Plant and Soil 121, 151–153 (1990).

PLSO 7969

The effect of selenium on sulfur uptake by barley and rice

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Received 15 September 1988. Revised July 1989

Key words: *Hordeum vulgare* L., *Oryza sativa* L., selenate, solution culture, sulfate, synergism

Abstract

Because of their chemical and physical similarities, plant uptake of S and Se are closely related. Barley (*Hordeum vulgare* L.) and rice (*Oryza sativa* L.) were grown in greenhouse solution culture to examine the synergistic interactions between SO_4 and Se^{6+} in plant uptake. In the presence of low concentrations of solution SO_4, shoot and root yields were decreased with additions of Se^{6+}. However, when SO_4 was present in elevated concentrations, no Se-induced yield reduction occurred. A synergistic interaction between SO_4 and Se^{6+} caused an increase in the shoot S concentrations with increasing concentrations of Se^{6+} at low SO_4 solution concentrations. At elevated SO_4 concentrations, no synergism was osberved. Selenium had a lesser effect on the S concentration in plant roots.

Introduction

Selenium accumulation by crops has been the focus of research for over 50 years, particularly as it relates to human and animal health. Although not required by plants, Se is required in very low concentrations for balanced human and animal nutrition. When out of balance, Se can cause health problems due to toxicity or deficiency.

The uptake of Se by plants (and subsequently into the food chain) is governed by many soil factors including the presence of ions such as SO_4 and PO_4 (Mikkelsen *et al.*, 1989). The antagonistic interaction between SO_4 and Se^{6+} for plant uptake has long been noted by researchers (Gissel-Nielsen, 1973; Hurd-Karrer, 1938; Wan *et al.*, 1988). The presence of abundant SO_4 in the root zone typically reduces the Se concentration in plants. This reduction in Se concentration can result from antagonistic interactions between Se^{6+} and SO_4 for plant uptake or in the case where S is added to S-deficient soils, may simply reflect a dilution of plant Se due to increased plant growth (Mikkelsen *et al.*, 1989).

In contrast to the antagonistic interaction between Se^{6+} and SO_4 a synergistic relationship has also been recently reported (Mikkelsen *et al.*, 1988a, b; Smith and Watkinson, 1984). It has been observed that elevated concentrations of Se in the root zone may increase plant S accumulation when SO_4 concentrations are low in the root zone. This greenhouse solution culture study was conducted to examine the nature of this synergistic relationship between SO_4 and Se^{6+} with two agricultural crops over a range of SO_4 and Se^{6+} concentrations.

Methods

Barley (*Hordeum vulgare* L. Briggs) and rice (*Oryza sativa* L. M101) seeds were planted into washed sand. Ten days after emergence, two rice or barley seedlings were transplanted into 11-L plastic solution culture reservoirs. Each reservoir held 10 L of basal nutrients containing 10 m*M* $Ca(NO_3)_2$, 12 m*M* KNO_3, 4 m*M* $Mg(NO_3)_2$, 1 m*M* KH_2PO_4, 5.0 mg Fe L^{-1}

(EDDHA), 0.5 mg B L^{-1}, 0.5 mg Mn L^{-1}, 0.05 mg Zn L^{-1}, 0.02 mg Cu L^{-1}, and 0.01 mg Mo L^{-1}. Treatment solutions were replaced twice each week to prevent excessive nutrient depletion. The reservoirs were aerated by continually bubbling air through the solutions.

For the barley solution cultures, a 4 × 5 factorial experiment was imposed in three replications in a randomized complete block design. The nutrient solutions were treated with Na_2SeO_4 to obtain concentrations of 0, 0.1, 0.5, or 1.0 mg Se^{6+} L^{-1}. Sulfate was added as equal amounts of Na_2SO_4 and $CaSO_4 \cdot H_2O$ to achieve concentrations of 3, 33, 167, 333, or 1000 mg SO_4-S L^{-1}. Plants were harvested 28 days after transplanting, washed, and divided into shoots and roots. Plant yields were measured after drying at 50 °C prior to grinding and chemical analysis.

For the rice solution cultures, a 3 × 4 factorial experiment was initiated with 0, 0.05, or 0.5 mg Se^{6+} L^{-1} in combination with 16, 32, 64, or 96 mg SO_4-S L^{-1}. The experimental design, nutrients, and reagents were identical to those used for the barley. Rice plants were harvested 60 days after transplanting.

Plant tissue was digested with HNO_3 and $HClO_4$ and then analyzed for Se with an atomic absorption spectrophotometer equipped with a hydride generator (Logan *et al.*, 1987). Sulfur was analyzed in the acid digest with inductively coupled plasma spectroscopy.

Results and discussion

Shoot yields of both barley and rice were adversely affected by Se (Table 1) although this occured mainly at the lowest SO_4 concentration in the treatment solution (Table 2 and 3). When SO_4 was present at elevated concentrations, no Se-induced yield suppression was observed. For example, in the 0.5 mg Se^{6+} L^{-1} treatment with barley, plant shoot dry matter was only 0.5 g when supplied with 3 mg SO_4-S L^{-1}, but suffered no yield reduction (3.4 g) when supplied with 33 mg SO_4-S L^{-1}. Shoot yields of barley were greater with increased concentrations of SO_4 except for the 1000 mg SO_4-S L^{-1} treatment. The lower yield observed for this treatment is likely due to the excess salinity caused by the high levels of added SO_4 (electrical conductivity of the 1000 mg SO_4-S L^{-1} treatment = 5.5 dS m^{-1}). Root yields followed a similar pattern as the shoots, demonstrating that the presence of abundant SO_4 can ameliorate the phytotoxic effects of excessive Se.

Plant Se concentrations generally increased with Se additions to the treatment solution but

Table 1. Analysis of variance for the effect of selenium (Se) and sulfur (S) on the tissue composition and growth of rice and barley. Significance levels *, **, NS[a]

Source	Se concentration		S concentration		Yield	
	Shoot	Root	Shoot	Root	Shoot	Root
Rice						
Se	**	**	**	**	*	**
S	**	**	*	**	NS	NS
Se*S	**	**	*	**	NS	NS
Barley						
Se	**	**	**	NS	*	NS
S	**	**	**	**	**	**
Se*S	**	**	**	*	NS	NS

[a] *, ** indicate significance at the 0.05 and 0.01 levels, respectively. NS = not significant.

Table 2. The effect of Se^{6+} and SO_4-S on barley tissue composition and yield

Treatment (mg L^{-1})		Plant Se (mg kg^{-1})		Plant S (mg g^{-1})		Yield (g)	
Se	SO_4-S	Shoots	Roots	Shoots	Roots	Shoots	Roots
0	3	0.06	0.11	3.4	3.1	3.7	1.3
	33	0.05	0.08	3.5	3.5	3.6	1.3
	167	0.08	0.06	3.9	4.4	4.5	1.6
	333	0.05	0.05	4.0	5.4	4.8	1.6
	1000	0.04	0.03	5.8	7.4	3.4	1.3
0.1	3	61.8	54.2	6.7	3.1	2.3	1.0
	33	10.1	9.6	3.8	3.5	3.5	1.5
	167	1.2	5.2	3.7	4.5	3.9	1.3
	333	0.9	4.4	4.1	4.8	4.3	1.4
	1000	0.4	1.7	5.1	7.7	3.3	1.2
0.5	3	1357.2	602.6	17.6	3.5	0.5	0.3
	33	61.0	51.0	6.9	3.8	3.4	1.3
	167	11.7	20.9	3.9	4.8	3.7	1.4
	333	4.4	12.1	4.5	4.9	4.7	1.7
	1000	3.5	5.0	6.2	6.5	3.2	1.0
1.0	3	XX	XX	XX	XX	XX	XX
	33	186.9	182.6	8.7	4.6	3.9	1.4
	167	36.5	38.1	5.0	4.7	3.8	1.4
	333	23.1	23.7	4.5	4.8	3.9	1.5
	1000	3.9	9.8	5.9	7.9	3.1	0.9

XX = plants died.

Table 3. The effect of Se^{6+} and SO_4-S on rice tissue composition and yield

Treatment ($mg\,L^{-1}$)		Plant Se ($mg\,kg^{-1}$)		Plant S ($mg\,g^{-1}$)		Yield (g)	
Se	SO_4-S	Shoots	Roots	Shoots	Roots	Shoots	Roots
0	16	0.09	0.06	3.1	2.9	20.4	4.8
	32	0.10	0.09	3.3	3.6	18.6	3.9
	64	0.08	0.05	3.1	4.1	18.0	3.3
	96	0.07	0.07	3.7	4.4	18.1	3.9
0.05	16	25.1	22.8	3.7	2.8	19.7	4.5
	3	13.2	18.4	3.4	3.1	21.9	4.9
	64	10.0	14.4	3.4	3.6	19.7	4.6
	96	7.9	12.6	3.6	5.2	27.7	6.3
0.50	16	405.5	268.4	4.6	2.3	9.1	2.3
	32	205.8	193.6	3.9	3.0	11.6	2.6
	64	105.5	122.4	3.5	3.5	17.5	4.2
	96	94.0	106.8	3.9	3.9	16.0	3.7

decreased with SO_4 additions (Tables 2 and 3). Even at the lower range of SO_4 additions to the treatment solutions used with the rice, shoot Se concentrations were reduced almost by half (from 405 $mg\,kg^{-1}$ to 205 $mg\,kg^{-1}$) when the SO_4-S concentration was doubled from 16 $mg\,L^{-1}$ to 32 $mg\,L^{-1}$ treatment at a Se^{6+} concentration of 0.5 $mg\,Se^{6+}\,L^{-1}$.

Selenium concentrations were generally comparable in the root and shoot portions of the plant except when high concentrations of Se were accumulated. When this occurred, Se concentrations were greater in the shoot portion than in the root of the plant.

There was a significant increase in the shoot S concentration for barley and rice with increasing

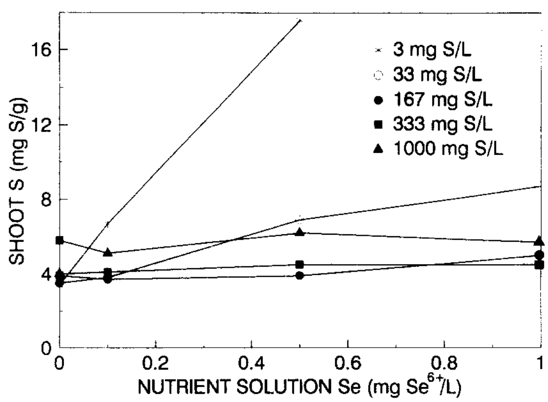

Fig. 1. The effect of Se concentration in the nutrient solution on S accumulation by barley shoots at 5 levels of substrate SO_4-S.

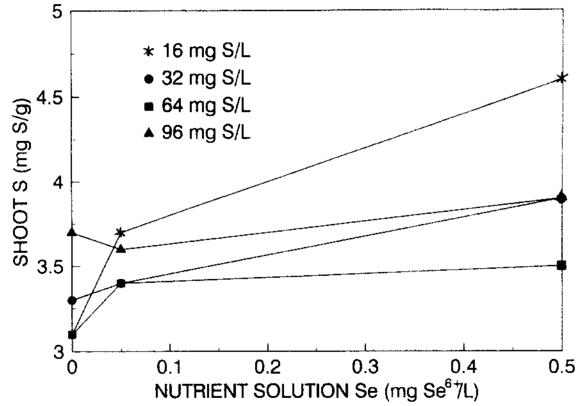

Fig. 2. The effect of Se concentration in the nutrient solution on S accumulation by rice shoots at 4 levels of substrate SO_4-S.

concentrations of solution Se (Table 1). However, this response was mainly found when SO_4 was present at low concentrations in the treatment solution (Figs. 1 and 2). When SO_4 concentrations were elevated in the treatment solution, this synergistic response was not observed. Sulfur in the root accumulated in proportion to the SO_4 concentration in the treatment solution, with less interaction with Se (Tables 1–3).

This study confirms that the synergistic interaction between Se^{6+} and SO_4 occurs in a variety of plant species at low concentrations of substrate SO_4. Additional research is required to determine the specific effect of increased concentrations of Se^{6+} on SO_4 uptake by plants. This observed synergism may involve interactions at the root uptake sites as well as transport processes within the plant, or it may be a simple concentration effect (Jarrell and Beverly, 1981). Detailed studies will be required before a complete explanation of this phenomenon can be given.

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