Long-Term Manure Application under Rain-fed and Irrigation Increases Cu and Zn in Forage

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Abstract

Copper and Zinc are essential micronutrients but at high levels could negatively affect plant growth. Long-term and residual effects of cattle manure application were studied on forage yield and Cu and Zn concentrations under rain-fed and irrigation. Experiment started in 1973 and continued till 2009. Cattle manure was applied at 0, 30, 60 and 90 Mg ha^{-1} under rain-fed and 0, 60, 120 and 180 Mg ha^{-1} under irrigation. One set of plots were subjected to continuous application of manure for 36 years (1973 – 2009), second set of plots were subjected to continuous applications for 30 years (1973-2002) followed by no application and third set of plots were under cultivation only for 14 years (1973–1986) followed by no application. Continuous manure application increased the Cu (5 to 49 mg kg^{-1}) and Zn (14 to 118 mg kg^{-1}) in forage. Copper and Zn contents were affected by the rate of manure application in some of the years where highest manure rate giving highest Cu and Zn in forage. Manure effect on yield was significant ($P<0.05$) for some of the years where lowest yields were recorded by the continuous highest manure application rate. Number of years of continuous manure application (14, 30 or 36 years) was significant for forage Cu and Zn contents where shortest length (14 years) recording significantly lower contents than 30 or 36 years. Long-term manure application suggests possible nutrient imbalances though the forage Zn and Cu contents did not reach to toxic levels in this study.

Key words: Manure rate, Manure application length, Phytotoxicity, Plant tissue analysis, Residual effect

Introduction

Copper and Zn are essential to both plants and animals to complete their life cycles. Animal manure is a good source of Zn and Cu, in addition to other plant macro and micronutrients. Addition of organic manure creates a situation where unknown quantities of micro-nutrients are added to soils since the base of applications would be the total N requirements for crops. When high levels of multi-elements are loaded to soils, synergistic and antagonistic interactions among elements are possible affecting crop growth and yield. Generally, at nutrient imbalance conditions some nutrient metal interactions synergistically reduce crop yields. Long-term application of cattle manure to forage crops causes tissue nutrient imbalances (Hao and Chang, 2003). The availability of Cu and Zn in soil mainly depends on pH, competing cations, sorption sites and phosphates. Excessive manure applications reported trace metal loading in soils (Benke *et al.*, 2008). Further long-term manure applications also provided evidence for build up total N, total P, NO_3-N, soil test P and electrical conductivity in soils (Indraratne *et al.*, 2009). Hence application of animal manure at required rates based on N to agricultural lands could increases Cu and Zn contents in soils to the levels higher than the plant requirements or even to the levels toxic to the plants. The objective of this study was to evaluate the manure application rate and length of manure application on forage yield and copper and zinc concentrations in forage grown under rain-fed and irrigation.

Materials and Methods

The experiment was conducted on a Dark Brown Chernozemic clay loam soil (Typic Haploboroll) at the Agricultural and Agri-Food Canada Research Centre in Lethbridge, Alberta, Canada, during 1973 to 2009. Details on the split-split plot design and soil properties were provided by Sommerfeldt and Chang (1985).

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Cattle feedlot manure was applied at 0, 30, 60 and 90 Mg ha^{-1} yr^{-1} under rain-fed and 0, 60, 120 and 180 Mg ha^{-1} yr^{-1} under irrigation. One set of plots were under continuous annual manure application for 14 years (1973–1986) followed by no application (1987-2009), second set of plots were subjected to continuous applications for 30 years (1973-2002) followed by no application (2003-2009) and third set of plots were subjected to continuous application of manure for 36 years (1973 - 2009). Hence 3 manure application durations, namely 36 years, 30 years and 14 years were considered in this study. Barely or corn forage were harvested for making silage each year.

Archived samples collected in 1998, 2000, 2001, 2002, 2003, 2007, 2008 and 2009 were used for determination of forage yields and total Cu and Zn concentrations in forage tissues. Yield data were available only for 1998, 2003, 2007, 2008 and 2009 under rain-fed and 1998, 2000, 2001, 2003, 2007, 2008 and 2009 under irrigation. In years 2000 and 2001 yield data in rain-fed treatments were not accounted due to drought and 2002 yield data not accounted due to hail damage. The total Cu and Zn contents were determined for all years except for 2001 rain-fed due to total loss of forage. Forage samples were analysed using 0.25g fine ground sample digested with 5 mL 50% HNO_3 and 2 mL 30% H_2O_2, digested for 1 hr at 90 °C while adding another 2 mL 30% H_2O_2 in half way. Samples were brought to 50 mL, filtered and Cu and Zn concentrations measured using an atomic absorption spectrometer.

Separate statistical analyses were performed for non-irrigated and irrigated treatments using the MIXED procedure in SAS for the analysis of variance (ANOVA).

Results and Discussion

Forage yield was significantly affected by irrigation giving higher yield under irrigated than under rain-fed conditions (Table 1). Manure effect on yield was significant for 4 out of 8 studied years and lowest yields were recorded by the continuous highest manure application rate (36 years at 180 Mg ha^{-1} yr^{-1}). Building up of large quantities of soluble salts in manure treatments (Hao and Chang, 2003) could have been the possible reason for the decline in yield. Copper concentrations in forage range from 5 to 49 mg kg^{-1} and Zn concentrations range from 14 to 118 mg kg^{-1}. The presence of Cu and Zn in excess can induce iron (Fe) and manganese (Mn) deficiencies in plants, aggravating the degree of phytotoxicity. Therefore, nutrient imbalances also could have contributed for yield decline in highest manure rate treatments. Copper contents were affected by rate of manure application in 3 out of 8 years whereas Zn content affecting 6 out of 8 years (Table 1). Highest manure rate applied contributed for highest Cu and Zn contents in forage. Forage Cu contents ranged from 5 to 37 mg kg^{-1} under rain-fed and 5 to 49 mg kg^{-1} under irrigated treatments over the years. Highest manure rate applied for longest period gave highest Cu in forage. Copper and Zn loadings in soils were calculated based on average Cu and Zn concentrations in manure and number of years of manure applications. Accordingly, 3 to 60 kg of Cu under rain-fed and 10 to 114 kg of Cu under irrigated were loaded in soils over the years of cultivation. Similarly, 33 to 420 kg of Zn under rain-fed and 66 to 808 kg of Zn under irrigated were also loaded in soils. Forage Cu contents did not correspond to the Cu loadings in soils. Zinc contents in forage vary from 14 to 93 mg kg^{-1} under rain-fed and 15 to 118 mg kg^{-1} under irrigated as a result of heavy Zn loadings occurred in soils over the years. Highest Zn contents showed in the highest manure rate, but the Zn content in silage is below the toxic limits reported for other crops (Macnicol and Becket, 1985).

Table 1. Probability values indicating statistical significance of irrigation type (rain-fed and irrigated) and manure effect (four manure rates and residual manure effect corresponding to each manure rate) on forage yield and Cu and Zn contents in forage

	1998	2000	2001	2002	2003	2007	2008	2009
forage yield (Mg/ha)								
Irrigation (I)	0.000	ND#	ND	ND	0.001	0.000	0.000	0.005
Manure (M)	NS*	0.002	0.026	ND	0.044	NS	0.007	NS
I x M	0.011	ND	ND	ND	NS	NS	NS	NS
Rain-fed -M	0.005	ND	ND	ND	0.044	NS	0.007	NS
Irrigated -M	NS	0.002	0.026	ND	NS	NS	NS	NS
Cu (mg/kg)								
Irrigation (I)	NS	0.000	ND	0.034	NS	NS	NS	NS
Manure (M)	0.000	NS	0.000	0.032	NS	NS	NS	NS
I x M	0.000	NS	ND	NS	NS	NS	NS	NS
Rain-fed -M	0.000	NS	0.000	0.011	NS	NS	NS	NS
Irrigated -M	0.000	NS	0.000	0.011	NS	NS	NS	NS
Zn (mg/kg)								
Irrigation (I)	NS	0.000	ND	0.030	NS	0.000	0.000	0.000
Manure (M)	NS	0.000	0.000	0.000	NS	0.000	0.000	0.000
I x M	NS	NS	ND	0.000	NS	NS	0.016	NS
Rain-fed -M	NS	NS	ND	0.000	NS	0.000	0.000	0.000
Irrigated -M	NS	0.000	0.000	0.000	NS	0.008	0.000	0.000

*non significance; # No data available or did not account due to high yield losses

Shortest length of manure application, *i.e.*, 14 years, showed lowest Cu and Zn in forage. No significant difference observed for Cu and Zn in forage between 36 years and 30 years of manure applications. It is clear from the results discontinuation of manure application after 14 years reduces the Cu and Zn contents in silage.

Yield reductions observed in highest continuous annual manure applications indicated nutrient imbalances. Forage Cu content increased with increasing manure applications for one-third of cropping events while that of Zn for two-third of events. Because of the high loading of Cu and Zn, high Cu and Zn uptake is possible leading to phytotoxicity. Maximum concentrations observed for Cu and Zn in plants were lower than the values claimed for toxicity. Therefore, the soil pH, possible Cu-Zn interactions and other soil related factors such as high loading of P and development of soil salinity might be the possible reasons for low Cu and Zn uptake in plants in soils loaded with Cu and Zn.

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