Potential Use of Plants for Selenium Reclamation

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Abstract. Seleniferous soils and groundwaters have been identified in many parts of the Western US. Because studies in the late 1980's indicated that excessive selenium (Se) can bioaccumulate to toxic levels in waterfowl and insect biota, ponds used for temporarily storing agricultural drainage effluent produced from Se-laden soils are potentially toxic sites for the biological ecosystem. The purpose of our multi-year field studies was to utilize plants and sometimes trees to manage Se content in waters, soils, and in drainage sediment by plant extraction and biological volatilization of Se. Field plots (ranging from 0.5 to 40 ha in size) were located in Western San Joaquin Valley of Central California. All sites had either Se-laden soils and/or waters with levels of soluble Se that ranging from 0.13 to 0.50 mg L^{-1} that were considered excessive concentrations. Because high levels of salts (6-10 dS m^{-1}) and boron (5-10 mg L^{-1}) are simultaneously present with Se in soils from the Westside of central California, selected boron (B) and salt tolerant plant species were identified and either planted in the Se-laden soil/sediment and/or used as recipients for the disposal of Se-laden water. For each study, soils were monitored for changes in extractable Se throughout the soil profile and plants were evaluated for the accumulation and volatilization of Se. Our results show that although high levels of soluble sulfate reduced plant accumulation of Se (< 12 mg L^{-1} DM), volatilization of Se occurred as high as 100 µg m^{-2} day^{-1} on a daily basis with canola. Both processes resulted in lower soluble Se in the soil. Canola, salado grass, and poplar trees can be used as biological tools for slowly managing soluble Se in soils and waters, however, monitoring the downward movement of soluble Se is recommended.

Additional Key Words: Phytoremediation

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Introduction

Seleniferous soils have been identified in many parts of the Western US. Interactions between irrigated agricultural practices and physical and chemical processes have led to the mobilization of soluble salts, including selenium (Se), in drainage discharges. Deleterious effects on birds and fish were documented on biological systems inhabiting or frequenting drainage ponds containing Se-laden agricultural drainage water. Excessive bioaccumulation of Se was clearly linked to a high mortality and reproductive failure (Ohlendorf et al., 1986). As a result, growers in the San Joaquin Valley of central California were in need of alternative practices to reduce their production of Se-laden effluent and/or reduce loads of Se from entering the effluent. A plant-based technology, defined as "phytoremediation", has received increasing recognition as a low-cost, environmentally-friendly approach for reducing selenium's entry into shallow groundwaters and/or drainage waters. The phytoremediation technology implies the use of plants in conjunction with microbial activity to extract, accumulate, and volatilize Se (Bañuelos et al., 2002; Losi and Frankenberger, 1997; Zayed et al., 2000). Any one or a combination of these biological responses may eventually lead to lower concentrations of soluble Se in the soil and thus lower amounts of Se entering the effluent. Hence, we evaluated a variety of plants and trees for their ability to lower soluble Se levels in different field conditions and thereby sustain agricultural production in the San Joaquin Valley in Central California.

Materials and Methods

Field studies were conducted with plants and trees from 1993-2003 at different field locations in central California known to have high Se concentrations in their soils (See Fig. 1). Some of the plant species planted include: canola (*Brassica napus*), broccoli (*Brassica oleracea*), saltbush (*Atriplex nummularia*), creeping saltbush (*Atriplex semibaccata*), Alkali sacaton (*Sporobolus airoides*), tall fescue (*Festuca arundinacae*), Paulownia trees (*Paulownia elongata*), and poplar trees (*Populus deltoidus*). Generally the field soils had a sodium sulfate-dominated salinity between 6-10 dS m^{-1} (electrical conductivity), pH of 7.9, and concentrations of water extractable Se (0.13-0.50 mg L^{-1}) and B (5-10 mg L^{-1}). Plants and trees were planted at various sites, and plots ranged from 0.5 to 40 ha in size. Normal agronomic and irrigation practices were followed by the respective grower at each site. Annual crops were harvested after flowering, and perennial crops were clipped periodically and allowed to continue growing. Soil samples were collected to a depth of 2 m (where possible) at least twice a year, and water samples (from shallow groundwater) were collected from access tubes installed to a depth of 3 m at each field site. Water-soluble Se and B, and EC were determined in a soil water extract of 1:1. Volatilization of Se was also measured at limited sites, where electricity was available. Plexiglas chambers (0.7x0.7x0.7 m) were placed over plants and volatile Se was trapped in a series of alkaline peroxide trapping solution and analyzed for Se after oxidation and reduction, (Zayed et al., 2000). Harvested plant material, soil and water samples were all acid digested with HNO3/H2O2/HCl as described by Banuelos and Akohoue (1994); and Se and B was analyzed by an atomic absorption spectrophotometer with an automatic vapor accessory and inductively coupled plasma spectrometer, respectively.

Results and Discussion

Visual observation indicated salt and boron (B) toxicity symptoms on plants and trees, especially on Paulownia trees, canola, broccoli that were grown at sites with high salinity (>8 dS m^{-1}) and high soluble B (>10 mg L^{-1}) levels; high salinity and B levels are often found in conjunction with Se (Parker et al., 1991). Dry matter yields decreased with increasing levels of salinity, which was probably due to the high accumulation of chloride ions. Selenium concentrations were greatest in both Brassica species (7-12 mg kg^{-1}), and ranged between 1-4 mg kg^{-1} for clippings from the perennial crops (Table 1). A sodium sulfate dominated salinity was likely responsible for the overall low plant tissue concentrations of Se. For those plants where volatilization of Se was measured, rates were greatest with canola and broccoli (as high as 102 µg Se m^{-2} day^{-1}) during the summer, but generally ranged from 13-35 µg Se $m^{-2}day^{-1}$ for the other plant species (Table 1). Extractable concentrations of Se were lower at final harvest in all vegetated soils, especially those planted to canola and broccoli. Good water management practices are important for minimizing leaching of extractable Se to deeper depths within the soil profile.

Conclusion

Large-scale assessment of Se removed from the soil via plant accumulation and volatilization is difficult to accurately quantify under field conditions, due to fluctuating groundwaters that often contain high concentrations of Se. Moreover, it is important to note that changes in soil Se concentrations are also occurring due to dynamic chemical transformations (e.g., reduction, volatilization) occurring within the soil profile. Effective management of soluble Se with plants/trees requires an integrated approach, which must consider crop selection, crop rotation, irrigation and drainage management, chemical transformations, pest management, harvest techniques, product utilization, economics, and public acceptance. Most importantly, using plants for Se reclamation will require time and a long-term commitment.

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Table 1. Selenium concentrations in the soil at preplant and postharvest (0-100 cm), in leaf tissue of and as different plant species, volatile Se from different field sites in the west side of central California†.

Plant Species	Extractable soil Se at: Preplant	Postharvest	Leaf Se	Volatile Se
	--------------mg L^{-1}	-------------	mg kg^{-1}	µg m^{-2} day^{-1}
Canola	0.34	0.09	12	25-102
Broccoli	0.23	0.05	7	30-65
Tall fescue	0.17	0.09	2	13-24
Saltbush	0.5	0.38	3	20-31
Creeping saltbush	0.41	0.32	3	23-35
Alkali sacaton	0.49	0.33	4	18-29
Paulownia trees	0.13	0.02	3	NA‡
Poplar trees	0.38	0.23	1	NA‡

†Mean values are presented from all soil and plant samples collected at different field sites.
‡NA- Not applicable; trees were too tall for volatilization chamber.

Fig. 1 Experimental field sites in the west side of the San Joaquin Valley in Central California