



Soils

Manure is a useful soil amendment that can serve as a low cost source of organic fertilizer for crop production and as a soil conditioner that may improve the chemical and physical conditions of the soil (Campbell et al., 1986; Freeze and Sommerfeldt, 1985; Sommerfeldt et al., 1988; Hillel, 1980). However, this remains realistic only as long as manure is managed properly. Unrestricted repeated applications of large volumes of manure might deteriorate the quality of soils and reduce crop production (Chang et al., 1990; Larson, 1991).

1.1. Soils

The effect of manure on soils is manifold. It can increase nutrient availability; alter chemical properties of the soil such as salinity, sodicity, pH, and organic matter as well as physical properties of the soil such as bulk density, aggregation, aggregate stability, crust strength, and water infiltration.

1.1.1. Nutrient availability, loading and losses

The use of manure or compost results in qualitative and quantitative differences in the transformation of nutrients in the soil. This affects nutrient availability to crops, either directly by contributing to the nutrient pool or indirectly by influencing the soil chemical and physical environment (Egrinya et al., 2001). If manure is applied according to soil tests and crop nutrient requirement it can optimize the availability of the nutrients in the soil. Manure application also needs to be done using the appropriate method. Unnecessary nutrient loading and losses can occur following over application and not using the appropriate method of manure application. For example, Meek et al. (1982) reported that high rates ($180 \text{ t}\cdot\text{ha}^{-1}$ every two years over a nine-year period of time) of cattle manure applications to field plots of a calcareous Holtville silty clay soil in an irrigated desert region in California led to large losses of N, increased levels of K and increased availability of P.

For more on this recent addition to the Environmental Issues Resource Centre please visit <http://www.prairieswine.usask.ca/online/EIRCHome.htm>

Soil is closely associated with water in the context of manure management and the nutrient cycle, so the chapter on water should be also consulted to complete the information given in this section.

Glossary

Ammonium: ammonium (NH_4^+) is a positively charged molecule (cation) composed of nitrogen and hydrogen. Much of the nitrogen in proteins that are metabolized by animals is excreted in a form, such as urea, that is readily converted to NH_4 . Its positive charge makes it not very mobile in soil.



Ammonia: ammonia (NH_3) is a nitrogen compound composed of nitrogen and hydrogen. Much of the ammonia released into the atmosphere by agriculture comes from the breakdown of urea.

Nitrate: nitrate (NO_3^-) is a negatively charged molecule (anion) composed of nitrogen and oxygen. It results from nitrification of other nitrogen compounds. Nitrate is very soluble and mobile in soils.

Nitrification: nitrification is a process by which soil bacteria oxidize nitrogen compounds (e.g. ammonium ions) to nitrite (NO_2^-) which is subsequently transformed to nitrate (NO_3^-).

Mineralization: mineralization is the process through which the organic matter is transformed into simpler inorganic molecules that are more available to plants.

Denitrification: denitrification is a process by which bacteria reduce nitrogen compounds (NO_3^- and NO_2^-) to compounds of lower oxidation such as nitrogen gas (N_2) and nitrous oxide (N_2O).

Immobilization: immobilization is the process by which a nutrient will be removed from the soil solution and become bound to soil particles or incorporated into organic molecules within soil organisms. Phosphorus, for example is immobilized by clay minerals.

■ Soil and the Nutrient Cycle

The soil provides a support for crops and plays an important role in the nutrient cycle, storing nutrients under some situations and making them available to crops under other conditions. Depending on the nutrient and variations in soil characteristics (e.g. texture, structure, pH, density, organic content, drainage, existing concentrations of macro and micro-nutrients, cation exchange capacity, and the activity of micro-organisms), and climate, the nutrient cycle and the ability of plants to recover nutrients will be greatly affected by location (OMAFRA, 1994b). The availability of nutrients to the crop varies with time; only a fraction of that applied being captured by the plants in the first season following application, and the remaining portion becoming available slowly over subsequent years. For nitrogen (N) this fraction varies from 50 to 70% used in the first year, for phosphorus (P) the variation is from 10 to 40% depending upon and the method of fertilizer application. For potassium (K) it varies from 20 to 25% (OMAF 1994b; FB 1994). The determination of exact application rates of nutrients from manure or fertilizers is often not as straight forward as simply considering crop requirements and the nutrient content of the material to be applied.

For nutrients such as N, which are released in relatively large amounts by mineralization of soil organic matter (50 - 100 kg N/ha per year), the capacity of the soil to release nutrients has to be considered, and soil testing has to be performed regularly in order to make an appropriate evaluation of the additional nutrients needed for the crop (Lorimer 1995; OMAF 1994b; Schmitt and Rehm 1997; Goss et al. 1996). Expected crop yields should be based on those obtained in previous years. Over-optimistic estimations can lead to excess applications and consequently to nutrient leaching or accumulation. Equally, conservative estimations can lead to reduce yield and



profit margin (OMAF 1994b; Schmitt and Rehm 1997; Lorimer 1995).

As manure is applied to the soil, different reactions will occur. Some losses will occur through volatilization of N (as is the case for ammonia (NH₃) losses), runoff, erosion, leaching and denitrification (direct losses of N under gaseous forms of N₂, N₂O or NO) (FB 1994; OMAF 1994b). Mineral forms of N and P are found in the manure but much N and some P are also present in organic forms. Reactions in the soil will eventually transform any organic forms of P and N to mineral forms.

P is held in the soil up to a certain concentration, but then when more P additions are made, leaching occurs (FB 1994; Evans et al. 1984; Lorimer 1995; Simard et al. 1996). The inorganic P however is very immobile and attaches to soil particles, movement of P will occur via erosion and surface runoff (OMAF 1994b; Lorimer 1995). Soil P tests that indicate P concentration of more than 30 ppm give a signal for changes in manure application rates and P should then be considered as the limiting factor in the application rate determination (Lorimer, 1995). As for P, high application rates lead to an increase of the P concentration in the soil over the time. For example, soil P tests for the 0 to 20 cm layer of a silt loam soil showed an increase of 50% in P concentration from 42 ppm in 1990 to 63 ppm in 1996 for application rates of 77 kg/ha-year of phosphate and from 49 to 85 ppm for application rates of 97 kg/ha-year of phosphate over the same period (Randall, 1997).

N present in raw manure is mostly in organic and ammonium (NH₄⁺) forms and is not mobile when incorporated into the soil (OMAF 1994b). Organic forms of N and NH₄⁺ can move into surface waters if manure is not incorporated after application and significant precipitation causes runoff. In the soil, mineralization transforms organic forms of N into NH₄⁺, and subsequent nitrification will generally follow to convert NH₄⁺ to NO₃⁻. Soils that have high levels of NO₃⁻ are at risk of being leached to ground water or of NO₃⁻ moving to surface water through sub-surface tile drains as this form of N is very mobile in the soil. Leaching through the soil into ground water aquifers can occur over a long period of time depending on the amount of the precipitation. In order to evaluate the N contribution to the soil before fertilizer or manure application, the mineralization of N from organic matter, the atmospheric contribution of N, and release of nutrients from the material applied all have to be taken into account (Lorimer 1995; FB 1994; Goss et al. 1996).

■ Application Technique

Incorporation lowers the risk of runoff and reduces the N lost through NH₃ volatilization (Lorimer 1995; Schoenau 1997; Schmitt and Rehm 1997). However with highly erodible soils, the risk of erosion and runoff can be increased if residue cover is disturbed with incorporation equipment (Randall, 1997).

■ Application Time

Temperature at the time of application has an effect on the potential risks associated with manure spreading and the ability for the soil to retain the nutrients and store it for plants to use (Beauchamp 1996). For example, ammonia volatilization will be greater in hot, dry conditions.



Nitrification will rapidly convert NH_4^+ to nitrate in warm soil conditions, so spreading in the spring close to the time the plant will use it quickly is the best application time. Manure application in the early fall results in higher concentrations of nitrate in the soil for a long period before the plants can utilize it, thus increasing the risk of nitrate leaching. When the manure is applied late in the fall, the transformation of N to nitrate is slowed, however N losses can occur by runoff during the fall and also early in the spring as soils are saturated with water (Lorimer 1995; Schoenau 1997; Simard et al. 1996).

■ Copper Accumulation in Soil

Manure spreading from hogs that have been fed copper (Cu) supplemented diets can lead to Cu accumulation in the soil. As a result Cu supplementation should be lowered in order to be the closest to pig's requirements. The maximum allowable Cu concentration in diets is 125 ppm (de Lange, 1997), and could be lowered to 35 ppm for growing/finishing pigs as other growth factors have been introduced (Coppenet, 1981). When Cu supplementation is high and manure application rates excessive, accumulation is even more rapid. The part of Cu present in the soil is absorbed by the plants which increases the risk for phytotoxicity (toxicity for plants) and also for toxicity for animals grazing or fed the forage grown on those soils. Sheep are more likely to react adversely to high copper manure concentration applied to grass compared to cattle as sheep are more susceptible to chronic copper poisoning (Bremmer, 1981). McGrath (1981) reports an experiment where soils and plants were sampled to determine their copper content. Experiments in pots were also performed to help analyze the results. The copper in herbage from fields that received manure varied from less than 0.004 gram per kg to greater than 0.1 gram per kg (4 to 100 ppm). Different factors influence copper content including cultural practices, season, precipitation patterns following manure spreading, and crop type. Copper build-up from slurry application occurred near or at the soil surface. Coppenet (1981) also investigated 190 fields to verify the Cu enrichment of soils in Brittany. Also pot and microplot experiments were done by incorporating CuSO_4 to soil. A survey made over 6 years on those soils showed that during the survey period Cu enrichment and also zinc (Zn) enrichment could be observed, with an average increase of 1.23 ppm and 2.96 ppm, respectively. On farms with the highest pig density the Cu enrichment measured was 2.82 ppm and for Zn, 9.06 ppm. A simulation was made assuming a manure application rate of 50 tons of manure/ha per year, manure coming from 70 pigs (represents a density of 70 pigs/ha) that would have received a diet supplemented with 125 ppm of Cu and 150 ppm of Zn. Results showed that it would take two centuries before the concentration of these two elements would reach 500 kg/ha in the arable layer. As the phytotoxicity of Cu and Zn is complementary, it is believed that the problems would appear after one century.

■ Soil Structural Stability

Liquid swine manure does not contain much organic matter, its dry matter content being generally around 4-5%. The small contribution of swine manure to soil organic matter is less likely to enhance structural stability compared to manure from other species. However as reported by Simard et al. (1996), application of swine manure can lead to an improvement of the soil structural stability and a reduction of the apparent soil density by the increase of microbial activity.



■ Soil Degradation through Compaction

Swine manure is a very diluted fertilizer product (Schoenau, 1997). A major part of the volume that has to be transported and applied is water, as the dry matter content is generally less than 5%. Compared to commercial fertilizers, the application rates necessary to supply the needs of the crop are large, and consideration must also be given to the total weight or volume to be applied. As herd size increases, more manure has to be spread and this situation is compounded by regulation that has shortened the period for application in some jurisdictions. Most farmers will tend to have liquid manure spreaders of large capacity to be able to apply all their manure during the short time available for spreading (Tessier et al., 1995). However, large spreaders are very heavy and can induce soil compaction as studies show in Quebec (Bédard et al., 1997). Depending on the soil types (clay soils that have little swell-shrink behaviour are particularly sensitive to heavy traffic), long term yield losses can be expected due to compaction. The negative effects associated with application must be considered as an important parameter in the choice of spreading equipment. Computer simulation and field experiments show that low pressure and oversize tires (28L-26) and also the use of medium size manure spreaders (13.6 m³) should be considered as a mean to lowering the impact of manure spreading on soils (Chi et al. 1993; Bédard et al. 1997; Tessier et al. 1995). Many manufacturing companies have put multiple-axle running gear systems on manure spreaders in an effort to reduce the compaction caused by spreading. However in most cases, the capacity of the spreader equipped with those systems has also been increased and the consequence of such capacity upgrading is more compaction even with multiple axles (Bédard et al., 1997).

■ What Else Needs to Be Done

More investigation on the availability of nutrients needs to be done as this is used to determine the application rates of manure, noting the soil storing capacity can be exceeded with over-applying manure (Schoenau, 1997). Other considerations include the contributions of N from the atmosphere, from mineralization in the soil (depending on the conditions) and denitrification which removes N from the soil (FB et al. 1994; Goss et al. 1996).

Spreading technologies that help lower the risks of compaction and allow manure to be applied at the appropriate times and rates for plant uptake also need to be developed and integrated to farm practices. More work is also needed to develop efficient techniques for manure injection on grassland and no-till cropping systems.

As technology and knowledge alone cannot protect water quality and soils, more emphasis on farmers education and awareness programs which reinforce best management practices will be an effective way to ensure minimal impact on the environment.

References

(N.B. Some references have letters following the year of publication. This is meant to help find the exact reference in the text but also in the database)

Beauchamp, E.G. Availability of Macronutrients to Field Crops from Alternative Manure



- Systems. In *Managing Manure for Dairy and Swine - Towards Developing a Decision Support System*. Edited by M.J. Goss, D.P. Stonehouse and J.C. Giraldez. Chapter 6.
- Bédard, Y., S. Tessier, C. Laguë, Y. Chen and L. Chi. 1997. Soil Compaction by Manure Spreaders Equipped with Standard and Oversized Tires and Multiple Axles. *Transactions of the ASAE*. Vol. 40(1):37-43.
- Bremmer, I. 1981. Effects of the Disposal of Copper-Rich Slurry on the Health of Grazing Animals. In *Copper in Animal Wastes and Sewage Sludge*. Edited by P. L'Hermite and J. Dehandtschutter. Proceedings of the EEC Workshop organized by INRA, France. October 8-10, 1980, pp. 245-255.
- Chi, L., S. Tessier and C. Laguë. 1993. Finite Element Modeling of Soil Compaction by Liquid Manure Spreaders. *Transactions of the ASAE*, Vol. 36(3): 637-644.
- Coppenet, M. 1981. Copper Accumulation in Brittany Soils through Enriched Pig Slurry; Phytotoxic Risks. In *Copper in Animal Wastes and Sewage Sludge*. Edited by P. L'Hermite and J. Dehandtschutter. Proceedings of the EEC Workshop organized by INRA, France. October 8-10, 1980, pp. 154-161.
- de Lange, C.F.M. 1997. Manipulation of Diets to Minimize the Contribution of Private Pigs to Environmental Pollution. 1997 Canadian BASF Tour. La nutrition porcine, Séminaire Technique BASF. 17 décembre, St-Hyacinthe, Québec, p. 15.
- Evans, R.O., P.W. Westerman and M.R. Overcash. 1984. Subsurface Drainage Water Quality from Land Application of Swine Lagoon Effluent. *Transactions of ASAE*. V:27(2): 473-480.
- FB - F. Bernard experts-conseils and INRS-EAU. 1994. Evaluation environnementale, agronomique et économique de différentes méthodes de gestion des engrais de ferme au champ à l'aide du logiciel FECES. Québec: ministère de l'Environnement et de la Faune. 1996, p. 188, AE96-6/6.
- Goss, M.J., P.D. Zwart and R.G. Kachanoski. 1996. Transport of Nitrogen, Phosphorus and Disease Organisms from Manure into Surface and Groundwater. In *Managing Manure for Dairy and Swine - Towards Developing a Decision Support System*. Edited by M.J. Goss, D.P. Stonehouse and J.C. Giraldez. Chapter 7.
- Lorimer, J. 1995. Manure Nutrient Management. Electronic document: www.ae.iastate.edu/waste/manmgmt.txt. Consulted on 12/23/1997.
- McGrath, D. 1981. Implications of Applying Copper-Rich Pig Slurry to Grassland - Effects on Plants and Soils. In *Copper in Animal Wastes and Sewage Sludge*. Edited by P. L'Hermite and J. Dehandtschutter. Proceedings of the EEC Workshop organized by INRA, France. October 8-10, 1980, pp. 144-153.
- OMAF - Ontario Ministry of Agriculture and Food and Agriculture Canada. 1994b. Nutrient Management - Best Management Practices. Best Management Practices. Ontario Ministry of



Agriculture and Food, p. 64.

- Randall, G.W. 1997. Ground and Surface Water Concerns During Land Application of Manure. In Environmental Issues in Pork Production. The Allen D. Lemay Swine Conference, pp. 17-24.
- Schmitt, M. and G. Rehm. 1997. Fertilizing Cropland with Swine. Electronic document. www.mes.umn.edu/Documents/D/C/DC5879.html. FO-5879-GO.
- Schoenau, J.J. 1997. Soil Fertility Benefits from Swine Manure Addition. Saskatchewan Pork Industry Symposium, November 13 and 14. Saskatoon, Saskatchewan, pp. 59-63.
- Simard, R.R., C. Hamel and M.J. Garand. 1996. Judicious Management of Swine Manure for Crop Production. Proceedings of the Symposium: The Swine Industry at the Forefront of the Environmental Issues, pp. 31-41.
- Tessier, S., L. Chi, S. Richard, C. Laguë and S. Pigeon. 1995. Traffic Induced Soil Compaction and Solutions: Farmer's Perspectives. Proceedings of the 5th North American Regional Meeting/Workshop of the International Society of Terrain Vehicle Systems. Saskatoon, May 10-12.

Abstract or Summary of Interesting Publications

- Bédard, Y., S. Tessier, C. Laguë, Y. Chen and L. Chi. 1997. Soil Compaction by Manure Spreaders Equipped with Standard and Oversized Tires and Multiple Axles. Transactions of the ASAE, Vol. 40(1):37-43.

A study was conducted on a heavy clay soil to evaluate soil compaction induced by different traffic treatments associated with liquid manure spreader systems. Five spreader weights (from 96 to 218 kN), 2 running gears (tandem and tridem, i.e. 3 axles) and 2 types of tyre (conventional low section, and oversized) were combined to obtain 6 traffic treatments, representative of liquid manure spreading operations in Quebec. Soil dry bulk density (ρ_{db}) and cone index (CI) were measured to evaluate compaction. Tyre rut depths and the lateral influence zone were also investigated. For a single pass of a spreader, soil compaction was confined to the tilled layer (approx. 0-250 mm deep) regardless of traffic treatments, and this did not affect emergence rates and yields of soyabean under the particular soil and climate conditions that prevailed. Neither tandem nor tridem running gears adequately contained soil compaction within the tilled layer for total spreader weights >154 kN. The acceptable limitation for a tandem spreader with conventional 21.5L-16.1 tyres would be a total load of approx. 96 kN, resulting in average ground pressures of 150 kPa or less. If medium capacity spreaders are required, oversized tyres are recommended for manure spreading on prairies or post-seeding applications on small grain crops. Finally, the recourse to multiple-axle running gears for larger spreaders to maintain or reduce unit load per axle or ground pressure does not result in less soil compaction than lower capacity tandem spreaders with comparable axle loads and ground pressure.

- Goss, M.J., P.D. Zwart and R.G. Kachanoski. 1996. Transport of Nitrogen, Phosphorus and



Disease Organisms from Manure into Surface and Groundwater. In *Managing Manure for Dairy and Swine - Towards Developing a Decision Support System*. Edited by M.J. Goss, D.P. Stonehouse and J.C. Giraldez. Chapter 7.

This chapter, the factors that can have an impact on water quality are reviewed particularly for contamination of ground and surface water by nitrate, phosphorus and disease organisms. The focus is made on potential contamination as a result of manure application on land. The first step is to present the unbalanced nutrients ratio N:P:K of the swine and dairy manure (2:1:1.5 and 4:1:3 respectively) compared to the need of heavy yielding corn (7:1:7) for example. This would suggest not to use N as the limiting factor but rather to use P and supplement for the other nutrients. However the availability of nutrients is difficult to assess particularly for N as many losses can occur depending on the climatic conditions and also on the spreading method as NH_3 can be emitted directly as gas, nitrification can occur and nitrate can be lost by leaching and denitrification can also occur resulting in N_2O and N_2 as gaseous emissions. N deposition can also come from the atmosphere, quantity which is difficult to evaluate. The survival of different pathogenic bacteria depends on different factors for example: soil pH, soil water and organic matter contents, soil texture, temperature and others. It is thus difficult to predict the bacteria becoming as a general trend. The transport of the contaminant is dependent of their concentration in the soil and also on the water flow available to move them. The application rate of the manure and also the number of years of repeated manure applications have a direct effect on the nitrate potentially available for leaching. So the higher are the rates and the more years the manure is applied, the higher are the risks for leaching contaminants in water. Manure spreading the closer to the crop growing period lower also the risk for nitrate leaching. Injection rather than surface application lower the risk of leaching. Some paths are given for further research particularly on the availability of nitrogen and other nutrients in the manure, the transport of those nutrients that can become contaminants under certain circumstances and the more information on disease organisms and the factors affecting their transport.

Lorimer, J. 1995. Manure Nutrient Management. Electronic document:
www.ae.iastate.edu/waste/manmgmt.txt. Consulted on 12/23/1997.

The cycle of nutrient from animal feed to manure to soil and than to crops is an efficient and environmentally sound practice for surface and groundwater if it is done properly done. Good manure management should include all the steps from storage to spreading. The document deals with proper ways to valorize manure particularly in determining the land surface needed for manure application. Two methods for such evaluation and optimization of the manure in order to maximize returns from the nutrients in the manure and avoid environmental consequences from over application are presented. The first method is for a new facility by evaluating the land needed and the second one is for an existent facility by fine tuning the operations. The first step is to set realistic yields goal, as yields goal that are too high will lead to over application of manure and nutrients wastes that could cause leaching and goal that are too low will result in less manure applied and less yield. The subsequent steps are presented for all the calculation for the two possible situations. For soils presenting a P concentration in the soil lower than 30 ppm, the application rate should be done according N requirements. For soil with high P content or if required by regulation, the application rate can be calculated considering P as the limiting element. Commercial fertilizer can than be used to complete the fertilizer requirements of certain elements in order to maximize the yield. Manure and soil sample should be taken every year to



evaluate the situation and in order to make appropriate evaluations of the application rates needed.

Simard, R.R., C. Hamel and M.J. Garand. 1996. Judicious Management of Swine Manure for Crop Production. Proceedings of the Symposium: The Swine Industry at the Forefront of the Environmental Issues, pp. 31-41.

As animal density has increased considerably in some regions in Québec, surplus in animal excretion has been experienced for farms while considering nitrogen and phosphorus requirements estimated for crop production. Water quality problems (by pathogenic bacteria, viruses, high nitrogen and phosphorus contents) can result from high application rates of manure as the climate in Québec is humid and water infiltration and runoff are frequent in the fall and the spring. Soils enrichment with copper and zinc can also cause problems as in a region of high production density, copper content varying from 1 to 12 mg/L has been measured in the water (Boyer River watershed) and the standard for drinking water is 1 mg/L. Even if the pig manure doesn't provide much organic matter, the soil structure can be improved by an important microbial activity, using the carbon input from manure. Spring manure application and later fall application are the best time in order to optimize nutrients use by the crop and also limit the nutrient losses through runoff and leaching. As the fertilizing value of the manure is almost equivalent to mineral fertilizers value, manure is valuable and should be used optimally in order to limit the environmental impacts and odour nuisance associated with applying.