Water

Glossary

Ammonium: ammonium (NH_4^+) is a nitrogen compound composed of nitrogen and hydrogen. Proteins that are ingested but not retained are excreted, and part of it is under the form of NH_4^+.

Ammonia: ammonia (NH_3) is a nitrogen compound composed of nitrogen and hydrogen. Considering manure, ammonia is produced as a chemical reaction of NH_4^+.

Nitrate: nitrate is a nitrogen (NO_3^-) compound resulting from nitrification of other nitrogen compounds. Nitrate is very soluble and very mobile in soils.

Nitrification: nitrification is a process by which soil bacteria oxidize nitrogen compounds (ammonium, atmospheric nitrogen) to nitrite (NO_2^- which is subsequently transform to NO_3^-) and NO_3^-.

Denitrification: denitrification is a process by which bacteria reduce nitrogen compounds (NO_2^- and NO_3^-) to compounds of lower oxidation such as nitrogen and nitrous oxide (ex: N_2, N_2O, NO).

Immobilization: immobilization is the process by which an elements will be retained to another element. If considering nutrients and soils, phosphorus is immobilized to soil particles.

Eutrophication: process when a lake, pond or water stream become rich in nutrient minerals. As a consequence, more aquatic plants and algae develop, increased degradation resulting from more vegetation resulting in an increase in the oxygen demand in the water, leaving less of oxygen available to aquatic life.

Riparian buffers: riparian buffers are zone around lakes or ponds or along rivers or streams where vegetation will works as a filter for nutrient.

■ Water Quality and Manure

Manure has been applied as fertilizer to crops for centuries, only in the past few decades has much attention been given to application rates, manure distribution and impact of improper manure management on the environment (Randall, 1997). As water is closely related to soil when considering manure management and nutrient cycle, the chapter on soil should be consulted to complete the information given in this section.

Manure spreading is not the only threat to water quality. In rural areas, faulty septic systems (nutrients and bacterial contamination from humans), livestock wastes (risks from all stages of manure management), and cropland (with commercial fertilizers and crop residues) all contribute nutrients to the environment (OMAF, 1994a). Due to the many potential sources, when water contamination occurs, thorough investigation has to done to find the pollution source.

■ The Threatening Elements

Water contamination from manure comes principally from two macro-nutrients and from biological components of the manure. The nitrogen (N), the phosphorus (P) and the coliform bacteria present threats to water quality when their concentration is higher than a prescribed regulated level. The consequences can be considered on two levels: water quality degradation with no direct impact on human health that comes mainly from nitrogen compounds and phosphorus through eutrophication (CCMRE 1987; Lorimer 1995), and water contamination that comes from NO_3^- and bacteria. Other than for accidental spillage and faulty manure storage which can be considered as point sources, nutrient runoff, leaching, and losses from erosion are considered non-point sources and are more difficult to assess (OMAF, 1994a). Higher nutrient content in the water can also trigger other reactions in aquatic micro-organisms and have a detrimental effect on aquatic life (Anderson, 1998).

Nitrogen (N)

Nitrogen is present in raw manure mostly under organic-N form and NH_4^+. When the manure is applied to soil and the N is incorporated into it, different processes will occur and chemical reactions transform the nitrogen compounds through nitrification, denitrification and immobilization, in the soil. The nitrification process converts the different N forms to NO_3^-, this form presents a threat if present in the water at concentration higher than 10 mg/L. Nitrate and NH_4^+ will be used by the plants as a fertilizer.

High NO_3^- concentration in the soils represent a risk to ground and surface waters as it is very mobile in the soil in this form. If the NO_3^- concentrations are high, leaching through the soil into ground water aquifers can occur over a long period of time or rapidly by leaching through the subsurface tile drainage flow in either cases affecting surface water such as streams, rivers and lakes. The other forms of N (organic N, NH_4^+) are much less mobile in the soil and are eventually transformed to NO_3^-. However organic N and NH_4^+ leaching can occur to surface water if the manure is not incorporated and significant precipitation causes runoff.

As presented before, the impact of high N compounds concentration in the water has two dimensions. As N is present in the form of organic N, NH_4^+ and NH_3, the aquatic vegetation will develop rapidly as nutrient is more available. Thus more aquatic plants and algae, increased degradation resulting from more vegetation combine to increase the oxygen demand in the water, leaving less of oxygen available to aquatic life. Concentration of NO_3^- in the water exceeding 10 mg/L for human (NSCU, 1995), and small animal consumption and 100 mg/L for large animal consumption present a threat to the health (OMAF 1994a-b; CCMRE 1987). High concentrations of NO_3^- taken into the organism through water consumption interfere with oxygen transport. Small children and elderly are particularly affected by NO_3^- (CCMRE, 1987).

Phosphorus (P)

Phosphorus is mostly present in an organic form in the manure and will be mineralized to an inorganic form in the soil. As with N, P is used by the plant and presents only a threat when its concentration in the soil is high. 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). P leaching through soil particle erosion will be more important for high P concentration in soil. Also at high P concentration and particles P saturation, leaching can happen (Evans et al., 1984), this leaching process has however to be investigated (FB, 1994). In surface water bodies, P is also used by algae and aquatic weeds. If after the application, manure is not incorporated and significant precipitation occurs, runoff will carry organic P to surface water.

Coliforms

Also present in the raw manure, the fecal coliform and other bacteria will be eliminated over time in the soil. However water can be contaminated with those bacteria and cause health problems to humans if manure runoff occurs. Bacterial contamination in some rural areas where housing density is high can also come from improper sewage management and ineffective septic systems (OMAF, 1994a). Investigations have to be made to identify the bacteria source in order to solve the problem and they are often difficult.

■ Ways to Control N and P

Application Rates of N and P

While considering nutrient recycling with lower possible environmental impact, a manure inventory has to be assessed and a fertilizing plan has also to be developed ideally on a long range basis considering soil analysis and planned crop rotation (Lorimer 1995; Schmitt and Rehm 1997). The application rate of N and P from manure depends on two factors; N and P content in the manure and manure application rate. N and P content vary according to 1) the stage of production or pig diet (generally a lower nutrient concentration is measured in manure produced from nursery pigs compared to grower/finisher) and 2) management and facilities of specific farms. As seen in the other sections of this work, different diet, manure treatment and storage will have an impact on the nutrients present in the manure. Considering those sources of variation, manure analysis is essential to provide specific information about the nutrient content and represents a significant difference in values available in tables (Lorimer 1995; Schoenau 1997). The manure application rate has to be determined considering the plants' requirements, nutrients losses associated with manure spreading and the nutrients already available in the soil (Lorimer 1995; Schoenau 1997; FB 1994; Goss et al. 1996). Fixing the manure application rate without knowing the N and P content could lead to improper nutrient application rates. In the case of over-application, leaching can occur and cause water quality problems, under-application limits yields obtained and profits.

High application rates of N lead to higher concentration of NO_3^- in the water and provide a crop yield that is not necessary much higher. As Randall (1997) presents an experiment done on a silt loam soil showed that N application rate was optimized at 165 kg/ha for a corresponding NO_3^- concentration in soil water of 15 mg/L when an extra 35 kg N/ha was added the NO_3^- concentration almost doubled. An optimal point has to set between crop requirement and leaching as higher yields can be obtained with resulting higher NO_3^- concentrations.

As for P, high application rates lead to an increase of the P concentration in the soil over time (Evans et al., 1984). As Randall (1997) presents, Soil tests P (STP, a specific soil test to evaluate the P content) done in the 0 to 20 cm soil layer (silt loam) showed an increase of 50 % in P concentration from 42 ppm in 1990 to 63 ppm in 1996 resulting from an 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. A significant relationship between STP and P losses in runoff and erosion has been established as a result of investigations around the world.

As most of the manure fertilization has been done considering the N requirements, this sometimes results in over-application of P of about 2 to 2.5 times the amount needed if manure is applied annually and for some crops it is up to 3 times (Evans et al., 1984). As a consequence, the application rates should be done considering the P as the limiting nutrients (Evans et al. 1984; Goss et al. 1996), particularly when the P concentration in soil tests exceed 30 ppm (Lorimer, 1995). As P is not mobile in the soil, manure could be applied every other year or every three years (Randall, 1997).

Gangbazo et al. (1992, 1993) measured nutrients' load in runoff after rain fall and found that the application rates have a direct effect on the nutrient load, on the runoff delay and also on the volume of runoff. Higher application rates tend to saturate the soil surface and result in more runoff. The nutrient load also varies with the rain fall duration and the delay between spreading and rain. N and P concentration measured in the runoff decreased as time passed between manure application and rain.

Application Technique

Incorporation will lower the risk of runoff and lower the N losses through NH_3 volatilization (Lorimer 1995; Schoenau 1997; Schmitt and Rehm 1997). However with highly erodible soils, the risk of erosion and runoff can be increased as the residue cover is disturbed (Randall, 1997). Runoff experiments have been conducted under controlled conditions and the results showed that in order to minimize pollution from N and P, incorporation had to be done 24 hours before a rainfall event (Gangbazo et al. 1992, 1993). For broadcast manure application the closer the rainfall event was to manure application the higher was the impact on the total runoff volume and the nutrient load (Gangbazo et al., 1992).

Application Time

Temperature conditions have an effect on the potential risk from manure spreading. Runoff of P will be more important during the planting season as the crop cover is minimal and heavy rain occurs. The winter application on frozen soils (as done in some regions) results in P concentrations higher in the river from March through June than any other time of the year (Randall, 1997). Considering N nitrification to NO_3^-, spreading in the spring the closer to the time the plant will use it is the best application time. Manure application in the early fall results in higher concentrations of NO_3^- in the soil for a long period before the plants can utilize it thus increasing the risk for NO_3^- leakage. When the manure is applied late in the fall, the transformation of N to NO_3^- is slowed however N losses can occur by runoff during the fall and also in the spring when soils are saturated with water (Lorimer 1995; Schoenau 1997).

Modeling and Nutrient Requirements

Water quality can be modeled through computer simulation (Rousseau et al., 1997). Those models are complex and unfortunately some parameters to describe the nutrients' movements and evolution in the soil over time are not well known. The accuracy of such a model is thus affected. Many aspects of N contribution have to be determined such as N mineralization from the soil itself, the atmospheric contribution for N, organic matter degradation and release of the nutrients. The real availability of the nutrients in the soils has also to be better estimated considering also this availability over time as the nutrients are not completely used during the first year after manure application (Schoenau, 1997).

Monitoring and Other Practices to Control Nutrients in Water

Watersheds' approaches are further steps in understanding the water movement, the contamination risks and best management practices. This approach is very demanding as data over many years has to be collected in order to consider all nutrients sources and movement in the area considered (Enright et al. 1997; Rousseau et al. 1997). To improve a water quality problem or to maintain water quality in a specific area, stream or watershed, monitoring (Firehock 1992; Kolega and Jeffrey 1988), and whole system investigations have to be done (EPA, 1994).

Riparian buffers along the waterways and wetlands can present interesting treatment characteristics as part of the nutrients going to waterways can be intercepted and transformed by plants utilization (OMAF 1994a; NCSU 1995).

■ What Else Needs to Be Done

Additional investigation on the availability of the nutrients in the soils is required as the application rates of manure is directly related to it and consequently to the impact on water quality (Schoenau, 1997). Other elements about N have to be studied such as its contributions from the atmosphere, from mineralization in the soil depending on the conditions and the denitrification which removes N from the soil (FB et al. 1994; Goss et al. 1996).

More frequent monitoring of the wells in rural areas, watersheds and streams is also necessary in order to control the water quality and also to evaluate the impact of new practices, and accidental spills.

A better control of the manure application rates and also the development of manure spreading technologies that allow for spreading closer to the growing season are technological aspects that have to be addressed.

As technology and knowledge alone cannot protect water quality, more energy has to be put on farmer education and awareness for better general management practices, as the way farms are managed have an important impact on the way the environment is handle (NCSU 1995; Lasley 1997).

References

Anderson, B.B. 1998. Facts on Pfiesteria. Hogs Today. January, p. 26.

CCMRE - Conseil Canadien des ministres des ressources et de l'environnement. 1987. Recommandations pour la qualité des eaux au Canada. Division des recommandations pour la qualité de l'environnement.

Enright, P., F. Papineau and C. Madramootoo. 1997. Water Quality and Pollutant Concentrations on Paired Agricultural Watersheds in Quebec. Proceedings of the 1997 Annual Conference of the Canadian Society of Agricultural Engineering. Edited by D.I. Norum and P. Savoie, pp. 142-151.

EPA - United States Environmental Protection Agency. 1994. The Watershed Protection Approach. 1993-1994 Activity Report. EPA840-S-94-001.

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.

Firehock, K. 1992. Do Your Best Management Practices Really Work? Assessing Effectiveness of Manure Management Practices through Biological Monitoring. National Livestock, Poultry and Aquaculture Waste Management. Proceedings of the 1991 National Workshop. Edited by J. Blake, J. Donald and W. Magett, pp. 63-66.

Gangbazo, G., A.R. Pesant, D. Cluis and D. Couillard. 1992. Etude en laboratoire du ruissellement et de l'infiltration de l'eau suite à l'épandage. Canadian Agricultural Engineering. 34(1): 17-25

Gangbazo, G., D. Cluis, A.R. Pesant and D. Couillard. 1993. Effets du lisier de porc sur la charge d'azote et de phosphore dans l'eau de ruissellement sous des pluies simulées. Canadian Agricultural Engineering. 35(2): 97-103.

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.

Kolega, J.J. and R.F. Jeffrey. 1988. A Self Environmental Audit for Dairy Farm Ground Water Quality. Livestock Environment III. Proceedings of the Third International Livestock Environment Symposium. April 25-27, Toronto. Published by the American Society of Agricultural Engineering. St. Joseph, Michigan. 49085-9659, pp. S-46 - S-51.

Lasley, P. 1997. Social Consequences of Environmental Concerns. In Environmental Issues in Pork Production. The Allen D. Leman Swine Conference. September 20. Minnesota Extension Service. University of Minnesota, pp. 5-8.

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

NCSU. 1995. Water Quality and the North Carolina Swine Industry. Electronic document: www.ces.ncsu.edu/whpaper/Wqswine.html. Consulted 09/1997.

OMAF - Ontario Ministry of Agriculture and Food and Agriculture Canada. 1994a. Water Management - Best Management Practices. Best Management Practices. Ontario Ministry of Agriculture and Food, p. 93.

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. Leman Swine Conference, pp. 17-24.

Rousseau, A.N., A. Mailhot, S. Morissette, J.F. Tremblay, P. Bolduc, M. Duchemin, J. Dupont, R. Turcotte and J.P. Villeneuve. 1997. GIBSI - A Watershed-Based Software System for Water Resources Management. Proceedings of the 1997 Annual Conference of the Canadian Society of Agricultural Engineering. Edited by D.I. Norum and P. Savoie, pp. 112-121.

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.

Abstract or Summary of Interesting Publications

Enright, P., F. Papineau and C. Madramootoo. 1997. Water Quality and Pollutant Concentrations on Paired Agricultural Watersheds in Quebec. Proceedings of the 1997 Annual Conference of the Canadian Society of Agricultural Engineering. Edited by D.I. Norum and P. Savoie, pp. 142-151.

In two small watershed (26.1 and 17.9 km2) in southwestern Quebec, hydrologic, climatologic and water quality parameters have been evaluated during a period of 3 years. In one of the watershed, an agronomist worked with the farmers to reduce the environmental impact of their practice on water and the other watershed was studied as an control or reference. The results showed that non point source pollution is the major problem in the watersheds and most water quality parameters were influenced with the precipitation pattern. Phosphorus and fecal coliforms where tow parameters that exceeded the water quality guidelines most frequently. Atrazine and metolachlor (pesticides) were also frequently detected. The data collected are very valuable toward a better understanding of watersheds and the dynamic of pollution on water quality. However most of the analysis has to be done to understand the effect of the measured parameters on the water quality of the watersheds and also to evaluate the impact of better management practices on the watershed. The database constructed with the information gather during the 3 years will be very valuable to develop and validate water quality models.

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.

The rates used for this experiment are very high and were selected with the idea to verify the long-term effect of manure disposal as opposed to valorization and optimization. In this experiment, the runoff represented less than 1% and the subsurface drainage 25% of the annual water input. The application rates of 325, 650 and 1300 kg N/ha - year represent 1 time, 2 and 4 times the recommended application rate for Coastal bermudagrass. Both the medium and the high rates resulted in NO_3^- concentration in the water higher than the recommended level of 10 mg/L. P accumulation in the soil resulted from the N application at N recommended rate. Considering N as the element to set the application rate, P recommended rate was exceeded by 3 times. P was fixed by the soil, however by the fifth year of the experiment, higher P concentrations were measured in the runoff. Even if many years are necessary before seeing P leaching, P should be considered to determine the application rates as well as N.

Gangbazo, G., D. Cluis, A.R. Pesant and D. Couillard. 1993. Effets du lisier de porc sur la charge d'azote et de phosphore dans l'eau de ruissellement sous des pluies simulées. Canadian Agricultural Engineering. 35(2): 97-103.

Total Kjeldahl (TKN), ammonium (NH_4-N), and nitrate nitrogen (NO_3^-N), total phosphorus (PT) and orthophosphate (PO_4-P) loads were measured in the runoff following rainfall after pig manure was applied to a clay loam (Humic Gleysol), in boxes of 0.26 m^2 area with a 3% slope, containing

400 mm of soil. A factorial treatment combination of three manure application rates (0, 27.3 and 54.6 m^3/ha) with and without incorporation, two simulated rainfalls with spring time intensities common in Quebec (11 mm/h for 142 min and 22 mm/h for 71 min for a total application of 26mm) and three different rainfall delays (1, 24 and 48 h between time of manure application and beginning of each rainfall) were studied. Pig manure had little effect on TKN and NO_3-N in runoff. More than 99% of TKN losses in runoff water were in the form of NH_4-N. Runoff from soils having received manure at the highest application rate (54.6m^3/ha, 230 kg of NH_4-N/ha) was eleven times higher in NH_4-N than that from untreated soil. Surface application of manure significantly increased all forms of nitrogen and phosphorus losses, especially when rainfall was applied within the first hour after application. Incorporation into the soil had no significant effects on nitrogen and phosphorus loads. At the one hour rainfall delay, surface application of manure produced a significant quadratic effect on NH_4-N loads (0.06, 6.8, and 40.6 kg/ha) which corresponded to the manure rates. For the two other rainfall delays (24 h and 48 h) manure rates had a linear effect with much lower loads. Total phosphorus and orthophosphate loads had similar trends to those of ammonium nitrogen but much lower values. To minimize all runoff pollution by nitrogen and phosphorus, optimum amounts of manure for plant requirements must be incorporated into the soil within 24 h before a rainfall event.

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 NH3 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.

Randall, G.W. 1997. Ground and Surface Water Concerns During Land Application of Manure. In Environmental Issues in Pork Production. The Allen D. Leman Swine Conference, pp. 17-24.

Different factors have an effect on the possibility of impact on ground and surface water. Some of those factors are: the proximity of a water body, where in the landscape the manure is spread and the management of the application such as the rate, the technique used and the time of application. To minimize the potential impact of manure application on the environment, the method used to spread manure has to be appropriate and the application rate has to be known. In sensitive land areas next to water bodies and where direct channels or conduits connect to water bodies, more attention has to be given to manure spreading in order to avoid water contamination. For soils that have a high P concentration (obtained from a soil tests), manure application is not recommended particularly when a surface water body is close by.