methane (CBM) representing the treatment, were applied once per week for a total of 32 weeks. Irrigation water chemistries were based on 30 years (1970-2001) of historical Powder River water quality data from Moorhead, Montana Geologic Survey gauging station. Powder River water quality data from Moorhead, Montana Geologic Survey gauging station. Data from the gauging station indicates that EC averages 1.30 dS/m and SAR averages between 3.2-3.5 in June. Composition of the simulated CBM discharge water was based on analysis of discharge data from 56 CBM wells located within the Powder River Basin. An EC standard of 1.80 dS/cm was chosen because 90 % of the data from the CBM wells fell beneath this number. The SAR chosen was 12. This value was chosen because 85 % of the values for SAR were found to be 12 or less.

Once the water quality treatment chemistries were defined, multiple runs of MINTEQA2 (Allison et al., 1991) were completed to determine appropriate reagent combinations needed to synthesize the desired water qualities. MINTEQA2 is a geochemical program used to model groundwater chemistry and identify possible precipitated or adsorbed species to target for analysis. Those reagent target parameters were SAR, EC, and pH (Table 1).

During early laboratory mixing trials, target SAR, EC, and pH values could not be recreated accurately. Although, it should be included that control water chemistry targets were far easier to replicate than treatment water chemistry. The reason for this inability to replicate in the laboratory could be attributable to the instability of the target water chemistries. During the mixing process, the unstable solutions were exposed to oxygen (O_2) in the atmosphere. Oxygen exposure facilitated the degassing of bicarbonates and the precipitation of calcium (Ca^{+2}). The precipitation of Ca^{+2} resulted in laboratory chemistry differences in SAR, EC, and pH from those chemistries compiled using the MINTEQA2 model. Those differences in SAR, EC, and pH are reflected in laboratory ran solution chemistries presented in Table 2.

Methods for mixing water

Seventy-two columns were constructed with schedule 120 PVC sewer pipe with dimensions of 20 cm diameter x 122 cm tall. External standpipes were equipped to each column to monitor and routinely re-establish the water table position. Three water table positions were imposed to create three non-saturated potential rooting depths. The three positions were 114 cm, 76 cm, and 38 cm depths to water table.

All columns were filled with mixed diameter (0.05-2.00 mm) sand and saturated with water to facilitate subsidence and packing of the soil material. Sand was used to minimize the potential confounding effects of sodium-induced dispersion. After a 24-hour period of saturation, columns were allowed to drain and dry for 48 hours. The drain holes were then plugged and tap water was applied to establish the appropriate water table position. After waiting several hours, baseline water samples were collected from each column. Baseline water samples were measured for EC, base cations sodium, calcium, magnesium, and pH. All chemistry analyses indicated that residual column chemistry and chemistries associated with using tap water instead of distilled water would not significantly mask effects from imposed water quality treatments

Table 1. MINTEQA2 geochemical model targets for control and treatment water chemistry SAR, EC, and pH.

	SAR	EC (dS/m)	pH
Control	3.5	1.3	7.9
Treatment	12.0	1.8	7.9

Table 2. Laboratory mixing targets for control and treatment water chemistry SAR, EC, and pH. These consistently replicated values are used as irrigation water treatments for a 32-week period of study

	SAR	EC (dS/m)	pH
Control	3.5	1.9	7.9
Treatment	10.5	3.5	8.0

<u>Harvesting procedure</u>

Although the second planting of *Atriplex wytana* took place nearly a week after the first planting, it did not seem to affect the timing of the first harvest (baseline) or any of the successive harvests to follow. The maturity of *Hordeum marinium* dictated harvesting times. At the point when 80 % of columns planted to this species began to drop seed, approximately 8 weeks from germination, above ground biomass (AGB) was harvested by cutting all material above a 5 cm height above the soil surface. All AGB from each column was separately bagged and oven dried for a six-day period. Oven-dry samples were weighed and logged into spreadsheets for later use in the statistical analysis. Plant materials are expressed as grams of dry biomass (g).

All samples were sent to an analytical laboratory. The laboratory analysis included Nitrogen (% of dry weight or g/100 g x 100%) and Na^{+1}, Ca^{+2}, and Mg^{+2} expressed in grams per gram of dry weight (g/g). From these laboratory results, total crude protein (CP) levels were estimated using the Kjeldahl method, which measures the N content of the feed. The average protein content of most feedstuffs is 16%, but this varies somewhat among different feeds depending on their amino acid composition. Therefore, by multiplying the percent of N by 6.25 (100/16 = 6.25) the protein content of feed can be estimated (Kellems and Church, 1998).

Two days after the first harvest (baseline), columns planted to *Hordeum marinium* were moved to cold/wet storage to facilitate the dormancy period. All *Hordeum marinium* columns were kept in storage for six weeks and were not sampled from during this period. At the end of six weeks, *Hordeum marinium* columns were placed back in the greenhouse. This dormancy procedure was not repeated again during this study.

All columns, with the exception of those *Hordeum marinium* columns in storage, were allowed a two-week growth recovery period following the initial harvest and subsequent to imposition of the water treatments. Recovery time was given to allow the disturbed plants to return to normal growth rates and meet cover criterion prior to beginning water sampling. Perennial regrowth was successful during this period and no new seeding was required to meet the 90-100% cover criterion. Three successive, treated harvests and one baseline harvest were taken during this study. All harvests coincided with the eight-week maturity of *Hordeum marinium* and methods for harvesting and AGB analysis were consistent for all harvests.

<u>Statistical analysis</u>

Statistical analyses of plant performance data were completed, using Sigma stat version 2.03, as a three-way analysis of variance for plant species, water quality, and water table position. Data from three consecutive treated harvests were accumulated to provide a single cumulative data set spanning the entire 32-week period of study. Cumulative biomass, crude protein, and base cation uptake will be presented as a table of results of between-subject effects and all between-subject pairwise multiple comparisons were generated using the Tukey Test.

Results and Discussion

Cumulative harvest analysis

The objective of harvest analysis was to determine the effects of species, irrigation water quality, and water table depth on biomass production, crude protein content, and species ability to uptake the base cations Na^{+1}, Ca^{+2}, and Mg^{+2}. Data from three consecutive harvests were accumulated to provide a single cumulative data set spanning the entire 32-week period of study. Providing the harvest data as a cumulative sum over 32- weeks reduced the effects from between harvest results attributable to species establishment over time. For example, harvest 1 mean biomass (g) was 1/3 the yields of harvests 2 or 3 because plant root systems were still developing and contributed to smaller biomass measurements during early plant establishment.

Baseline harvest samples were collected prior to application of treatment. As discussed in the *Experimental design and methods,* a pre-treated harvest was collected to determine if harvests yields amongst species irrigated with tap water and no shallow groundwater source differed significantly from one another. Baseline harvest data were analyzed as a three-way analysis of variance for species, water quality, and water table position. Yields differed significantly between species at the $p = 0.05$. This was an expected result based upon known harvest yields for these species presented by Goodin and Mckell (1970) and Redman and Fedec (1987).

Pairwise comparisons of the baseline harvest determined that *H. marinium* had significantly higher cumulative biomass than both *Atriplex* species and those *Atriplex* species did not differ significantly from each other. Results indicated that there were no significant water quality or water table position effects to harvest yields, therefore eliminating water quality and water table position as contributing factors.

Cumulative biomass, crude protein, and base cation uptake will be presented as a table of results of between-subject effects, followed by a series of graphs. Graphs illustrate the effects to biomass, crude protein, and base cation uptake for columns maintained at three water table positions and planted to *A. wytana, A. lentiformis*, and *H. marinium*.

Main effects for biomass: Species, water quality, and water table position

Tests of between-subject effects for cumulative biomass yielded significant results for both species and water table position treatments (Table 3). Water quality was not significant. Mean biomass (g) for columns planted to *A. wytana* ranged from 21.51 at the 114 cm water table position to 28.88 at the at the 38 cm position. Mean biomass (g) for columns planted to *A. lentiformis* ranged from 27.64 at the 114 cm water table position to 35.41 at the 38 cm position. Mean biomass (g) for columns planted to *H. marinium* ranged from 48.73 at the 114 cm water table position to 60.76 at the 76 cm position. Although significant yield differences can be attributed to natural species variation, columns planted to *H. marinium* yielded significantly greater biomass than either *Atrilpex* species, over two times the biomass of *A. wytana* and nearly one and a half times the biomass of *A. lentiformis* (Table 4). From a management perspective, harvest data results suggest that planting *H. marinium* would, if given similar conditions, produce the most biomass (g) over time.

Table 3. Data table, results from three-way ANOVA of biomass production for *A. wytana, A. lentiformis*, and *H. marinium*. Table contains analysis of significance for species, water quality, and water table position treatment effects and interactions.

Source	df	Sum of Squares	Mean Square	F	P
Species	2	11996.768	5998.384	77.539	<0.001
Water quality (WQ)	1	48.791	48.791	0.631	0.431
Water table position-cm (WTP)	2	589.576	294.788	3.811	0.028
Species x WQ	2	202.118	101.059	1.306	0.279
Species x WTP-cm	4	516.790	129.198	1.670	0.170
Residual	60	4177.439	69.623		
Total	71	17937.195	252.637		

Computed using alpha = 0.05

Table 4. Data table, mean biomass for *A. wytana*, *A. lentiformis*, and *H. marinium*.

Species	Mean Biomass (g / spp)	Production (kg/ha/3 cut)	Production (lbs/acre/3 cuts)	Production (tons/acre/1 cut)
A. wytana	24.63	5996.51	5322.89	0.89
A. lentiformis	30.49	7423.20	6589.19	1.10
H. marinium	54.47	13261.46	11771.51	1.96

For *Atriplex* species, columns maintained at the 38 cm water table position (shallowest) showed greater biomass production than those columns maintained at any other position (Figure 2). There were no significant differences amongst water table positions for *H. marinium*. There

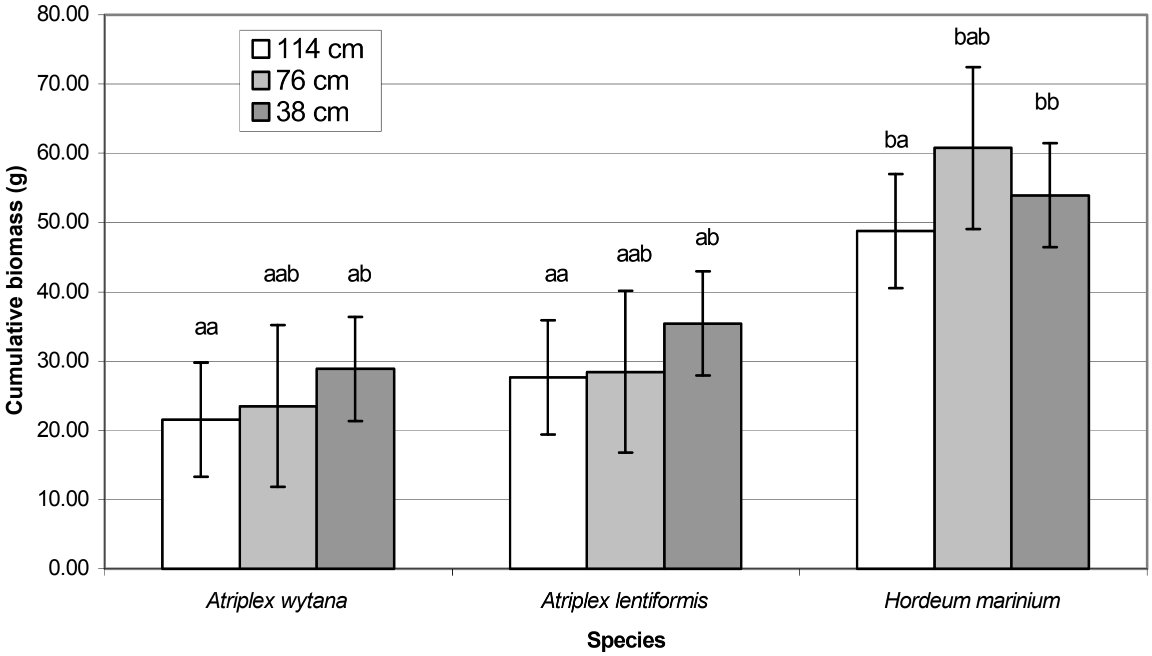

Figure 2. Cumulative biomass of *A. wytana, A. lentiformis*, and *H. marinium* maintained to 114, 76, and 38 cm water table positions and collected over time. Error bars are presented as a standard error from the mean. Columns followed by the same letter are not significant at the alpha = 0.05 level. First letter characterizes the species effect. Second letter characterizes the effect of water table position.

are several explanations for these results. First, *H. marinium* may adapt or tolerate flooding to a greater degree, thus making water table position less of a factor affecting biomass production. Second, *Atriplex* biomass data indicates that the extra water availability provided at the 38 cm position directly affected the species ability to produce extra biomass. Therefore, *Atriplex* species may have the ability to use more water when water is more available. This interpretation refutes the historic range designation of *Atriplex* as upland flood intolerant species and suggests that current sources tend to underestimate the species-water relationship with respect to biomass production. Figure 2 illustrates the species and water table position effects to biomass production. Water table position effects for each species are shown by comparing shaded columns to unshaded columns.

Main effects for crude protein: Species, water quality, and water table position

Tests of between-subject effects for cumulative crude protein yielded significant differences between all species (Table 5). Mean crude protein (g) ranged from 3.68 14% total N) for columns planted to *A. wytana* to 6.16 (11% total N) for columns planted to *H. marinium*. Although *H. marinium* showed the greatest crude protein content of the species used in this experiment (Table 6), percent total N (%) for *H. marinium* was less than either *Atriplex* species. In fact, the two-fold increase in biomass over *Atriplex* seen in the previous data does not carry over to crude protein results. These results indicate that while *H. marinium* produces the greatest total biomass, this species does not contain the quality of crude protein found in the *Atriplex* species. Land managers concerned with forage quality and total N quantity production should perhaps consider other plant species. Figure 3 illustrates the species effects to crude protein content. Species effects are shown by comparing shaded columns to unshaded columns.

Table 5. Data table, results from three-way ANOVA of crude protein for *A. wytana, A. lentiformis*, and *H. marinium*. Table contains analysis of significance for species, water quality, and water table position treatment effects and interactions.

Source	df	Sum of Squares	Mean Square	F	P
Species	2	74.019	37.010	40.296	<0.001
Water quality (WQ)	1	0.266	0.266	0.290	0.592
Water table position-cm (WTP)	2	5.246	2.623	2.856	0.066
Species x WQ	2	1.292	0.646	0.703	0.500
Species x WTP-cm	4	2.430	0.608	0.661	0.621
Residual	60	49.596	0.827		
Total	71	137.815	1.941		

Computed using alpha = 0.05

Main effects for base cation uptake: Species, water quality, and water table position

Tests of between-subject effects for cumulative base cation uptake of Na^{+1}, Ca^{+2}, and Mg^{+2} yielded significant results for both species and water table position treatments (Table 7). Mean base cation uptake (g) for columns planted to *A. wytana* ranged from 2.21 at the 114 cm water table position to 3.25 at the at the 38 cm position. Mean base cation uptake (g) for columns planted to *A. lentiformis* ranged from 4.38 at the 114 cm water table position to 6.30 at the 38 cm position. Mean base cation uptake for columns planted to *H. marinium* ranged from 1.44 at the 114 cm water table position to 1.74 at the 76 cm position.

Table 6. Data table, mean crude protein for *A. wytana*, *A. lentiformis*, and *H. marinium*.

Species	Mean Crude Protein (g / spp)	Total N (%)	Crude Protein (kg/ha/3 cut)	Crude Protein (lbs/acre/3 cuts)	Crude Protein (tons/acre/1 cut)
A. wytana	3.68	14	895.95	795.30	0.13
A. lentiformis	4.79	16	1166.19	1035.17	0.17
H. marinium	6.16	11	1499.74	1331.24	0.22

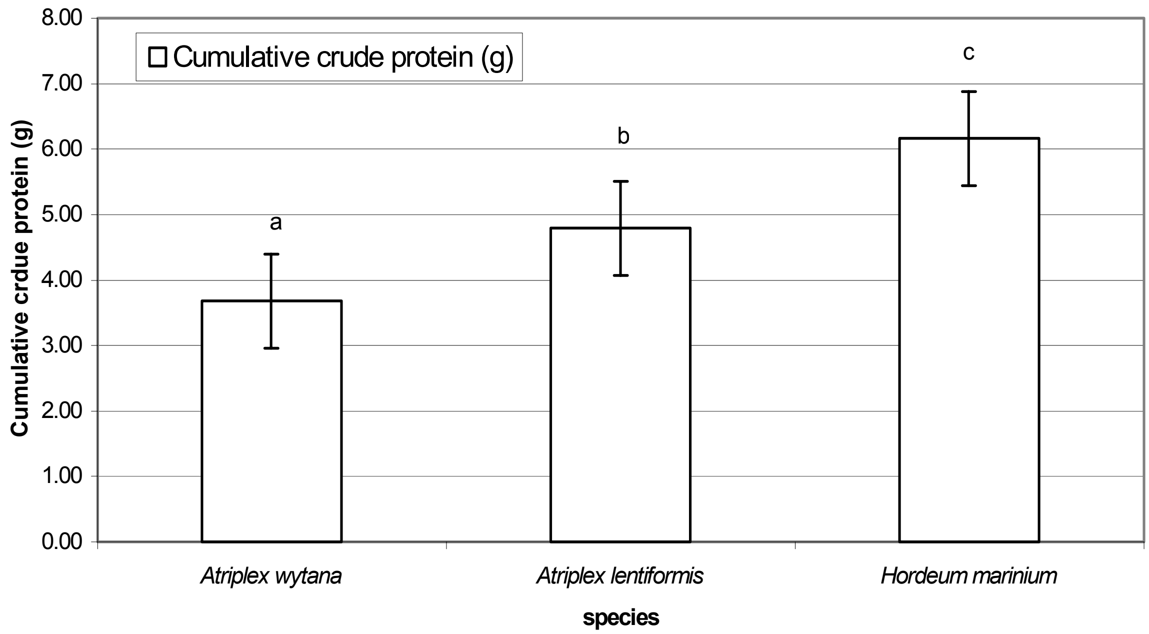

Figure 3. Cumulative crude protein expressed in grams for *A. wytana, A. lentiformis,* and *H. marinium*. Columns followed by the same letter are not significant at the alpha = 0.05 level. Error bars are presented as standard error from the mean.

Table 7. Data table, results from three-way ANOVA of base cation uptake by *A. wytana, A. lentiformis*, and *H. marinium*. Table contains analysis of significance for species, water quality, and water table position treatment effects and interactions.

Source	df	Sum of Squares	Mean Square	F	P
Species	2	166.776	83.388	100.227	<0.001
Water quality (WQ)	1	0.299	0.299	0.395	0.551
Water table position-cm (WTP)	2	14.737	7.368	8.856	<0.001
Species x WQ	2	0.808	0.404	0.486	0.618
Species x WTP-cm	4	5.590	1.397	1.680	0.168
Residual	60	44.927	0.749		
Total	71	238.977	3.366		

Computed using alpha = 0.05

As with crude protein results, pairwise comparisons of species differ significantly from one another with respect to base cation uptake. Although significant uptake differences can be attributed to natural species variation between halophytes (*Atriplex*) and glycophytes (*Hordeum*), columns planted to *A. lentiformis* yielded significantly greater base cation uptake than either *H. marinium* or *A. wytana* (Table 8). *A. lentiformis* removed over three times as much base cations as *H. marinium* and double the uptake of *A. wytana*. From a phytoremediation perspective, base cation uptake data results suggest that planting *A. lentiformis* would, if given similar conditions, uptake more of the base cations Na^{+1}, Ca^{+2}, and Mg^{+2} over time and therefore would be considered the most effective phytoremediation species used in this experiment. However, results from this experiment showed that *Atriplex* species reduced overall salinity while overall sodicity increased due to preferential calcium uptake. Increased sodicity did not affect plant growth but does have the potential to negatively effect soil physico-chemical properties when SAR levels are allowed to reach 13, a result that land mangers and reclamationists should consider. Outcomes from this hypothesis need to be addressed further and may refute the promotion of halophytes as phytoremediators of sodic soils.

As with species effects, water table position effects were significantly different for base cation uptake (Figure 4). Columns maintained at the 38 cm water table position (shallowest), regardless of species composition, showed greater base cation uptake than those columns maintained at any other water table position. This is a consistent pattern throughout this experiment. In addition, *H. marinium* shows the least effects from water table position, corroborating thus making water table position less of a factor affecting the base cation uptake for this species. Figure 4 illustrates the species and water table position effects to base cation uptake of Na^{+1}, Ca^{+2}, and Mg^{+2}. Water table position effects for each species are shown by comparing shaded columns to unshaded columns.

Table 8. Data table, mean cation uptake for *A. wytana*, *A. lentiformis*, and *H. marinium*.

Species	Mean Cation Uptake (g / spp)	Cation Uptake (kg/ha/3 cut)	Cation Uptake (lbs/acre/3 cuts)	Cation Uptake (tons/acre/1 cut)
A. wytana	2.66	647.61	574.86	0.10
A. lentiformis	5.22	1270.88	1128.09	0.19
H. marinium	1.59	387.11	343.61	0.06

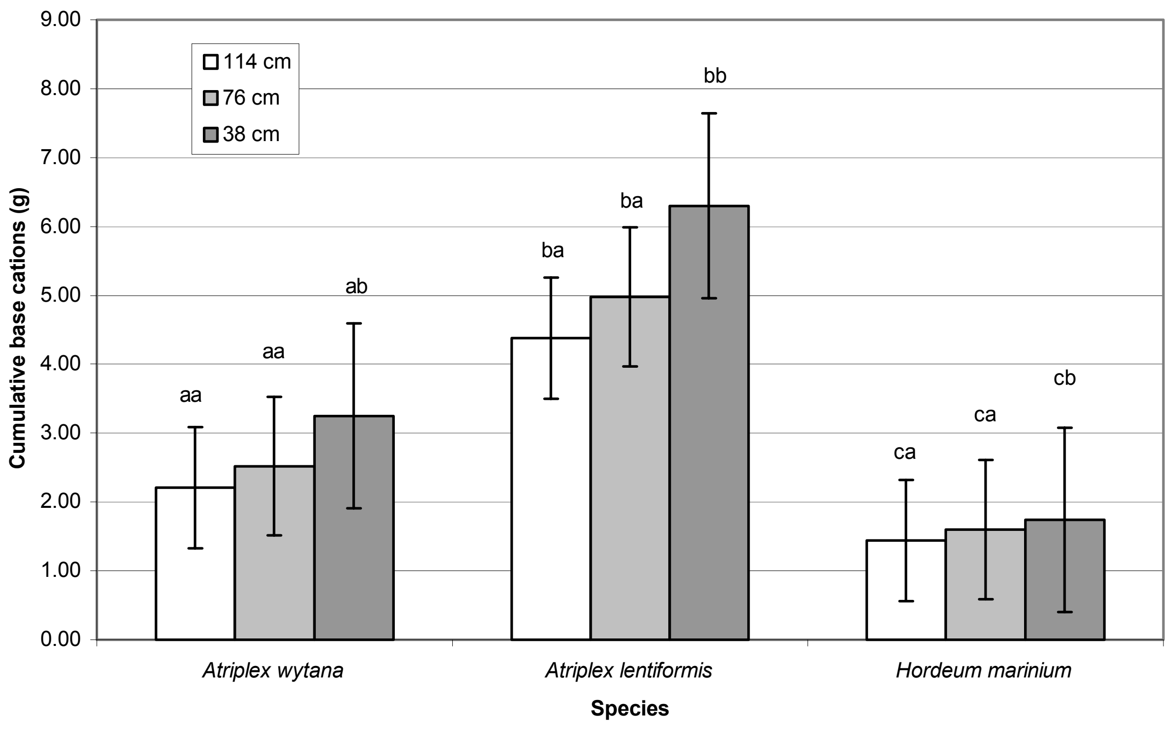

Figure 4. Cumulative cation uptake of *A. wytana, A. lentiformis*, and *H. marinium* maintained to 114, 76, and 38 cm water table positions and collected over time. Error bars are presented as a standard error from the mean. Columns followed by the same letter are not significant at the alpha = 0.05 level. First letter characterizes the species effect. Second letter characterizes the effect of water table position.

Summary

This research was conducted to examine the effects of surface irrigation water quality and water table position on the ability of selected plant species to produce biomass, crude protein, and to remove the base cations sodium (Na^{+1}), calcium (Ca^{+2}), and magnesium (Mg^{+2}) from shallow groundwater. It was hypothesized that selected species could effectively produce biomass, crude protein, and potentially phytoremediate saline-sodic irrigation water by reducing the sodicity and salinity of that water.

Harvest analyses evaluated selected plant species ability to produce biomass, crude proteins, and uptake the base cations from shallow groundwater. Plant biomass, crude protein, and base cation uptake were less affected by irrigation quality and more a result of column species and water table position. This is a very important result given this study's focus on the control versus the treatment. The analysis of water quality on harvest production suggests that selected species were not affected significantly by either the control (Powder River) or the treatment (CBM). From these results, it can be concluded that water quality thresholds for the selected species were not exceeded during this study, even though, current water quality standards were exceeded (EC>4.00 dS/m).

Tests of between-subject effects for cumulative biomass yields differed significantly between species. This result is attributable to natural species variations between crop *(H. marinium*) and forage (*Atriplex*). *H. marinium* yielded nearly two tons per acre per cut of dry biomass and would, if given similar environmental conditions and time frame, produce the greatest total biomass of the three selected species.

All species were significantly affected by water table position, but as with species results to biomass production, crop species differed significantly from forage species. In all cases, *Atriplex* biomass increased when the water table was maintained to the shallowest position, an effect not seen in columns planted to *H. marinium*. These results illustrate two conclusions. The first is that *H. marinium* can adapt or tolerate flooding, or in this case the imposition of a shallow water table, thus making water table position less of a factor effecting biomass production. The second is that *Atriplex* has the potential to use more water if there is more water available to the plant. The increased water availability provided by the shallowest water table resulted in increased biomass production of this species. These results suggest that current sources tend to underestimate *Atriplex* species water relationship with respect to biomass production.

Tests of between-subject effects for cumulative crude protein yielded significant differences between all species, but found no significant results from water quality or water table position. Results indicated that while *H. marinium* produced the greatest biomass, this species did not contain the quality of crude protein found in *Atriplex* species. Implications from these results may be of interest to land managers concerned with selecting species for forage quality and total N quantity.

Tests of between-subject effects for cumulative base cation uptake from shallow groundwater were found to significantly differ amongst the three plant species. These differences can be attributed to natural species variation in the base cation uptake of halophytes (*Atripex spp*.) and glycophytes *(H. marinium*). Results indicated that *A. lentiformis* doubled the uptake of *A. wytana* and tripled the uptake of *H. marinium* suggesting that halophytes accumulate far more base cations in their tissues than do glycophytes. More specifically, results indicate that not all halophytes, even within species, function alike to uptake base cations.

From a phytoremediation management perspective, *A. lentiformis* would, in similar conditions, uptake more base cations over time (1,128 lbs/over 32-weeks) and therefore should be considered the most proficient phytoremediator of the species selected. However, results show that while selected halophytes' removal of base cations facilitated reductions to overall salinity the preferential removal of calcium by these species also facilitated increases to overall sodicity. While increased sodicity did not affect plant growth, there is the potential to adversely affect soil structure and profile, a result that land managers and reclamationists should consider prior to species selection.

From study conclusions, several observations and assumptions can be made. First, irrigation water quality needs to be considered with respect to both plant productivity and soil structure. Efforts should be made to maintain irrigation water quality in its current condition, although irrigating with saline or sodic water may be possible, given a well draining soil and a salt tolerant plant. Second, water table position does directly affect *Atriplex* plant production. *Atriplex* produced greater biomass when shallower water tables were imposed suggesting the underestimation of the plant water relationship with respect to biomass production. Third, base cation accumulating species are not the "silver bullet" in saline or sodic water remediation. The use of halophytes or salt tolerant glycophytes as phytoremediators of saline shallow groundwater has merit, but may promote increased groundwater sodicity through the preferential removal of calcium over sodium. Although certain species may be salt and flood tolerant, excessive volumes of low quality water would eventually negatively impact plant performance and soil structure.

It is recommended that halophytes or salt tolerant crops be use as a "best case" scenario for the beneficial use of low quality irrigation water. If EC-SAR relationships could be modeled over time and plants could be used, having both marketable qualities and the ability to actively remove base cations from the shallow groundwater, the producer may benefit economically through irrigating with this water. If a reduction of excessive salts and sodium within the rooting zone could be managed, then the magnitude of negative effects to soils and plants resulting from irrigation with poor quality water could be reduced.

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