The Role of Plants in the Phytoremediation of Discharge Water Associated With Extraction of Coal Bed Methane

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This page illustrates the process and results of a greenhouse phytoremediation experiment conducted at the Montana State University Plant Growth Center in Bozeman (shown left) during 2001 and 2002.

ABSTRACT

Coal bed methane (CBM) exploration and development has increased substantially over the past ten years. The Powder River Basin in Wyoming and Montana has emerged as one of the most active new locations for exploration. Today, almost 6% of the total United States production occurs in this area.

Methane extraction in the Powder River Basin co-produces an excess of saline-sodic water. This water has the potential to elevate saline-sodic conditions within the soil-water interface causing decreases in land productivity. It is hypothesized that specific species of plants can function to uptake excess salts and remediate the saline-sodic conditions associated with CBM discharge water. Halophytic species are defined as "salt tolerant accumulators." These species have the potential to accumulate high levels of sodium and other salts within their above ground tissue and, in some cases, excrete these salts onto leaf surfaces. It is also hypothesized that these halophytic species have the ability to provide substantial volumes of high quality forage. Literature suggests that some halophytic species can provide adequate crude protein and nutrients comparable to common cultivated crop and forage species.

Column experiments were conducted using maritime barley, Wytana saltbush, and Big saltbush to determine soil water response over a 32 week period with no column drainage and species' abilities to uptake and remove salt from the soil profile. Species were exposed to one of two water chemistries and one of three water table positions. Based on experimental data, selected plant species are well adapted to CBM quality water and appear to perform best within a shallow water table.

Above ground biomass was harvested a total of four times and analyzed for total biomass production, nutrient content, and salt concentrations. Preliminary results indicate that there is potential for significant biomass production and salt uptake by these species.

Objectives:

- Analyze changes to shallow groundwater chemistry during irrigation with CBM product water.
- Determine selected plants' abilities to uptake and remove salt from soil.
- Determine selected plant species' abilities to produce adequate forage, based on biomass production and crude protein content.

Experimental Design:

Table 1. Selected Species

Species	Common	Scientific
1	Wytana saltbush	*Atriplex wytana*
2	Big saltbush	*Atriplex lentiformis*
3	Maritime barely	*Hordeum marinum*

Table 2. Depth to Water Table

Position	Depth
A	45" (114 cm)
B	30" (76 cm)
C	15" (38 cm)

Table 3. Water Quality Treatments

Water Type	EC (mmhos/cm)	SAR	pH
Powder River water	1.9	3.5	8
CBM product water	3.5	10.5	8

Stage I: Construction of the Columns

72 columns were constructed of 8-inch diameter x 4 feet length PVC pipe. A monometer located on the side of each column regulated water table position by manipulating hydraulic head. Three water table positions simulated a range of conditions from dry to saturated, such as might be found in and around outflow and impound sites associated with CBM extraction.

Monometer on sides of columns.

Sampling port at 38 cm water table position.

The columns were constructed with three sampling ports at 15, 30, and 45 inches (38, 76, and 114 cm) from the base. These ports allowed three separate sampling sites and were intended to report differences in water level-root interactions for the different irrigation/impounding strategies.

Completed columns in greenhouse.

Sampling port.

Stage II: Planting

Each column was planted to one of three species: 1) Maritime barley (*Hordeum marinum*), 2) Big saltbush (*Atriplex lentiformis*), or 3) Wytana Saltbush (*Atriplex wytana*). Each species was seeded directly into the growth medium (0.05-2.0 mm sand) and watered regularly with tap water to promote germination.

Emerging saltbush and maritime barley.

Results:

Emergence: Maritime barley-100%, Big saltbush-85%, Wytana saltbush-10%. The Wytana variety had limited success in germination and needed a second seeding to fill the columns. The other two species germinated and grew rapidly. After germintation, all species filled their columns and created a thin root network that increased with further species establishment.

Columns during 8-week establishment period.

Well established plants.

Stage III: Changes to Shallow Groundwater Chemistry During Irrigation with CBM Product Water

After an 8-week establishment period, a baseline harvest was conducted, followed by commencement of irrigation with treatment water chemistries. The two treatment water chemistries simulated common CBM chemistry in the Powder River Basin and a common Powder River chemistry.

After the first week of treatment, 100 mL water samples were taken from each of the columns at the appropriate sampling position and analyzed for electrical conductivity (salinity), SAR (sodium adsorption ration), base cations (Na^{+}, Ca^{2+}, and Mg^{2+}), and pH.

These samples were taken once per week for 20 weeks, then once every two weeks for 4 weeks, and finally once per month for the final 8 weeks of the 32 week study period. No drainage was allowed throughout the study. These data were used to determine species effectiveness at remediating effects of saline/sodic water. All water samples were analyzed by Agvise Laboratories-Northwood, ND.

Results:

- Irrigation with CBM water doubled or tripled rates of increase of EC and SAR in groundwater compared to irrigation with Powder River water.
- Continuous irrigation with simulated CBM and Powder River water resulted in column salt loading over time, irrespective of species composition.

Figure 1. EC Over Time of Columns Planted to Wytana saltbush

Figure 2. EC Over Time of Columns Planted to Big saltbush

Figure 3. EC Over Time of Columns Planted to Maritime barley

- Groundwater in columns planted to Wytana saltbush and Big saltbush with water tables maintained at 38 cm consistently had greater EC and SAR values than those with 76 and 114 cm water table positions. Elevated EC and SAR values most likely reflect enhanced evapotranspiration (ET) with the water table close to the soil surface. Groundwater in columns planted to Maritime barley showed no response to water table position

Figure 4. EC of Columns Planted to Wytana saltbush with Various Water Table Positions

Figure 5. SAR of Columns Planted to Wytana saltbush with Various Water Table Positions

Figure 6. EC of Columns Planted to Big saltbush with Various Water Table Positions

Figure 7. SAR of Columns Planted to Big saltbush with Various Water Table Positions

- For columns planted to Wytana saltbush and Big saltbush, the rate of increase of SAR over time was double or triple the rates of increase of EC, while for Maritime barley, the rates of increase of SAR and EC were similar. This probably occured because of preferential uptake of Ca^{2+} by Wytana and Big saltbush, resulting in a larger proportion of Na^{+} in the groundwater solution compared to Maritime barley.

Stage IV: Above Ground Biomass Analysis and Forage Component.

Harvested biomass was dried and weighed to determine total above ground biomass, then analyzed for crude protein content and forage potential. This component of the research spanned the initial untreated baseline harvest and three continuous harvests during the imposed 32-week irrigation period, each conducted based on maturity of maritime barley. Biomass and forage potential from the baseline harvest were compared to post treatment harvest to provide a baseline scale.

Results:

- No plant death over the 32-week period.
- Maritime barley biomass production exceeded that of Big saltbush by 79% and that of Wytana saltbush by 122%. Increasingly shallow water table position led to increased biomass production for both saltbushes, while Maritime barley performed best at the intermediate water table position.

Figure 8. Cumulative Biomass Production with Various Water Table Positions

Table 4. Cumulative Biomass Production

Species	**Cumulative Biomass** (g/column)	**Production** (tons/acre/harvest)
Wytana saltbush	24.6	0.13
Big saltbush	30.5	0.17
Maritime barley	54.5	0.22

- Maritime barley produced the most total crude protein, but its percent total nitrogen content was only 11%, in comparison to 16% total N for Big saltbush and 14% total N for Wytana saltbush. Thus, even though Maritime barley produced far more biomass than the saltbushes, its crude protein concentration was significantly lower.

Table 5. Crude Protein Production

Species	Mean Crude Protein (g/column)	Total N (%)	Production (tons/acres/harvest)
Wytana saltbush	3.68	14	0.10
Big saltbush	4.79	16	0.19
Maritime barley	6.16	11	0.06

Stage V: Determine Selected Species' Abilities to Uptake and Remove Salt from Growth Media

All harvested above ground biomass was analyzed for salt concentrations. Na^{+}, Ca^{2+}, and Mg^{2+} concentrations were computed and cumulative salt uptake was calculated. Analysis was completed by Midwest Laboratories-Omaha, Nebraska.

Results:

- Selected plant species can accumulate salts within their above ground tissues.
- For all species, shallower water table depth led to increased cation uptake.
- Martime barley accumulated approximately half the cations of Wytana saltbush and appproximately a third the cations of Big saltbush.

Figure 9. Cumulative Base Cation Uptake of Selected Species

Summary:

- Continued irrigation with CBM product water will elevate sodicity and salinity of a system lacking drainage.
- Selected plant species are well-adapted to CBM quality water and have the potential for significant biomass production.
- Salt-tolerant species appear to perform best within shallow water tables.
- Although plant bioaccumulation of salts was significant in both saltbush species, halophytes are only a single component of the remediation strategy needed to manage CBM product water.