The Role of Hog Manure Application in Maintaining Air, Water & Soil Quality

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The changing role of manure in agriculture in Manitoba

Our perspective on animal has changed over the past several years. Traditionally the vast majority of manure production in Manitoba has been associated with rangeland cattle production. The increase in pork production and intensive cattle production in Manitoba has resulted in the production of more manure and a greater percentage of that manure in intensive livestock systems, where the manure is collected and spread one or two times throughout the year. The decreased reliance on grazing systems has resulted in a greater concentration of livestock systems in some areas of the province and has brought these systems closer to the general public. The expansion of the industry and increased awareness of the industry by the public has increased the scrutiny placed on this industry. Recent province-wide public hearings into the sustainability of intensive livestock production are evidence of this concern.

Here we examine some of the potential impacts of animal manure on soil, air and water quality and the opportunities to manage these impacts. In considering the negative impacts of manure it is important to also highlight the potential benefits of effective manure utilization.

Benefits of Manure

The increasing number of animals being raised in Manitoba, and the manure they produce, has the potential to significantly increase the sustainability of prairie agriculture. For decades the organic matter and nutrient content of prairie soils has been declining as rates of removal under annual cropping and grain export have outpaced the return organic matter and nutrients to the soil. Animal manure, an excellent source of nutrients and organic matter, provides the opportunity to replenish the soil.

Manure contains all of the major crop nutrients (nitrogen, phosphorus and potassium) as well as many, if not all of the minor nutrients needed by plants. Manure has an additional agronomic benefit beyond its nutrient content. Manure contains many organic compounds. These compounds help to build and maintain soil structure which in turn helps to maintain soil tilth, water holding capacity, soil aeration and reduces soil erosion. The organic compounds in manure are food for the soil microbial population, which may enhance nutrient availability, residue decomposition, or in some cases the removal of nitrate from the soil.

In addition to providing agronomic benefits, manure may provide environmental benefits, as well. Manure application onto cropland recycles nutrients locally, reducing the need for commercial fertilizer and the environmental impacts of manufacturing and transporting that commercial fertilizer. The application of animal manure also increases the organic matter content in some soils, thus reducing net CO_2 emissions to the atmosphere (increasing C sequestration).

To realize the positive aspects of manure we must ensure that we have minimized any negative impacts. The challenge is to design cost effective systems that can take advantage of all of the positive aspects of manure while minimizing negative impacts.

Public scrutiny is causing producers to reexamine their manure handling systems. In the past the primary design considerations for manure management systems have been convenience and cost effectiveness. Few producers would debate their importance. Increasingly however, nutrient recovery and environmental impact are being emphasized. Many jurisdictions have begun to require detailed manure management plans to ensure efficient and safe manure utilization. This is due in-part to public concerns over sustainability of agricultural systems and environmental impact of intensive animal production. While reduced environmental impact represents an indirect benefit to the farmer, the value of the nutrients recovered from the manure provides direct economic benefit.

Effective manure management strives to balance the amount and timing of nutrient supply with plant demand, applying the correct amount of manure, at the right time, to the most appropriate crop in the most effective manner.

Forms and Transformations of Manure Nitrogen and Phosphorus

Nitrogen Forms, Availability and Accumulation

Nitrogen is one of the principle components of animal manure. The nitrogen content of manure can vary dramatically, depending upon animal species, feeding regime and overall management practices (Tables 1 and 2). Guidelines for rates of manure application in Manitoba are based upon the nitrogen content of the manure (http://www.gov.mb.ca/agriculture/). This is due to the potential adverse impacts of the accumulation of excessive amounts of nitrate in soil. Nitrate can have a negative impact on groundwater if it is leached from the soil, surface water in agricultural runoff or on the atmosphere if converted to nitrous oxide by a process known as denitrification. To manage manure in a way that will minimize the risk of excess nitrate accumulation, we must examine the processes that convert manure N to nitrate.

Table 1. Typical manure production values for various species (Source: adapted from U.S. Natural Resources Conservation Service, Agricultural Waste Management Handbook, 1992).

Livestock type	Total manure	Nitrogen	Phosphorus[1]	P:N
	------Lbs/day/1000-lb animal unit------			
Beef[2]	59.1	0.31	0.25	0.81
Dairy[3]	80.0	0.45	0.16	0.36
Swine[4]	63.1	0.42	0.37	0.89
Chickens (layers)	60.5	0.83	0.71	0.86
Chickens (broilers)	80.0	1.10	0.78	0.71
Turkeys	43.6	0.74	0.64	0.87

[1]Expressed as P_2O_5 equivalent
[2]High Forage diet.
[3]Lactating Cow.
[4]Grower.

Manure contains organic nitrogen sources derived from partially digested feed and feces and inorganic nitrogen sources derived from the urea contained in urine and the bacterial transformation of the organic nitrogen sources. Transformations occurring in manure during the handling and storage will determine the relative magnitude of these forms. Most common methods of manure storage result in the accumulation of ammonium as the predominant inorganic form of nitrogen. In liquid hog manure ammonium may account for as much as 80% of the total nitrogen content of the manure. Manure storage systems that actively aerate the manure, such as the systems used to treat human sewage, allow nitrification to proceed, converting ammonium to nitrate.

During manure storage and following land application, soil organisms utilize the organic nitrogen forms and release ammonium in a process known as mineralization. In situations where the organic material does not contain sufficient nitrogen to support microbial growth, some of the inorganic ammonium or nitrate may be converted to organic nitrogen in a process known as immobilization. This immobilization phase is generally relatively short-lived and mineralization predominates. With time the majority of the nitrogen contained in manure will be converted to nitrate through the combined processes of mineralization and nitrification. The conversion of organic nitrogen components of the manure may take several years. As a result manure releases plant available nitrogen to the soil for several years after its application.

Table 2. Summary of nutrient analyses from liquid hog manure samples in Manitoba (Source: Norwest Labs analyses for 1996-1998).

Parameter	Total Nitrogen	Ammonia	Organic N	Phosphorus[1]	Potassium[2]	P:N Ratio[3]	Dry Matter
	------------------------------------- Lbs/1000 gallons			----------------------------			-%-
Average	25.4	17.1	7.5	18.2	14.4	0.72	2.8
Minimum	2.0	0.8	0.3	0.5	0.4	-	0.1
Maximum	69.0	51.5	42.5	117.8	44.4	-	12.5

[1] Expressed as P_2O_5 equivalent
[2] Expressed as K_2O equivalent
[3] Estimated only, from separate estimates of average N content and average P content

As a result of the time required for the organic components of manure to be mineralized, the repeated application of manure to soil results in the accumulation of organic nitrogen in soil. This increased organic nitrogen content results in an increased nitrogen supplying capacity of the soil organic fraction. It has been estimated that approximately 20% of the plant available N results from the mineralization of organic nitrogen in the year of application (Figure 1). The majority of the organic nitrogen (40% of total N) accumulates in the soil. This fraction is slowly available to subsequent crops. Failure to account for this increased mineralization potential in calculating fertilizer requirements will result in the over application of nitrogen.

Current soil tests do not include direct measures of the mineralization potential of soils. In some cases estimates of nitrogen mineralization are based on previous management (legume in rotation or manure application). More direct measures of nutrient mineralization potential are needed to improve nutrient management and to avoid the accumulation of excess nutrients.

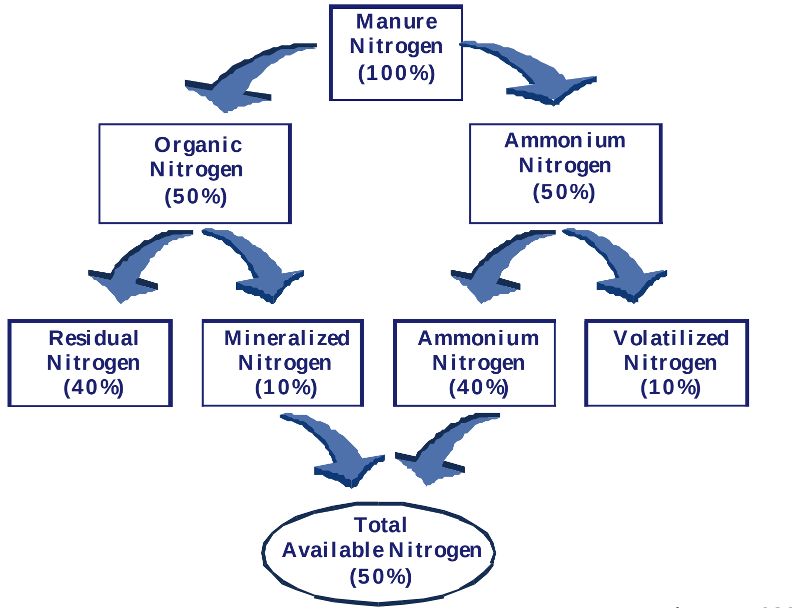

Figure 1: Generalized description of the fate of manure nitrogen added to soil. Note that the relative proportions of organic and inorganic N in manure will vary with animal species and manure management system.

Phosphorus Forms, Availability and Accumulation

The phosphorus in swine manure is initially present in both organic (up to half of the total P) and inorganic forms (Mikkelson 1997). The organic P fraction is not immediately available to crops. Therefore, as with organic N, the availability of the organic P in manure depends on the rate of mineralization, the process whereby micro-organisms convert the organic P into inorganic P. The micro-organisms that mineralise organic P are active in soil and in manure storage systems. Therefore, the fraction of manure P present in the organic form tends to decline with time in both environments. The availability of inorganic P is determined by the form of the inorganic P (e.g., moderately soluble dicalcium phosphate or relatively insoluble octacalcium phosphate) and the capacity of the soil to precipitate or adsorb that P. Overall, the agronomic availability of P in swine manure is estimated to be 50% of commercial, water soluble fertilizer P within the first year after application (Man. Farm Practices Guidelines 1998).

Most of the agricultural land in Manitoba is naturally low in P and will benefit from the application of P in manure. However, if excessive rates of P are applied or if manure is applied improperly, P can move off the land or through the soil and into surface water bodies, damaging water quality. The main pathways for P movement to surface waters are:

- soluble P dissolved in surface runoff
- release of soil-bound precipitated or adsorbed P from eroded soil entering water bodies
- flow of suspended or dissolved P from groundwater contaminated by P leaching

Long term applications of P-rich manure based on the crop's requirements and withdrawal for N only may cause accumulations of environmentally harmful concentrations of P. Swine manure usually contains less P than N and crops generally remove less P than N (Table 3). However, the P:N ratio of swine manure (Table 2) is often greater than the P:N ratio of the harvested portion of typical Manitoba crops. Furthermore, in contrast to N, which is lost relatively easily during storage, handling and application of manure, P is relatively stable. Therefore, P:N ratios in manure often rise with time, as the N content of manure declines.

Table 3. Nutrients removed by typical Manitoba crops (Source: Adapted from Manitoba Agriculture and Food Soil Fertility Guide and Manure Management Facts: Crop Rotations and Timing of Manure Applications)

Crop	Yield	Crop Part	Nitrogen	Phosphorus[1]	Potassium[2]	Sulphur	P:N Ratio
			Lbs/acre				
Spring Wheat	40 bu/ac	seed	60	23	17	4	0.38
		straw	25	9	55	5	0.36
		total	85	32	72	9	0.38
Winter Wheat	50 bu/ac	seed	52	26	17	7	0.50
		straw	15	5	54	3	0.33
		total	67	31	71	10	0.46
Barley	80 bu/ac	seed	78	34	25	7	0.44
		straw	28	9	68	5	0.32
		total	106	43	93	12	0.41
Oats	100 bu/ac	seed	61	26	18	5	0.43
		straw	45	15	127	8	0.33
		total	106	41	145	13	0.39
Rye	55 bu/ac	seed	59	25	20	5	0.42
		straw	33	21	111	11	0.64
		total	92	46	131	16	0.50
Corn (grain)	100 bu/ac	seed	97	44	28	7	0.45
		straw	56	19	101	8	0.34
		total	153	63	129	15	0.41
Corn (silage)	6 t/ac	total	156	63	202	13	0.40
Canola	35 bu/ac	seed	68	41	21	12	0.60
		straw	44	17	72	10	0.39
		total	112	58	93	22	0.52
Flax	24 bu/ac	seed	51	15	15	5	0.29
		straw	14	3	20	6	0.21
		total	65	18	35	11	0.28
Sunflowers	2000 lb/ac	seed	53	16	12	4	0.30
		straw	21	10	25	4	0.48
		total	74	26	37	8	0.35
Peas	50 bu/ac	seed	117	35	35	7	0.30
		straw	36	8	102	6	0.22
		total	153	43	137	13	0.28
Soybeans	25 bu/ac	seed	100	20	35	3	0.20
		straw	32	4	51	6	0.13
		total	132	24	86	9	0.18
Potatoes	300 cwt/ac	tubers	96	28	162	9	0.29
		vines	75	22	62	5	0.29
		total	171	50	224	14	0.29
Alfalfa (forage)	4 t/ac	total	232	55	240	24	0.24
Clover (forage)	4 t/ac	total	215	55	202	11	0.26
Grass @ 10% CP	3 t/ac	total	103	30	130	13	0.29
Grass @ 20% CP	3 t/ac	total	200	30	130	13	0.15

[1] Expressed as P_2O_5 equivalent
[2] Expressed as K_2O equivalent

Impacts on Soil and Water Quality

To understand how to best manage manure we must understand the potential impacts it may have on the environment and consider these impacts in the design of our manure management systems. Here we will focus on impacts associated with the land application of animal manure.

Nitrate Leaching

Process

When NO_3^- accumulates in the soil it can be carried with draining water through the soil profile, beyond the plant root zone and into groundwater. This process is known as NO_3^- leaching and can impair groundwater quality. Soils with high potential for NO_3^- include soils able to conduct water rapidly (course texture) to which high rates of manure or nitrogen fertilizer has been applied. As indicated earlier, manure generally contains little or no NO_3^- but rather, contains ammonium that is converted to nitrate by soil organisms. The potential for NO_3^- leaching loss from manure is no greater, and most cases is less, than equivalent rates of a fertilizer such as urea (Beauchamp, 1983; Younie et al., 1994). When applied in excess of that required by the crop, manure application can result in significant NO_3^- leaching.

Management

The most effective approach to minimizing the risk of NO_3^- associated with the application of manure is to apply appropriate rates of manure. Appropriate rates are generally defined in relation to crop nitrogen demand. If manure is not applied at excessive rates, large amounts of NO_3^- do not accumulate in the soil and there is low risk of NO_3^- movement to groundwater. Time of manure application is also important. Where possible manure should be applied close to the time of crop nitrogen demand. This minimizes the time period where nutrients accumulate in the soil, in a form susceptible to loss, prior to crop uptake. Application of manure onto crops with a high requirement for nitrogen and water (e.g., perennial forage) will also help to minimize the risk of accumulating excess NO_3^-.

Nitrogen and Phosphorus Runoff and Erosion

Process

When the amount of rainfall exceeds the infiltration capacity of the soil there is the potential for runoff of excess water and eroded soil to move into surface water bodies. The runoff and eroded soil from manured fields can contain significant amounts of nitrogen and phosphorus and organic compounds. In the receiving water bodies, this type of nutrient enrichment can damage surface water quality by increasing growth of algae, followed by depleted oxygen concentrations, foul odours, sedimentation, fishkills and release of algal toxins when the algae decompose (in most cases, phosphorus is the nutrient that limits the eutrophication process).

The runoff water can carry significant amounts of dissolved or suspended nutrient, particularly when manures have not been injected or incorporated into the soil following application. Soil erosion also carries nutrients, especially P, into surface water bodies. When the P-enriched soil particles reach a water body, they release precipitated or adsorbed P into solution. In the early spring the infiltration capacity of the soil may be very low because of ice contained within the soil. The potential for runoff and erosion is greatest at this time. The potential for runoff and erosion is also increased on sloping land.

Klausner et al. (1976) found that solid dairy manure application during thawing periods resulted in significant nitrogen and phosphorus movement to surface water bodies. Young and Mutchler (1976) found under conditions in Minnesota that up to 20% of nitrogen and 16% of orthophosphate was lost during spring runoff when manure applied to frozen soil. In the same study losses of less than 3% of nitrogen and 4% or phosphorus were observed when the manures were incorporated into the soil in the fall following application. Under Manitoba conditions, Green (1996) found that the surface application of manure to frozen soil resulted in increased ammonia and phosphate concentrations in spring runoff relative to control fields. Nitrate concentrations spring melt waters were not elevated relative to the control sites. In another study in Manitoba, Green and Turner (1999) found elevated concentrations of total nitrogen (total nitrogen, ammonia, nitrate) and total phosphorus in spring runoff water from a field to which manure had been applied and incorporated during the previous fall relative to fields not receiving manure. In general, application procedures which introduce the manure directly into the soil matrix or incorporate it as soon as possible after application reduce nutrient loss. Application of manure to frozen soil when it cannot be incorporated and is subject to drying should be avoided.

Management

Surface runoff and erosion of N and P results from two processes: accumulation of high concentrations of N and P at the soil surface and transport of that N and P to water bodies. The best strategy for avoiding accumulation of excess N and P is to apply manure at rates to balance nutrient addition with nutrient withdrawal by crops. The accumulation of high soil test concentrations of N and P should be avoided.

The most effective means for reducing the transport of manure nutrients to water bodies is to inject manure beneath the soil surface or to incorporate the manure into the soil as soon as possible after application. Manure should not be applied to frozen land. Manure applied to frozen land cannot be incorporated and remains on the soil surface during spring period when the potential for runoff and erosion is at is greatest. Designing animal holding operations with at least 6-9 months storage capacity ensures that manure need not be applied to frozen land. Minimum tillage (e.g., leaving standing stubble in the field in the fall) will also reduce soil erosion and the runoff of nutrients. Application of manure onto crops that utilize large quantities of water and which provide year-round vegetative cover (e.g., perennial forage) may also decrease erosion and runoff losses. Recommendations for establishing riparian areas and respecting setback distances along watercourses and water bodies should also be followed.

Phosphorus Leaching

Process

Phosphorus is usually considered to be a nutrient that does not move easily with water. Therefore, P losses with runoff and erosion are generally considered to be the greatest environmental risk associated with manure P. However, P can leach below the crop's root zone, especially where the P is applied in the organic form and where the rate of P applied exceeds the P retention capacity of the soil (Campbell and Racz, 1975). Over the long term, leached P could eventually reach groundwater, which in turn, can often reach surface water bodies. Therefore, P leaching eventually poses a threat to surface water quality through eutrophication. And, unfortunately, by the time at which such a problem reveals itself, the problem will be impossible or extremely difficult to correct. European researchers have also observed significant P movement through manured soil and have predicted a breakthrough of high P concentrations in groundwater within 20-30 years under continuous large loadings of manure (Smith et al., 1998).

Management

As with other environmental risks, the most important management strategy is to balance manure P application rates with the rate of P withdrawal by crops. Such a strategy will help to ensure that P concentrations will not accumulate to levels that exceed the soil's retention capacity for P. The use of crops that utilize large amounts of P and water will also minimize the risk of P leaching into groundwater.

Atmospheric Impacts

Atmospheric impacts can result from either the loss of ammonia from recently applied animal manure or from the production of nitrous oxide during the process of denitrification.

Ammonia Volatilization

Process

Ammonia volatilization is the gaseous loss of ammonia gas from the soil. In the presence of water ammonia gas (NH_3) is in equilibrium with the ammonium ion (NH_4^+).

$$NH_{3\,(gas)} + H_2O \Longleftrightarrow NH_4^+ + OH^-$$

Soil pH is commonly near neutrality (6-8) or slightly acidic and thus ammonia does not tend to accumulate and ammonia losses are small. Significant ammonia loss may occur form soils with a high pH or when high NH_4^+ concentrations are present. Examples include urine patches in pastures, surface applied urea and anhydrous ammonia applied to dry soils. Ammonia volatilization from manure occurs when excessive amounts of manure are applied or when manure high in ammonium is applied to the surface and not incorporated immediately.

Significant volatilization losses can occur during the handling and storage of manure. Undiluted animal urine, whether on the barn floor or animal pastures, is the source of significant ammonia loss. The longer urine remains in a concentrated form in the animal barn the greater the potential for loss. Rapid transfer to storage has been shown to enhance nitrogen conservation (Table 4). Once manure is transferred to storage its exposure to the atmosphere is minimized and the material is diluted by wash water and other constituents contained in the system.

Table 4: Ammonia losses as influenced by the duration of retention in swine housing (Burton and Beauchamp, 1986).

Management System	Approximate Retention on Barn Floor	NH_3 Loss
Slotted floor over pit	~1 hour	5-9%
Daily scrapping to pit	~1 day	19-21%
Gravity incline to pit	~1 week	27%

The method of storage is also of importance. Storage conditions that minimize exposure to the atmosphere generally reduce ammonia loss. Biological activity in unstirred containment is usually sufficient to consume all of the oxygen contained in stored manure. These storages are referred to as being anaerobic. Anaerobic storages have been shown to conserve ammonia to a greater extent than lagoons. Continuously mixed or aerated manure treatment, designed to convert ammonia to nitrate, can result in nitrogen losses in excess of 50% (Vanderholm, 1975). Ammonia loss from anaerobic storage ranges for negligible in storages where surface crusts form to as much as 50-60% (Vanderholm, 1975).

Volatile losses of ammonia are greatest for application technologies that involve extensive contact with the atmosphere. It has been estimated that approximately 50% of the manure nitrogen produced in the U.S. is lost via ammonia volatilization (Porter, 1975). Losses of the ammonia, as great as 40%, occur as a result of the irrigation of manures containing a high ammonium content such as swine manure (Pote et al., 1980). Drying can result in significant ammonia loss as well. Heck (1931) observed 40-50% of total manure N could be lost on drying. Lauer et al., 1976 observed that losses of 61-99% of the ammonium in manure could occur if manure was allowed to remain on the soil surface for periods ranging from 5 to 25 days.

Denitrification

Process

Denitrification is a microbial process occurring in the soil that results in the conversion of a plant available form or nitrogen, nitrate (NO_3^-), to gaseous non-available form.

$$NO_3^- \text{=====>} N_2O \text{=====>} N_2$$

In moist to wet soils, biological activity consumes oxygen at a rate greater than it can be supplied. When oxygen is depleted, bacteria use nitrate in place of the oxygen. This process is driven by substrate availability (organic carbon), the presence of nitrate, and sufficient water to restrict the supply of oxygen to the soil. Manure application can create ideal conditions for denitrification and can result in significant loss of plant available nutrients. Note that one of the intermediates of this reaction, N_2O, is an important greenhouse gas.

The sporadic nature of the denitrification process makes estimation of the rates of N_2O production difficult. It has been assumed that on a global basis, 1-3% of manure nitrogen is released as N_2O, although there is insufficient data to assess the reliability of this estimate. Animal production systems have been estimated to result in approximately 7 Mt CO_2eq./year from Canadian agriculture (Table 5), approximately 20% of total N_2O emissions from agriculture and 10% total agriculturally related GHG emissions. Plot studies have suggested that animal manure may have much greater N_2O production than inorganic fertilizers. In particular solid manure has been shown to stimulate large losses of N_2O. Further research is needed before we are able to say with any certainty whether the N_2O production from manure is sufficient to offset the enhanced sequestration of carbon in the soil, making manure a net greenhouse gas emitter. There is also the potential for the development of technologies which N_2O emissions from manure.

Table 5: Nitrous Oxide Emissions from Agriculture in Canada in 1991 and 1996. (Emissions are expressed as Mt CO_2 equivalent, with a 100-year time horizon).

	1991	**1996**
	------ Mt CO_2 equivalent /year -----	
Direct Emissions from soils	**17.9**	**21.5**
Direct Emissions in animal production systems	**6.7**	**7.6**
Indirect Emissions from agricultural systems	**9.6**	**11.8**
Total Emissions	**34.3**	**40.9**

Source: Monteverde et al., 1997 as reported by Agriculture and Agri-Food Table Foundation Paper prepared for the Nation Climate Change Process (www.nccp.ca)

Management

The key to managing denitrification losses from manure amended soil is to avoid accumulation of NO_3^-. When the soil is wet, primarily in the spring and fall, accumulated NO_3^- will be lost as a result of denitrification. As mentioned previously, manure contains mostly NH_4^+ and very little NO_3^-. Following land application, NO_3^- is formed from ammonium by the process of nitrification. The nitrification of late fall and early spring applied manure will be relatively slow and thus little nitrate will accumulate during these periods and there will be little loss from denitrification. Early fall application of manure can result in significant nitrification and during a wet spring much of this nitrogen could be lost as a result of denitrification. The accumulation of NO_3^- in the soil can also be limited by applying manure to high N demanding crops and applying the recommended rates of manure the majority of the nitrate produced from the manure will be utilized by the crop. Also avoid application of large amounts of manure to wet areas of the landscape. The use of nitrification inhibitors for delaying nitrate production is being examined. Feeding strategies that reduce the total nitrogen content of manure also have the potential to reduce the accumulation of NO_3^- in soil.

Manure management for the maximal gain and minimal risk

To avoid adverse environmental impact the land application manure must be carried out prudently and judiciously. Much is known about the effective management of animal manures. The following management approaches can help to ensure manure is effectively used in crop production. The use of alternate feed sources, feed additives and feeding strategies adjusted to the animal's growth stage are being examined.

Limit nitrogen and phosphorus content of manure

There has been recent interest in examining the ability of modifying animal feeding strategies to increase the efficiency of feed utilization and decrease the nitrogen and or phosphorus content of manure (Baidoo, undated). Minimizing feed spillage and wastage can significantly reduce P concentrations in liquid hog manure. Livestock diets can be adjusted to eliminate dietary excesses and to improve the utilization of dietary nutrients by the animal. For example, most of the P in swine feed supplements is present as moderately soluble monocalcium or dicalcium phosphate, forms of P that is relatively available to the animal. However, in the feed grains, 40-70% of the P is present as phytin, a very stable ring-type chemical form of P that is not available to animals unless it is broken apart by the phytase enzyme. In cattle, rumen microbes supply sufficient phytase enzyme to break down organic P so that the P can be used by the animal. However, the digestive tract of non-ruminants like hogs, has small quantities of phytase and is not capable of using organic P efficiently. As a result, typically, more 70-90% of ingested P is excreted as manure and urine (Mikkelson 1997). Therefore, researchers are attempting to increase P availability by adding phytase as a swine feed supplement and breeding Highly Available Phosphorus (HAP) feed grains, which have low concentrations of phytin.

Manure may also be processed mechanically to separate and remove solids from effluent to increase the cost-efficient transport radius. Passive sedimentation also results in separation and concentration of nutrients. For example, a significant proportion of the P settles as sludge in the bottom of liquid manure storage systems. As a result, P:N ratios of manure vary significantly with depth in such storage systems.

Rates of application... how much is enough?

While we have discussed the positive aspects of manure application to soil, this is one of those situations where there can clearly be "too much of a good thing"? The intent of a sustainable manure application strategy is to balance the application of nutrients with crop withdrawals and to avoid environmental impact. In some jurisdictions, manure application guidelines are based on the nitrogen content of the manure. However, the accumulation of phosphorus from repeated applications of manure can also pose an environmental threat and in those situations manure applications should be based on acceptable phosphorus loading rates.

So how much manure is that? As an example in the Manitoba 1998 Farm Practices Guidelines for Hog Producers, Manitoba Agriculture and Food recommends that manure application rates should match crop nitrogen requirements. Depending on the crop that may range from 65 - 250 kg N/ha. Application rates on sandy soils are lower than medium to fine textured soils.

Phosphorus-based manure application guidelines have not yet been developed for Manitoba. However, as with nitrogen, the goal of any long term nutrient management strategy for manure application should be to match application rates to crop withdrawals.

Manure application rates should also reflect anticipated loss rates associated with the chosen method of application. Calibration of manure spreaders is also an important aspect in applying the appropriate rates of manure.

Timing of application

In addition to knowing how much to apply, it is important to know when to apply the manure. Clearly the timing of manure application will be a compromise between the optimal date for nutrient utilization and the date most convenient for the operator. From a nutrient utilization perspective, the closer to the time of maximum plant nutrient demand the manure can be applied the greater the likelihood that the nutrients will reach the crop and the less opportunity there is for nutrient loss. Thus spring is better than fall. Winter applications should be avoided as the manure cannot be incorporated and significant losses of ammonium to the atmosphere and nitrogen and phosphorus in runoff are likely to occur. Summer application to fallow land is also not recommended because nitrates can accumulate in the soil during the fallow period and be leaching to groundwater in the fall and spring rains.

Where should manure be applied?

Manure should be applied to the land that needs it the most. High rates of manure should not be applied to the same land year after year. If manure is applied to the same land each year the rate of nitrogen mineralization will soon exceed crop demand, allowing for the accumulation of NO_3^- and the potential for loss. In addition, repeated applications on the basis of the crop's requirement for nitrogen, alone are likely to cause excessive accumulations of phosphorus.

To what crops should manure be applied

Manure should be applied to high nitrogen and water demanding crops wherever possible. This allows for the greatest amount of withdrawal of the nitrogen by the plant.

Conclusions

In conclusion, manure is a resource to be utilized effectively and not a waste to be disposed. Effective manure management can provide for plant nutrient demands with little or no risk to the environment. The following general guidelines should be followed in planing a manure management strategy.

1. Use appropriate manure application rates based on plant nitrogen and phosphorus withdrawal.

2. Incorporate manure as soon as possible after application.

3. Do not apply manure to frozen soils.

4. Test the nutrient content of manure regularly.

5. Have routine soil tests performed on soils to which manure has been applied.

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