Soil Conditions and Early Crop Growth as Influenced by Repeated Swine Manure Application

Mitchell T. Japp[1], J.J. Schoenau[1], M.C.J. Grevers[1] and L. Bohrson[2]

[1] Department of Soil Science, University of Saskatchewan, Saskatoon, SK, S7N 5A8
[2] Irrigation Crop Diversification Corporation/Saskatchewan Agriculture, Food and Rural Revitalization, Box 1088, Swift Current, SK, S9H 3X3

Key Words:

Manure, soil strength, soil resistance, soil crust, emergence, penetrometer,

Abstract

Previous research on land applications of manures has focused on soil fertility and the relationship to final crop yield, but there is little research that quantifies the effects of changes in soil physical and chemical properties on early crop development that may ultimately be a factor in determining final yield. Surface crusting, sealing and soil strength may have significant impacts on crop emergence and early root growth that may explain final grain yield differences in some years. Research was carried out at Dixon, Saskatchewan in 2003 to examine the effect of manure addition on soil physical and chemical parameters important to crop emergence and early root development. The effects were then related to field observations made on emergence and root development of barley. This paper covers the results of this study.

Introduction

The livestock industry has always been important to Saskatchewan agriculture. It is often a topic of discussion because animals are concentrated into feedlots and large hog barns. Over 1.25 million hogs (SAFRR, 2003a) and 3.2 million cattle (SAFRR, 2003b) produce 6400 tonnes and 66800 tonnes of manure respectively per day (Bennett and Olson, 1996). The economics of transporting manure are poor due to a high concentration of animals in a small area and low nutrient concentration of manure. Therefore, large quantities of manure are applied to a small land base near the barn or feedlot. Sound manure management practices must be used to ensure that the soil and environmental quality is preserved.

Agricultural producers use the manure as a nutrient source because it is inexpensive and provides a suite of nutrients. In addition to fertility, manure also has the potential to affect soil physical and chemical properties. Research has shown changes to have occurred in light fraction organic carbon (King, 2002), aggregate size, aggregate stability, infiltration and crust strength (Assefa, 2002). Some small changes have occurred in salinity and pH (Assefa, 2002), but not beyond critical limits. These studies have been strictly directed at the soil. This study will attempt to determine how these factors affect early plant growth.

Properties of Manure

Animal effluent has been traditionally evaluated on the basis of fertility and the economics of acquiring it as a nutrient source. Manure has a low nutrient concentration and must be applied in large volumes order to meet plant demand.

Producers can apply all macronutrients and many micronutrients through manure, but are limited by the ratio of nutrients in the manure. Cattle manure in particular has a low N:P ratio when compared with a higher N:P ratio required by many crops. The result is an N deficiency if only P requirements are met and P loading if N requirements are met. Therefore, manure should be viewed as a compliment to inorganic fertilizer, not a replacement.

Manure has one additional benefit beyond a strictly inorganic fertilizer application. The organic nutrients in a manure application will be released slowly throughout the growing season. Because organic nutrients are released slowly and do not leach, N is available for the crop until late in the growing season which can increase grain protein and ensures late season N deficiencies will not occur (Mooleki et al., 2002; Wen et al., 2003).

In addition to improved crop growth, manure has been found to alter the soil physical and chemical environment. Results have been variable, depending on location and manure source. King (2002) observed an increase in soil light fraction organic carbon. Assefa (2002) observed increases in aggregate stability, decreases in crust strength, decreased bulk density, increased SAR (sodium adsorption ratio), decreased crust strength and variable effects on EC (electrical conductivity) and aggregate size in swine and cattle manure application study sites. Electrical conductivity is a measurement of soil salinity and SAR is a measurement of soil sodicity. Increases in EC and SAR and decreases in aggregate size were reported on hog manure sites (Zeleke, 2003). However, the EC and SAR values were not beyond the critical limit in either study.

The conclusions from these studies would suggest that earlier concerns expressed by Weiterman *et al.* (2000) are worth noting. Weiterman *et al.* (2000) suggest that manure management should be based on the threat of sodicity. Although the studies by Assefa (2002) and Zeleke (2003) did not find any changes to soil physical or chemical environment, care must be taken as small but significant increases in EC and SAR did occur sometimes.

Sodium salts added to the soil via manure application are a potential problem. Sodium is a monovalent cation with a large hydrated radius relative to calcium, a divalent cation. Due to the large hydrated radius of sodium, fewer ions can adsorb to clay particles. Sodium is only moderately effective at reducing the negative charge of clay, causing clay particles to repel, disperse and deflocculate. Alternatively, calcium ions are much more effective in reducing the negative charges on clay particles, thereby promoting clay flocculation and soil aggregation (Henry et al., 1987). Deflocculation leads to surface sealing after rainfall, which increases soil strength and produces harder soil crusts, making crop emergence more difficult. Conversely, the nutrients contained in manure increases biomass return to the soil, in addition to direct organic matter inputs from manure have the potential to increase soil organic matter. There is a contrasting interaction between organic matter and sodium, as the former can increase aggregate size and stability, while the latter can decrease the same.

The relationship between the changes in physical properties from manure application and early crop growth and development has not been studied yet. Manure has been shown to decrease crust strength (Assefa, 2002), but has the potential to increase it as well due to sodium salt addition. The main concern is whether or not the crop will successfully emerge and become established. Literature suggests that crust development decreases with increases in organic matter (Nuttall, 1970) and soil crusts are inhibitory to plant emergence.

Approach

The main research site is at Dixon, Saskatchewan and has limited potential for salinity and sodicity problems as the soils are well drained and the manure is low in sodicity. Hog barns using water from the Judith River formation, which has a total dissolved solids of 3000-4000ppm, have a greater potential for environmental damage (Whitaker, 1976). Soil samples are taken from the Dixon field research site as well as some fields that have had manure and irrigation waters applied from highly saline and sodic water sources in order to quantify crust strength under these conditions.

Soil strength was quantified in the field at 5, 10, 15 and 20cm depths in 2003 because this would reflect limitations to root growth at these depths (Lowery and Morrison, 2002). Corresponding measurements of plant emergence were taken to address the concern of crusting. Similar measurements were taken in the lab after a simulated rainfall on undisturbed cores. Only crust strength was measured.

Soil Penetration Resistance – Field Study

The Dixon site is a loam textured soil in the Black soil zone, of the Cudworth soil association. Swine manure has been applied at this research site from a earthen storage unit since 1997, in a randomized block design, replicated four times. The crop in 2003 was barley. The four treatments of interest are:

1) Disturbed Check. No manure or fertilizer applied. The coulters are run through the ground to give this treatment the same disturbance as the hog manure treatments.

2) 1x Treatment: The agronomic rate applied is based on the fertility analysis of the manure and estimated crop uptake. 37,000L ha^{-1} which adds 70 – 100kg N ha^{-1} yr^{-1}. Injected using low disturbance coulters.

3) 4x Treatment. Four times greater than the agronomic rate is applied, which is an excessive rate to see potential for damage from over-application. 148,000 L ha^{-1} which adds 280 – 300kg N ha^{-1} yr^{-1}. Injected using low disturbance coulters.

4) Fertilized Treatment. Urea fertilizer banded at 100kg N ha^{-1} yr^{-1}.

Soil strength was measured on May 28 and June 16, 2003 using a recording cone penetrograph, taking 5 sub-samples in each plot. The penetrograph measures the resistance to penetration on a card, giving a log of the soil strength in relation to depth. It is important to note that the soil resistance is related to soil moisture. Resistance increases with decreases in soil moisture (Lowery and Morrison, 2002). Therefore, gravimetric soil moisture was taken at each sampling location. The resistance at 5, 10, 15 and 20cm was assessed and analyzed using least squares means on the SAS program with moisture as a covariant.

Convention seems to indicate that at a soil strength of 2.0MPa root growth inhibition begins. However, this varies depending on crop and soil type. Taylor et al. (1966) found that 2.5MPa was the extreme limit at which no roots penetrated, while at 1.9MPa, root penetration was good.

Crop emergence was measured at the 2-3 leaf stage using $0.25m^2$ quadrats. Five sub-samples were taken.

The May 28 (Figure 1) sampling is likely most representative of the soil strength conditions as it would affect plant growth, as affected by the manure before the impact of differential plant growth between treatments. The control treatment consistently had the highest resistance, although differences were not significant at the 10cm depth. At the 15 and 20cm depths the control treatment was significantly higher than only that of the high rate of manure.

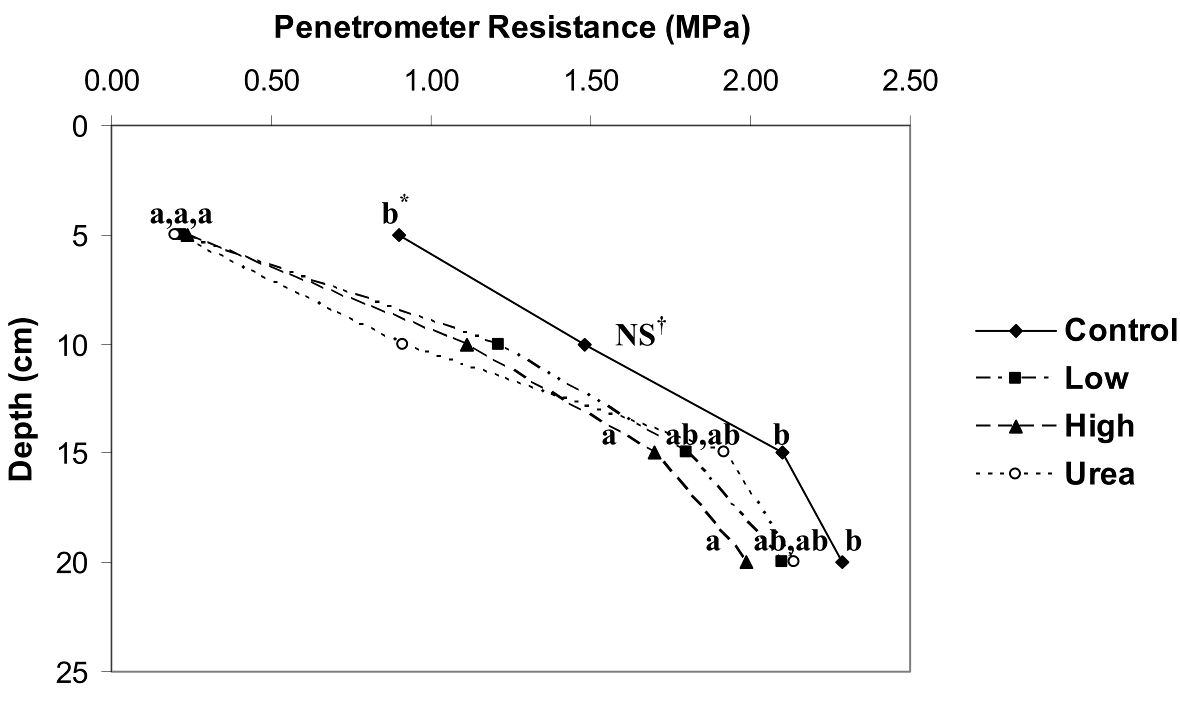

Figure 1. The soil penetration resistance in four treatments on May 28, 2003 at four different depths in a barley crop at Dixon, SK.

* Points with the same letter are not significantly different at the 90% confidence level.
† No points are significantly different.

Since 1997, the control treatment has had reduced crop biomass due to declining fertility (Mooleki et al., 2002). The difference in the amount of biomass returned to the soil and lower organic matter (King et al., 2004) could explain why the control treatment had significantly higher soil strength. In support of this concept, the manure treatments also never significantly differed from the urea treatment.

The June 16 (Figure 2) sampling shows results from a later time after crop growth in the plots (Figure 1). The low rate of hog manure had the greatest resistance at the 15 and 20cm depths. Both the low hog manure and the urea were significantly higher than the control at the 5 cm depth.

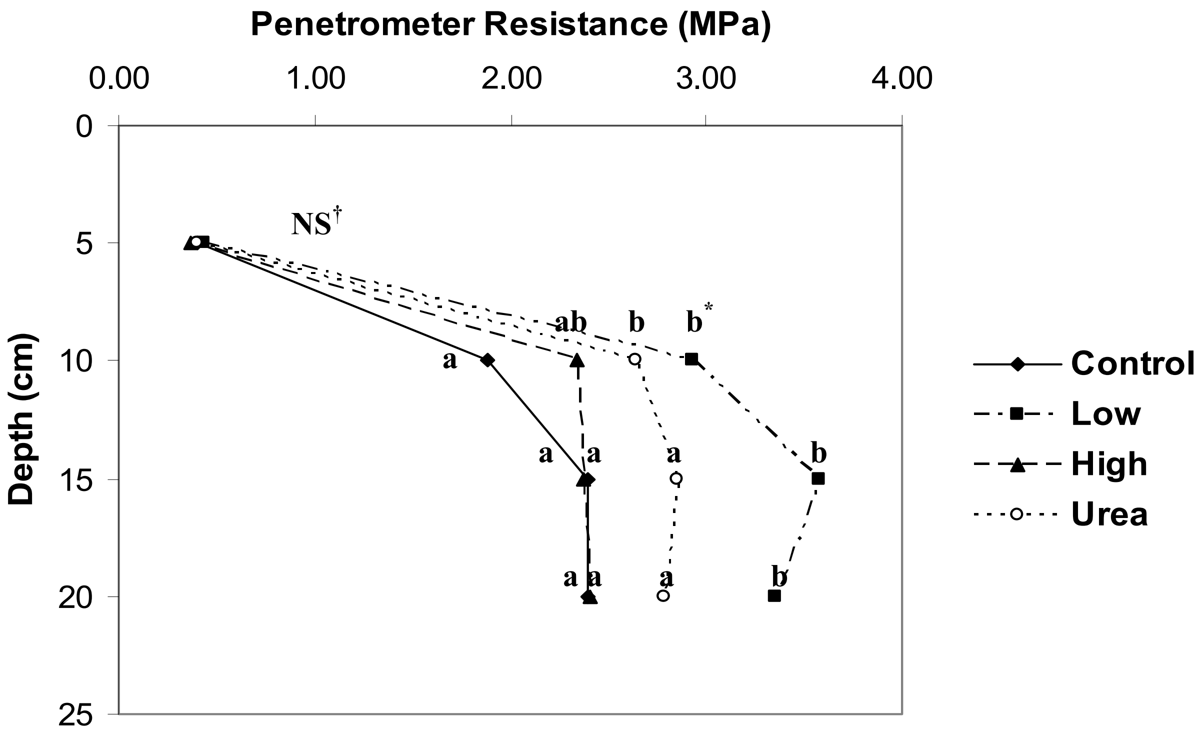

Figure 2. The soil penetration resistance in four treatments on June 16, 2003 at four different depths in a barley crop at Dixon, SK.

* Points with the same letter are not significantly different at the 90% confidence level.
† No points are significantly different.

The impact of crop growth is more of a consideration at the later sampling date. Although the differences were not significant, the control tended to have the highest water content due to poor moisture use from lack of fertility and the low rate manure and urea treatments had the lowest water content, indicating greater water usage by the crop due to better crop growth. The final grain yields also confirm this observation, as the low (agronomic rate) swine effluent yielded 3708kg ha^{-1}, while the high rate and urea treatments were 3375kg ha^{-1} and 3000kg ha^{-1} and the control was 1570kg ha^{-1} (King et al., 2004).

Plant emergence of the barley at the Dixon site (Table 1) showed no statistical differences between the manure treatments and the control. However, the high rate of manure tended to be lower than the low rate and was significantly lower than the urea treatment. This may be indicative of a salt effect from the excessively high rate of manure causing reduced emergence. However, the difference does not seem to be biologically critical.

Table 1. Barley Emergence at the 2-3 Leaf Stage at Dixon, 2003.

Treatment	Emergence
	----*Count per 0.25m²*----
Control	38.02a
Low Manure Rate	42.90ab
High Manure Rate	38.30a
Urea	46.35b

Rainfall Simulator: Work in Progress

A Guelph Rainfall Simulator II (Tossell et al., 1987) was used to simulate the effect of rain on undisturbed soil cores 15 cm diameter and 18cm deep that were taken from the field in spring 2003. A 1/4GG 14W nozzle (Spraying Systems Co., Wheaton Ill.) was used which was found to give a rainfall intensity of approximately 91mm h^{-1} with an 85% uniformity. After rainfall, the cores were placed in a growth chamber set to a 14 hour, 18ºC day and an 10 hour, 12ºC night. The cores were re-randomized every day after sampling. A CL-700 pocket penetrometer (Soiltest Inc., Chicago, USA) was used to measure the crust strength of the soil each day for 10 days. Only the 10th day of measurements is reported here. This experiment was very recently completed and a statistical analysis has not yet been completed. An average of 4 cores is presented.

Arndt (1965) determined that seedlings can tolerate up to 0.63 to 0.94MPa dry soil crust strength in order to emerge. However, this may vary with soil and crop type. Nonetheless, the crust strengths at the Dixon site (Figure 3) are well below this critical limit. The low treatment tends to have higher crust strength, but the values would not be biologically significant.

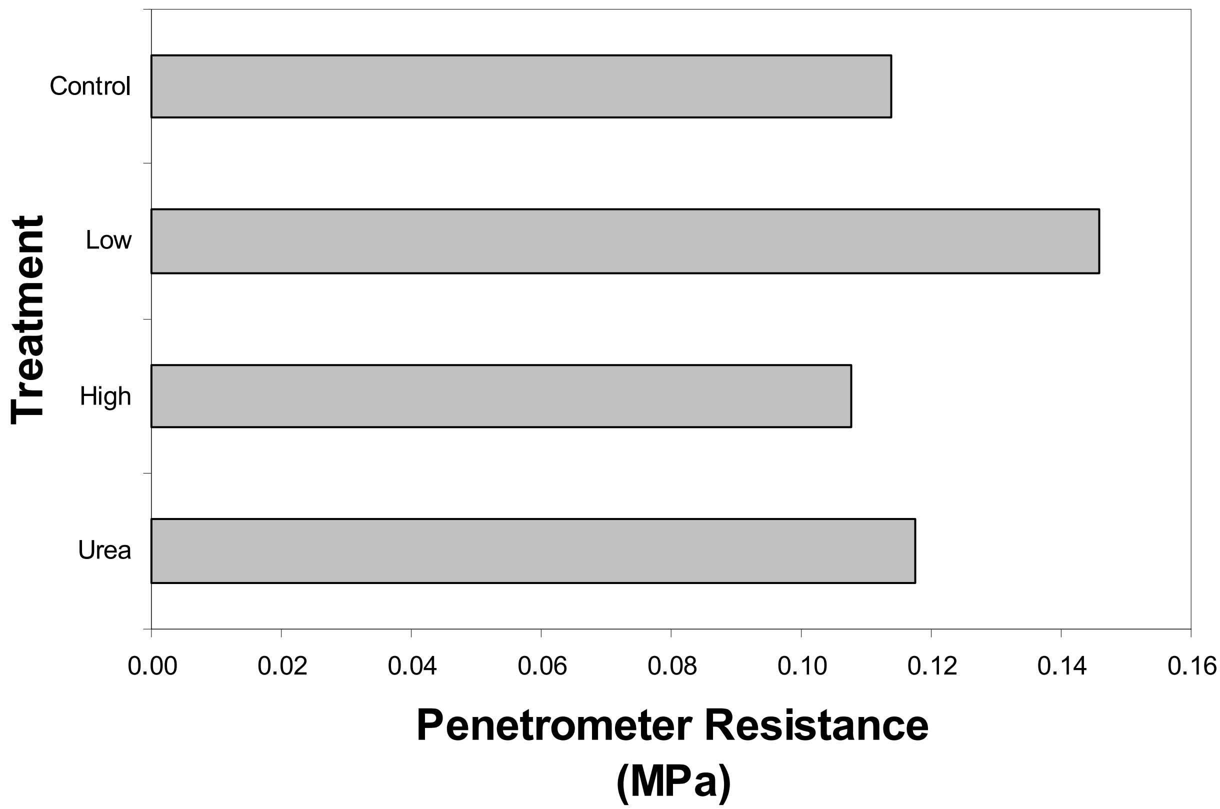

Figure 3. The crust strength of four treatments at Dixon, SK under the conditions after a rainfall simulation.

The soils sampled from Southern Saskatchewan (Figure 4) show stronger crusts than Dixon.

The sites indicated as RM 17 are from near Val Marie. The soil associations are mapped as Frontier with some Chaplin and Robsart (Saskatchewan Soil Survery, 1992a). Dairy, poultry and swine effluent are mixed in a primary and secondary cell lagoon. The water source drawn from has an approximate SAR of 50.8 (sodic), while the effluent has an approximate SAR of 25 with an EC of 12. The *RM 17 None* is a field where manure has never been applied. *RM 17 Manure and Forage* has had manure applied every year for about 10 years from the secondary cell. The field has been in smooth and meadow brome grass for that entire time. *RM 17 Fall 1x* had manure applied for the first time in the fall of 2002 from the primary cell. There appears to be a difference between the field without manure application and the fields that have received manure. None have passed the critical threshold of soil strength, but it does warrant caution.

The *Irrigated* and *Non-Irrigated* sites are from an irrigation failure near Cadillac, Saskatchewan. The soil associations of the area are Ardill and Valor (Saskatchewan Soil Survey, 1989). Water with an SAR of about 30 was applied for 5 years in the early 1980s which caused a dramatic increase in soil SAR and EC. The *Non-Irrigated* site was sampled from just outside and upslope from the irrigated area. A dramatic difference between the two sites is observed. The values of soil strength for the *Irrigated* site are not beyond the critical threshold, but nonetheless this field has not grown a crop since irrigation ceased.

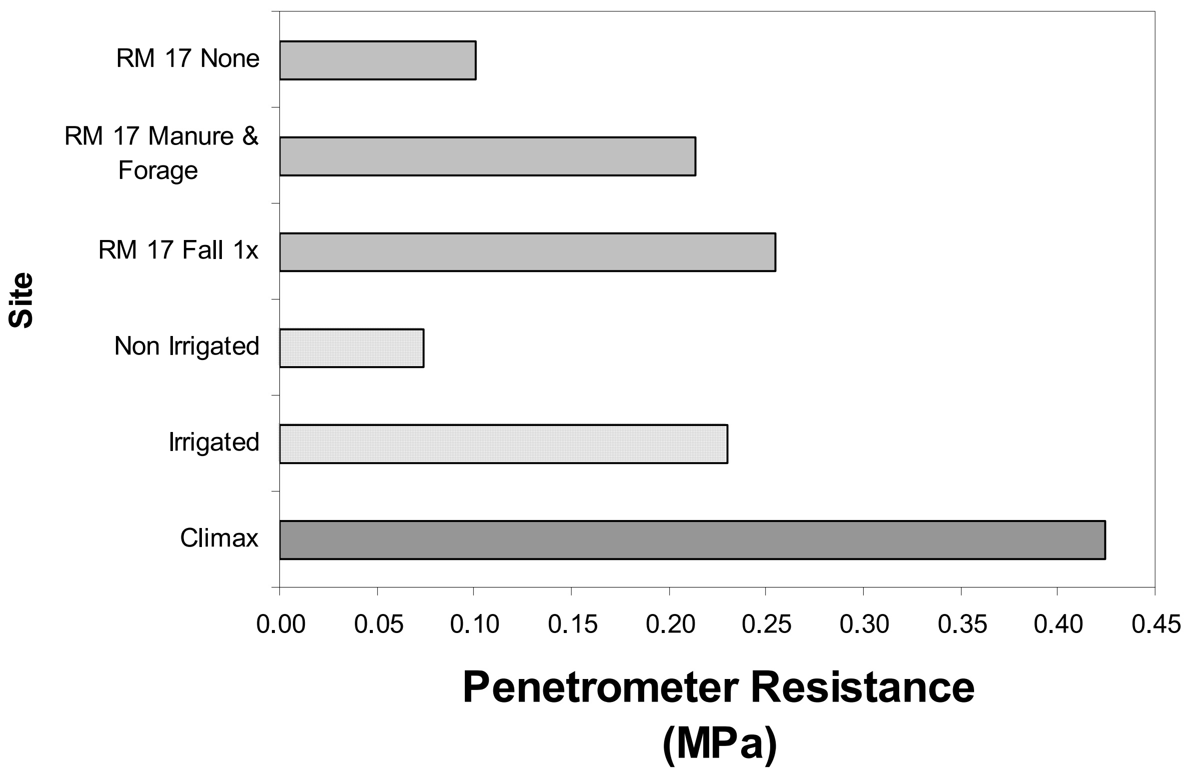

Figure 4. The crust strength of different sites in south-western Saskatchewan with potential for development of hard crusts under the conditions after a rainfall simulation. Values represent the average of two cores.

The Climax site is a municipal waste irrigation failure. Frontier and Robsart are the soil associations mapped in the area (Saskatchewan Soil Survey, 1992b). The Climax water source has a SAR of 5.1, but the sewage would be higher due to additions from households, such as the use of NaCl in water softeners. This soil had a particularly high crust strength.

Conclusions to Date

Hog manure was found to decrease soil strength in the top 20cm of the soil profile early in the growing season probably because of greater organic matter inputs. Manure had no effect on emergence compared to the control, but the salt effect may have decreased emergence at the high rate of manure compared with urea. Sodium concentration in relation to crust strength is a concern, especially in extreme situations where the sodium concentration of the water source is high. Additionally, sodium salts remain near the surface while soluble salts migrate to greater depths. Long term testing is necessary because sodification may progress with time.

References

Assefa, B.A. **2002**. Single and repeated applications of hog and cattle manure and their effects on soil conditions and plant growth in gray luvisolic and black chernozemic soils. University of Saskatchewan, Saskatoon, Saskatchewan, Canada. 131 p.

Bennett, D.R. and B.M. Olson. **1996**. Environmentally responsible manure management. Irrigation and Resource Management Division, Alberta Agriculture, Food and Rural Development, Agriculture Centre, Lethbridge, Alberta. pp. 34-36. In Charles, J.J. 1999. Soil and crop response to hog and cattle manure additions in east central Saskatchewan. M.Sc. thesis. Department of Soil Science, University of Saskatchewan, Saskatoon, SK.

Henry, L. B. Harron and D. Flaten. **1987**. The nature and management of salt-affected land in Saskatchewan. Soils and Crops Branch, Saskatchewan Agriculture.

King, T., J.J. Schoenau, M. Grevers, S.S. Mahli and G. Hultgreen. **2004**. Surface soil nutrient contents and crop yields after four to seven annual applications of manure. Proc. Soils and Crops Workshop, Saskatoon, Saskatchewan, Canada.

King, T.N. **2002**. Liquid swine manure application to forage soil: Effect on soil carbon and economic returns. University of Saskatchewan, Saskatoon, Saskatchewan, Canada. 31 p.

Lowery, B. and J.E. Morrison, Jr. **2002**. Soil penetrometers and penetrability. p.363-388. In J.H. Dane and G.C. Topp (ed.) Methods of soil analysis. Part 4 – Physical methods. SSSA Book Series 5, Madison, WI.

Mooleki, S.P., J.J. Schoenau, G. Hultgreen, G. Wen and J.L. Charles. **2002**. Effect of rate, frequency and method of liquid swine manure application on soil nitrogen availability, crop performance and N use efficiency in east-central Saskatchewan. Can. J. Soil Sci. **82**:457-467.

Nuttall, W.F. **1970**. Effect of organic amendments on some physical properties of Luvisolic soils in relation to emergence of rapeseed in the growth chamber. Can. J. Soil Sci. **50**:397-402.

Saskatchewan Agriculture Food and Rural Revitalization. **2003a**. July 1, 2003 Pigs on farms [Online]. http://www.agr.gov.sk.ca/docs/statistics/livestock/pigsonfrm0307.pdf (posted 2003.08.19).

Saskatchewan Agriculture Food and Rural Revitalization. **2003b**. July 1, 2003 Cattle on farms [Online]. http://www.agr.gov.sk.ca/docs/statistics/livestock/cattleonfrms0307.pdf (posted 2003.08.19).

Saskatchewan Soil Survey. **1989**. Preliminary soil map and report. Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, SK.

Saskatchewan Soil Survey. **1992a**. The soils of Val Marie Rural Municipality no. 17. Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, SK.

Saskatchewan Soil Survey. **1992b**. The soils of Lone Tree Rural Municipality no. 18. Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, SK.

Taylor, H.M., G.M. Robertson and J.J. Parker Jr. **1966**. Soil strength-root penetration relations for medium- to coarse-textured soil materials. Soil Sci. **102**:18-22.

Tossell, R.W., W.T. Dickinson, R.P.Rudra and G.J.Wall. **1987**. A portable rainfall simulator. Can. Agric. Eng. **29**:155-162.

Weiterman, G., L.Bohrson, H. Steppuhn and W. Eilers. **2000**. Can land utilization of swine effluent pose a soil sodicity hazard? Proc. Soils and Crops Workshop, Saskatoon, Saskatchewan, Canada.

Wen, G., J.J. Schoenau, J.L. Charles and S. Inanaga. **2003**. Efficiency parameters of nitrogen in hog and cattle manure in the second year following application. J. Plant Nutr. Soil Sci. **166**:490-498.

Whitaker, S.H. **1976**. Geology and groundwater resources of the Cypress area (72-F) (map). Department of Energy. Mines and Resources. York Litho Ltd., Toronto, Canada.

Zeleke, T.B. **2003**. Surface soil physical properties after crop residue incorporation and injection of liquid swine effluent. University of Saskatchewan, Saskatoon, Saskatchewan, Canada. 104 p.