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Impact of Repeated Manure Applications on Metal Load and Plant Availability in Saskatchewan Soils

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Introduction

As intensive livestock production increases, more and more livestock manure is being disposed of by applying it to agricultural land as fertilizer. Repeated manure addition may alter the plant availability of metals such as copper and zinc as well as nonfunctional elements such as cadmium. Manure could impact soil pools of these elements both directly and indirectly. Manure addition could directly increase the total amount of elements in the soil. Indirect effects would include changes in the plant availability of an element already present in the soil due to changes in the chemical and physical environment in the soil, such as pH changes, interactions with organic matter, or increased rates of weathering.

Copper and zinc are of interest as they are micronutrients that may be affected by the manure applications. Plants take up copper in the Cu^{2+} form and as an organic complex. Normal plant tissue concentrations of copper are 5 to 20 ppm, and plants become deficient when levels are under 4 ppm (on a dry matter basis). Soil solution concentrations usually range from 10^{-8} to 10^{-6} M. Copper is used in plants by “enzymes that create complex polymers such as lignin and melanin” (Tisdale et al., 1993). Zinc is taken up by plants as Zn^{2+} or as an organic complex. Normal plant tissue concentrations of zinc are 25 to 150 ppm with deficiency occurring at <20 ppm and toxicity occurring at >400 ppm. Soil solution concentrations usually range from 2 to 70 ppb, mostly complexed with soil organic matter. Zinc is needed for a number of plant enzymatic activities and the production of tryptophane (Tisdale et al., 1993).

It has been shown that while copper and zinc do not seem to increase in total amounts, the percentage in the moderately labile fraction can be affected by a high rate of manure application (Qian et al., 2002). It has been found that nitrogen application changes plant uptake of a number of elements including cadmium, copper and zinc (Mitchell et al., 2000). Copper and zinc are known to compete with each other, thus inhibiting plant availability of one when the other is present in high concentration (McLaughlin et al., 2000). Iron and manganese ions can inhibit plant uptake of zinc. High phosphorus levels have been known to “induce Zn deficiency” (Tisdale et al., 1993). Plant availability of zinc and copper decreases as soil pH increases. Zinc can be reversibly bound by clay minerals and form both plant available and non-available complexes with soil organic matter. Copper is strongly adsorbed to clays and Fe, Al, and Mn oxides. It is also very strongly bound to organic matter, forming both available and non-available complexes (Tisdale et al., 1993).

Cadmium is an element that can be toxic to both plants and to consumers of plant products. If cadmium levels in plants increase it is a concern for international grain buyers. It has been found that as soil salinity increases, cadmium plant availability also increases (McLaughlin et al., 1994) especially if a high level of chloride ions is present (Weggler-Beaton et al., 2000). Zinc may also interact with cadmium to decrease its plant availability (Oliver et al., 1994). The influence of repeated manure application on soil and plant cadmium is still unknown.

Procedure

A study was done at four Saskatchewan sites located near Dixon, Melfort, Plenty, and Riverhurst. The Dixon site has a Cudworth Association soil with a loamy texture in the Black soil zone. The Melfort site has a loamy textured Gray Black Melfort /Kamsack Association soil. The Plenty site has a Regina Association soil with a clay texture in the Dark Brown soil zone while the Riverhurst site has a Birsay Association soil with a sandy loam texture in the Brown soil zone.

At each of the four sites, liquid swine manure from a nearby earthen storage pit was injected 10-13 cm deep into test plots using a low disturbance injector. At the Dixon site, cattle manure was broadcast by hand and incorporated. Treatments began in 1997 at Dixon, 1998 at Riverhurst and Plenty, and 1999 at Melfort. Treatments were applied using a randomized complete block design. The same treatment was applied once each year over the duration of the experiment with the exception of the 67,000 L/ha treatment at Melfort, which was applied only every second year. Four replications were used at Dixon and Melfort and three replications were used at Plenty and Riverhurst. The treatments included in this study are:

Riverhurst and Plenty:
2 rates of injected hog effluent:
    -37,000 L/ha
    -74,000 L/ha
-Urea (46-0-0) (80 kg N/ha) application
-Disturbed Check Strips

Dixon (hog):
-3 rates of injected effluent:
    -37,000 L/ha
    -74,000 L/ha
    -148,000 L/ha
-Urea (46-0-0) (112 kg N/ha) application
-Disturbed Check Strips

Dixon (cattle):
-3 rates of broadcast and incorporated manure:
    -7.6 tonnes/ha
    -15.2 tonnes/ha
    -30.4 tonnes/ha
-Urea (46-0-0) (112 kg N/ha) application
-Disturbed Check Strips

Melfort:
-2 rates of injected hog effluent:

-34,000 L/ha
-67,000 L/ha every second year
-Urea (46-0-0) (80 kg N/ha) application
-Disturbed Check Strips

Soil samples were taken in the spring using PVC pipe. The samples were dried and ground using an agate mortar and pestle. To determine total soil metal content, 1 g of each sample was digested with 10 ml nitric acid using microwave digestion. The resulting solutions were analyzed using an atomic absorption spectrophotometer for total copper and zinc content. A graphite furnace was used to determine the total cadmium content. To determine available soil metal content, an AB-DTPA extraction was performed (Soltanpour and Workman, 1980). The resulting solutions were analyzed using an atomic absorption spectrophotometer for available copper, zinc, and cadmium content of the AB-DTPA extractable fraction. An analysis of variance was performed separately for the data from each site using the general linear model procedure in SAS. Tests for normality showed no reason for doubting the normality of the data.

Results

The Dixon hog (Table 1), Dixon cattle (Table 2), Riverhurst (Table 3), and Plenty (Table 4) sites all showed a significant increase in available soil copper and zinc with increasing rates of manure fertilizer while there were no significant differences at the Melfort site (Table 5). The Dixon cattle (Table 2), Riverhurst (Table 3), and Plenty (Table 4) sites also showed a significant increase in total soil copper but there were no significant differences at Melfort (Table 5) and the Dixon hog (Table 1) sites. The Riverhurst (Table 3), and Plenty (Table 4) sites showed a significant increase in total soil zinc but there were no significant differences at Dixon cattle (Table 2), Melfort (Table 5) and the Dixon hog (Table 1) sites. It is possible that the Melfort site did not show significant changes when some of the other sites did due to the fact that it has been receiving manure for the shortest period of time. A small but significant difference in available soil cadmium was only observed at Plenty (Table 4). No significant changes in the amount of total or available cadmium with increasing rates of manure fertilizer were observed at any other site. The difference in available cadmium at Plenty may be due to the fact that it has a greater total amount of naturally occurring cadmium than the other soils, which became more available as more manure was added.

In summary, total and available soil copper and zinc either increase or remain unchanged as manure fertilizer rates are increased. Total and available soil cadmium generally remains unchanged as manure fertilizer rates are increased. Future work will look at the levels of these elements found in grain and straw grown on the same plots.

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Tables

Table 1 Total and available soil copper, zinc, and cadmium at Dixon under varying hog effluent treatments.†

Treatment	Copper		Zinc		Cadmium	
	Total ‡	Available§	Total¶	Available#	Total ††	Available‡‡
	mg kg^{-1}					
37,000 L ha^{-1}	16.41 a	2.18 b	74.74 a	2.93 ab	0.37 a	0.24 a
74,000 L ha^{-1}	16.85 a	2.47 ab	72.08 a	2.88 ab	0.41 a	0.24 a
148,000 L ha^{-1}	16.94 a	2.64 a	76.36 a	3.60 a	0.39 a	0.24 a
Urea, 112 kg N ha^{-1}	15.48 a	2.16 b	71.20 a	2.29 b	0.40 a	0.25 a
Disturbed Check	15.64 a	2.11 b	72.09 a	2.28 b	0.38 a	0.22 a

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD= 1.50
§ LSD= 0.39
¶ LSD=8.53
# LSD=0.77
†† LSD=0.09
‡‡ LSD=0.03

Table 2 Total and available soil copper, zinc, and cadmium at Dixon under varying cattle manure treatments.†

Treatment	Copper		Zinc		Cadmium	
	Total ‡	Available§	Total¶	Available#	Total ††	Available‡‡
	mg kg^{-1}					
7.6 tonnes ha^{-1}	18.42 b	2.69 b	78.04 a	3.73 b	0.41 a	0.24 ab
15.2 tonnes ha^{-1}	18.53 b	3.69 a	76.50 a	5.35 a	0.41 a	0.26 a
30.4 tonnes ha^{-1}	19.82 a	3.81 a	75.23 ab	6.05 a	0.40 a	0.24 ab
Urea, 112 kg N ha^{-1}	16.60 c	2.56 b	70.95 b	2.59 bc	0.37 a	0.25 ab
Disturbed Check	16.89 c	2.29 b	73.71 ab	2.06 c	0.41 a	0.22 b

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD=1.12
§ LSD=0.71
¶ LSD=5.48
# LSD=1.15
†† LSD=0.07
‡‡ LSD=0.04

Table 3 Total and available soil copper, zinc, and cadmium at Riverhurst under varying hog effluent treatments.†

Treatment	Copper		Zinc		Cadmium	
	Total ‡	Available§	Total¶	Available#	Total ††	Available‡‡
	mg kg^{-1}					
37,000 L ha^{-1}	9.03 a	1.48 a	55.87 ab	3.19 a	0.28 a	0.18 a
74,000 L ha^{-1}	9.15 a	1.71 a	57.95 a	4.04 a	0.28 a	0.19 a
Urea, 80 kg N ha^{-1}	7.78 b	1.13 b	53.47 ab	1.02 b	0.21 a	0.17 a
Disturbed Check	7.69 b	1.06 b	51.62 b	0.95 b	0.29 a	0.18 a

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD=0.52
§ LSD=0.27
¶ LSD=5.35
# LSD=0.93
†† LSD=0.14

‡‡ LSD=0.04

Table 4 Total and available soil copper, zinc, and cadmium at Plenty under varying hog effluent treatments.†

	Copper		Zinc		Cadmium	
Treatment	Total ‡	Available§	Total¶	Available#	Total ††	Available‡‡
	mg kg^{-1}					
37,000 L ha^{-1}	28.46 ab	5.47 b	107.07 ab	2.11 b	0.49 a	0.17 b
74,000 L ha^{-1}	29.59 a	6.43 a	113.60 a	5.22 a	0.51 a	0.19 a
Urea, 80 kg N ha^{-1}	27.71 b	5.12 b	104.00 b	0.79 c	0.43 a	0.17 b
Disturbed Check	27.92 b	5.49 b	106.78 b	0.91 c	0.54 a	0.17 b

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD=1.49
§ LSD=0.58
¶ LSD=6.68
# LSD=0.92
†† LSD=0.13
‡‡ LSD=0.01

Table 5 Total and available soil copper, zinc, and cadmium at Melfort under varying hog effluent treatments.†

	Copper		Zinc		Cadmium	
Treatment	Total ‡	Available§	Total¶	Available#	Total ††	Available‡‡
	mg kg^{-1}					
34,000 L ha^{-1}	21.66 a	1.61 a	73.18 a	2.82 a	0.35 a	0.21 a
67,000 L ha^{-1}	20.95 a	1.76 a	72.00 a	2.88 a	0.40 a	0.21 a
Urea, 80 kg N ha^{-1}	20.83 a	1.71 a	73.59 a	2.50 a	0.36 a	0.22 a
Disturbed Check	21.18 a	1.62 a	72.11 a	2.81 a	0.40 a	0.23 a

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD=1.40
§ LSD=0.23
¶ LSD=3.98
# LSD=0.42
†† LSD=0.09
‡‡ LSD=0.03

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