Influence of Manure Application on Extractable Potassium in a Range of Prairie Soils

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ABSTRACT

Increasing use of animal manures in Saskatchewan requires information on the effect of manure addition on soil K availability. To address this issue, we examined the effects of repeated application of liquid and solid manure at low and high rates on extractable potassium in soils from four different long-term field trials in Saskatchewan and on K uptake by plants growing on the soils. After four to seven years of manure application, extractable potassium in the soils was significantly increased, with Kelowna extractable K (0-15 cm) increasing from 500 - 600 kg K ha^{-1} to over 1,000 kg K ha^{-1} at medium to high rates of annual addition (6,000 - 10,000 gpa swine manure and 15 -30 T ha^{-1} cattle manure). The K concentration and uptake by the cereal crops was also increased.

INTRODUCTION

Potassium (K) is a major element for plant nutrition and livestock manures contain significant amounts of K (Fraser, 1985). Potassium, unlike nitrogen and phosphorus, causes no known off-site environmental problems when it leaves the soil system. It is not toxic and does not cause eutrophication in aquatic systems. The plant requirement for nitrogen is the primary consideration for land application of livestock manure (Gburek et al. 2000), and phosphorus has become a consideration recently, especially for manures rich in P (O'Dell et al. 1995). When only two elements are the primary consideration for manure application, it is quite possible that insufficient supply of some elements or accumulation of certain other elements in soils will occur. The fate of manure potassium has received relatively little attention. The objective of this study was to evaluate the effects of repeated applications of solid cattle manure and liquid swine manure on the amounts of extractable K at four different experimental locations in Saskatchewan.

MATERIALS AND METHODS

Experimental Locations and Designs

The main field experiment was conducted at the Dixon long-term manure application field trial in Saskatchewan. The soil at this site is a Black Chernozem (Cudworth association) which occurs on very gently slopping land. The soil has a loamy texture and is considered to be a land with good production potential (Saskatchewan Soil Survey 1989). Liquid swine and solid cattle manures have been applied at this site every year since the fall of 1996 (Mooleki et al., 2002). Application rates include a zero rate as control, and low, medium and high rates equivalent to approximately 100, 200 and 400 kg total N ha^{-1}. A treatment of urea at a rate of 200 kg N ha^{-1} was used as a comparison. The field plots are laid out as a randomized complete block design with 3 replicates. Swine manure is directly injected into the soil in all the trials with an additional placement method of broadcasted and incorporated at the low rate treatment.

Similar experiments were also conducted at three other locations - Plenty (Regina soil association), Riverhurst (Birsay soil association), and Melfort (Tiger Hills-Northern Lights association). At these sites, the manure was liquid swine manure and the trial consists of 2 rates, equivalent to about 150 and 300 kg total N ha^{-1}, along with a control. The history of manure application is 5 year at Plenty and Riverhurst (Grevers et al., 2002) and four years at Melfort (Mooleki et al., 2003). As with Dixon site, the controls in these trials received no fertilizer or manure application, and there is a treatment of urea only at 80 kg N ha^{-1} as comparison. The field plots were also laid out as a randomized complete block design with 3 replicates, and swine manure was directly injected into the soil.

Table 1. Some characteristics of soils at four locations

Experimental Site	pH	EC mS cm^{-1}	Organic C g kg^{-1}
Dixon	7.5	0.22	26
Melfort	6.8	0.14	38
Plenty	8.3	0.28	16
Riverhurst	7.1	0.18	15

Sampling and Analysis of Soil, Manure and Crop

Soil were sampled from each plot (0-15 cm) in the spring of 2003. Four cores from each plot were taken randomly and mixed thoroughly to get a composite sample. Visible crop residues were removed. After being shipped to the lab, soil samples were further air-dried, crushed, passed through 2-mm sieve, mixed, and stored at room temperature before analysis. Basic soil characteristics were measured on soil samples from the control plots that had never received manure. The pH was measured using saturated paste of the soil samples (Rhoades, 1982). Organic C was measured by dry combustion method using Leco carbon analyzer (LECO© Corporation, 1987). The amount of extractable K was determined by a modified Kelowna (KM) solution (Qian at al., 1994) and measured using atomic absorption spectroscopy (Varian SpectrAA 220). Selected soil characteristics are summarized in Table 1.

Table 2. Rates of total K added as liquid swine manure and solid cattle manure at the low, medium and high application rates from 1997 to 2003 growing seasons on Cudworth soil at Dixon site

Treatment	1997	1998	1999	2000	2001	2002	2003
	------	------	------	kg ha^{-1}	------	------	------
Swine Manure							
Low	38	36	49	51	44	56	37
Medium	77	72	99	102	88	112	74
High	154	144	198	204	176	224	148
Cattle Manure							
Low	127	134	85	99	41	160	51
Medium	253	268	170	198	82	320	102
High	506	535	340	396	164	640	204

The liquid swine manure was from a single-cell earthen storage unit, and was injected in the field in the fall of the year in October, just before freeze-up at 8 - 10 cm depth in bands at 30 cm spacing. The cattle manure was approximately one year old stockpiled cattle feedlot manure from pens that was collected and homogenized using a rototiller before application in the fall at the same time as the swine manure. Cattle manure was broadcasted and then incorporated into the soil by rototilling. Equipment was calibrated and manure applied by the Prairie Agricultural Machinery Institute. To determine the actual amount of nutrient applied in the field plots, several manure samples were collected during application and the rates of nutrients applied were then calculated based on the analysis. Manure samples were immediately chilled to 4°C before shipping to the laboratory where they were frozen and stored. The samples were allowed to thaw to room temperature shortly before analysis of nutrients. At Dixon site, we measured the total K in both swine and cattle manures using the leftover solution of acid-hydrogen peroxide digestion used for N and P measurements (Thomas et al. 1967), followed by determination of K using atomic adsorption spectroscopy (Varian SpectrAA 220). We calculated the rates of potassium applied as manure for the 1997 to 2003 growing seasons based on the concentration of manure-K measured and the application rate of manure product. The rates of total K as liquid swine manure and solid cattle manure at the low, medium and high application rates from 1997 to 2003 growing seasons at the Dixon site are reported in Tables 2.

Plant analysis was done on grain and straw at three of the locations - Dixon, Plenty and Riverhurst. Grain and straw yield were determined in each plot and straw and grain samples were ground for analysis. Plant K was measured by digesting plant tissue in sulfuric acid-peroxide using a temperature-controlled digestion block (Thomas et al. 1967), followed by flame emission spectrometry. Plant K concentration and uptake are expressed as grams of K per kilogram of straw or grain, and kilograms of K taken up per hectare of soil, respectively.

Statistical Analyses

Data for soil available K and plant K uptake as well as plant K concentration among treatments were examined statistically based on the least significant difference (LSD) using standard analysis of variance techniques and multiple comparison via the Walter-Duncan k-ratio procedure. Computations were performed by the GLM procedure (SAS 1985).

RESULTS AND DISCUSSION

Effect of Manure on Extractable K in Soil

After application of liquid swine manure for seven consecutive years, extractable K in soils at Dixon site was significantly increased and a linear relationship with rate was observed (Table 3). There was no significant difference between injected and boradcast/incorporate application methods. As expected, broadcasting and incorporating manure into the soil does not affect the extractable K in the manured surface soil as there is no volatization mechanism for K and runoff from the plots is negligible. Introduction of injection method is to avoid N loss from volatization (Mooleki et al., 2002). After seven years of cattle manure application, large increases in extractable K were also observed with the high rate of cattle manure resulting in a tripling of extractable K compared to the control (Table 3).

Table 3. Amounts of potassium extracted by Modified Kelowna solution in soils of 4 different locations after repeated annual manure applications.

Treatment	Dixon	Melfort	Plenty	Riverhurst
	---------- kg K ha^{-1} soil ----------			
Swine manure				
Control	572	570	551	421
Low rate	831	814	637	593
Low rate (B&I*)	775			
Medium rate	932	995	757	629
High rate	1125			
Urea only	545	540	507	429
LSD 0.10	130	137	96	135
Pr. > F	<0.10	<0.10	<0.10	<0.10
Cattle manure				
Control	647			
Low rate	975			
Medium rate	1177			
High rate	2057			
Urea only	689			
LSD 0.10	393			
Pr. > F	<0.10			

* B&I = broadcasted and incorporated into the soil; in all the other three treatments liquid swine manure was injected into the soil directly. Cattle manure was broadcast and incorporated.

Soil extractable K was also increased in the three other sites after shorter periods of amendment with liquid swine manure (Table 3). In the Melfort, Plenty and Riverhurst sites, the history of manure application was only 4 to 5 years, but the relationship of extractable K in manured soils with rates of application was similar to that in Dixon site where manure has been applied for 7 consecutive years. Similar results were reported with cattle (both solid and liquid) and liquid swine manures (Evan et al., 1977) even after just 2 successive years of treatments in a silt loam soil in Minnesota, USA. Cherney et. al. (2002) also showed increase in soil extractable K after dairy manure had been applied for 4 years in perennial grasses in a clay soil in New York, USA, but returned to initial level after 3 years of no further manure amendments as grasses will deplete soil K when no K is added to the soil. In a report by Neilsen et al. (1998), annual application of composted swine manure for 3 years increased extractable soil K relative to the control, and extractable K was lower if municipal biosolid was used. As expected, incorporating urea alone had no significant influence on extractable K in soil (Table 3).

Evans et. al. (1977) reported that application of solid and liquid cattle manure, and liquid swine manures for 2 successive years increased not only soil available K but also salt levels. However, this was not the case in our study. Even at the Dixon site where manure has been applied annually at low and high rates for 7 years, the EC in manure treatments was only 0.1 to 0.2 mS cm^{-1} higher than in untreated soils. One of the reasons may be that higher application rates were used in the study by Evans et. al (1977). The manure rates they used were at 224 (solid) and 636 (liquid) metric tons/ha (wet weight), and the highest rate we used was 60 (solid) and 153 (liquid) metric tons each year. In a study in which cattle manure was applied for up to 25 years in southern Alberta, Hao and Chang (2003) reported that long-term application of cattle manure led to salinity problems, and K salts were a contributor.

Effect of Manure on Plant K Concentration and Uptake

Potassium concentration in cereal straw was significantly affected by amendment with swine and cattle manure at all three locations where plant analysis was conducted (Table 4). Straw K concentration was much more sensitive to increasing K availability than grain K concentration. Cherney et. al. (2002) reported herbage K concentration increased after two years of manure application. In a study conducted by Neilsen et. al. (1998), addition of composted swine manure for 3 years did not increase the leaf K concentration in both Swiss chard and carrot plants.

A significant effect of manure application was observed in K uptake associated with both straw and grain (Table 5), which mostly resulted from yield increases related to manure application. In a study conducted by Evans et. al. (1977) from 1970 through 1974, application of solid beef, liquid beef and liquid hog manures for two successive years resulted in "luxury consumption" of K by corn plants after 2-4 years due to residual effects. At the Dixon site, increases in rate of manure applications led to increases in K uptake in both straw and grain, and this was more evident in cattle manure treatments, which produced the greatest increases in soil extractable K (Table 5).

Table 4. Potassium concentrations in cereal crops grown in 2003 at 3 different locations with a history of five to seven annual manure applications.

	Dixon site		Plenty site		Riverhurst site	
Treatment	Barley		Hard Red Spring wheat		CPS wheat	
	Straw	Grain	Straw	Grain	Straw	Grain
	g K kg^{-1} plant material					
Swine manure						
Control	15.6	5.1	22.6	3.6	13.5	3.7
Low rate	18.0	4.8	31.1	3.6	24.7	4.1
Low rate (B&I*)	17.9	4.9				
Medium rate	20.6	4.8	33.2	3.7	25.3	4.1
High rate	28.0	5.0				
Urea only	19.0	4.8	26.0	3.4	15.9	3.6
LSD 0.10	3.2	0.5	2.5	0.2	6.3	0.3
Pr. > F	<0.10	NS	<0.10	<0.10	<0.10	<0.10
Cattle manure						
Control	15.7	5.4				
Low rate	20.8	5.8				
Medium rate	20.5	5.9				
High rate	25.5	7.3				
Urea only	18.7	6.3				
LSD 0.10	4.1	0.6				
Pr. > F	<0.10	<0.10				

* B&I = broadcasted and incorporated into the soil; in all the other three treatments liquid swine manure was injected into the soil directly. Cattle manure was broadcast and incorporated.

Table 5. Crop potassium uptake (kg K ha^{-1}) at the three different locations.

Treatment	Dixon site Barley		Plenty site Hard Red Spring wheat		Riverhurst site CPS wheat	
	Straw	Grain	Straw	Grain	Straw	Grain
	---------- kg K ha^{-1} soil ----------					
Swine manure						
Control	12.4	7.5	47.6	6.1	24.6	6.7
Low rate	60.4	17.4	69.2	6.1	78.8	11.1
Low rate (B&I*)	51.4	16.3				
Medium rate	84.6	19.4	73.8	6.0	94.6	12.2
High rate	109	18.5				
Urea only	49.2	13.8	54.1	5.2	29.6	6.1
LSD 0.10	16.5	4.8	16.1	1.2	27.6	2.6
Pr. > F	<0.10	<0.10	<0.10	NS	<0.10	<0.10
Cattle manure						
Control	21.3	9.5				
Low rate	51.1	15.7				
Medium rate	69.3	20.0				
High rate	111	30.2				
Urea only	69.6	21.9				
LSD 0.10	20.2	5.7				
Pr. > F	<0.10	<0.10				

* B&I = broadcasted and incorporated into the soil; in all the other three treatments liquid swine manure was injected into the soil directly. Cattle manure was broadcast and incorporated.

CONCLUSION

Repeated application of liquid swine and solid cattle manure contributes to increases in extractable soil K and enhanced K uptake by plants grown on the soils. This impact is greatest when large amounts of manures are applied. The effect of manure application was more significant at the Dixon site where history of manure application is longer. Cattle manure resulted in the greatest increases in soil and plant K. Increase in extractable K in soil may influence availability of other cations due to competitive cation effects. This may result in plant material with high rates of K to Ca and Mg.

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