SECTION 4

Application of Manure

4.1 Manure – An Agronomic Resource

Manure is both a natural by-product of livestock production and an excellent source of plant nutrients. The use of manure as a fertilizer for crop production is a very beneficial way to recycle manure nutrients within an agricultural system. Most livestock operations are on or surrounded by, large areas of productive agricultural land where manure can be applied in a sustainable manner. In many instances, manure can be a substitute for commercial, inorganic fertilizers. Manure not only acts as a source of plant nutrients but, through the addition of organic matter, it also helps to improve soil tilth, structure, aeration and water holding capacity.

Manure application is a sustainable agricultural practice. To maximize the benefits of manure nutrients, prevent crop damage and minimize the risk of pollution, manure application rates should be based on crop nutrient requirements or removals.

The goals of using livestock manure as a fertilizer should be to:

- maximize the use of the manure nutrients by crops
- minimize the risk of polluting surface water and groundwater

4.1.1 Manure as a fertilizer

Manure contains both macro- and micro-nutrients needed for crop production in organic and inorganic forms. Inorganic nutrients are readily available to the growing crop, while the organic nutrients become available gradually over time. A crop responds to inorganic nutrients in soil, whether they originate from manure or commercial fertilizer.

As not all of the nutrients are available at the same time, proper management is needed to ensure sufficient nutrients are available when required by the crop. This will maximize nutrient use as well as crop yield and crop quality.

4.1.2 Manure content

A large proportion of the nutrients in livestock feed is excreted and not used by the animal. There are many factors that affect the nutrient composition of manure including the type of housing system, whether or not bedding is used, the type of bedding, the age of the animals, the feeds and feed supplements that are being used and the type of manure storage and handling system. The results of the manure nutrient analyses can be greatly affected by how the manure sample is taken. Information on how to take a manure sample is provided in Section 4.3.2. Typical nutrient concentrations for liquid and solid pig manures are provided in Tables 4a and 5.

These tables provide data on nutrient concentrations in manure prior to the adoption of phytase use to reduce the phosphorus (P) content of the manure. Table 4b contains nutrient data collected after the adoption of phytase use by the pig industry.

Housing system – The type of housing system influences various management practices including the quantity of washwater and bedding that is used. These differences will be reflected in the moisture and nutrient content of the manure.

Animal age – As pigs grow, their ability to convert the nutrients in feed to body tissue changes. Pigs that are actively growing will utilize some nutrients more efficiently than mature animals.

Feed type – The nutrients in pig manure are predominantly excess and undigested feed nutrients that have been excreted by the pig. Therefore, the nutrient content of manure is directly affected by the nutrient content of pig feed. Some of the nutrients in the feed are in a form that is not available to the pig and are excreted in the manure. If a ration is unbalanced, the pigs can not use all of the nutrients and the nutrients will also be excreted. Various feeding strategies, such as multi-phase feeding and the use of enzymes, can be adopted to minimize the amount of nutrient excreted by the animal.

Manure storage, handling and application – The manure handling system (e.g. liquid vs. solid) and storage type and duration affect the nutrient content of manure. Crop nutrient availability depends on the equipment selected to apply manure, the timing of application, post application field operations (such as tillage) and weather conditions during and after application. Nitrogen is the nutrient most affected by the various components of the manure management system.

■ Nitrogen

The nitrogen (N) content of manure is highly variable. A manure analysis is required to determine how much N is in the manure and in what forms. A proper manure analysis contains three N measurements:

Table 4a: Nutrient (kg/m³ Or kg/1000 L) And Dry Matter (%) Content For Liquid Pig Manure[1] (Pre-phytase Use)

Parameter[2]	Farrow			Nursery			Finisher			Farrow to Finish		
	Avg	Min	Max	**Avg**	Min	Max	**Avg**	Min	Max	**Avg**	Min	Max
Total N	**1.7**	0.6	6.5	**2.7**	1.5	4.6	**3.4**	1.5	6.4	**2.8**	1.2	4.0
NH_4-N	**1.2**	0.5	3.2	**2.0**	1.3	3.0	**2.6**	1.2	4.1	**2.4**	1.1	3.4
Total P_2O_5	**1.5**	0.1	12.7	**2.7**	0.3	5.9	**2.3**	0.1	8.1	**2.4**	0.3	4.8
Total K_2O	**1.2**	0.3	4.2	**2.0**	1.5	2.4	**1.8**	1.1	3.2	**1.7**	0.8	2.1
Dry Matter	**3.0**	0.3	38.6	**3.1**	1.1	5.6	**3.7**	0.0	11.8	**2.1**	0.6	4.0

[1] Values are on an as-is basis (i.e. untreated). See Appendix C for imperial units. SOURCE: Racz and Fitzgerald 2001. Nutrient and Heavy Metal Contents of Hog Manure – Effect on Soil Quality and Productivity. Proceedings: Livestock Options for the Future. Results based on 37, 11, 92 and five samples for farrow, nursery, finisher and farrow to finish, respectively.

[2] Total N refers to all forms of nitrogen in manure, but typically only includes ammonium N (NH_4-N) and organic N. NH_4-N is the inorganic, readily available form of nitrogen in manure. Total P_2O_5 refers to all forms of phosphorus in manure expressed in the fertilizer equivalent (P content x 2.3). Total K_2O refers to all forms of potassium in manure expressed in the fertilizer equivalent (K content x 1.2).

- total nitrogen
- ammonia (or ammonium) nitrogen
- organic nitrogen

As the term suggests, total nitrogen is an estimate of all of the N contained in the manure. It includes ammonium N, organic N and any nitrate N that may be present. Not all of this N will be available to the crop following application.

Ammonium nitrogen (NH_4-N) is the predominant inorganic form of N in manure and it is immediately available to the crop following application. It may be expressed as either ammonium or ammonia on the soil test report and it is the same form of N as is in ammonium-based commercial fertilizers. Ammonium N is very susceptible to atmospheric losses through volatilization.

Nitrate nitrogen (NO_3-N) is another inorganic form of N. Although soil can contain significant quantities of nitrate N, it is typically present in manure in very low or insignificant amounts.

Organic nitrogen is determined indirectly by calculating the difference between total N and ammonium N. Organic N is slowly released to the crop and can have a significant impact on the N-supplying power of the soil if it is allowed to build up after several years of manure application.

Organic N = Total N – Ammonium N

In liquid manure, a larger fraction of the total N is typically in the ammonium form than in solid manure. The N in solid manure is mostly in the organic form. This has great bearing on the N value of the manure as a fertilizer and manure nutrient management. As well, many solid manure systems use large amounts of bedding materials that are high in carbon (C). This can increase the carbon to nitrogen ratio (C:N) in the manure significantly. A high C:N ratio in manure can delay the availability of the N to the crop following application.

- **Phosphorus**

The phosphorus (P) content of the manure is also highly variable. Pig manure is a mixture of organic and inorganic P. Studies have

Table 4b: Nutrient (kg/m^3 Or kg/1000 L) And Dry Matter (%) Content For Liquid Pig Manure From Operations (Phytase Use)

Parameter[2]	Farrow			Nursery			Finisher		
	Avg	Min	Max	**Avg**	Min	Max	**Avg**	Min	Max
Total N	**2.2**	0.4	6.0	**2.7**	1.1	5.6	**3.4**	0.4	6.7
NH_4-N	**1.6**	0.4	2.7	**2.0**	0.6	3.3	**2.4**	0.4	4.7
Total P_2O_5	**1.5**	0.0	9.4	**1.1**	0.1	4.7	**1.5**	0.0	6.5
Total K_2O	**1.3**	0.7	2.0	**1.9**	1.3	2.8	**1.8**	0.1	3.4
Dry Matter	**2.1**	0.3	9.1	**2.2**	0.6	7.4	**3.4**	0.4	11.2

[1] Values are on an as-is basis (i.e. untreated). See Appendix C for imperial units. SOURCE: Industry co-operators. Results based on 132, 58 and 181 samples for farrow, nursery and finisher, respectively.

[2] Total N refers to all forms of nitrogen in manure, but typically only includes ammonium N (NH_4-N) and organic N. NH_4-N is the inorganic, readily available form of nitrogen in manure. Total P_2O_5 refers to all forms of phosphorus in manure expressed in the fertilizer equivalent (P content x 2.3). Total K_2O refers to all forms of potassium in manure expressed in the fertilizer equivalent (K content x 1.2).

shown that the relative proportions of organic P ranges from 20 to 50 per cent of the total P, depending upon the age of pig, diet, and production system. The balance which is inorganic P ranges from 50 to 80 per cent. However, manure analyses routinely measure only total P. Most of the P is contained within the solids, which tend to settle to the bottom of the liquid manure storage resulting in an increasing concentration of P with depth. This makes obtaining a representative manure sample very difficult. As the organic portion is only slowly available to the crop and some of the inorganic fraction is readily bound to soil, not all of the P in manure is available to the crop following application.

■ Organic Matter (Carbon)

The application of manure to cropland can help maintain or improve soil organic matter levels and improve soil tilth, soil structure, water infiltration, nutrient and water holding capacity and reduce soil erosion. When the soil is tilled and fields are cropped, a portion of the organic matter is broken down and lost from the field. Organic matter is also lost from upper hill slope positions when topsoil is transported down slope by repeated tillage.

The use of commercial, inorganic fertilizers does not replenish the lost organic material. Depending on soil type, a steady depletion of soil organic matter can result in a soil structure that is more susceptible to erosion and crusting. Application of manure, particularly solid manure, will help to slow or reverse this trend of degrading soil quality and potentially improve crop yields as a result.

■ Potassium

Pig manure can contain relatively high levels of potassium (K). Most Manitoba soils with the exception of sandy or peat soils are naturally high in K. As a result, crop productivity is not likely to benefit from additions of manure K.

Multiple applications of manure can increase the amount of plant-available soil K. High

Table 5: Nutrient (kg/tonne) And Dry Matter (%) Content For Solid Finishing Pig Manure[1] (Pre-phytase Use)

Parameter[2]	Fresh			Stockpiled[3]			Composted[4] Fresh			Composted Stockpiled		
	Avg	Min	Max	**Avg**	Min	Max	**Avg**	Min	Max	**Avg**	Min	Max
Total N	**6.3**	4.8	8.9	**6.0**	3.7	12.9	**6.4**	5.0	8.1	**7.2**	5.8	8.8
NH_4-N	**1.4**	1.0	1.8	**2.1**	1.1	3.1	**0.5**	0.1	1.2	**0.7**	0.2	1.0
Total P_2O_5	**6.5**	5.0	9.9	**5.5**	3.4	8.8	**9.2**	7.6	10.5	**8.6**	6.4	9.9
Total K_2O	**8.8**	6.0	15.1	**9.0**	6.8	13.2	**10.4**	8.9	12.0	**10.8**	9.0	14.2
Dry Matter	**33.2**	24.0	45.3	**47.1**	32.1	63.7	**66.4**	63.4	69.4	**58.2**	44.0	63.4

[1] Values are on an as-is basis (i.e. untreated). See Appendix C for imperial units. SOURCE: Agriculture and Agri-Food Canada 2005. Results based on 10 samples.

[2] Total N refers to all forms of nitrogen in manure, but typically only includes ammonium N (NH_4-N) and organic N. NH_4-N is the inorganic, readily available form of nitrogen in manure. Total P_2O_5 refers to all forms of phosphorus in manure expressed in the fertilizer equivalent (P content x 2.3). Total K_2O refers to all forms of potassium in manure expressed in the fertilizer equivalent (K content x 1.2).

[3] Maintained in a pile for approximately six months and minimally disturbed (i.e. not moved repeatedly or mixed).

[4] Carefully managed to maintain necessary moisture and temperature, resulting in the breakdown of manure to form a stable and uniform material.

soil K can lead to increased uptake of potassium by forages, which can pose a health risk to dairy cows. High K levels in dry cow diets elevate the risk of certain metabolic disorders, such as milk fever. If high K levels in forage are a concern, tissue testing should be used to ensure that the forage is of acceptable quality. In some instances, it may be necessary to avoid manure applications on those fields producing low K forage for dry cows.

■ Sulphur

Manure contains sulphur (S) in both organic and inorganic forms. As with other nutrients, the organic fraction must be broken down by soil microorganisms before it is available to the crop. The inorganic portion in the sulphate (SO_4) form is readily available to the crop. However, manure analysis typically provides a result for total S only. Liquid pig manure can be low in S relative to N. This should be taken into account when fertilizing crops such as canola that have a relatively high S requirement.

■ Micronutrients

Micronutrients, such as copper (Cu), zinc (Zn), cobalt (Co), boron (B) and other metals are found naturally in soil as well as in both manure and some commercial fertilizers. They are required in small amounts for optimum crop performance. Reduced crop performance can result from either a deficiency or an excess of micronutrients. Micronutrient concentrations in manure often reflect the levels of micronutrients in the feed. Unless micronutrients are being fed at high levels, the micronutrient contents of manure will not result in a build up to toxic levels in the soil if manure is applied at rates to meet the N or P requirements of the crop.

Pigs require Cu and Zn for normal growth and reproduction. These minerals are routinely added at low levels to all pig diets. However, Cu and Zn concentrations are sometimes increased in pig feed since these minerals have been shown to improve growth performance (Cu) and have some pharmacological effects (Zn) in young and growing pigs. Feed samples can be analyzed to verify the levels of these micronutrients in pig diets. Manure, soil and plant tissue tests can also be used to monitor micronutrient levels if necessary.

■ Salts

Manure and soil contain the salts of ammonium (NH_4), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na). When manure is applied to soil, varying amounts of salts are also applied. In areas of adequate precipitation and drainage, salt accumulations in soil are rare and crop production is unaffected. In areas with borderline saline soils and low annual precipitation, manure applications may elevate the soluble salt content of the soil above crop tolerance. Elevated soil salinity can hinder the ability of a plant to absorb water from the soil. In these instances, salt levels in manure should be minimized through dietary changes. Salt accumulation in soil can also be monitored with soil testing. It is expressed as electrical conductivity (EC).

■ Weed seeds

Some weed seeds in manure may retain their viability even after digestion by livestock. Weed seeds can be effectively destroyed before they are fed to livestock by feed grinding, rolling or other aggressive treatment during the feed milling process. Weed seed viability can also be reduced by proper composting in which high temperatures are maintained. Weed flushes following manure application may in fact be caused by an existing seed bank in the soil that responds to the addition of readily available nutrients.

- **Microorganisms**

As discussed in Section 3.6, livestock manure contains a broad spectrum of microorganisms. Proper hygiene is required when handling livestock manure in order to reduce the transmission of pathogens.

4.2 Manure and Soils

When manure is applied, the nutrients can undergo a number of transformations that may accelerate or delay their availability for crop uptake. The fate of the N in the manure is highly variable and is influenced by the forms of N in the manure, application techniques and timing, along with weather conditions. The availability of the P in the manure depends on the forms of the P and its placement relative to the plant root system.

4.2.1 Manure nitrogen (N) after application

Manure N is affected by several processes after it is applied. Some make N available for plant uptake, while others make it less available to plants or even cause its permanent loss. Application techniques that conserve N maximize the fertility value of the manure and reduce the risk of N loss to air or water.

- **Mineralization**

The organic N in manure must go through a decomposition process known as mineralization – the conversion of organic N to ammonium N. It can be slow and as a result, the N is released throughout the growing season rather than being immediately available following application as it is with commercial fertilizer. In Manitoba, it is estimated that about 25 per cent of the organic N in pig manure is mineralized and available to the next crop. The remainder becomes available during subsequent years at a significantly decreased rate.

- **Nitrification**

Although nitrate is present at low concentrations in manure, manured soils can contain significant amounts. This is because the ammonium from the manure is converted to nitrate by soil microorganisms through the nitrification process.

- **Volatilization**

The ammonium N in manure can be lost to the atmosphere as ammonia gas through the chemical process of volatilization. Nitrogen losses through this process can occur during storage as well as during application. Volatilization losses during storage are higher for open than enclosed structures and increase with exposed surface area for open structures. The amount of N lost through volatilization during application of manure depends on the amount of ammonium in the manure, exposure of the manure to the atmosphere and weather conditions (Table 6). The actual amount of ammonium available to the crop is calculated by subtracting the amount of ammonia estimated to be lost by volatilization during application, from the amount of ammonium in the manure.

Available Ammonium N = Total Ammonium N x (100% - % Volatilization loss)

■ **Immobilization**
Immobilization is the conversion of inorganic N to organic N (i.e. the opposite of mineralization). As soil microorganisms decompose plant material and manure, they use the carbon (C) as a source of food. As C is consumed, N is also consumed, making it temporarily unavailable to plants. Therefore, when high C materials (such as straw and manure with a lot of bedding) are added to soil, the availability of N to the crop can be reduced or delayed. When these microorganisms die, the nutrients they contain are released back into the soil.

■ **Nitrate Leaching**
Nitrate is highly soluble in water. As water moves down through the soil, such as after snowmelt or heavy rainfall, it can carry nitrate with it. Nitrate is more prone to leaching in coarse textured soils (e.g. sands) at times of the year when the crop is not actively growing and soil moisture levels are high. Nitrate and other dissolved forms of nitrogen are also contributed to adjacent water bodies through runoff both during spring melt as well as during runoff associated with rainfall events. Studies in Manitoba have shown that runoff can be an important source of nitrogen to surface waters where, along with phosphorus, it can cause large algal blooms.

■ **Denitrification**
Soils become anaerobic (lack oxygen) when saturated or during periods of high microbial activity. When soils are anaerobic, the soil bacteria can continue to breathe using nitrate instead of oxygen. During this process, nitrate is consumed and N gases (such as N_2 and N_2O) are released to the atmosphere. This process is called denitrification.

■ **Crop Uptake and Removal**
The amount of N that the crop takes up from the soil largely depends on crop yield. Crop yield depends on crop type, agricultural capability of the soil, weather conditions and management practices. The amount of N removed by the crop is also a function of the protein content of the plant and the amount of plant material harvested from the field.

4.2.2 Manure phosphorus (P) after application

Although P is less dynamic in soil than N, its management in manure is challenging. Most Manitoba soils are naturally deficient in plant-available P. Crops growing on low P soils require fertilization to reach optimal yields and will benefit from a build up in soil P until agronomic requirements are met. However, repeated applications can result in soil P levels well above agronomic requirements. In addition to being a valuable crop nutrient, at elevated levels, P is a serious contaminant in surface water. For this reason, loss of P from agricultural lands is of particular concern to surface water quality.

■ **Mineralization**
As with N, mineralization of organic P to inorganic P takes place in the soil and contributes to the supply of plant available P.

■ **Retention**
Inorganic P tends to bind readily in both alkaline and acidic soils to organic matter, calcium (Ca), magnesium (Mg), iron (Fe), and aluminum (Al). Fine textured soils (i.e. clays) are able to bind considerably more P than coarse textured soils (i.e. sands).

- **Solubilization**

Soil does not have an unlimited capacity to bind P. Rising soil test P levels are often accompanied by an increase in soluble P (P dissolved in water). Soluble P can be easily transported to surface water in runoff and it is more difficult to control than P transported by soil erosion.

- **Crop Uptake and Removal**

The amount of P that the crop takes up from the soil largely depends on crop yield. Crop yield depends on the crop type, agricultural capability of the soil, weather conditions and management practices of the producer. The amount of P removed by the crop is also a function of the P content of the plants and the amount of plant material harvested from the field.

4.3 Using Manure as a Fertilizer

The most common way to take full advantage of manure as a resource on the farm is to use it as a fertilizer for crop production. Producers who use manure as a fertilizer benefit economically because they can replace expensive commercial sources of plant nutrients with the manure nutrients. Good nutrient management practices also minimize the risk to the environment from manure nutrients. Following are the basic steps to integrating manure into a farm's nutrient management program.

4.3.1 Test the soil

Soil sampling and analysis are the only way to directly determine the plant-available nutrient status of a field and to receive field-specific fertilizer recommendations. There are a number of soil sampling strategies that may be adopted, depending on site-specific conditions. Whichever strategy is employed for a field, soils should be sampled at the 0 to 15 centimetres (cm) (0 to 6 in) and 15 to 60 cm (6 to 24 inch in) depths, and composite samples for each depth should be kept separate for analysis.

Although a variety of analytical packages are available, one that includes nitrate-N, exchangeable K, and available P should be selected. Nitrate-N should be determined on the both the 0 to 15 cm and 15 to 60 cm (0 to 6 in and 6 to 24 in) samples, whereas exchangeable K and available P only need to be determined on the 0 to 15 cm samples. There are several analytical methods for determining available P, and results from each can be considerably different. The P_2O_5 fertilizer recommendations contained in the Manitoba Soil Fertility Guide are based on sodium-bicarbonate extractable P or Olsen P. In areas where salinity (concentration of soluble salts) or sodicity (excess sodium relative to calcium and magnesium) is a concern, electrical conductivity (EC) and sodium adsorption ratio (SAR), should be considered.

Qualified professionals should be consulted for advice in selecting the most appropriate sampling strategy, analytical package and proper protocols for collecting, handling and shipping soil samples for laboratory analysis (see Appendix F).

- **Fertilizer recommendations**

The soil test report should also contain recommendations for any additional fertilizer that is required. The amount of additional nutrients required should be based on the soil test results and a realistic crop yield target provided by the producer. Realistic yield goals can be determined using producer experience and knowledge of the productive capacity of soils on a given farm.

4.3.2 Test the manure

Testing manure for each livestock operation and each application event is the best way to estimate the nutrient content of manure. A manure analysis should be based on a well-mixed, representative sample. Manure is very heterogeneous and obtaining a representative sample can be very difficult. Sometimes, more than one sample is required to estimate the nutrient concentration because the characteristics of the manure change (for example, during pump-out of a liquid manure storage structure).

It is ideal to know the nutrient content of the manure before application so that application rates can be set to meet crop nutrient requirements. Receiving test results prior to manure application can be challenging, particularly for liquid manure. This is because the manure storage structure is not typically agitated until just before and during pump-out for application. One way to address this concern is to have a database of historical manure test results for a given operation to use until recent test results can confirm nutrient contents.

Manure samples should be analyzed by an accredited laboratory on at least an annual basis. More frequent manure analyses may be required if the manure is applied at multiple times during the year (such as spring and fall) or if management practices are likely to create a change in the nutrient content of the manure. Rapid field test kits for liquid manure exist for estimating the readily available portion of N, however, the result of a field test should be verified by comparing it to a laboratory analysis of the same manure sample. Historical laboratory test results for a given operation can be used to assess the accuracy of recent laboratory and field test results.

A basic manure analysis package should include total nitrogen (TKN), ammonium N, total P, total K, and dry matter content. Organic N is calculated by subtracting the ammonium N from total N. In some instances, micronutrient analyses may also be desired.

Application rates are often based on estimated manure nutrient levels or book values. Estimated values are not as reliable as multiple manure tests for an operation because manure nutrient levels vary widely. Inaccurate estimates will lead to application rates that are either lower or higher than required.

4.3.3 Crop selection and rotation

Designing a crop rotation system that uses manure as the nutrient source should be no different than designing a crop rotation system using commercial fertilizer. However, since manure is handled and applied differently than commercial fertilizer, some modifications may be necessary. The crops included in the rotation should not only use the nutrients from the manure as efficiently as possible, but the overall rotation should have the intensity and diversity to overcome other agronomic challenges such as weeds, disease, insects, residue management, moisture management and timing of field operations. Contact Manitoba Agriculture, Food and Rural Initiatives for information on crop selection and rotation (or refer to Manitoba Agriculture, Food and Rural Initiative's fact sheet Crop Rotations and Timing of Manure Application).

■ Annual Crops and Forages

The amount of nutrients, particularly N, used by different crops varies widely. Grass-based forage crops require much more N than annual cereal crops. Legume-based forage crops, such as alfalfa, can fix atmospheric N and require little fertilizer N. Although alfalfa is capable of fixing N, it is also capable of utilizing large quantities of N from soil, manure or commercial fertilizer. As such, it is a good recipient for manure. Alfalfa is also a deep-rooted plant, which is capable of withdrawing nitrate-N that has leached below the root zone of annual crops.

Forage crops offer other advantages to manure management planning. In-season and split applications are more feasible on forage crops. High yielding forages also have the ability to remove more P than most annual crops. Silage crops offer a similarly high P removal potential when yields are high.

■ Pasture

Pastures generally respond well to fertilization by manure because their soil fertility is typically depleted after many years of grazing. Unlike forage fields that are mechanically harvested, most of the nutrients applied to pastures will be re-deposited on the pasture by the livestock. Soil nutrient build-up should be monitored when manure is used regularly to fertilize pastures.

Fertilization of native or tame pastures, can affect the relative dominance of different forage species. Over time, species that respond well to applied nutrients tend to become dominant after manure application. Species that thrive under low fertility conditions tend to become less dominant after manure application. Although forage yield may increase with manure application, the potential shift in species on pasture should be considered when planning where to apply manure.

Consideration should be given to providing a period of time between manure application and subsequent grazing so that the stand can make use of the applied nutrients. This practice will ensure a stronger regrowth of the pasture forages and minimize the risk of nutrient loss to the environment. Delaying grazing following broadcast application of manure is also suggested as a preventive measure against transmission of potentially pathogenic organisms that may be present in livestock manure. A rest period provides the opportunity for natural environmental factors to inactivate potential pathogens. A minimum 30-day rest period is recommended before livestock are reintroduced to pastures on which manure has been broadcast applied. Certain application techniques or other circumstances may allow shorter rest periods. Manitoba Agriculture, Food and Rural Initiatives can provide advice on this issue. Application of manure from a particular livestock species onto a pasture that will be grazed by a different livestock species may be another effective way to interrupt the chain of infection from pathogens to livestock. Livestock should never be present on the pasture while manure is being applied.

■ Fallow land

Applying manure to fallow land is not a recommended practice for environmental reasons, and is prohibited before August 15 unless prior approval has been obtained from Manitoba Conservation. The absence of a growing crop in the year of application means manure nutrients will not be utilized until the following growing season and increases the risk of nutrient loss from the field. Accumulation of nutrients in a fallow field, particularly nitrate-N, is likely to be accelerated as nutrients from manure and the soil are released through microbial activity. The build-up of soil nitrate-N may exceed the N requirements of the next crop. Soil sampling for N to a depth of 1.2 m (4 ft), either in the fall of the fallow year or the next spring, is recommended when applying manure to fallow land. Deeper sampling may detect leached nitrate-N that can be taken into account in crop selection and future manure management planning.

Under the Livestock Manure and Moralities Management Regulation, manure can only be applied to land as a fertilizer and the land must be cropped no later than the following growing season.

4.3.4 How to calculate the manure application rate

Manure application rate calculations are based on fertilizer recommendations. These fertilizer recommendations should be based on soil test results for nitrate-N and P and a realistic target yield for the crop to be grown. The target yields should be appropriate for the region, productive capacity of the soil and the producer's management practices. Crop insurance data and historical yield records for the operation provide guidance for establishing target yields. Agriculture Capability ratings, which are based on natural soil and landscape characteristics, can be used to identify the severity and kind of limitations to crop production for a given field. Manitoba Agriculture, Food and Rural Initiatives may be contacted for information on agriculture capability ratings. If the target yield chosen is not realized, soil nutrient levels should be monitored and future target yields should be adjusted accordingly.

The soil test report should provide fertilizer recommendations. When necessary, the Manitoba Soil Fertility Guide can also provide nutrient recommendations based on soil test values. In some situations, estimates of crop nutrient removals from appropriate published sources may also be useful when determining target manure application rates.

■ Nitrogen based application rates

Manure application rates are based on the soil analyses and fertilizer recommendations, manure analyses, timing and method of application and weather conditions. Traditionally, manure application rates have been based on N. For all crops except legumes, the rate of manure application has been based on the amount of fertilizer N required to achieve a target yield. Since legumes can fix their own N and do not require additional fertilizer, manure application rates for legumes have been based on the potential N removal of the crop (Table 6).

The N requirements of a crop can be provided by manure N. However, not all of the N in the manure will be available to the crop in the first year after application. Therefore, the available N in the manure must be calculated.

The manure test report provides results for total N (TKN) and ammonium N. Organic N is calculated from the manure test report as the difference between total N and ammonium N.

Table 6: Crop Removal Rates For N And P_2O_5 [1]

Crop[2]	Example Target Yield[3]	Average Nutrient Uptake Rate[4]		Average Nutrient Removal Rate[5]	
		N	P_2O_5	N	P_2O_5
Spring Wheat	2.69 t/ha	35.2 kg/t	13.4 kg/t	25.1 kg/t	9.8 kg/t
Winter Wheat	3.36 t/ha	22.5 kg/t	10.2 kg/t	17.4 kg/t	8.5 kg/t
Barley	4.30 t/ha	29.0 kg/t	11.7 kg/t	20.3 kg/t	8.8 kg/t
Oats	3.81 t/ha	31.5 kg/t	12.1 kg/t	18.3 kg/t	7.7 kg/t
Rye	3.45 t/ha	29.9 kg/t	15.0 kg/t	19.0 kg/t	8.1 kg/t
Grain Corn	6.27 t/ha	27.4 kg/t	11.3 kg/t	17.4 kg/t	7.9 kg/t
Canola	1.96 t/ha	63.9 kg/t	29.5 kg/t	38.7 kg/t	20.8 kg/t
Flax	1.50 t/ha	52.0 kg/t	14.8 kg/t	38.1 kg/t	11.6 kg/t
Sunflowers	1.68 t/ha	49.8 kg/t	17.0 kg/t	35.7 kg/t	10.7 kg/t
Alfalfa	11.2 t/ha	N/A[6]	N/A	29.0 kg/t	6.9 kg/t
Grass	6.7 t/ha	N/A	N/A	17.1 kg/t	5.0 kg/t
Corn Silage	11.2 t/ha	N/A	N/A	15.6 kg/t	6.4 kg/t
Barley Silage	10.1 t/ha	N/A	N/A	17.2 kg/t	5.9 kg/t

[1] Adapted from Nutrient Uptake and Removal by Field Crops, Western Canada, 2001. Compiled by the Canadian Fertilizer Institute.

[2] As bushel weights can vary considerably among some crop varieties, values other than those presented here may need to be chosen to better reflect a given cropping scenario.

[3] Example target yields for Manitoba. Site specific and actual yields for any parcel of land will depend on the agricultural capability of the land, climate and the producer's management practices.

[4] Total nutrient taken up by the crop

[5] Nutrient removed in the harvested portion of the crop

[6] Not applicable

Organic N = Total N – Ammonium N

Nitrogen availability is estimated for both the inorganic (ammonium) and organic forms. All of the ammonium is available to the crop, however, it is also highly susceptible to volatilization losses as ammonia gas. The actual amount of ammonium N available is the amount remaining after volatilization:

Available Ammonium N = Total Ammonium N x (100% – % Volatilization Loss)

Volatilization loss estimates are provided in Table 7.

Two factors are considered when estimating volatilization loss: weather conditions at the time of application and method of application. Generally, volatilization losses are expected to be greater under warmer and dryer conditions (e.g. summer) and lower under cooler and wetter conditions (e.g. early spring or late fall). Volatilization losses also increase with prolonged exposure of manure on the soil surface. Therefore, injection of liquid manure, or rapid incorporation following broadcast application, should minimize loss of ammonia to the atmosphere.

Table 7: Volatilization Losses (%)[1]

Method of Application	Cool Wet	Cool Dry	Warm Wet	Warm Dry	Average
Injected	0	0	0	0	0
Incorporated within 1 day	10	15	25	50	25
Incorporated within 2 day	13	19	31	57	30
Incorporated within 3 day	15	22	38	65	35
Incorporated within 4 day	17	26	44	72	40
Incorporated within 5 day	20	30	50	80	45
Not Incorporated	40	50	75	90	64
Irrigated	Above + 10%	Above + 10%	Above + 10%	Above + 10%	Above + 10%
Applied to Standing Crop	25	25	40	50	35

[1]MARC 2005. Manitoba Agriculture, Food and Rural Initiatives.

Organic N must be mineralized before it can be used by the crop. The proportion of organic N in manure that is estimated to be available to the following crop is 25 per cent:

Available Organic N = 25 per cent Organic N

For solid manure that contains considerable amounts of straw or other bedding materials, less than 25 per cent of the organic N may be available in the first year following a single application. As soil microorganisms consume the carbon (C) from the bedding materials, they tie up N from the manure and/or soil that would otherwise be available to the crop. Solid manure, that contains a lot of bedding, returns a significant amount of carbon to the soil. Application of this type of manure may result in temporary immobilization of N, reducing plant-availability. Repeated applications of solid manure, however, may result in a build-up of soil N that becomes available to crops grown in subsequent years.

The C:N ratio of the manure may provide information on how much N will be available to the crop in the year following application. Research has indicated that manures with C:N ratios higher than 15:1 are not likely to release N very quickly to the crop in the year following application. In these cases, less than 25 per cent of the organic N will be available in the first year. Eventually most of the additional N will be released and this must be taken into account, preferably through a soils test, when calculating the soil requirement for N in subsequent years.

The estimated total available N is determined by adding the available organic and inorganic fractions:

Total Available N = Ammonium N x (100% – % Volatilization loss) + 0.25 Organic N

■ Phosphorus based application rates

Unlike commercial fertilizer, manure nutrients are usually not in balance with the nutrient requirements of the crop. Manure application rates are based on the most limiting nutrient for crop production, which is most frequently N. Although P is usually found in manure in smaller quantities than N, crops require significantly less P than N to reach optimum yields. It is therefore common for more P to be applied than the crop can remove when application rates are based on N. This results in a build-up of soil test P.

This nutrient imbalance is magnified when manure is applied using a practice that does not conserve N for crop use and, instead, exposes the N to greater loss from the field. For example, broadcast application of manure without incorporation leads to increased loss of N through volatilization. To compensate for this fact, the manure application rate must be increased to ensure that the N demand of the crop is satisfied. A higher manure application rate leads to a higher application of manure P and a more rapid rise in soil P. The same situation also arises with annual applications of manure having a low available N content (common with solid manure).

As soil test P levels increase, soluble P also increases. Soluble P is more mobile in water and can threaten surface water quality if it moves from the field to a watercourse. Controlling the build-up of soil test P will reduce the formation of soluble P. This can be achieved by reducing the P in manure or by basing manure application rates on P.

As soil test P builds, the requirement for additional fertilizer P decreases, often to only starter P levels. The fertilizer recommendation for P can be found on the soil test report. Fertilizer P is expressed as P_2O_5:

P x 2.3 = P_2O_5

It is often not feasible to apply manure at the typically low rates recommended in soil test reports to meet crop P requirements. When manure is applied based on P, the target application rate should be based on the crop-specific removal rate for P, expressed as P_2O_5 (Table 6). In order to slow the build up of soil test P, at moderate to high soil test P levels (60 to 119 ppm Olsen P), the manure P_2O_5 application rate should not exceed two times the crop P_2O_5 removal rate:

At 60 to 119 ppm Olsen P
Manure P_2O_5 Application Rate ≤ 2 x Crop Removal P_2O_5

When soil test P values are very high (120 to 179 ppm Olsen P), manure P2O5 application rates should not exceed the total amount of P_2O_5 that the crop can remove. This will prevent further build-up of soil test P.

At 120 to 179 ppm Olsen P
Manure P_2O_5 Application Rate ≤ 1 x Crop Removal P_2O_5

Manure should not be applied to soils that already have excessive levels of soil test P (>180 ppm Olsen P). These soils should be cropped to bring down soil test P levels before additional manure is applied. If an application rate based on P_2O_5 removal is still prohibitive, it may be necessary to apply manure once at a rate that is equivalent to multiple years of P_2O_5 removal (e.g. total removal by crops that will be grown over several years). After this single application, no additional manure is applied during that multi-year period; therefore, other nutrient requirements are met using synthetic fertilizer or other sources (e.g. N fixation by legumes).

Table 8a and 8b are worksheets for calculating N or P-based manure application rates (see appendix C for imperial version).

Table 8a: Manure Application Rate Calculation Worksheet[1] Based On Liquid Manure

Field I.D.:________________ Crop: ____________________ Target Yield: __________________			
Step 1. Target Nutrient Rate			Units [2]
Nitrogen (based on soil test recommendation)	(A)	90	kg/ha
Phosphorus (as P_2O_5): 2x Crop Removal	(B1)	60	kg/ha
Phosphorus (as P_2O_5): 1x Crop Removal	(B2)	30	kg/ha
Other:	(B3)		kg/ha
Step 2. Manure Test Data			
Total Nitrogen	(C)	3.1	kg/m^3
Ammonium Nitrogen	(D)	1.9	kg/m^3
Organic Nitrogen = (C) - (D)	(E)	1.2	kg/m^3
Phosphorus	(F)	1.0	kg/m^3
P_2O_5 = (F) x 2.3	(G)	2.3	kg/m^3
Step 3. Amount of manure nitrogen available to crop:			
Application method	Incorporated within 1 day		
Volatilization losses due to application method (Table 6)	(H)	25%	
Ammonium nitrogen available = (D) x [100-(H)]% = 1.9 x 0.75 = 1.4	(I)	1.4	kg/m^3
Organic nitrogen available to the next crop = (E) x 0.25 = 1.2 x 0.25 = 0.3	(J)	0.3	kg/m^3
Total available N = (I) + (J) = 1.4 + 0.3 = 1.7	(K)	1.7	kg/m^3
Total available N in spring = (K) x 100% = 1.7 x 1.0 = 1.7	(L)	1.7	kg/m^3
Total Available N in fall = (K) x 83% = 1.7 x 0.83 = 1.4	(M)	1.4	kg/m^3
Step 4. Application rate based on N requirements:			
Spring N-based Application Rate = (A) ÷ (L) = 90 ÷ 1.7 = 52.9 or Fall N-based Application Rate = (A) ÷ (M) = 90 ÷ 1.4 = 64.3	(N)	64.3	m^3/ha
Amount of P_2O_5 applied = (G) x (N) = 2.3 x 64.3 = 147.9	(O)	147.9	kg/ha
P_2O_5 balance[3] (using 1x crop removal) = (O) - (B2) = 147.9 - 30 = 117.9	(P)	+117.9	kg/ha
Step 5. Applicaton rate based on P removal:			
2x crop removal P-based Application Rate[2] = (B1) ÷ (G) = 60 ÷ 2.3 = 26.1 or 1x crop removal P-based Application Rate[2] = (B2) ÷ (G) = 30 ÷ 2.3 = 13.0	(Q)	26.1	m^3/ha
Amount of available N applied in spring = (L) x (Q) = 1.7 x 26.1 = 44.4 or Amount of available N applied in fall = (M) x (Q) = 1.4 x 26.1 = 36.5	(R)	36.5	kg/ha
N balance[5] (N applied - N recomended) = (R) - (A) = 36.5 - 90 = -53.5	(S)	-53.5	kg/ha
Step 6. Compare N Rate (N) with P rate (Q):			
If soil test P is low to moderate (<60 ppm), apply manure at N rate (N)	64		m^3/ha
If soil test P is high)> 60 ppm), apply manure at P rate (Q)[6]	26		m^3/ha

[1] See Appendix C for imperial units and a blank template worksheet.

[2] 1 kg/m^3 = 1 kg/ 1000 L

[3] A positive value indicates that more P_2O_5 will be applied than the crop will remove (1x crop removal) when manure is applied based on N. A negative value indicates that less P_2O_5 will be applied than the crop will remove (1x crop removal) and the rate should be compared to the soil test recommendation to determine if the crop requirement for P will be met.

[4] When soil test phosphorus (STP) is low to moderate, manure can be applied based on N. When STP is high, a P-based application rate can be used up to 2X the crop removal of P_2O_5. At very high to excessive STP, no more than 1X crop removal of P_2O_5 should be applied.

[5] Positive value indicates N application rate is above soil test recommendation when manure is applied based on P_2O_5. Negative value indicates N application rate is below soil test recommendation and supplemental commercial fertilizer is required to meet crop requirements.

[6] If annual applications are too low, multi-year application rates and rotation of fields should be considered.

Table 8b: Manure Application Rate Calculation Worksheet[1] Based On Solid Manure

Field I.D.:________________ Crop: ____________________ Target Yield: __________________			
Step 1. Target Nutrient Rate			Units [2]
Nitrogen (based on soil test recommendation)	(A)	90	kg/ha
Phosphorus (as P_2O_5): 2x Crop Removal	(B1)	60	kg/ha
Phosphorus (as P_2O_5): 1x Crop Removal	(B2)	30	kg/ha
Other:	(B3)		kg/ha
Step 2. Manure Test Data			
Total Nitrogen	(C)	6.0	kg/t
Ammonium Nitrogen	(D)	2.1	kg/t
Organic Nitrogen = (C) - (D)	(E)	3.9	kg/t
Phosphorus	(F)	2.4	kg/t
P_2O_5 = (F) x 2.3	(G)	5.5	kg/t
Step 3. Amount of manure nitrogen available to crop:			
Application method	Incorporated within 1 day		
Volatilization losses due to application method (Table 6)	(H)	25%	
Ammonium nitrogen available = (D) x [100-(H)]% = 2.1 x 0.75 = 1.6	(I)	1.6	kg/t
Organic nitrogen available to the next crop = (E) x 0.25 = 3.9 x 0.25 = 1.0	(J)	1.0	kg/t
Total available N = (I) + (J) = 1.6 + 1.0 = 2.6	(K)	2.6	kg/t
Total available N in spring = (K) x 100% = 2.6 x 1.0 = 2.6	(L)	2.6	kg/t
Total Available N in fall = (K) x 83% = 2.6 x 0.83 = 2.2	(M)	2.2	kg/t
Step 4. Application rate based on N requirements:			
Spring N-based Application Rate = (A) ÷ (L) = 90 ÷ 2.6 = 34.6 or Fall N-based Application Rate = (A) ÷ (M) = 90 ÷ 2.2 = 40.9	(N)	34.6	t/ha
Amount of P_2O_5 applied = (G) x (N) = 5.5 x 34.6 = 190.3	(O)	190.3	kg/ha
P_2O_5 balance[3] (using 1x crop removal) = (O) - (B2) = 190.3 - 30 = 160.3	(P)	+160.3	kg/ha
Step 5. Applicaton rate based on P removal:			
2x crop removal P-based Application Rate[2] = (B1) ÷ (G) = 60 ÷ 5.5 = 10.9 or 1x crop removal P-based Application Rate[2] = (B2) ÷ (G) = 30 ÷ 5.5 = 5.5	(Q)	10.9	t/ha
Amount of available N applied in spring = (L) x (Q) = 2.6 x 10.9 = 28.3 or Amount of available N applied in fall = (M) x (Q) = 2.2 x 10.9 = 23.9	(R)	28.3	kg/ha
N balance[5] (N applied - N recomended) = (R) - (A) = 28.3 - 90 = -61.7	(S)	-61.7	kg/ha
Step 6. Compare N Rate (N) with P rate (Q):			
If soil test P is low to moderate (<60 ppm), apply manure at N rate (N)	35		t/ha
If soil test P is high)> 60 ppm), apply manure at P rate (Q)[6]	11		t/ha

[1] See Appendix C for imperial units and a blank template worksheet.

[2] 1 tonne = 1000 kg

[3] A positive value indicates that more P_2O_5 will be applied than the crop will remove (1x crop removal) when manure is applied based on N. A negative value indicates that less P_2O_5 will be applied than the crop will remove (1x crop removal) and the rate should be compared to the soil test recommendation to determine if the crop requirement for P will be met.

[4] When soil test phosphorus (STP) is low to moderate, manure can be applied based on N. When STP is high, a P-based application rate can be used up to 2X the crop removal of P_2O_5. At very high to excessive STP, no more than 1X crop removal of P_2O_5 should be applied.

[5] Positive value indicates N application rate is above soil test recommendation when manure is applied based on P_2O_5. Negative value indicates N application rate is below soil test recommendation and supplemental commercial fertilizer is required to meet crop requirements.

[6] If annual applications are too low, multi-year application rates and rotation of fields should be considered.

4.3.5 Calibrate field equipment to deliver target rate

Calibration refers to the combination of settings needed to deliver manure at a particular rate. The calculation of manure application rates is of little value if the equipment is not properly calibrated to deliver the required application rate. Details on how to calibrate manure application equipment can be found in the Tri-Provincial Manure Application and Use Guidelines (Manitoba Version, 2004).

Solid, semi-solid and liquid manure application systems can discharge manure at various rates, depending on factors such as speed of travel, flow meter setting, width of application or other parameters. Whenever possible, data from the manufacturer should be used to calibrate application equipment.

4.3.6 Record keeping

Every livestock operation should keep track of soil and manure test results, manure application rates, application methods, application dates, crop rotations and yields, and any other relevant information for each field that receives manure.

Maintaining detailed records on an ongoing basis is an essential part of proper manure nutrient management. Complete sets of historical soil and manure test results, crop performance, weather conditions and management practices can help producers make sound decisions and document proper management of land and fertilizer resources on the farm. For instance, soil test results can be used to track nutrient levels over time and detect build-up in the soil before it becomes excessive. A manure test database for a particular operation can be used to determine more accurate manure application rates, confirm the accuracy of a single manure test and indicate changes in management that have affected the composition of the manure. Documenting weather conditions during and after manure application may help explain the fate of manure nutrients (e.g. loss from the field or uptake by the crop). Cropping information can indicate any adverse effects of manure application (e.g. compaction leading to depressed growth), as well as the suitability of soils for manure application (i.e. consistently high yields and quality on more productive land, consistently low yields and quality on less productive land).

4.4 Benefits of Using Manure as a Fertilizer

The costs of handling and applying manure are high when compared on an equivalent weight basis with commercial, inorganic fertilizers. However, proper periodic applications can also result in substantial long-term improvements in the physical and chemical characteristics of the soil. Manure should be viewed as a resource to be properly managed, rather than as a waste requiring disposal.

The direct economic benefits of livestock manure management rest in its ability to replace commercial fertilizers as a source of plant nutrients. The manure nutrients, particularly N and P, will reduce or replace the need for additional synthetic fertilizer, thereby reducing fertilizer purchasing costs.

Caution should be exercised not to over-apply manure. In addition to increasing environmental risks, excessive applications of manure can have a negative impact on crops by causing excessive vegetative growth, lodging, and/or delayed maturity. Applying manure nutrients in excess of crop requirements also represents a missed opportunity for putting those nutrients to use on other fields where a crop response is likely to be observed.

4.5 Environmental Health Concerns

Manure is a valuable source of nutrients and organic matter that can replace or reduce the need for synthetic fertilizer and improve soil quality. However, there are risks associated with using manure that must be minimized through proper management.

4.5.1 Odour

The potential relationship between odours and health is addressed in detail in Section 5. This section also provides management options to address odour concerns when applying manure in close proximity to neighbours.

4.5.2 Nitrate contamination of drinking water

Groundwater may contain nitrate from natural sources (e.g. peat bogs), commercial fertilizers, domestic sewage systems or manure. Nitrate is very soluble in water and can be easily leached in soils with good internal drainage (e.g. sandy soils) when moisture levels are high. Nitrate that leaches below the crop rooting zone may eventually reach groundwater, which may serve as a drinking water source.

The guideline maximum acceptable concentration of nitrate in drinking water, set by Health Canada, is 10 milligrams per litre (mg/L) nitrate-N (or 45 mg/L nitrate). Below 10 mg/L, nitrate does not appear to cause health problems. Above this level, there may be heath concerns, particularly for infants less than one year of age and pregnant women. For infants, ingestion of nitrate may result in a shortage of oxygen in the blood, which manifests itself in a bluish colouration of the skin and mouth. This condition is called methemoglobinemia or "blue-baby syndrome". In pregnant women, the presence of nitrate may cause a lack of oxygen for the fetus. The possibility of blue-baby syndrome is entirely preventable by avoiding the consumption of water high in nitrates.

Although adults have a higher tolerance for nitrates, some studies suggest an association between nitrates in drinking water and the development of stomach cancer. For adults, food is generally the main source of ingested nitrate unless drinking water contains elevated concentrations. A link between drinking water high in nitrates and gastric cancer has been observed in some studies, however, other studies have not supported this association and, to date, no firm conclusions about drinking water high in nitrates causing gastric cancer have been made.

As there are many potential sources for elevated nitrate levels in private drinking water wells, it is advisable to have the water tested regularly. This is particularly important if members of the household include pregnant women or infants. Your regional Manitoba Water Stewardship office can be contacted for advice on how to have your drinking water tested.

- **Managing manure to reduce the risk of nitrate contamination of groundwater**

Careless or improper storage, excessive N applications, as well as improperly protected well casings may result in groundwater contamination. The best preventive measures consist of ensuring that N sources, whether manure or commercial fertilizer, are stored properly and applied at rates that match plant requirements.

Although nitrate-N levels are very low in manure, the organic-N and ammonium-N can be converted to nitrate-N when manure is applied to soil. Heavy or repeated applications of manure can result in a build-up of N in the soil. All fields that are to receive manure should be tested for residual nitrate-N so that the appropriate manure application rate can be targeted. Fields that have received heavy or repeated applications of manure, or have supported low crop yields and quality, may have adequate N to supply crop needs and may not be suitable for additional applications. Those fields that require additional N should only receive enough manure to meet the crop's N requirement.

Ideally, manure should be applied so that N is available to the crop at the appropriate time and in the required amount. While spring, in-season or split applications may be the most desirable in this respect, fall applications may be more practical in areas where spring soil conditions limit opportunities for manure application, or in cases of limited manure storage capacity. Extra care should be taken when applying manure at times that increase the length of time during which nitrate leaching may occur.

Although the risk is low for many of Manitoba's agricultural soils and aquifers, **manure applications, like commercial fertilizers, must always be properly managed to minimize the risk of contaminating groundwater.**

Additional information on N management can be found in the Manitoba Agriculture, Food and Rural Initiatives fact sheets *Nitrogen Dynamics, Retrieval Strategies for Deep Leached Nitrates and Manure Nitrogen Losses and Prevention.*

4.5.3 Sensitive groundwater areas

In some areas, soil and groundwater conditions are more sensitive to agricultural practices, specifically the application of either inorganic or organic (manure) N fertilizers. The degree of sensitivity of an aquifer to contamination depends on many factors. These may include the depth to the aquifer, the type of aquifer, the properties of overburden material overlying the aquifer (soil, subsoil, and parent material composition and structure), the type of vegetation at the soil surface, and whether the area is located within a recharge source. Where very permeable soils, such as coarse sands or gravels, immediately overlay an aquifer or where the overburden above an aquifer is shallow, nutrients applied to the soil surface may leach rapidly downward beyond crop rooting depths and eventually reach the aquifer. Since these areas tend to be excessively well drained, crop productivity is often relatively low and plant uptake of nutrients tends to be limited.

4.5.4 Nutrient loss to surface water

Nitrogen and phosphorus are the two primary manure nutrients of concern with respect to surface water quality. Excess nutrients in water result in eutrophication and have been associated with fish kills.

Nitrogen – Manure contains N as ammonium (NH_4) which is toxic to aquatic life and can convert to the more toxic ammonia (NH_3) form. The greatest risk of ammonium from manure entering surface water is through direct runoff or erosion soon after application.

Phosphorus – Eutrophication is the enrichment of water bodies by nutrients – both N and P. Phosphorus, however, is the nutrient that most commonly limits plant growth in fresh water bodies. Excess P entering water can result in increased production of algae and other aquatic plants, affecting water quality and the diversity of organisms present. During winter, the increased algae and aquatic plants decay and may deplete the oxygen supply in the water, potentially causing fish kill. At high concentrations of P in fresh water, blue-green algae can flourish and can release toxins that can harm wildlife, livestock, and humans if they drink the water.

- **Managing manure to reduce the risk of surface water contamination**

Manure nutrients can contaminate surface water if manure enters surface water directly or through runoff or soil erosion from lands that receive manure. Liquid manure application rates should not exceed the ability of the soil to absorb the manure. Heavy-textured soils, such as clay soils, have much slower infiltration rates than light textured soils. Manure application rates on these soils should avoid ponding or runoff. Reduced application rates may also be necessary on sloping lands and manure should not be applied when heavy rain is in the forecast. Tillage and cropping practices that reduce soil erosion should also be adopted.

4.5.5 Pathogen transfer to surface water or groundwater

Livestock manure contains bacteria, viruses, protozoa and parasites, some of which may be pathogenic (cause disease) in humans. Such organisms in manure may enter surface water if manure leaves the field through runoff or erosion or if manure is accidentally spilled or intentionally discharged into surface water. Although the soil tends to act as a natural filter that protects groundwater from contamination by pathogens, there may be a risk of micro-organisms moving through the soil profile to groundwater under certain conditions, such as the presence of coarsely textured surficial material, shallow water table, fractured bedrock or poorly constructed wells.

Manure applications must always be properly managed to minimize the risk of contaminating surface and groundwater. The risk of water contamination from pathogens will be reduced when the setbacks listed in Table 9 and Table 10 are maintained. Community health risks from pathogens are further reduced when the precautions in Section 3.6 are followed.

Table 9. Setback Requirements For Livestock Manure Application On Land Adjacent To Surface Water Or A Surface Watercourse[1] (m)

Surface Water or Surface Watercourse Feature	Manure Application Method	Manure Application Setback Width with Permanently Vegetated Buffer Width	Manure Application Setback Width with no Permanently Vegetated Buffer
Lakes	Injection or low-level application followed by immediate incorporation	15 m setback, consisting of 15 m permanently vegetated buffer	20 m setback
	High-level broadcast or low-level application without incorporation	30 m setback, including 15 m permanently vegetated buffer	35 m setback
Rivers, creeks and large unbermed drains, designated as an Order 3 or greater drain on a plan of Manitoba Water Stewardship, Planning and Coordination, that shows designations of drains	Injection or low-level application followed by immediate incorporation	3 m setback, consisting of 3 m permanently vegetated buffer	8 m setback
	High-level broadcast or low-level application without incorporation	10 m setback, including 3 m permanently vegetated buffer	15 m setback
All other types of surface water or surface watercourses	No manure application allowed		

[1] See Appendix C for imperial units.

4.5.6 Setback requirements for livestock manure application on land adjacent to surface water or a surface watercourse

To reduce the risk of runoff contaminated with manure entering drinking water wells, wells should be located and constructed to protect water quality over the long-term (See Section 6.3).

Setbacks from application on land adjacent to surface water or a surface watercourse reduces the risk of runoff contaminated with manure entering water. The effectiveness of the setbacks depends on such factors as its width, soil and landscape conditions and the intensity and duration of rainfall. To reduce the risk of overland flow entering sinkholes, springs or wells, the area immediately around these features should be sown to permanent cover. Table 9 provides setback requirements for livestock manure application on land adjacent to surface water or a surface watercourse.

Topography should be considered when applying manure. As the slope increases, the chance that manure may run off also increases. Therefore, added caution and management is needed when applying manure to sloping lands, particularly steeply sloping land (six per cent or greater). Soil management practices that reduce runoff and soil erosion should be practiced on lands fertilized with manure. Susceptible areas could be avoided during application. Crop or residue cover should be maintained to provide protection against erosion. In some instances, a grassed buffer strip may be required.

4.5.7 Greenhouse gas emissions

Greenhouse gases are compounds in the air that increase the amount of the sun's energy that is trapped on the earth, resulting in rising atmospheric temperatures. This is known as the greenhouse effect. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the three greenhouse gases linked to agriculture. Manure application is a source of CO_2 and N_2O. Carbon dioxide is generated by the burning of fossil fuels to manufacture commercial fertilizer and operate manure application equipment. It is also produced when soil is tilled to incorporate surface application of manure because the tillage results in the breakdown of soil organic matter. Denitrification produces N_2O which is a potent greenhouse gas. Denitrification is most common in saturated soils where microorganisms are forced to use nitrate to respire because oxygen is unavailable.

Beneficial management practices that reduce greenhouse gases from the application of manure often have other environmental or economic benefits. Carbon dioxide emissions from application of manure can be reduced by minimizing the number of equipment passes in the field which burns less fossil fuel. This can be done by injecting manure to eliminate the need for an additional pass to incorporate the manure or by scheduling tillage operations to coincide with incorporation of surface applied manure so that additional tillage passes are avoided. Maximizing the N value of the manure reduces the need to purchase additional synthetic N fertilizer,

Table 10: Required[1] Distances From Watercourses, Sinkholes, Springs, Wells And Recommended Distances From Residential Property Lines For Applying Manure Between November 10 And April 10 [2] (m)

Slope	Application Method		
	Surface Applied and Irrigation		
	No incorporation	Incorporation within 48 hours	Injection
less than 4%	150	N/A	N/A
4 – less than 6%	300	N/A	N/A
6 – less than 12%	450	N/A	N/A
Greater than 12%	Prohibited	Prohibited	Prohibited

[1] Refer to the Livestock Manure and Mortalities Management Regulation – Appendix B.

[2] See Appendix C for imperial units.

the manufacturing of which generates CO_2. As well, maximizing crop uptake of manure N will reduce the amount of nitrate remaining in the soil at times of the year (such as early spring) when the risk of leaching or denitrification is high. This can be achieved through optimal timing of manure applications (as close to crop growth as possible) at rates that closely target crop requirements.

4.6 Regulations on Manure Application

The Livestock Manure and Mortalities Management Regulation (Appendix B) contains the environmental laws specific to manure management.

4.6.1 General rules regarding pollution of water

It is illegal to allow manure to enter surface or groundwater. Section 11 of the Livestock Manure and Mortalities Management Regulation requires that no person shall handle, use or dispose of livestock manure, or store manure in an agricultural operation, in such a manner that it is discharged or otherwise released into surface or groundwater.

4.6.2 Prohibition on winter application

Applying manure in the winter is not a recommended practice because manure can not infiltrate into frozen soil and thus is more susceptible to runoff and entry into surface watercourses. Furthermore, winter application of manure is the least desirable time to apply manure to land because more nutrients in the manure will be lost due to volatilization and spring runoff than applications at any other time of the year. However, where over-winter storage capacity is inadequate, winter application of manure may be necessary.

Under Section 14 of the Livestock Manure and Mortalities Management Regulation, all livestock operations are prohibited from application of livestock manure from November 10 until April 10, unless they are exempted by regulation. Existing livestock operations (defined as those in existence prior to March 30, 2004) with fewer than 300 animal units of any one type of livestock are exempt from the prohibition unless they have been ordered to cease winter application because it is causing unacceptable environmental risk. Existing operations between 300 and 399 animal units in size have until November 10, 2010 to comply with the prohibition. Existing producers with 400 or more animal units are currently required to comply with the prohibition on winter application. New producers must comply with the prohibition on winter application as soon as their operations are established. Upon approval by Manitoba Conservation, emergency situations may warrant exceptions to the prohibition on winter application.

Livestock operations that are exempt from the prohibition of winter manure application must meet minimum setback distance requirements from sensitive areas as set out in the Livestock Manure and Mortalities Management Regulation. The required winter setback distances from watercourses, sinkholes, springs, wells and the recommended setback distances from residential property lines are provided in Table 10. Winter application on land with slopes greater than 12 per cent is not permitted.

If manure must be applied in the winter, stubble fields with adequate trash cover or perennial forage fields should be used. Surface cover reduces runoff volumes. Fields with limited access should receive manure first, leaving nearer fields for later when access is more difficult due to snow or thawing conditions.

4.6.3 Registering manure management plans

Section 13 of the Livestock Manure and Mortalities Management Regulation (Appendix B) requires that all livestock operations, 300 animal units or greater in size, register a Manure Management Plan annually. The deadline for submission is February 10 for spring applications and July 10 for fall applications. Alternatively, for a $100 fee, the operator may submit a manure management plan up to 14 days prior to application of manure. See Appendix G for the Manure Management Plan registration form or contact Manitoba Conservation.

Manitoba Agriculture, Food and Rural Initiatives has developed a computer software program that calculates manure application rates. The Manure Application Rate Calculator (MARC 2005) facilitates the preparation of manure management plans for all livestock operation types. It supports easy record keeping of nutrient management information on a field-by-field basis. The software is programmed to fill in the manure management information directly on the Manure Management Plan registration form required by Manitoba Conservation. Alternately, persons who wish to electronically file a Manure Management Plan may do so using the MMP Filer program available on Manitoba Conservation's website.

Those who prepare and certify manure management plans on behalf of livestock producers must have successfully completed a manure management planning course acceptable to the director of Manitoba Conservation and must be a member in good standing of the Manitoba Institute of Agrologists or hold the designation of Certified Crop Advisor under the international Certified Crop Advisor program of the American Society of Agronomy.

4.6.4 Soil nitrate-N limits

To reduce the risk of nitrate contamination of groundwater, for those lands receiving manure, the Livestock Manure and Mortalities Management Regulation (Appendix B) sets enforceable limits on the amount of residual soil nitrate-N and the amount of nitrate-N that can be present in the soil at any point in time. The soil nitrate-N limits apply to the top 60 cm (24 in) of soil and vary depending on the agricultural capability rating of the soil. Nitrates in excess of these values may be subject to enforcement action by Manitoba Conservation.

To ensure soil nitrate-N limits are not exceeded, the rate of manure application should not exceed the additional N required to achieve a realistic crop yield. The rate should consider the residual soil nitrate-N and the N content of the manure.

4.7 Training and Licencing of Manure Applicators

Changes to *The Pesticides and Fertilizers Control Act* were assented to in 2002. These changes will require commercial applicators that apply manure from large (300 animal units or greater) operations off-farm to be formally trained, certified and licenced. The training requirements will be established by regulation and will cover nutrient management, environmental issues associated with the application of manure, equipment calibration, spills and liability issues.