Plants that remove selenium from soils

Researcher Gary Bañuelos evaluates blooming and seeding of wild mustard, one of the potential "selenium-accumulator" plants tested in greenhouse studies.

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Initial results from greenhouse experiments suggest that some plants are able to lower selenium concentrations in soils by up to 50%. Use of these plant species to reduce concentrations to acceptable levels in problem soils on the west side of the San Joaquin Valley may be economically feasible.

Selenium occurs naturally in both insoluble and soluble forms in the soil on the west side of California's San Joaquin Valley. Over 90% of the selenium in the soil is bound chemically in a sparingly soluble form. The region's selenium problem in agricultural drainage waters, however, is caused by the remaining soluble fraction that can be leached from the soil and into subsurface drains. Recent research indicates that it is the combination of dissolution from selenium-containing soils and the volume of water passing through the soils that results in the relatively high selenium concentrations in drainage water.

Improved irrigation management and other remedial actions are being investigated by University of California researchers and state and federal agencies. Another potential technique is to lower the soil-selenium level by growing crops that take up large amounts of selenium through their root systems. The U.S. Department of Agriculture-Agricultural Research Service Water Management Research Laboratory in Fresno, California, is selecting selenium-tolerant plants that might be grown as crops to remove soluble selenium from the soil. We are also studying the uptake of selenium in vegetables that naturally accumulate high levels of sulfur, since selenium and sulfur are chemically similar.

Selenium (Se) can occur in four oxidation states, each with distinct chemical properties: selenate (SeO_4^{-2}); selenite (SeO_3^{-2}); elemental selenium (SeO); and selenide (Se^{-2}). Selenate and selenite are the dominant forms (species) of selenium in most soils and waters; elemental selenium and selenide are found in only small concentrations. Of the two dominant forms, selenate salts are more mobile in the soil than selenite salts. The mobility of selenium depends on many soil properties including pH, oxidation potential, organic carbon, calcium carbonate, and cation exchange capacity. Because elemental selenium is relatively unstable, it can be reduced to selenide forms or oxidized to selenite forms. Selenide can occur in solid, aqueous, and gaseous forms. Fungi, bacteria, and other soil microorganisms can convert selenate and selenite into selenide gas. This volatilization process, called "microbial catalyzed reduction," is a natural means by which high levels of selenium are removed from the soil.

Some plants are also able to volatilize selenium. This unique physiological characteristic may enable plants to prevent selenium from poisoning plant cells by disrupting biochemical reactions and specific enzyme functions. Many plants that accumulate selenium can probably volatilize selenium as well as sequestering it within the plant by binding it with free amino acids, the precursors to proteins. This occlusion mechanism prevents selenium from disturbing amino acids for protein synthesis in the plant. Consequently, selenium-accumulators can tolerate high selenium concentrations.

Plants can be divided into three groups according to their ability to accumulate selenium (based on work by I. Rosenfeld and O. A. Beath at the University of Wyoming). Group I plants, which accumulate very high levels (1,000 to 10,000 parts per million [ppm]), include milkvetch (*Astragalus*), woody aster (*Machaeranthera*), mustard (*Brassica*), and prince's plume (*Stanleya*). Group II plants—secondary selenium absorbers—rarely contain more than a few hundred parts per million. They belong to

TABLE 1. Effect of plant species on the removal of selenium from soil treated with selenite or selenate before planting

Plant & group	Selenite			Selenate		
	Se in: Soil	Se in: Plant	Relative amount of Se not in soil or plant	Se in: Soil	Se in: Plant	Relative amount of Se not in soil or plant
	μg Se/pot		%	*μg Se/pot*		%
Group I:						
Milkvetch	2,850	75	16	1,750	880	25
Black mustard	3,050	85	10	2,100	890	15
Wild mustard	3,000	400	3	800	2,500	6
Group II:						
Australian saltbush	2,950	85	13	1,650	1,640	6
Saltbush	3,199	70	9	1,800	875	24
Group III:						
Fescue grass	3,050	60	11	2,300	580	18

NOTE: Soil (1 kg in plastic pots) treated with 3,500 μg selenium as selenate or selenite in solution added before planting. Selenium in soil and plant tissue measured after harvest.

a number of genera, including aster (*Aster*), saltbush (*Atriplex*), paint-brush (*Castilleja*), gum-plant (*Grindelia*), and matchweed (*Gutierrezia*). Plants in group III include many grains and grasses that normally do not accumulate selenium to levels above 50 parts per billion (ppb), even when grown in selenium-laden soils.

Our plant selection study was based on the theory that plants containing high levels of sulfur, such as cabbage, might also accumulate selenium if the selenium/sulfur ratio in the root medium were increased. It is thought that mechanisms responsible for ion uptake in the roots do not distinguish thoroughly between the chemically similar ions of selenate and sulfate. Plants like cabbage growing in a high-selenium soil may thus take up a greater quantity of selenium than do other types of plants.

Greenhouse study

We selected examples of plant species from the three selenium-accumulator groups (table 1) and sulfur-accumulating vegetables (table 2) for greenhouse trials during the early summer of 1988. Our purpose was to determine the uptake of selenium from soils containing selenate and selenite. All plants were grown in plastic pots containing 1 kg (2.2 pounds) of dry soil. No measurable amount of soluble selenium was present originally in the soil. A total of 3,500 micrograms (μg) of selenium, either as selenate (Na_2SeO_4) or selenite (Na_2SeO_3) in solution was added directly in the 1 kg of soil before growing the plants listed in table 1. In the experiments with the sulfur-accumulating vegetables, 5 milligrams selenium of either selenium compound was dissolved in water and added to the soil. All plants were watered daily; any leachate was reapplied in the irrigation water the following day.

Tested plants in groups I and II were more effective in removing from the soil the selenium from selenate than that from selenite (table 1). Results with both selenate and selenite show that inexplicable losses of selenium occurred in either the soil environment or the tissue of all plants tested. Insignificant amounts of selenium were measured in the roots. Additional studies are needed to determine if any portion of the unrecovered selenium in the soil or plants may have been volatilized by soil-microbial activity or by the selenium-accumulator plants themselves.

In the sulfur-accumulating vegetables, the total selenium concentration near the end of the vegetative growth stage was much higher in the selenate-irrigated plants than in the selenite-irrigated plants (table 2). Selenium accumulated to relatively high concentrations in leafy plants. The accumulated selenium in the broccoli floret was the highest concentration measured in the experiment.

Conclusions

The results show that selenium accumulators, most notably wild mustard, take up selenium in the selenate form more readily than in the selenite form. The high concentrations found in vegetables tested, namely the edible floret of broccoli, suggest that a substantial amount of selenium was substituted for sulfur as selenium-methionine or selenium-cysteine in protein complexes. These plants, however, did not show symptoms of selenium toxicity.

Despite the high concentrations of selenium in the vegetables in this study, it is important to recognize that plants were grown under controlled conditions. Interrelated factors present under field conditions, such as sulfate levels in soil, and their mutual interactions were absent. Data from field samples of the crucifer species reported by R. G. Burau at UC Davis, suggest that exaggerated levels of selenium have not yet accumulated in the vegetables planted in the San Joaquin Valley. Growing selected selenium accumulator plants under greenhouse conditions led to considerably lower concentrations in soil-added selenium. Interestingly, the amount of selenium measured in the above-ground plant tissue resulting from plant uptake did not correspond to the losses from the selenium-spiked soil.

If we were to assume that our greenhouse results prevailed in the field, accumulator plants could be evaluated as hypothetical crops to remove selenium from the soil. At 100,000 wild mustard plants per acre with a dry weight per plant averaging 8 grams, 800 kilograms (1,750 pounds) of hay would be produced at each harvest. In our study, the typical selenium content was over 350 milligrams per kilogram of dry plant material, or 280 grams (0.5 pound) of selenium per acre. With five harvests, a total of 2.5 pounds of selenium would be removed in the hay. Results also indicated that about 0.25 pound of selenium was presumably volatilized by the time of each harvest, by either soil microorganisms or the mustard plants. Thus, more than 3.5 pounds of selenium could be removed from the soil if the rate of selenium uptake in the greenhouse were sustained in the field.

We assessed the economics of growing the hypothetical wild mustard crop compared with treatment of the drainage water to remove selenium. Treatment costs at least $300 per acre-foot of subsurface drainage water. Drainwater containing 300 ppb of selenium, such as water in the San Luis Drain during 1982-84, would contain 0.8 pound of selenium per acre-foot. Thus, to remove 3.5 pounds of selenium, the cost of treatment would be $1,312 (3.5 lb. Se/0.8 lb. per ac.-ft. water x $300/ac.-ft.). The value of harvesting wild mustard five times would thus be $1,312 (minus the costs of producing the crop).

Even if some of the assumptions regarding removal of selenium from the soil by growing accumulator crops are optimistic, the analysis suggests that the approach warrants consideration. In addition, soils with high selenium levels often have high salt and boron content. This coexistence of salts, which may influence the growth of selenium-accumulator plants, is currently under investigation. The outcome of this research on plant selection should provide more information on whether selenium-accumulator plants can be economically used to remove selenium from soils on the west side of the San Joaquin Valley.

TABLE 2. Total selenium concentrations in the tissue of vegetables

Vegetable species	Plant part	Total Se concentration* Selenite	Selenate
		mg/kg dry weight	
Swiss chard			
(*Beta vulgaris*	Mid-rib	30	115
var. *cicla*)	Leaf	12	750
Collards			
(*Brassica oleracea*	Mid-rib	23	350
var. *acephala*)	Leaf	38	235
Cabbage			
(*Brassica oleracea*	Old leaves	38	260
var. *capitata*)	Young leaves	65	450
Broccoli			
(*Brassica oleracea*	Floret	200	1,200
var. *botrytis*)	Leaves	50	370

* Vegetables irrigated with water containing selenite or selenate to raise the concentration of Se to 5 mg/kg soil.

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