MUSHROOM COMPOST REMEDIATES ZINC TOXICITY IN COTTON

By

Larry M. Shuman
Crop and Soil Sciences Department
University of Georgia
Georgia Experiment Station
Griffin, Georgia

INTRODUCTION

Flue dust is a by-product of steel industry where electric arc furnaces are used. It contains as much as 10% Zn (Weeks, 1993). A flue-dust by product was spread on cropland in the Coastal Plain of Georgia as a liming agent, both in the Tifton area (Davis et al., 1995) and in Johnson and surrounding counties. In recent years severe Zn toxicities have occurred in a number of crops in the areas where the material was spread including peanuts, soybeans, and cotton. Zinc levels in severely stunted cotton plants in Johnson county were above 2000 mg kg^{-1}, well above the critical toxicity level of 200 mg kg^{-1} for cotton (*Gossypium hirsutum* L.) found by Ohki (1975).

The most obvious method for reducing plant Zn toxicity is to raise soil pH through liming to reduce the plant availability of the metal. Williams (1980) found that for most crops tested which suffered from metal toxicity from sewage sludge, raising the soil pH to 7.0 -7.2 reduced metal toxicity compared to pH 6.2-6.5. At high pH Zn is adsorbed mostly by the organic matter where it is held as an organic complex. Therefore, raising soil pH and adding organic amendments can work together to help ameliorate Zn toxicity (Jahiruddin et al., 1985).

Higher organic matter in soils leads to lower Zn in plants whether the organic matter is natural (Romney et al., 1977) or added as an amendment to contaminated soils (Marquenie et al., 1981). Cattle manure and maize straw added to two different soils reduced Zn availability as much as 50% (Tagwira et al., 1992). White and Chaney (1980) found that organic matter was more important than Fe oxides in moderating the effects of excessive soil Zn and limiting plant uptake. It has been found that liming alone does not account for the ameliorative effect on municipal wastes in lowering plant uptake of Zn, so the organic material also contributes an effect (Mortvedt and Giordano, 1975). McGrath et al. (1988) showed that lower Zn was extracted at all pHs from soil samples with the highest organic matter than from those with the lowest organic matter indicating that organic material lowers plant availability regardless of the pH.

Since remediation of toxic soil Zn is a problem in certain Coastal Plain soils, a pot experiment was carried out to test remediation strategies and to determine the alteration of Zn in soil fractions with liming and organic matter additions. The objectives of the research were to: 1) determine the pH level that would remediate Zn toxicity to cotton in flue-dust contaminated soil; 2) to examine the effect of adding a mushroom compost on Zn toxicity remediation.

MATERIALS AND METHODS

Bulk soil samples were taken from 0-15 cm depth from a cotton field in Johnson county in the Coastal Plain of Georgia, where a flue-dust had been applied as a liming agent for approximately 10 years, ceasing four years before sampling. The flue-dust was contaminated with Zn, Pb, and Cd with the major pollutant being Zn. Two adjacent sites were sampled which were termed high-Zn soil and low-Zn soil. The high-Zn soil was from an area where the cotton plants were severely stunted (terminal growth about 5 cm) and tissue analysis confirmed that they were suffering from Zn toxicity and not from Pb or Cd toxicity. The other area had cotton plants growing well and was used as a control. The soil types for the two areas were Clarendon loamy sand (Plinthaquic Paleudult) and Dothan sand (Plinthic Kandiudult). Soil physical and chemical characteristics (Black, 1965)are given in Table 1 (Shuman and Li, 1997). Total metals were determined according to Shuman (1979).

A greenhouse experiment was carried out with 4 lime treatments (0 control, 2.24, 4.48, and 8.96 Mg ha^{-1}) and 2 spent mushroom compost treatments (67.2 Mg ha^{-1} compost and the same amount of compost plus 4.48

Table 1. Soil Properties

Zinc Status	Soil Type	Soil Classification	Sand	Clay	Organic Matter	CEC	pH	Total Zn
			---------- g kg^{-1} ----------			$cmol_c$ kg^{-1}	1:1	mg kg^{-1}
High Zn	Clarendon ls	Plinthaquic Paleudult	808	128	25	1.7	4.89	414
Low Zn	Dothan s	Plinthic Kandiudult	912	52	18	1.4	5.39	95

Mg ha^{-1} lime). The lime was laboratory grade calcium carbonate and the spent mushroom compost was screened through a 2 mm sieve. Soils were mixed with lime and spent mushroom compost and a blanket N-P-K-Mg treatment in a V-blender and potted in 3 kg-size pots. The N-P-K-Mg was 100-30-145-25 mg kg^{-1} from NH_4NO_3, KH_2PO_4, KCl, and $MgSO_4 \cdot 7H_2O$. Germinated cotton seeds (variety HS46) were planted and thinned to 4 per pot. There were 4 replications in a completely randomized design. The pots were watered daily to approximately field capacity.

Plants were harvested after 8 weeks by cutting near the soil surface and the leaves were separated for analysis. Plant tissue samples were dried at 70°C in a forced-draft oven and weighed. Leaves were ground in a Wiley mill to pass a 425μm stainless steel screen. A 0.5 g leaf sample was wet digested using a nitric-perchloric acid mix (4:1 v/v basis) with digestion completed in aluminum block heaters at 205°C. Ashed extracts were made to 25-mL volume and Zn and Mn analyzed by flame atomic absorption spectrometry. Soils were air dried, screened through a 2 mm sieve and analyzed for pH (1:2 soil:water) and for Zn by the DTPA method (Lindsay and Norvell, 1978).

A Zn adsorption experiment was carried out where one gram of soil or amended soil was placed in a 50 mL centrifuge tube and 15 mL of 0.01 mol L^{-1} $CaCl_2$ added. The pH of the suspension was adjusted using dilute HCl or KOH. Fifteen mL of the appropriate zinc solutions, as $ZnCl_2$, were added at twice the final strength and with the pH adjusted according to the treatment. The final background salt concentration was thus 0.005 mol L^{-1} $CaCl_2$. The pH treatments were 4.0 to 8.0 in steps of 1 pH unit. The Zn concentration was 1.00 mmol L^{-1}. Each treatment was replicated three times. These suspensions were shaken for 10 min. on a reciprocating shaker and placed in a 25°C water bath for 23 hr. The tubes were shaken once again for 10 min., centrifuged, and the supernatant filtered through Whatman number 42 filter paper. The solutions were analyzed for Zn by flame atomic absorption spectrometry.

RESULTS AND DISCUSSION

PLANT GROWTH

The high-Zn soil was extremely toxic to cotton with most plants stopping growth at a two-leaf stage and exhibiting severe toxicity symptoms such as yellowing of the entire leaf and development of necrotic areas as well as severe stunting. Ohki (1975) found interveinal chlorosis and enlarged necrotic areas in cotton affected by Zn toxicity in nutrient solution experiments. In strongly acidic soils, most plants become chlorotic when they are exposed to excessive soil Zn because Zn interferes with Fe uptake, translocation, and utilization in the leaves (Kabata-Pendias and Pendias, 1984; Chaney, 1993). However, in most soil systems, leaves do not contain deficient levels of Fe even when they are severely chlorotic due to excessive soil Zn (Rosen et al., 1977; White et al., 1979). In this study leaf Fe was above 100 mg kg^{-1} indicating that sufficient Fe was present for normal plant growth. Thus, the chlorosis caused by excessive Zn was likely a result of the Zn interfering with the utilization of Fe in chlorophyll biosynthesis (Chaney, 1993).

Lime treatments up to 9 Mg ha^{-1} did not ameliorate the Zn toxicity (Fig. 1), since the plant growth was statistically the same for the 9 Mg ha^{-1} as for the control. Only the compost was able to produce normal growth on this very toxic soil and adding lime to the compost did not increase growth (Fig. 1). For the low-Zn soil the lime rates

Table 2. Plant Zn for cotton grown in two soils amended with lime or mushroom compost

Zinc Status	Lime				Compost	Compost + Lime
	Control	2 Mg/ha	4 Mg/ha	9 Mg/ha	67 Mg/ha	67 Mg/ha + 4 Mg/ha
	mg kg^{-1}					
Low Zn	1079 a†	872 b	425 c	111 d	36 d	38 d
High Zn	965 d	1706 b	1975 a	1368 c	219 e	198 e

†Values followed by the same letter within a row are not different at the 5% level according to an LSD.

dramatically increased the growth up to 9 Mg ha^{-1} (Fig. 1.). The plants at the highest lime rate had no visual toxicity symptoms and no further increase in growth would be expected from higher lime rates, especially since the plants for the compost were similar to those at the highest lime rate and the soil pH was higher for the compost. This low-Zn soil was adjacent to the high-Zn soil in the field and was supporting normal plants. Evidently the Zn level in this soil was high enough to cause toxicity in the greenhouse where the roots were confined. In the field the roots may have grown below the toxic surface layer giving better plant growth than experienced in the greenhouse where no additional lime was added (control). Other data on the low-Zn soil indicated that at 40 cm depth the total Zn was at background levels (Li, 1996), so plant roots could grow into less toxic layers in the field.

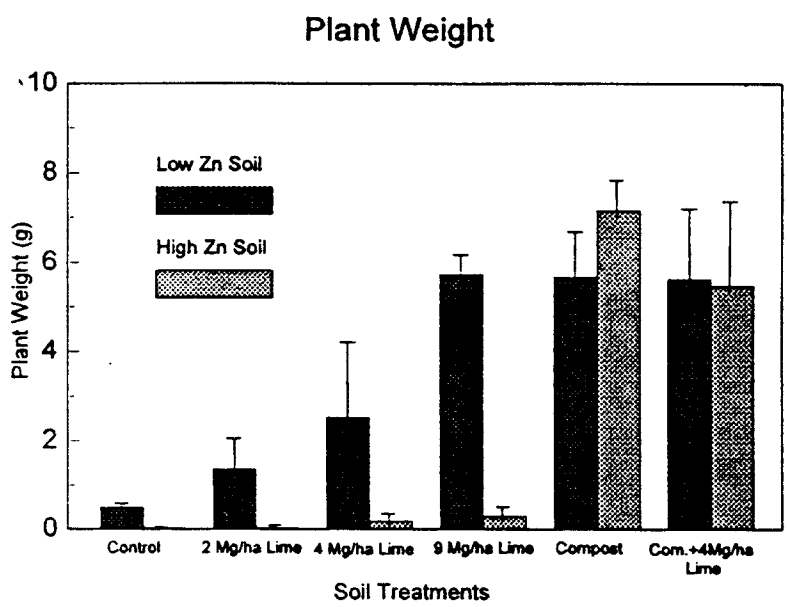

Fig. 1. Plant weights for two soils amended with four lime and two compost treatments. Error bars are for one standard deviation. (Shuman and Li, 1997)

PLANT ZINC

Plant Zn levels for the severely stunted plants grown on the high-Zn soil at the control and the 3 lime rates were variable, but obviously were in a toxic range (Table 2. Shuman and Li, 1997). The control plant Zn values for the high and low Zn soils were similar, but the plant Zn for the high-Zn soil and the 3 lime rates were higher than for the low-Zn soil. This result is unexpected and reveals the problems with analyzing very small, stunted plants which continued to live for the life of the experiment and continued to accumulate Zn during that time. These levels of Zn up to nearly 2000 mg kg^{-1} were very toxic to the plants. Only the compost treatment produced normal plants with Zn below the toxic range of 200-300 mg kg^{-1} (Ohki, 1975). The critical toxic level for cotton is also confirmed by Lee and Page (1967), who found that cotton would grow normally below 200 mg kg^{-1}, grew intermediately at 200 to 250 mg kg^{-1}, and very poorly above 250 mg kg^{-1} leaf Zn. The leaf data here suport the theory that the field problem was Zn toxicity. The lime for the low-Zn soil lowered the Zn in the plants with each increment (Table 2) and produced non-toxic levels at the 9 Mg ha^{-1} rate and for the compost as evidenced by plant growth and by the Zn levels being below the 200 mg kg^{-1} range given by Ohki (1975).

Table 3. Soil pH (1:1, soil:water) for two soils amended with lime or mushroom compost.

Zinc Status	Lime				Compost	Compost + Lime
	Control	2 Mg/ha	4 Mg/ha	9 Mg/ha	67 Mg/ha	67 Mg/ha + 4 Mg/ha
Low Zn	5.39 e†	6.08 f	6.67 c	7.06 b	7.61 a	7.57 a
High Zn	4.89 e	5.45 d	5.82 c	6.26 b	6.84 a	7.03 a

†Values followed by the same letter within a row are not different at the 5% level according to an LSD.

SOIL pH

Lime additions raised soil pH incrementally to near 7.0 for the low-Zn soil but the pH values were lower at similar lime rates for the high-Zn soil (Table 3, Shuman and Li, 1997). The results indicate that the high-Zn soil was more acid to start with (controls) and needed higher amounts of lime to ameliorate the Zn toxicity than the low-Zn soil. Amelioration of the toxicity came at pH levels of ≥7.0 for the low-Zn soil and ≥6.8 for the high-Zn soil for the compost treatments only. These results indicate that for these soils, high pH levels are necessary to ameliorate the Zn toxicity caused by the flue-dust amendment.

Compost treatments raised the pH to higher levels than did the lime at 9 Mg ha^{-1} and gave remarkable increases in growth. Adding lime with the compost did not raise the pH further. The compost may have added plant nutrients to aid plant growth, but the blanket fertilizer would have elimnated any nutrient effects. The pH level for the compost plus lime for the high-Zn soil was higher than for the compost alone, but the values were not statistically significant. It is interesting to note that where no compost was added, 9 Mg ha^{-1} lime that raised the pH to above 7.0 was necessary to ameliorate the Zn toxicity for the low-Zn soil. However, with the compost treatment for the high-Zn soil, the Zn toxicity was ameliorated at a pH level of only 6.8. Thus, it would appear that more than the soil pH was involved in the compost being able to ameliorate the Zn toxicity similar to the results of Mortvedt and Giordano (1975) with sewage sludge. The fact that the toxicity was ameliorated at lower pH by the compost is even more remarkable when the amounts of Zn in the two soils are taken into account with the high-Zn soil having over 4 times the total Zn as the low-Zn soil. Since the plants grew so poorly at the 9 Mg ha^{-1} rate for the high-Zn soil, it would seem that even at a limed pH the same as the compost, the plant growth would not have been comparable.

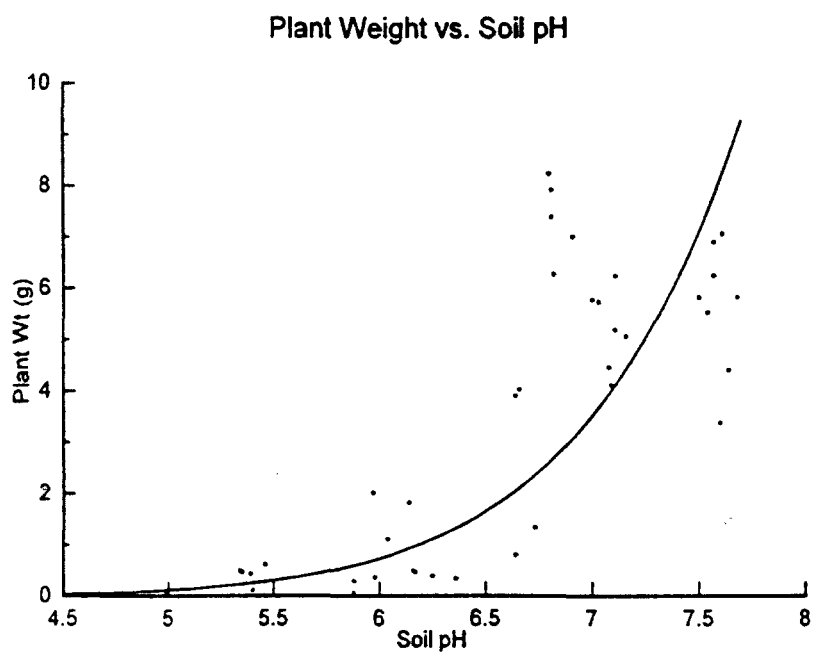

Fig. 2. Plant weight versus soil pH values. (Shuman and Li, 1997)

PLANT WEIGHT VS. SOIL pH

The regression for the plant weights and the soil pH was curvilinear and the best fitting curve was a power or geometric equation (Fig. 2) Plant weights were low at pH values below 6.5. At the higher pH values there were two groups with the highest plant weights being at pH 6.8 for the high-Zn soil with compost alone, and the other group being at pH 7.1 to 7.6, which were the other compost treatments. Thus, the amelioration of the Zn toxicity related to soil pH was fairly clear-cut with the amelioration coming at soil pH values of about 6.8 and above. This is the pH level where Zn would begin to precipitate as $Zn(OH)_2$ and the Zn would be strongly adsorbed in specific sites on clay and organic surfaces (Jahiruddin et al., 1985). Adsorption of Zn greatly increases at high pH values (Shuman, 1975). More Zn would be present in the $Zn(OH)^+$ form than the Zn^{2+} at pH >7 (Lindsay, 1979). Zinc adsorption was increased in a Norfolk soil that is from the same physiographic region as the soil used in the pot experiment at pH 5 and 6, but not at higher pH values (Fig. 3).

PLANT WEIGHT VS. DTPA ZN

Extractable soil Zn should be negatively correlated with plant growth in this toxic situation for suitability in predicting plant toxicity. The DTPA method of Lindsay and Norvell (1978) was successful in predicting Zn toxicity in that the linear correlation coefficients were negative and significant (Fig. 4) The data for the low-Zn soil gave a fairly uniform linear pattern throughout the range of soil pH. The high-Zn soil data, however, formed two groups representing a toxic group and a non-toxic group.

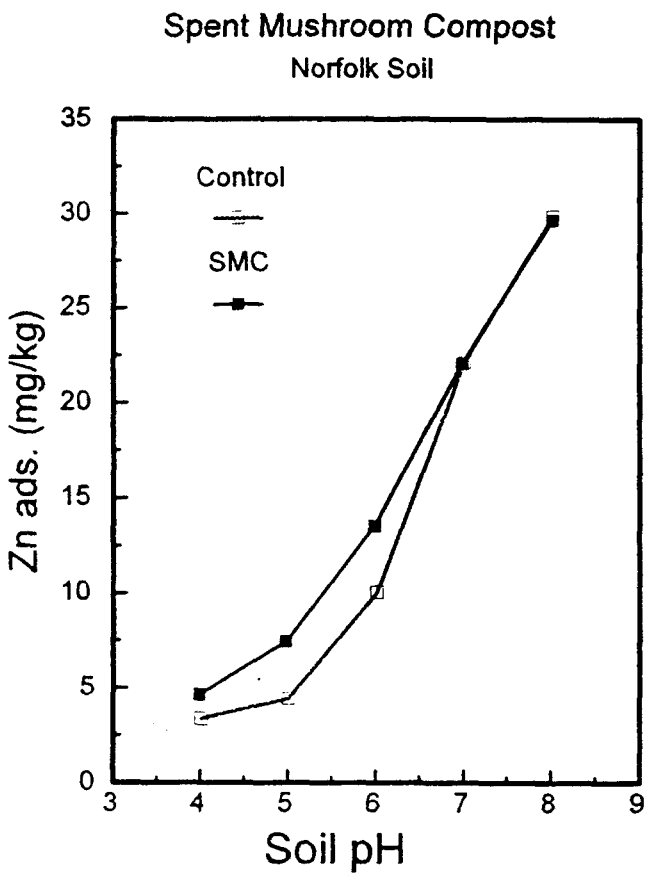

Fig. 3. Effect of spent mushroom compost on Zn adsorption by a Norfolk soil.

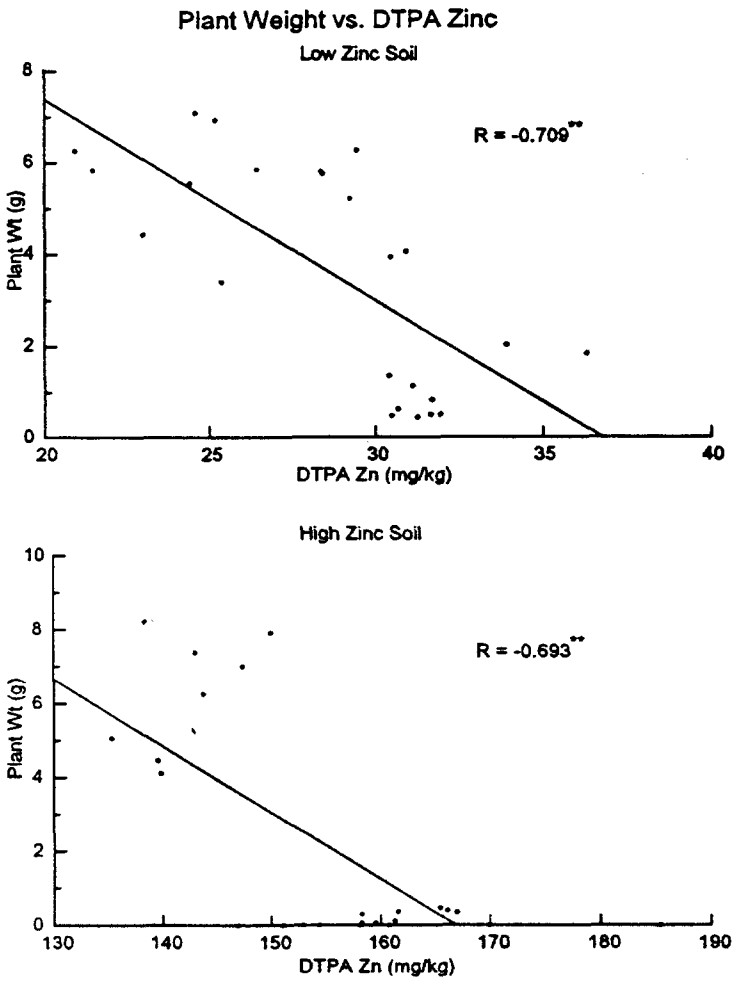

Fig. 4. Plant weight versus DTPA-extractable soil Zn for two soils. (Shuman and Li, 1997)

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