Cadmium Uptake by Soybean from Phosphorus Fertilizer

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INTRODUCTION

Phosphorus fertilizers are an important source of cadmium (Cd) contamination on agricultural lands (Adriano, 2001, p. 12). Cadmium occurs geologically with phosphorus, and Cd in phosphorus fertilizers originates from phosphate rock. Differences in Cd content of phosphate rocks mined in various areas are caused by impurities co--precipitated with the phosphates at the time of deposition (Adriano, 2001, p. 12).

Cadmium is highly toxic to humans, even at low concentrations. It accumulates in liver and kidneys. It is linked to bone fractures, cancer, kidney failure, and hypertension (Wu et al., 2010). Annually there are 31,800 and 16,600 new cases of kidney and liver cancer, respectively, reported yearly in the USA (National Cancer Institute). It is not known how many of these cases might be due to Cd in food eaten by the people who got these diseases.

Several countries now recognize that Cd is a pollutant in phosphorus fertilizers and control it. These countries include Austria, Australia, Denmark, Germany, Japan, the Netherlands, Norway, Sweden, and Switzerland. They regulate the Cd content of fertilizers (Adriano, 2001, p. 802). The United States has no regulations (Adriano, 2001, p. 802).

Figure 1. Soybean field in Manhattan, KS

There is need to know if Cd in phosphorus fertilizers from the USA is being taken up by crops. In the Midwest of the USA, the two most important crops are corn and soybeans. Soybeans are becoming an increasingly more valuable export crop (Fig. 1). This year, they represent nearly 46% of the projected marketing year exports (http://www.AgNetwork.com, 21 Sept. 2010). Exports might be reduced, if Cd is present in soybeans. The objective of this research was to determine if soybeans grown with and without phosphorus fertilizer accumulated different amounts of Cd.

MATERIALS AND METHODS

The experiment was done in a greenhouse in Manhattan, Kansas, between 25 Aug. 2009 (planting) and 4 Dec. 2009 (harvest). It was part of a larger experiment to study the effect of phosphorus on water use of soybean.

The soil was a Morrill loam, collected from a field near Manhattan, Kansas. It was naturally low in phosphorus (7.44 ppm). Plants grew in large pots (28 cm tall; 15 cm diameter). Half of the pots had no P fertilizer added to the soil, and half of the pots had P fertilizer added to the soil. Fertilized soil received 40 ppm P. The phosphorus fertilizer was granular triple super phosphate (0-46-0), and it came from Lange-Stegmann Co., Lange Specialty Products Group, St. Louis, MO.

Two cultivars of soybean [Glycine max (L.) Merr.] were used:

- ‘Chiangmai 60’ (a traditional Thai cultivar)
- ‘KKU 74’ (an improved cultivar developed by Khon Kaen University in Thailand)

Figure 2 shows an overview of the experiment on 15 Sept. 2009, 21 days after planting. The plants did not form pods, because we did not know that the greenhouse at night was receiving light from a neighboring greenhouse. Soybeans need short days to flower. On 7 Oct. 2009, 43 days after planting, when we realized that the plants were not getting short days, we put up black plastic to darken the plants at night (Fig. 3). When the plants were harvested on 4 Dec. 2009, a few immature pods had begun to form.

Figure 2. Experimental setup in a greenhouse. Picture was taken on 15 Sept. 2009, when the plants were 21 days old.

Figure 3. Black plastic put up along one wall of greenhouse to block out light that was coming from the neighboring greenhouse at night.

MATERIALS AND METHODS cont.

At harvest, we sampled the above-ground plant organs as one sample (leaves, stems, immature pods). Figure 4 shows the stage of development of the soybean pods when we harvested them.

We extracted roots by wet sieving. We determined dry weights of shoots and roots. They were analyzed for Cd using inductively coupled plasma-atomic emission spectroscopy (ICP-ES).


Figure 4. Immature soybean pods

RESULTS

- Roots and shoots of both cultivars grown with phosphorus fertilizer had higher concentrations of Cd than those grown without phosphorus fertilizer (Table 1).
- Dry weights of roots and shoots grown with phosphorus fertilizer were greater than those grown without phosphorus fertilizer (Table 2).

Cultivar	Treatment	Roots	Shoots
KKU 74	No P	5.74±0.23	0.89±0.06
KKU 74	P	9.89±0.66	1.38±0.12
Chiangmai 60	No P	8.92±0.83	1.11±0.06
Chiangmai 60	P	9.73±0.98	1.50±0.09

Table 1. Cadmium concentration (µg/g) in roots and shoots of two cultivars of soybeans grown with and without phosphorus fertilizer. Mean and SE are shown.

Cultivar	Treatment	Roots	Shoots
KKU 74	No P	4.44±0.44	20.96±2.44
KKU 74	P	5.93±0.68	39.61±5.56
Chiangmai 60	No P	3.31±0.38	16.29±1.24
Chiangmai 60	P	5.70±0.73	33.40±4.84

Table 2. Root and shoot dry weight (g/plant) at harvest (101 days after planting) of two cultivars of soybeans grown with and without phosphorus fertilizer. Mean and SE are shown.

- Figure 5 shows the difference in size of the plants due to phosphorus fertilization, when the plants were 21 days old.
- Figure 6 shows what the plants looked like on 10 Oct. 2009, 46 days after planting.
  - They got tall because the plants were not receiving the short day-lengths that were necessary to initiate reproduction and limit height growth.
- Table 3 shows the total content of Cd in the roots and shoots, which was determined by multiplying the concentration of Cd in each plant part by its dry weight. Content of Cd in the roots (Fig.7) was doubled by the use of the phosphorus fertilizer. Content of Cd in the shoots was almost tripled by the use of the phosphorus fertilizer.
- Both cultivars grown with phosphorus fertilizer had more than 50 µg Cd in their shoots.


Figure 5. Difference in height due to phosphorus fertilization. Plant on the right received 40 ppm P and plant on the left grew in unfertilized soil that had 7.44 ppm P. Picture was taken on 15 Sept. 2009, when the plants were 21 days old.

RESULTS cont.

Figure 6. Overview of the experiment

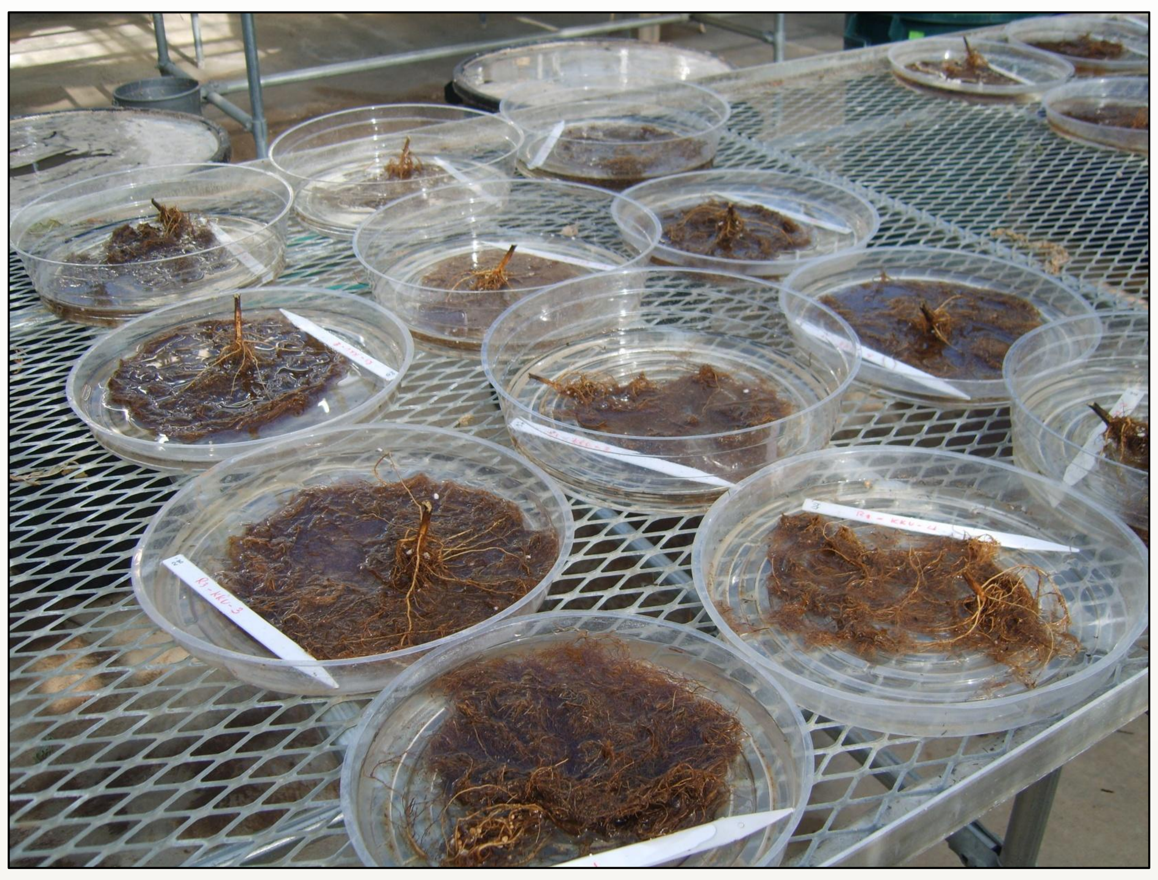

Figure 7. Roots at harvest

Cultivar	Treatment	Roots	Shoots
KKU 74	No P	5.74±0.23	0.89±0.06
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Table 3. Cadmium concentration (µg/g) in roots and shoots of two cultivars of soybeans grown with and without phosphorus fertilizer. Mean and SE are shown.

DISCUSSION

Cadmium content was increased in the soybeans that received the phosphorus fertilizer, especially in the shoots. Wu et al. (2010) state that exposure levels to Cd of 30 to 50 µg per day are linked to increased risk of disease. The shoots with phosphorus fertilizer in our experiment had a Cd content greater than 50 µg. Even though the shoots would not be eaten by humans, they could be eaten by animals as forage. Soybeans are used as forage. Animals grazing on the shoots high in Cd might accumulate the Cd in their livers and kidneys. Humans eating these organ meats may then be ingesting Cd.

Organic farmers do not use inorganic fertilizers. If they do not have manure, the source of phosphorus in organic farming, they must turn to rock phosphate for phosphorus (Ed Reznicek, Kansas Rural Center, Goff, Kansas, personal communication, 22 Sept. 2010). Therefore, organic farmers that use rock phosphate may have soybeans that are accumulating Cd.

CONCLUSION

Phosphorus fertilization increased the Cd in the shoots and roots of soybean. Because the phosphorus-fertilized shoots had more Cd than the non-fertilized shoots, Cd needs to be considered as a contaminant in soybean shoots when used as a forage.

REFERENCES

- Adriano, D.C. 2001. Trace Elements in Terrestrial Environments. Biogeochemistry, Bioavailability, and Risks of Metals. Springer-Verlag, New York. 867 p.
- Wu, Q., T. Shigaki, K.A. Williams, J.-S. Han, C.K. Kim, K.D. Hirschi, and S. Park. 2010. Expression of an *Arabidopsis* Ca^{2+}/H^{+} antiporter CAX1 variant in petunia enhances cadmium tolerance and accumulation. J. Plant Physiol. (In press) (doi:10.1016/jplph.2010.06.005)

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