Surface Soil Nutrient Contents and Crop Yields after Four to Seven Annual Applications of Manure

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Introduction

The expansion of the swine and cattle livestock industries over the past ten years has led to an increase in effluent and solid manure to be land-applied.. This manure can be used as an effective compliment to commercial fertilizers if used in an agronomically and environmentally viable manner. There is an ongoing need to properly utilize manure supplies from large-scale intensive livestock operations (Chang and Janzen, 1996). This report is part of an ongoing series of studies initiated in 1996 (Dixon), 1998 (Plenty and Riverhurst) and 1999 (Melfort) to examine the impact of different rates and types of application of liquid swine manure and solid cattle manure (Dixon) on soil and crop response. This paper summarizes the crop yield response and impact on nitrogen and soil organic carbon from repeated field application of different rates of liquid swine manure in four soil-climatic zones in Saskatchewan. The paper also encompasses crop and soil responses for the field application of solid cattle manure at the Dixon site in Saskatchewan.

Materials and methods

The liquid swine manure and solid cattle manure study at Dixon has been ongoing since 1996. The Plenty and Riverhurst studies began in 1998 while the Melfort study began in 1999. The Dixon site is situated on a Black Chernozem (Cudworth Association) of loamy texture. The Melfort site is situated on a Gray-Black Chernozem (Kamsack Association) of loamy texture. The Plenty site is situated on a Dark Brown Chernozem (Regina Association) of heavy clay-clay texture while the Riverhurst site is situated on a Brown Chernozem (Birsay Association) of sandy-loam texture. The Riverhurst site is an irrigated site. The experimental design at Dixon is a randomized complete block design (RCBD) replicated four times. Test plots are 30 meter by 3meter strips for the swine manure plots and 3 meter by 3 meter squares for the cattle manure plots.

Experimental design at both Plenty and Riverhurst is the same RCBD, replicated three times and test plots are 30 meter by 6 meter strips. The experimental design at Melfort is RCBD, replicated four times. Test plots are 30 meter by 6 meter strips. Rates of manure and urea fertilizer for each site are summarized in Table 1. Liquid swine manure and solid cattle manure were applied in the previous fall (October 2002) at Melfort, Plenty and Riverhurst. A delayed flax harvest and the early onset of winter weather conditions made application of manure impossible at the Dixon site in the fall of 2002.

Table 1. Manure and Urea Fertilizer Application Regimes for the Growing Seasons at Dixon, Melfort, Plenty and Riverhurst, Where 1X is Considered an Agronomic or Recommended Annual Rate.

Dixon Hog Manure Site

Rate of Manure Application

Treatment		Rate						
		1997	1998	1999	2000	2001	2002	2003
Check	0 L ha^{-1}	0	0	0	0	0	0	0
Low	37,000 L ha^{-1}	1X	1X	1X	1X	1X	1X	1X
Medium	74,000 L ha^{-1}	2X	2X	2X	2X	2X	2X	2X
High	148,000 L ha^{-1}	4X	4X	4X	4X	4X	4X	4X
B&I Low 37,000 L ha-^{1}		1 B&I	1 B&I	1 B&I	1 B&I	1 B&I	1 B&I	1 B&I
Urea 100 kg ha^{-1}		U	U	U	U	U	U	U

Dixon Cattle Manure Site

Rate of Manure Application

Treatment		Rate						
		1997	1998	1999	2000	2001	2002	2003
Check	0 tonnes ha^{-1}	0	0	0	0	0	0	0
Low	7.6 tonnes ha^{-1}	1X	1X	1X	1X	1X	1X	1X
Medium	15.2 tonnes ha^{-1}	2X	2X	2X	2X	2X	2X	2X
High	30.4 tonnes ha^{-1}	4X	4X	4X	4X	4X	4X	4X
Urea 100 kg ha^{-1}		U	U	U	U	U	U	U

Plenty Hog Manure Site

Rate of Manure Application

Regime 6

Treatment		Rate				
		1999	2000	2001	2002	2003
Check	0 L ha^{-1}	0	0	0	0	0
Low	37,000 L ha^{-1}	1X	1X	1X	1X	1X
High	74,000 L ha^{-1}	2X	2X	2X	2X	2X
Urea 80 kg ha^{-1}		U	U	U	U	U

Riverhurst Irrigated Hog Manure Site						
Rate of Manure Application						
Regime 6						
Treatment		Rate				
		1999	2000	2001	2002	2003
Check	0 L ha^{-1}	0	0	0	0	0
Low	37,000 L ha^{-1}	1X	1X	1X	1X	1X
High	74,000 L ha^{-1}	2X	2X	2X	2X	2X
Urea 80 kg ha^{-1}		U	U	U	U	U

Melfort Hog Manure Site					
Rate of Manure Application					
Treatment		Rate			
		2000	2001	2002	2003
Check	0 L ha^{-1}	0	0	0	0
Low	37,000 L ha^{-1}	1X	1X	1X	1X
Medium	67,000 L ha^{-1}	2X	0	2X	0
Urea 80 kg ha^{-1}		U	U	U	U

Manure was applied in the spring of 2003, after soil samples were obtained. Note, that at the Melfort site, the medium manure treatment (2X rate) was not applied in the fall of 2002. At the Plenty and Riverhurst sites, urea was applied as a broadcast application in the spring of 2003, after soil samples were obtained.

Soil samples (0-15 cm soil depth) were obtained using PVC cores from each treatment plot at each site in the spring of 2003. Samples were transported back to the College of Agriculture, University of Saskatchewan for organic carbon, total nitrogen, nitrate-N, ammonium-N and sulfate analysis. Grain and straw yield samples were obtained at crop maturity in August 2003 and transported back to the College of Agriculture, University of Saskatchewan. Crop samples were threshed, cleaned and weighed to obtain grain and straw weights.

Results

Dixon hog manure

Six growing seasons of swine manure application showed no significant increases in total soil organic carbon (SOC) when comparing the hog manure and urea fertilizer treatments to the control plots (Table 2). Soil organic carbon concentrations were slightly higher in the low (2.9%), medium (2.8%) and high rate manure applications versus 2.6 % SOC for the control plots and 2.8% for the urea fertilizer plots. Total N concentrations followed a similar pattern as the SOC. All three rates of manure (low, medium and high)) and the urea fertilizer had higher total N concentrations as opposed to the control plot (4505 kg ha^{-1}). Total N for the low treatment (4928 kg ha^{-1}) and the urea fertilizer treatment were significantly ($p<0.10$) higher than the control plot.

Table 2. Spring 2003 soil data for Dixon swine manure site.

Treatment	Organic Carbon	Total N	NO_3-N	NH_4-N	SO_4-S
	-----(%)-----	----------------------------(kg ha^{-1})----------------------------			
	--(0-15 cm)--				
Check	**2.6**	**4505**	**8.8**	**9.2**	**25.4**
Low	**2.9**	**4928**	**22.6**	**9.0**	**19.3**
Medium	**2.8**	**4788**	**23.1**	**10.1**	**24.3**
High	**2.7**	**4783**	**32.0**	**6.6**	**38.6**
B&I Low	**2.6**	**4475**	**15.5**	**9.9**	**12.3**
Urea	**2.8**	**4827**	**18.8**	**9.5**	**39.1**
LSD $_{(0.10)}$	**0.4**	**474**	**5.2**	**2.6**	**27.4**

Nitrate-N levels for the manure and urea fertilizer treatments were all significantly higher than the control plots (Table 2). There was little difference in ammonium levels amongst the six different treatments. Sulfate levels varied among the treatments, although the high swine manure and urea treatments (38.6 and 39.1 kg ha^{-1}, respectively) showed the highest sulfate levels versus the control plots (25.4 kg ha^{-1}).

Swine manure application significantly increased barley grain yields (3708 kg ha^{-1}) when compared to the control plot grain yields (1570 kg ha^{-1}). Increasing swine manure application rate tended to decrease grain yield versus the low swine manure application rate (Fig. 1). There was no significant difference in grain yields when comparing the medium rate (3805 kg ha^{-1}) to the low rate.

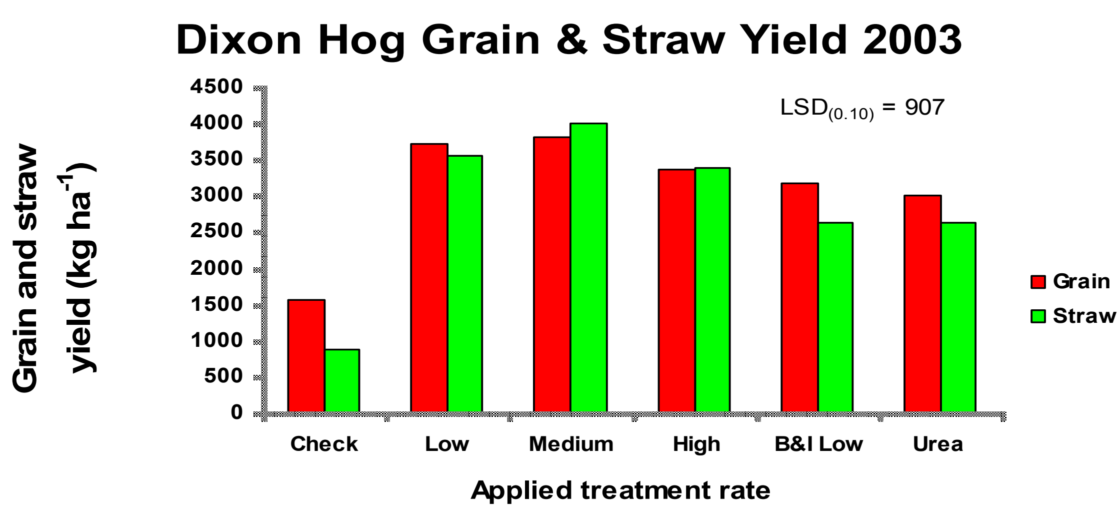

Figure 1. Grain and straw yield for the 2003 barley crop in the swine manure study at Dixon, SK.

Urea fertilizer produced a grain yield of 3000 kg ha^{-1}. This grain yield was approximately double the grain yield in the control plot but lower than the grain yield in the low (agronomic) rate of swine manure. The B & I swine manure application had a lower grain yield (3183 kg ha^{-1}) versus the three injected swine manure application rates.

Dixon cattle manure

Soil organic carbon levels in the Dixon cattle manure plots were significantly higher versus the cattle manure control plots (Table 3). The medium and high cattle manure applications had SOC values of 3.4 % each, which was significantly higher than the control plots SOC concentration of 3.0%.

Table 3. Spring 2003 soil data for Dixon cattle manure site.

Treatment	Organic Carbon	Total N	NO_3-N	NH_4-N	SO_4-S
	-----(%)-----	----------------------------(kg ha^{-1})-------------------------------			
	--(0-15 cm)-------------------------------------				
Check	3.0	5070	22.9	8.7	22.1
Low	3.2	5270	29.6	11.6	47.1
Medium	3.4	5609	29.2	8.6	25.1
High	3.4	5826	38.8	8.9	39.9
Urea	3.1	5203	34.9	8.3	51.3
LSD $_{(0.10)}$	0.3	554	16.4	2.8	54.4

Urea SOC values (3.1%) were only slightly above the control plot organic carbon values. Total N increased with increasing rate of cattle manure with the medium (5609 kg N ha^{-1}) and high (5826 kg N ha^{-1}) cattle manure rates significantly higher than the control plot (5070 kg N ha^{-1}). Nitrate-N levels increased with the increase in cattle manure treatments as opposed to the control plot. Sulfate levels in the cattle manure plots were highly variable, with the urea fertilizer treated plots showing the highest level (51.3 kg ha^{-1}) versus the control plots (22.1 kg ha^{-1}).

Increasing application rates of solid cattle manure resulted in significant ($p < 0.10$) increases in barley grain and straw yields when compared to the control plots (Fig. 2). The low cattle manure rate resulted in 2750 kg ha^{-1} of grain yield versus 1650 kg ha^{-1} in the control plots. Grain yields more than doubled in the medium (3680 kg ha^{-1}) and high (4040 kg ha^{-1}) cattle manure treated plots. Urea fertilizer plots produced a grain yield of 3000 kg ha^{-1}. Straw yields followed similar patterns to the grain yields (Fig. 2).

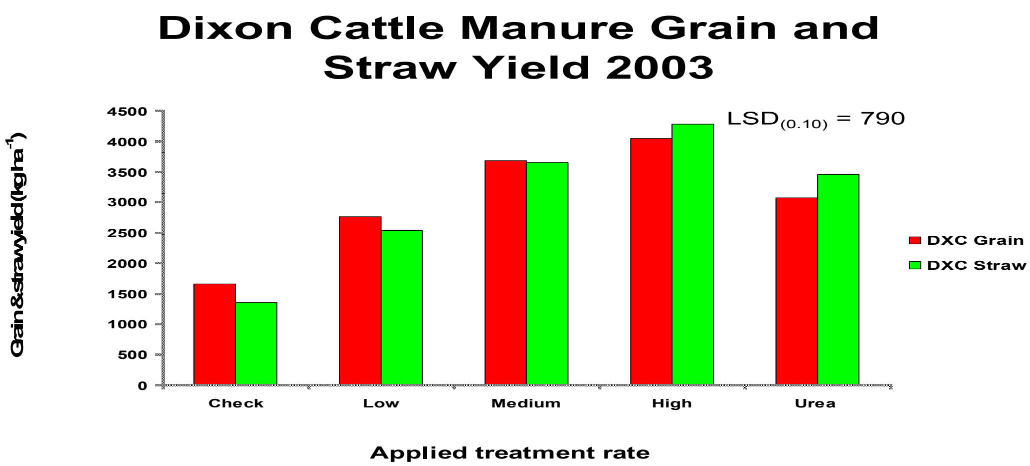

Figure 2. Grain and straw yield for the 2003 barley crop in the cattle manure study at Dixon, SK.

Melfort swine manure

Soil organic carbon levels in the Melfort swine manure treated plots were similar to the control plots (Table 4). However soil organic carbon levels in the urea fertilized plots (3.5%) were significantly lower than the control plots (3.8%). There were no significant differences in total N levels amongst the four treatments. Nitrate-N levels in the low rate manure plots were five times higher (42.5 kg ha^{-1}) than the control plots (8.5 kg ha^{-1}).

Table 4. Spring 2003 soil data for Melfort swine manure site.

Treatment	Organic Carbon	Total N	NO_3-N	NH_4-N	SO_4-S
	-----(%)-----	---------------------------(kg ha^{-1})------------------------------			
	--(0-15 cm)------------------------------------				
Check	**3.9**	**5966**	**8.5**	**8.0**	**2.0**
Low	**3.9**	**6061**	**42.5**	**10.1**	**3.0**
Medium	**3.9**	**5744**	**16.7**	**9.4**	**6.0**
Urea	**3.5**	**5503**	**13.2**	**10.0**	**1.0**
LSD $_{(0.10)}$	**0.3**	**697**	**8.5**	**1.6**	**3.7**

Despite no manure addition the previous fall, the medium manure treatment (16.7 kg ha^{-1}) is significantly higher than the control plot. The application of urea fertilizer increased nitrate from 8.5 (control plots) to 13.2 kg ha^{-1}. Ammonium levels were significantly ($p < 0.10$) higher in the low rate and urea plots versus the control plots (Table 4). Sulfate levels in the medium manure treatment were significantly higher (6.0 kg ha^{-1}) versus the control plot sulfate level (2.0 kg ha^{-1}). The urea fertilizer treatment sulfate level was half (1.0 kg ha^{-1}) of the control plots. Soil sulfate levels at this site are much lower compared to the other three soil sites in this study.

Application of manure at the low rate for the fourth consecutive year almost tripled canola seed production from 635 kg ha^{-1} in the control plots to 1783 kg ha^{-1} (Fig. 3).

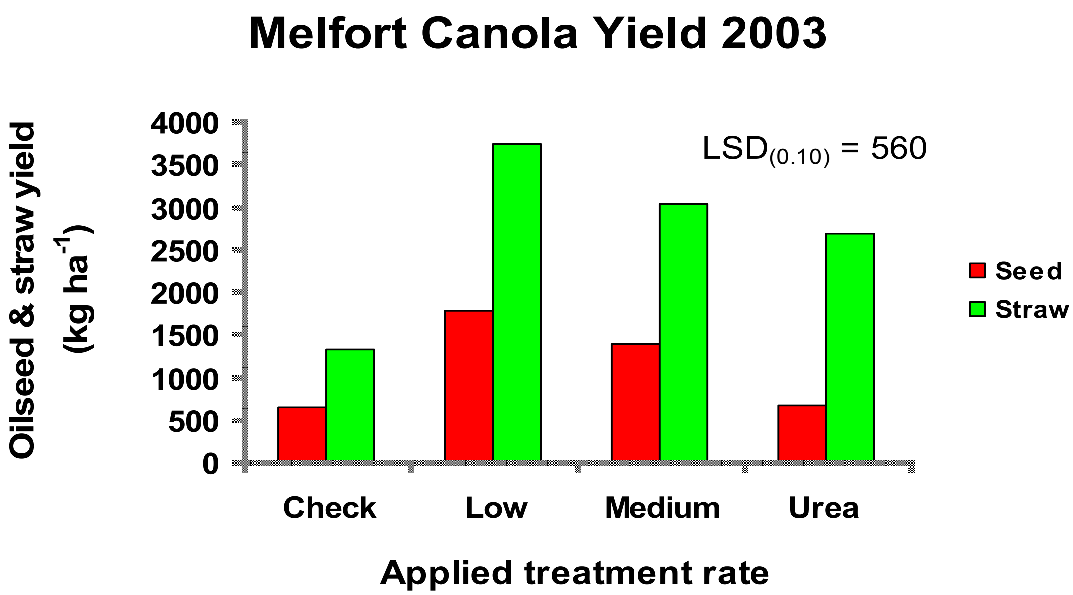

Figure 3. Canola seed and straw yield for the 2003 canola crop in the swine manure study at Melfort, SK.

Straw yield followed the same trend. The medium manured rate doubled (388 kg ha^{-1}) seed production, but urea fertilized plots produced the same amount of oilseed as the control plots due to sulfur deficiency.

Plenty swine manure

Both manure application treatments and the urea fertilizer significantly increased SOC levels from 1.6% in the control plots to 1.8 % for the three treatments (Table 5). Total N levels increased with increasing rate of swine manure compared to the control plots (3079 kg ha^{-1}).

Table 5. Spring 2003 soil data for Plenty swine manure site.

Treatment	Organic Carbon	Total N	NO_3-N	NH_4-N	SO_4-S
	-----(%)-----	-----------------------------(kg ha^{-1})--------------------------------			
	--(0-15 cm)------------------------------------				
Check	1.6	3079	21.3	10.2	6.5
Low	1.8	3477	73.2	11.1	32.2
High	1.8	3503	100.1	9.9	36.0
Urea	1.8	3323	31.4	9.6	15.5
LSD $_{(0.10)}$	0.1	236	17.9	2.3	14.4

Urea fertilizer treatment total N was also significantly higher (3323 kg ha^{-1}) than the control plots. Surface soil nitrate-N levels increased 4 to 5 times after five years of swine manure application versus the control plots (Table 5). Urea nitrate-N levels (31.4 kg ha^{-1}) were similar to the control plots (21.3 kg ha^{-1}). There were no significant differences between ammonium levels amongst the four treatments. Sulfate levels were approximately five times higher for the two manure treatments compared to the control plots.

There were no significant differences in wheat grain and straw yields amongst the four treatments at this site. The medium swine manure treatment grain yield (1817 kg ha^{-1}) was slightly higher than the control plot mean yield of 1720 kg ha^{-1} (Fig. 4).

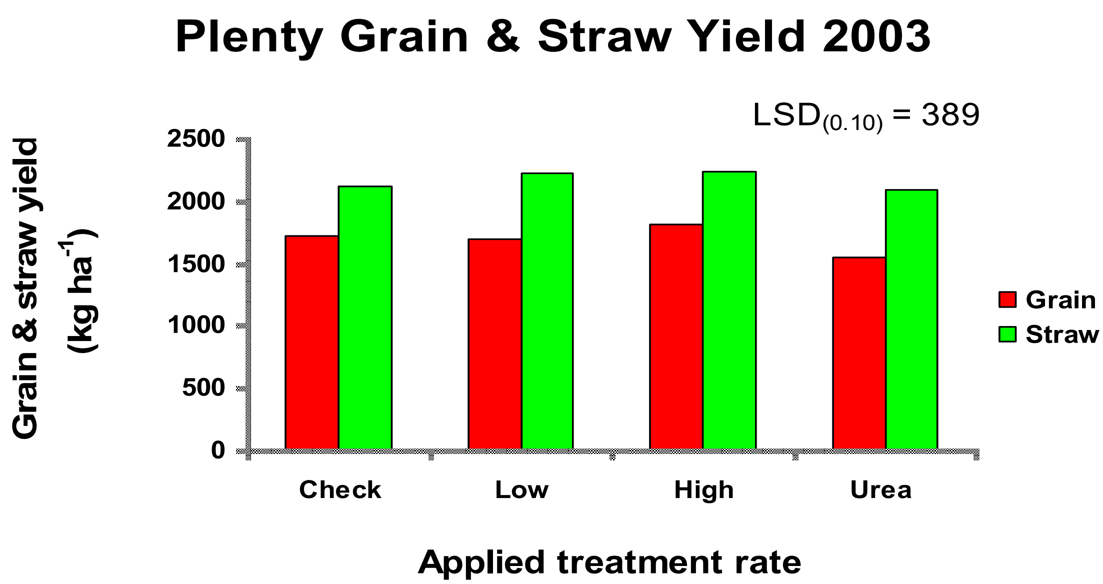

Figure 4. Grain and straw yield for the 2003 spring wheat crop in the swine manure study at Plenty, SK.

Riverhurst swine manure

There were no significant differences in SOC amongst the four treatments at this site. Total N levels increased significantly with the addition of swine manure compared to the control plots level of 2883 kg ha^{-1} (Table 6). Nitrate-N levels increased with added swine manure compared to the control plots. The low and high swine manure treatments (36.0 and 43.8 kg ha^{-1}, respectively) were significantly higher than the control plots nitrate level of 24.9 kg ha^{-1}. As with the other sites, there were no significant differences in ammonium levels. Sulfate levels were double (20.8 kg ha^{-1}) in the manured plots compared to the control plots (10.5 kg ha^{-1}) (Table 6).

Table 6. Spring 2003 soil data for Riverhurst (Irrigated) swine manure site.

Treatment	Organic Carbon	Total N	NO_3-N	NH_4-N	SO_4-S
	-----(%)-----	----------------------------(kg ha^{-1})-------------------------------			
	--(0-15 cm)------------------------------------				
Check	**1.5**	**2883**	**24.9**	**9.9**	**10.5**
Low	**1.6**	**3204**	**36.0**	**7.5**	**20.8**
High	**1.5**	**3330**	**43.8**	**7.7**	**20.8**
Urea	**1.5**	**3069**	**25.1**	**7.8**	**9.2**
LSD $_{(0.10)}$	**0.1**	**269**	**9.2**	**1.4**	**8.9**

CPS wheat grain and straw yields increased significantly in the manured plots versus the control plots (Fig. 5). The low and high manure treatments produced 2737 and 2957 kg ha^{-1} of grain respectively, as opposed to 1803 kg ha^{-1} of grain produced in the control plots. The urea fertilizer plots produced grain yield similar to the control plots (Fig. 5).

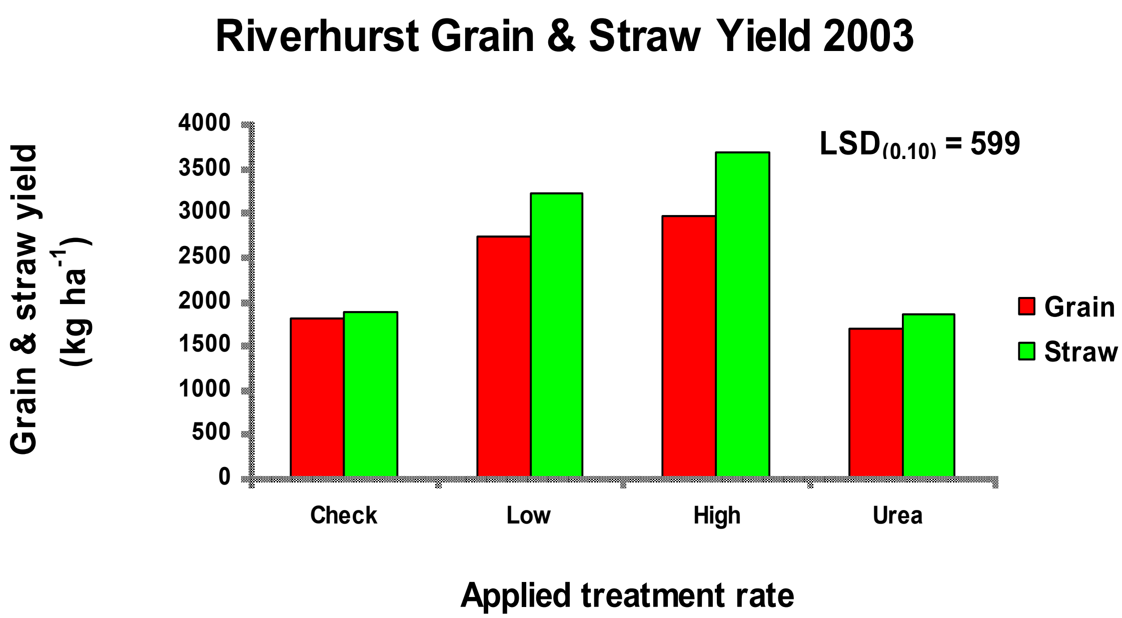

Figure 5. Grain and straw yield for the 2003 CPS wheat crop in the swine manure study at Riverhurst, SK.

Discussion

Dixon swine manure

The increase in soil organic carbon levels in the manured plots was probably due to the increase in above and below ground plant biomass produced as a result of the fertilizing effect of the manure. Most of the nitrogen in the liquid swine manure is in an inorganic form, and is therefore available for plant uptake (Schoenau et al., 2000). Total N concentrations followed similar patterns as the SOC with the greatest apparent accumulation of organic N was in the low 1X agronomic rate treatment. The lack of difference in ammonium levels among the treatments was probably due to nitrification to nitrate and/or plant uptake. The variance in sulfate levels likely reflects high variability in sulfate-S across the plot area. Generally, sulfur deficiency is not a problem at the Dixon site due to high levels of subsoil sulfate-sulfur.

As in previous years, grain yield tended to be highest in the low rate (1X or 100 kg N ha^{-1}) treatment. Grain yields decreased in the high swine manure treatment versus the other two manure treatments due to a toxicity effect of the manure. Manure was applied in spring 2003 so there could have been a salt effect and ammonium toxicity effect on the crop that aggravated crop growth in the high manure rate plots.

Dixon cattle manure

The increase in soil organic carbon levels in the cattle manured plots are probably due to the cumulative effect of adding organic matter directly as manure. The increase in SOC could also be attributed to stimulated plant growth and residue addition. The nitrogen availability is increasing with increasing rate of repeated manure application and this follows a similar pattern to the increases in grain yields. It is speculated that the mineralization potential of N has been greatly enhanced in the cattle manured plots by repeated addition of organic N. Cattle manure has a relatively high C:N ratio which can initially cause immobilization of nitrogen (Mooleki et al., 2001), but eventually as the C:N ratio narrows with decomposition, mineralization can take place releasing plant available N. Sulfate levels were higher in the cattle manured plots and urea fertilized plots. Grain and straw yields in the cattle manured plots increased with increasing rate of cattle manure application, probably due to the cumulative effect of increasing availability of nitrogen.

Melfort swine manure

No significant effect of swine manure addition on SOC at this site may be explained by the shorter time period of study (4 years) and the fact that the site has relatively high soil carbon levels. Furthermore, addition of N may have stimulated microbial activity and organic matter decomposition. Lower organic C and organic N in the urea treatment compared to the control may be explained by low yields due to sulfur deficiency and enhanced microbial decomposition. Total N and nitrate-N levels in the medium rate manured plots are lower due to the fact that manure was not applied in the previous fall (2002). Despite these plots not having received any swine manure for over 1.5 years (last application was in fall 2001), nitrate levels are still double that of the control plots.

The annual application of the low swine manure treatment resulted in significantly higher oilseed yields. The residual effect of the medium rate produced double the grain yield of the control plots. Sulfur deficiencies were likely the cause of very low canola seed yields in the urea fertilized plots compared to the control plots (Schoenau et al., 2003).

Plenty swine manure

The increase in soil organic carbon levels in the manured plots was probably due to the fertilizing effect that the swine manure has had on plant biomass production. This site is a heavy clay soil with low amounts of SOC, and thus has the capability of accumulating and storing increased supplies of carbon (Mensah et al., 2003). Most of the total N is organic and the increase in total N levels is consistent with an increase in soil organic N as well as inorganic N. Soil nitrate levels are increasing with increasing rate of swine manure. This heavy clay soil has experienced drought the last two years, with no yield in 2002. There is little leaching occurring on this soil so nitrate supplies are building up in the soil. The previous two crop years have seen the effects of drought and grasshoppers, resulting in little to no crop production and leaving the site in a "summer fallow" state. Sulfate levels are quite high in the manured plots and could be due to high levels of sulfate in the manure. This could be a result of the swine diet or related to high levels of sulfate in the water source.

Climatic conditions over the past two years has had an effect on the production of grain at this site. Nitrate levels are high due to little previous crop uptake and the lack of leaching due to the heavy soil texture and little moisture received at this site, thus explaining the general lack of yield response in 2003. Other nutrient levels could also be high due to little crop uptake over the previous two years as a result of moisture limitations. Urea fertilized plots could be producing less grain due to the spring surface broadcast application of fertilizer.

Riverhurst swine manure

Soil organic carbon levels could be low at this site due to the inherent low organic matter (Brown soil zone) and the fact that previous crops (beans in 2002) have added little crop material, to be incorporated back into the soil. As well, the producer at this site has removed straw materials after harvest operations, thus leaving little material to be incorporated back into the soil. Organic N is building up in these soils from swine manure application and nitrate-N levels are higher. This would explain grain yield response to manure. Sulfate levels have significantly increased in the manured plots and could be due to the high sulfate levels in the water used in the swine barn. Neither the Riverhurst or Plenty site has ever shown evidence of sulfur deficiency.

Grain production in the urea plots was lower than the other plots and could be due to the surface broadcast application of the fertilizer. This is an inefficient practice and the fertilizer could have been lost due to volatilization since it was not incorporated until seeding.

Conclusion

Repeated additions of swine manure increased soil organic carbon and nitrogen in the surface soils at the four study sites. These increases in soil organic carbon could be attributed to the fertilizer effect on increased biomass production which would add organic C and N. Increase in SOC in the cattle manured plots could be due to the high amount of organic matter contained in the manure that has had a direct additive effect on adding more organic nutrient to the soil. Grain and straw yields at all four sites increase with the addition of liquid swine manure and solid cattle manure in line with increases in soil available N. Yield responses were greatest at Dixon and Melfort with greater moisture and lower soil available N in controls. The yield response at Plenty was held suppressed to high residual supplies of nitrogen.

Acknowledgement

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