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Several conclusions can be derived from the data presented. Small feedlots and even pastured cattle can contribute distillable N to the atmosphere. Also, these data show noteworthy quantities of N-containing compounds other than NH_3 were released from a feedlot to the air. Feedlot disturbances, such as mounding, greatly increased the release of distillable N to the atmosphere. Also, precipitation seemed to be followed by increased distillable-N release.

While the cattle areas tested were much smaller than the units checked by Hutchinson and Viets (7), significant quantities of nitrogen could be detected in the atmosphere around these cattle areas. The nitrogen values shown here for the feedlot area agreed closely with those reported by Hutchinson and Viets (7). However, in this case, the traps were much closer to the sampling area.

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DIVISION S-4—SOIL FERTILITY AND PLANT NUTRITION

Effects of Chromium on Growth and Mineral Nutrition of Soybeans[1]

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ABSTRACT

Chromium additions [0–5 ppm Cr(VI)] to soybeans, *Glycine max* (L) Merrill, grown in nutrient culture resulted in decreased concentrations and total uptake of Ca, K, P, Fe, and Mn in tops and of K, Mg, P, Fe, and Mn in roots. These effects were often apparent at Cr treatments as low as 0.5 ppm.

In soil culture Cr additions [0–60 ppm Cr(VI)] appeared to interfere with the accumulation of Ca, K, Mg, P, B, and Cu by soybean tops, with little or no effect on Fe, Mn, or Zn uptake. These effects were generally first observed at the 5-ppm Cr treatment.

The initial symptoms of Cr toxicity appeared as severe wilting of tops of treated plants.

It could not be concluded from the results of these experiments that Cr, as the hexavalent anion, specifically interfered with uptake of Fe or P by plants, as earlier reported.

Additional Key Words for Indexing: nutrient culture, soil culture, hexavalent chromium, toxicity.

RECENT interest in the element Cr stems from the elucidation of its role in human health (13) along with the finding that decline in Cr levels in human tissues is probably the result of reduced dietary intake (11).

Reports on the role of Cr in plant growth suggest that while low rates of addition may prove stimulatory (1, 4, 5, 18), higher rates generally tend to be toxic (5, 9, 10, 12, 14).

The stimulatory effect of Cr on plant growth has been interpreted as limited substitution of chromate for molybdate (18), while inhibitory effects are thought to be the result of specific interaction between Cr and P (12, 14, 15, 16) or Fe (2, 3, 6, 7, 17) in plant nutrition.

The objective of the present report was to investigate the effects of a range of Cr treatments on the growth and mineral uptake by two soybean [*Glycine max* (L.) Merr.] varieties in both nutrient and soil culture.

NUTRIENT CULTURE STUDIES

Experimental Methods

Seeds of 'Chippewa-64' and 'Norsoy' variety soybeans were germinated by positioning along the top of moistened paper towels, which were then rolled into tubes and placed into plastic bags. Sufficient distilled water was added to the bags to maintain a saturated water atmosphere throughout the germi-

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Table 1—Yield and elemental concentration in Norsoy soybean tops and roots with increasing amounts of Cr added to nutrient solution

Cr treatment	Yield	Elemental concentration*									
		Macronutrients					Micronutrients				
		Ca	K	Mg	Na	P	Fe	Mn	Zn	B	Cu
ppm	g	%					ppm				
					Tops						
0	0.597 a†	1.06 a	3.78 ab	0.38 a	0.03 a	0.98 a	141 b	38 a	36 a	39 a	8 b
0.05	0.625 a	1.13 a	4.10 a	0.41 a	0.01 a	1.06 a	186 a	43 a	47 a	37 a	8 b
0.10	0.634 ab	0.98 a	3.66 ab	0.37 a	0.03 a	0.94 a	127 b	39 a	46 a	37 a	6 c
0.50	0.493 bc	0.78 b	3.13 b	0.37 a	nd‡	0.73 b	71 c	26 b	41 a	34 a	6 c
1.00	0.469 c	0.79 b	3.19 b	0.35 a	nd	0.69 bc	83 c	29 b	39 a	34 a	7 c
5.00	0.291 d	0.54 c	2.39 c	0.21 b	0.03 a	0.51 c	88 c	11 c	55 a	28 b	10 a
					Roots						
0	0.169 a	0.40 a	6.61 a	0.43 ab	0.15 b	1.71 a	1,278 b	56 b	55 a	26 a	16 a
0.05	0.171 a	0.40 a	6.06 a	0.49 a	0.14 b	1.93 a	2,081 a	91 a	50 a	29 a	23 a
0.10	0.159 a	0.39 a	6.43 a	0.37 ab	0.13 b	1.80 a	1,625 ab	62 b	66 a	28 a	15 a
0.50	0.159 a	0.39 a	4.19 b	0.36 ab	0.15 b	1.18 b	476 c	24 c	36 a	23 a	15 a
1.00	0.148 b	0.36 a	4.23 b	0.34 b	0.14 b	1.27 b	521 c	36 c	43 a	24 a	14 a
5.00	0.107 c	0.48 a	3.32 b	0.22 c	0.30 a	0.94 b	381 c	nd	41 a	32 a	20 a

* Results are averages of 3 replicates.
† Values not followed by the same letter within a column are significantly different at P = .05.
‡ nd = nondetectable.

nation period, and the bags were closed with rubber binders. These germination "kits" were placed upright in a darkened cabinet at 25C for 4–5 days.

After germination, seedlings were transferred to 2-liter plastic beakers covered with aluminum foil to exclude light and containing half-strength Hoagland's nutrient solution no. 2 (8) adjusted to pH 6.0. In all experiments Fe was added as the chelate Fe DTPA (Sequestrene 330, Geigy Agricultural Chemicals)[3] to produce a final concentration of 20 ppm Fe in the full-strength nutrient solution.

The nutrient culture containers were aerated with filtered compressed air flowing through capillary-size glass tubing. The water level was periodically adjusted throughout the experiment to compensate for losses due to evapotranspiration.

The experiment was conducted in a climate-controlled growth chamber with a 16-hour light, and 8-hour dark period. The air temperature was approximately 27C during the light period and 15C during the dark. Measurements made using an ISCO Spectroradiometer (Model SR, Instrument Specialties Company) revealed that the light energy in the wavelength region 400/700 mμ amounted to approximately 5.4×10^4 ergs/cm^2/sec (i.e., nearly 20% of total daily solar radiation in the visible region, received at 45° latitude N, on a clear day in June).

When the plants were 9 days old they were treated with Cr. Treatments of 0, 0.05, 0.10, 0.50, 1.00, and 5.00 ppm Cr were prepared in full-strength nutrient solution by adding the appropriate aliquot of 1,000 ppm Cr standard potassium dichromate solution, prior to adjustment of the nutrient solution to volume and correction of pH.

Soybean plants were individually treated for 5 days with the Cr solutions in 500-ml polyethylene bottles, which were enclosed in aluminum foil to exclude light and were aerated through glass capillaries.

After the treatment period the plants were individually removed from the containers, thoroughly washed with deionized H_2O, separated into tops and roots, and dried in a forced-air oven at 65C for 24 hours. Dry-matter yields were recorded and the plant parts were ashed at 550C for 16 hours and analyzed for content of 10 elements (B, Ca, Cu, Fe, K, Mg, Mn, Na, P, and Zn) using an emission spectrograph.

Three replicates were used for each treatment of each soybean variety and the results were statistically analyzed using analysis of variance.

[3] Trade names and company names are included for the benefit of the reader and do not imply endorsement.

Table 2—Total content of elements in Norsoy soybean tops and roots with increasing amounts of Cr added to nutrient solution

Cr treatment	Macronutrients*					Micronutrients				
	Ca	K	Mg	Na	P	Fe	Mn	Zn	B	Cu
ppm	mg/pot					μg/pot				
				Tops						
0	6.3 a†	22.6 a	2.3 a	0.2 a	5.9 a	84 b	23 a	21 b	23 a	5 a
0.05	7.1 a	25.6 a	2.6 a	0.1 a	6.6 a	116 a	27 a	29 a	23 a	5 a
0.10	6.2 a	23.2 a	2.4 a	0.2 a	6.0 a	81 b	25 a	29 a	23 a	4 a
0.50	3.9 b	15.4 b	1.8 b	nd‡	3.6 b	35 c	13 b	20 b	17 b	3 b
1.00	3.7 b	15.0 b	1.6 b	nd	3.2 b	39 c	14 b	18 b	16 b	3 b
5.00	1.6 c	7.0 c	0.6 c	0.7 a	1.5 c	26 d	3 c	16 b	8 c	3 b
				Roots						
0	0.7 a	11.2 a	0.7 a	0.3 a	2.9 a	216 b	9 a	9 a	4 a	3 a
0.05	0.7 a	10.4 a	0.8 a	0.2 a	3.3 a	356 a	16 a	9 a	5 a	4 a
0.10	0.6 a	10.2 a	0.6 b	0.2 a	2.9 a	258 b	10 a	10 a	4 a	2 a
0.50	0.6 a	6.7 b	0.6 b	0.2 a	1.9 b	76 c	4 b	6 a	4 a	2 a
1.00	0.5 a	6.3 b	0.5 b	0.2 a	1.9 b	77 c	5 b	6 b	4 a	2 a
5.00	0.5 a	3.6 c	0.2 c	0.3 a	1.0 c	41 c	nd	4 b	3 a	4 a

* Results are averages of 3 replicates.
† Values not followed by the same letter within a column are significantly different at P = .05.
‡ nd = non detectable.

Plant Symptoms of Cr Toxicty

The initial visual symptoms of Cr toxicity appeared as wilting of the tops of the soybean plants, especially with the 5-ppm Cr treatment after only 2 days' treatment. Wilting occurred before any specific deficiency symptoms were observed.

At the time of harvest older leaves of those plants receiving the 5-ppm Cr treatment showed interveinal chlorosis with the development of interveinal necrotic areas.

RESULTS

Since essentially identical responses to Cr treatment were observed for both soybean varieties, only the results for Norsoy are discussed in this section. The results for Chippewa are available elsewhere.[4]

Yield and elemental concentrations for tops and roots of Norsoy soybeans, following Cr treatments, are presented in Table 1, and total element contents in Table 2.

Compared with the control (0 ppm Cr), the lowest Cr treatment produced an apparent but nonsignificant enhancement in the yield of tops, while treatments > 0.1 ppm Cr resulted in significant decreases in yield of both tops and roots (Table 1). Similarly, the concentrations (Table 1) and total contents (Table 2) of Ca, K, P, Fe, and Mn in tops and Mg, P, Fe, and Mn in roots showed apparent, nonsignificant increases at 0.05-ppm Cr treat-

[4] Turner, M. A. 1969. Chromium: Effect on the mineral nutrition of two varieties of *Glycine max* (L) Merrill, and the adsorption by selected Minnesota soils. Ph.D. thesis, Univ. of Minnesota, Oct. 1969. 164 pages.

Table 3—Yield and Cr content of tops of 18-day-old Norsoy soybeans treated for 4 days with Cr in nutrient solution

Cr treatment	Yield	Tissue Cr
ppm	g	ppm
0	0.49	*
1	0.44	*
5	0.36	11.9
10	0.31	32.8

* Less than detectable limit.

ment and significant decreases at all treatments > 0.1 ppm Cr.

Magnesium and boron concentrations in tops (Table 1) remained sensibly constant for all Cr treatments except the 5-ppm treatment, and total contents (Table 2) decreased at treatments greater than 0.1 ppm Cr. There was no significant effect of Cr treatment on Na or Zn concentrations, but total Zn content tended to decrease with the highest Cr treatments.

In the roots Cr treatments > 0.1 ppm reduced concentration and total content of K. There was no significant effect of Cr on concentrations of Ca, Zn, B, or Cu (Table 1), but total contents of Ca and Zn were decreased at the highest Cr treatments (Table 2).

Results from a separate investigation[4] showed that for 2-week-old soybean plants, treated for 4 days prior to harvest with varying rates of Cr, no Cr could be detected in the tops at Cr treatments below 1 ppm Cr in the nutrient solution. A summary of these results for Norsoy soybeans is presented in Table 3.

The effects of Cr noted at concentrations as low as 0.5 ppm Cr, as shown in Tables 1 and 2 accompanied by information in Table 3, suggest that Cr may exert its primary toxic influence at the root, the manifestations of which are observed as changed concentrations and total contents of a range of nutrients in the tops and roots of treated soybeans.

SOIL POT STUDY

The purpose of this experiment was to investigate whether effects ascribed to Cr treatment of soybeans grown in nutrient culture could be demonstrated for soybeans grown in soil pot culture.

Experimental Method

The soil used in this experiment was Nicollet loam sieved to pass a 2-mm mesh screen.

The equivalent of 400 g of air-dried soil was weighed into each of 30 wax-coated Dixie cups (500-g capacity). A basal treatment comprising 68 ppm P and 86 ppm K was applied to each pot in the form of 4 ml of a solution of KH_2PO_4 (30 g/liter) evenly watered over the soil surface from a pipette. Additional water was added to each pot to approximate field capacity—i.e., approximately 25% water by weight.

Seven soybean seeds of either the Norsoy or Chippewa-64 variety were then planted to a depth of 2 cm in each of 15 pots. Each pot was weighed and the weight was recorded and used to determine daily moisture additions required throughout the experimental period.

The pots were housed in the growth chamber under the same environmental conditions as described earlier for the nutrient culture study.

One week after seeding, the plants were thinned to four per pot.

Table 4—Yield and elemental concentration in Norsoy soybean tops grown in Nicollet loam following Cr additions

Cr treatment	Yield	Elemental Concentration*								
		Macronutrients				Micronutrients				
		Ca	K	Mg	P	Fe	Mn	Zn	B	Cu
ppm	g	%				ppm				
0	0.901 a†	1.22 b	1.20 b	0.58 bc	0.36 b	152 a	49 a	45 a	31 b	7 b
5	0.805 b	1.09 c	0.89 c	0.52 d	0.32 b	133 a	45 a	41 a	30 b	7 b
10	0.752 bc	1.14 c	0.98 c	0.57 cd	0.38 b	151 a	50 a	43 a	32 b	8 b
30	0.633 d	1.36 a	1.24 b	0.67 a	0.50 a	145 a	54 a	46 a	40 a	11 a
60	0.671 cd	1.31 a	1.45 a	0.63 b	0.55 a	118 a	51 a	43 a	41 a	12 a

* Results are averages of 3 replicates.
† Values not followed by the same letter within a column are significantly different at P = .05.

Chromium treatments were applied as potassium dichromate (an aqueous standard of 1,000 ppm Cr) when the seedlings were 15 days old. The levels of Cr treatment chosen were 0, 5, 10, 30, and 60μg Cr/g soil, based on a previously determined maximum chromate adsorptive capacity[4] for this soil of approximately 40 μg Cr/g soil. The treatments were administered as 0, 2, 4, 12 or 24 mls of the 1,000 ppm dichromate solution, dispensed evenly over the surface of the respective soil pot from a pipette. Each treatment was randomly allocated to three pots for each soybean variety.

Three days after the application of the Cr treatments, the plant tops above the cotyledons were harvested, washed thoroughly in deionized water, weighed and prepared for analysis of 9 elements (B, Ca, Cu, Fe, K, Mg, Mn, P, and Zn) by emission spectrograph.

All results were statistically analyzed using the analysis of variance procedure.

Plant Symptoms of Cr Toxicity

Plants receiving 10 ppm Cr showed the severe wilting symptoms at harvest as observed in nutrient culture, whereas those plants receiving 30 and 60 ppm Cr had been killed by the high Cr dose.

RESULTS

The results of yield and elemental concentrations of tops of Norsoy soybeans, following Cr treatment, are shown in Table 4, and total element contents in Table 5. Results for Chippewa soybeans which were essentially the same as for Norsoy are available elsewhere[4].

Chromium treatment significantly decreased dry-matter yield of tops of Norsoy soybeans (Table 4).

From Table 4 it is evident that Cr treatment significantly increased concentrations of Ca, K, Mg, P, B, and Cu in Norsoy tops. However, these results need careful interpretation in view of the rather constant total contents of these elements shown in Table 5, at all rates of Cr addition from 5 to 60 ppm. If it can be assumed that plants treated with 30 and 60 ppm Cr made little or no growth over the treat-

Table 5—Total content of elements in Norsoy soybean tops grown in Nicollet loam following Cr additions

Cr treatment	Macronutrients*				Micronutrients				
	Ca	K	Mg	P	Fe	Mn	Zn	B	Cu
ppm	mg/pot				μg/pot				
0	11.0 a†	10.8 a	5.2 a	3.2 a	137 a	44 a	41 a	28 a	6 a
5	8.8 b	7.2 b	4.2 b	2.6 b	107 b	36 a	33 b	24 a	6 a
10	8.6 b	7.4 b	4.3 b	2.9 a	114 b	38 a	32 b	24 a	6 a
30	8.6 b	7.9 b	4.2 b	3.2 a	92 c	34 b	29 b	25 a	7 a
60	8.8	9.7 a	4.2 b	3.7 a	79 c	34 b	29 b	28 a	8 a

* Results are averages of 2 replicates.
† Values not followed by the same letter within a column are significantly different at P = .05.

ment period, which seemed likely judging by the appearance of these plants at harvest, these plants probably reflect the conditions present at the commencement of the treatment period. The extra increments of growth produced at the lower Cr treatments did not appear to result in increased total contents of most elements analyzed (Table 5), suggesting that Cr apparently interfered with their uptake into the tops. It is therefore proposed that Cr interfered with the accumulation of Ca, K, Mg, P, B, and Cu by the plant tops.

For the elements Fe, Mn, and Zn increasing Cr addition resulted in no significant change in concentrations (Table 4), but total contents decreased (Table 5), implying that Cr had no significant effect on the ability of plants to obtain these elements from the soil.

From data in Table 5 it appears that total plant requirement for P, B, and Cu had been met at the time of application of Cr treatments since control plants (0 ppm Cr) contained similar total contents of these elements to Cr-treated plants in spite of considerable yield differences (Table 4).

SUMMARY AND DISCUSSION

Symptoms of Cr toxicity appeared similar with plants grown in nutrient and soil pot culture. In both instances initial symptoms appeared to be wilting of tops. High Cr addition (30 or 60 ppm) to plants in soil culture resulted in death of plants within 3 days of treatment application.

Dry-matter yields were significantly reduced following Cr treatments in both types of culture methods used. In nutrient culture, plants receiving 5 ppm Cr for 5 days produced about 50% of the yield of untreated controls. In soil pot culture plants receiving 60 ppm Cr for 3 days made 70% of yield of untreated controls. These results probably reflect the advanced maturity and lowered percentage growth rate of the soil-grown soybeans.

In both types of culture Cr treatment resulted in changes in concentrations and total contents of a wide range of nutrient elements. Of particular interest was the observation that while Fe and Mn concentrations in tops were lowered by Cr treatment in nutrient solution, there was no significant change in concentration of these elements in soil culture.

The results presented in this report indicate that Cr treatments as low as 0.5 ppm in nutrient culture and 10 ppm in soil culture significantly reduced dry-matter yields of two soybean varieties tested.

In nutrient culture Cr treatments > 0.1 ppm resulted in decreased concentrations and total contents of Ca, K, P, Fe, and Mn in tops and of Mg, P, Fe, and Mn in roots when compared to untreated control plants. For tops only, Cr treatment had no significant effect on concentrations of Mg, Zn, or B, although total contents of these elements tended to be reduced at the highest Cr treatment.

For roots Cr treatments > 0.1 ppm reduced K concentration and total content. No significant effect of Cr treatment on Ca, Zn, B, or Cu concentrations was found, but total contents of Ca and Zn were depressed at the highest Cr additions.

In soil culture Cr treatment resulted in significantly increased concentrations of Ca, K, Mg, P, B, and Cu in tops of both soybean varieties. It was concluded that Cr interfered with the ability of plants to obtain these elements from the soil. There was evidence that Cr had little or no effect on the accumulation of Fe and Mn in soybean tops.

It could not be concluded from these results that Cr in the hexavalent form specifically interfered with the uptake of Fe or P by plants, as has been previously reported. It appeared that a broad range of elements was affected by treating soybean plants with Cr solutions.

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