Rhizosphere Effects on Strontium Uptake in Crested Wheatgrass

J. Chard*, M. Hamilton°, D. Maiers°, and B. Bugbee*

* Utah State University, Logan, UT ° Idaho National Environmental and Engineering Laboratory, Idaho Falls, ID

Abstract

The soil-plant transfer of an element is determined not only by the soil solution concentration of the element, but also by the concentration of competing elements. For example, ammonium (NH_4^+) displaces strontium (Sr) on soil surfaces, leading to an increase in Sr concentration in the soil solution. Fertilization with ammonium should therefore increase plant uptake of Sr. However, ammonium strongly inhibits calcium uptake and therefore should also inhibit Sr uptake as plants do not differentiate between Sr and Ca in nutrient acquisition. While similarities in uptake between Sr and Ca are well documented, the effect of ammonium on plant uptake of Sr is poorly characterized. The literature has focused on displacement of Sr, Cs and other cations from the soil surface and has not addressed the competitive effect of ammonium on plant uptake. We conducted Sr plant uptake studies both in hydroponics and in soil. The uptake rate, distribution, and phytotoxicity of Sr in crested wheatgrass (*Agropyron cristatum*) was determined in hydroponics with treatments of 0, 3, 10, 100, and 1000 µM Sr in two separate trials. For the soil studies, our goal was to quantify the effect of ammonium on Sr uptake in crested wheatgrass. Two soils with similar native Sr content but varying native Ca and Mg contents were fertilized either with nitrate or ammonium. The results of the soil study are compared to the hydroponic study to separate the differential effects of soil chemistry and plant nutrition on plant uptake of Sr.

Materials and Methods

Hydroponic Studies

Experimental Protocol

HYDROPONIC SYSTEMS: Crested wheatgrass plants were grown in a growth room containing **four separate hydroponic systems** connected to **three replicate plots per system** (Fig 1). The systems have automated nutrient solution and acid/base addition to provide steady-state nutrient concentrations, stable pH, and real-time transpiration measurements. The three replicate plots were randomized to minimize effects of light, temperature, and humidity gradients in the growth room. High pressure sodium (HPS) lamps provided a PPF of 1000 mmol m^{-2} s^{-1}

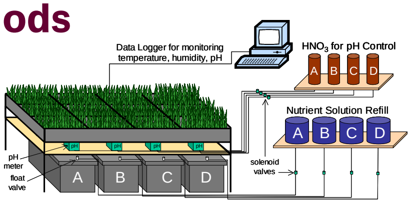

Figure 1. Hydroponics setup. Four separate hydroponics systems with three replicate plots each provided automatic nutrient solution addition and pH control.

TREATMENTS: Two separate trials were conducted with Sr concentrations of **0, 3, 10, 100, and 1000 µM**. All treatments received **1 mM Ca**. The trials ran until the plants headed and flowered (60 and 75 days).

MONITORING: Non-destructive measures of plant growth indicated relative plant growth differences among strontium treatment levels:

- **Transpiration rates**
- **Nitrogen uptake rates**
- **Trends in nutrient solution electrical conductivity**
- **Radiation interception**

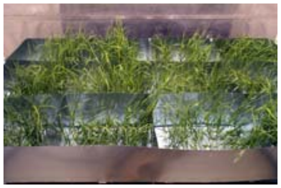

Figure 2. Hydroponic crested wheatgrass.

SAMPLING: Plant tissue samples - composite samples of **root, stem, leaf and head** (when available) - and solution samples were taken **weekly**. **Total biomass** in each of the twelve plots was measured at the end of each trial.

ANALYTICAL: Plant tissue samples were oven dried at 80°C for 24 hours and then ground. Plant and solution samples were analyzed by inductively coupled plasma emission spectrophotometry (**ICP-ES**).

Hydroponic Study Results

Sr UPTAKE: Strontium accumulated in plant tissues at concentrations of up to 5000 mg/kg. Accumulation ratios (Sr in plant:Sr in solution) were greater at lower solution Sr concentrations.

Sr DISTRIBUTION: Strontium acted as a calcium analogue and accumulated in older plant parts with older leaves having the highest Sr concentrations (Figure 3). The Sr:Ca ratio in plant tissues was similar to Sr:Ca in the solutions (Figure 4). Higher Sr:Ca ratios in plant tissue relative to solution indicate that Sr is taken up relatively more rapidly than Ca at lower solution Sr concentrations.

Sr PHYTOTOXICITY: Strontium was not toxic to crested wheatgrass at any of the tested concentrations, as indicated by our measures of plant growth.

Root growth in one of the 12 plots.

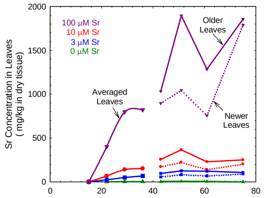

Figure 3. Strontium accumulation in older and newer leaves over time in Trial #2.

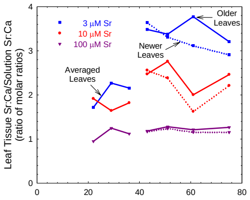

Figure 4. The ratio of Sr:Ca in plant tissue to Sr:Ca in solution.

Soil Studies

Experimental Protocol

SOIL COLUMNS: Soil columns were constructed with PVC pipe (Figure 5). **Two sandy loam soils** with similar native Sr content (~20 mg/kg) were used (Table 1). The "High Ca+Mg" soil had a total Ca + Mg concentration that was ~50% higher than the "Low Ca+Mg" Soil. Each of the two soils was **mixed with sand** (50/50, v/v) to improve drainage, and 12 columns were filled with each of the two soil/sand mixtures. Half of the columns were planted with crested wheatgrass.

Figure 5. Crested wheatgrass growing in soil columns.

Table 1. Mineral nutrient content (mg/kg) of two experimental soils. Values are shown for both total and plant-available P and K.

	Ca	Mg	Sr	P (total)	K (total)	P (avail.)	K (avail.)
High Ca+Mg Soil	15180	4028	19	619.5	958.0	55	> 400
Low Ca+Mg Soil	10050	2048	22	1239	1680	98	> 400

PLANT GROWTH CONDITIONS: Soil columns were kept in a climate-controlled (25 day/20°C night) **greenhouse**. Supplemental lighting provided a PPF of 300 µmol m^{-2} s^{-1} during a **16-hour photoperiod**.

TREATMENTS: Four treatments were applied per soil type, for a total of eight treatments. Each treatment was replicated 3 times, for a total of 24 columns. For each soil the four treatments were:

- **planted - watered with ammonium [1 mM $(NH_4)_2SO_4$] and nitrate-N**
- **planted - watered with nitrate-N only**
- **unplanted - watered with ammonium [1 mM $(NH_4)_2SO_4$] and nitrate-N**
- **unplanted - watered with nitrate-N only**

Nitrapyrin (N-Serve®, Dow Agrosciences) was used to inhibit nitrification in columns receiving ammonium. Planted columns were watered daily. Unplanted columns were watered as needed to maintain a soil moisture content similar to that of the planted columns.

SAMPLING: Columns were leached periodically with excess solution and **leachates** were collected. Leachates were analyzed for **ammonium, strontium, calcium and magnesium content**. Leachate pH and electrical conductivity (EC) were also monitored and remained stable throughout the study. Samples of **plant tissue** were periodically collected from random locations on each plant and analyzed for strontium content.

ANALYTICAL: Plant tissue samples were oven dried at 80°C for 24 hours and then ground. The Sr, Ca and Mg contents of plant extracts and leachate samples were determined by **ICP-ES**. Leachate pH and EC were measured directly using a pH electrode and EC meter. Leachate NH_4^+ concentrations were determined by **colorimetery**.

Soil Study Results

INFLUENCE OF SOIL Ca and Mg: There was no significant difference in plant tissue (Figure 6) and leachate strontium concentration (Figure 7) between the two soils.

INFLUENCE OF AMMONIUM: Although the pH of leachate solutions was consistently high (8.0 ± 0.5), the plants took up ammonium (Figure 8), which decreases rhizosphere pH. At the high pH values of these soils Sr is present as $SrCO_3$. Strontium carbonate would be solubilized in the acid rhizosphere, as is indicated by increased leaching of Sr from planted treatments (Figure 7). Sr was likely leached from the column before it could re-precipitate as $SrCO_3$. Increased leaching of Ca and Mg in these treatments (data not shown) further support this hypothesis.

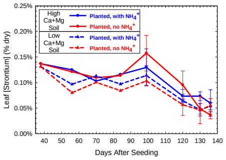

Figure 6. Leaf strontium concentrations over time.

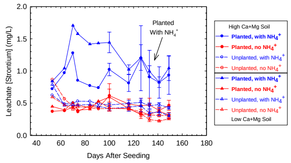

Figure 7. Leachate strontium concentrations over time.

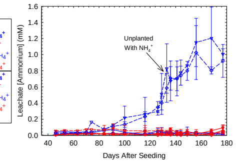

Figure 8. Leachate ammonium concentrations over time.

Conclusions

- Crested wheatgrass plants do not discriminate between uptake of Sr and Ca.
- NH_4^+ increased solubility of Sr in the rhizosphere, but Sr uptake was not increased because the ammonium acted as a competing cation for plant uptake of Sr.
- The addition of ammonium fertilizer to planted fields may result in leaching of strontium and radiostrontium down the soil profile.