

## **2. MANURE MANAGEMENT STRATEGIES**

Land application of manure can be beneficial as a means of recycling of nutrients and using organic matter contained in manure to raise and maintain the quality of soils for crop production. It can also be a major source of deterioration of soil quality as well as pollution of water bodies. For example, excessive or unmonitored long-term manure applications may cause accumulation of salts that can eventually lead to reduced crop growth and production. Also, continued applications of manure at rates based on N needs of crops may result in P accumulation in soils that can contribute to P loading of surface and subsurface water sources and subsequent eutrophication. Manure management is an important tool that strives to ensure that the balance between the beneficial and detrimental effects of land application of manure is shifted toward the benefits. Along with the increased productivity and economic gains that may be expected from manure application in agriculture, due consideration must also be given to its effects on environment quality in the short and long-term. This leads to the need for development and establishment of manure management strategies for safe and sustained utilization of manure for optimum crop production.

In western Canadian agriculture, the livestock sector is becoming more and more important and intensive livestock operations are expanding. This may enable the grain farms to increase their productivity by way of increased opportunities for selling grains locally, coupled with decreased freight costs. Producers can also benefit from using the manure from the animals instead of commercial fertilizers. The large volumes of manure produced from intensive livestock operations, however, are generally applied in the vicinity of the livestock operations, perhaps largely due to the high cost of transporting manure. This leads to the tendency to apply manure at high rates close to its source, making areas of intensive livestock production particularly vulnerable to environmental damage such as leaching of nitrogen to groundwater and its loss to the atmosphere and salt accumulation in the soil.

In an effort to provide information on which to base recommendations, several researchers have been conducting studies on different aspects of manure management. This is necessary to capture the economic benefits of using manure as a fertilizer resource while reducing the risk of environmental pollution. Allison (1973) suggested returning manure to land as directly and efficiently as possible. Logan (1990) indicated the urgent need for best management practices (BMPs) to fully exploit the agronomic benefits of manure while minimizing the release of excess nutrients into the environment. Chang and Entz (1996) reported that, in Alberta, disposal of manure without pollution of the soil and water resources could be challenging.

Manure management practices are subject to a varied perception amongst society towards the material, not the least of which are issues related to odor control. Manure is also variable in its moisture content and nutrient content, which makes it difficult to determine exactly how much of a nutrient is being applied. Nonetheless, its agronomic importance as a source of plant nutrients is widely accepted. When available in close vicinity to farms, manure contributes to reducing the cost of production by enabling farmers to cut back the amount of commercial fertilizer needed on land.

Schoenau et al. (2000) indicated some of the challenges in effectively using manure as a nutrient source for crop production. The challenges include: a) variability in nutrient

content and form which makes it difficult to determine appropriate rates of application to meet crop nutrient requirements, b) that manure is not an “off-the-shelf” source of nutrients and may not match the crop’s relative requirement (example: manure with more phosphorus relative to nitrogen than what the crop can use), and c) low nutrient content per unit volume limits the distance to which manure can be transported economically. They, however, suggested that through the use of sound nutrient management practices, the risk of manure nutrient accumulation and loss could be minimized while realizing the maximum agronomic benefit from the nutrients. Similarly, Huber, et al. (1993) suggested that managing manure as a fertilizer resource for crop production can increase the return to the producer, minimize the pollution potential of manure, and enhance overall production efficiency of an animal-crop farming system.

## **2.1. Manure Sampling and Soil Sampling**

It is important to match manure application rates with crop requirements. This calls for knowledge of forms and quantity of nutrients contained in a given manure that is intended to be applied for the production of a specific type of crop. Technically, it is possible to obtain information on the nutrient concentrations and forms in “typical” manure from publications. However, such values are only averages that are good only for making general interpretations and recommendations when it is not possible to do an analysis on the particular manure in question. Laboratory analysis of the manure intended to be soil-applied is the recommended practice in determining appropriate rate of application (Schoenau et al., 2000). So far, the only practical way of knowing the forms and amounts of all nutrients in manures that are applied to fields is through analysis of representative samples submitted to laboratories. It is also essential to know how much available nutrients the soil supporting the crop growth can provide. Like manure, soils are variable in their nutrient contents and there is a need to do soil analysis prior to each growing season.

It is often impractical to analyze all the manures and all the soils that would be used in a given production system. As such strategic and sound sampling of manure and soil are integral components of manure management strategies.

### **2.1.1. Manure sampling**

The key point in a manure sampling strategy is to obtain a sample that is best representative of the manure material to be applied. There is a continual change in the forms and concentrations of nutrients in manure due to various processes from the time of excretion by animals to land application. This is true for manure even within a storage unit. Furthermore, there can be considerable spatial variability in manure composition depending on the position of the manure in the unit. For example, manure taken from the top part of a liquid storage unit would typically be of lower solids content due to settling and with a higher concentration of ammonia than at the bottom where higher solids content may contribute to higher concentrations of total phosphorus and potassium.

The potential for changes in manure composition over time dictates that manure sampling is best performed just prior to or during its application to obtain the most representative indication of manure nutrients being applied. Sampling near or at the time of application allows accounting for possible changes in nutrient forms and concentrations resulting from nutrient transformations, losses into the atmosphere via volatilization, evaporation, and dilution during the residence time of the manure in the

storage. Homogenization of the manure through mixing or agitation prior to sampling will also enable a more representative sample to be obtained.

The results of analysis of manure samples taken can be used to determine the rates of manure nutrients applied in the year of application, if additional inorganic fertilizers are required or not, and help make decisions on the next year's rate of manure application. However, analysis of manure collected near or at the time of application poses challenges for determining the appropriate rate of manure application in the year of application because it usually does not allow enough time for analysis of the manure in the laboratory to be completed prior to the land application. There are some methods for conducting rapid field tests that can be used to estimate nutrient contents of manure on site immediately prior to land application. The resulting estimates obtained as such can be used in the determination of the rates of application of the manure in the year of application.

Barker (1996) reported hydrometer method and nitrogen meter method as two promising "quick-test" field methods for determining the nutrient value of manure. In the hydrometer method the specific gravity of manure slurry is determined by using a soil hydrometer and, while on farm, the reading can be transferred to a chart or graph where a correlating (laboratory-determined) total nutrient concentration can be read directly. The plant-available percentage of the total nitrogen in the manure in the year of application can then be calculated from laboratory-determined correlations between specific gravity and ammonia-nitrogen; i.e. usually all of the ammonia fraction of the nitrogen conserved plus one-half of the organic N. Barker (1996) indicated that "Nitrogen Meter" is a device that was introduced in Sweden in 1983 and is used for estimating available nitrogen in manures. It measures the increase in pressure due to formation of nitrogen gas upon oxidation of ammonium following a reaction process between manure-water mixture and a strong oxidizing agent (calcium hypochlorite, 30-37% available chlorine). The pressure gauge is calibrated in units of nitrogen per unit of manure volume. Ammonia nitrogen as well as easily oxidized organic nitrogen in manures can be measured by the nitrogen meter method and this offers a fairly accurate direct estimate of the plant available nitrogen. While both methods can be easily used on the farm, the nitrogen meter method is more expensive than the hydrometer method.

The field test methods are reported to give better estimates of manure nutrient contents than using average values by allowing for accounting of the variability in manures that exist on a farm as well as between farms. Besides, they offer the advantages of: 1) detecting changes in manure characteristics as the storage facility is unloaded, and 2) allowing mixing of the stored manure slurry before sampling. Similarly, Fleming et al. (1993), from results of their evaluation of on-farm manure test procedures that involved 106 manure samples from pig, beef, dairy, and poultry farms, reported that nitrogen and electrical conductivity methods yielded reasonably accurate results that were far superior to those obtained using standard tables. However, Barker (1996) cautions that "field quick test" methods should not substitute for laboratory analysis of well mixed manure samples.

Lack of information on nutrient value of manure to be land-applied is more of a problem for producers applying manure for the first time and it is in such cases that the use of "book" or published average nutrient values of typical manure may be best. It may be possible to do the manure analysis at an early enough time to allow completion of the analysis prior to the land application in order to obtain estimates of the manure nutrients

for the purpose of determining the rates of application. However, results from a single manure nutrient analysis can be unreliable owing to the variability both in the manure and analyses procedures and it may best to refer to published average values of nutrients in different types of manure to start out with. Once results of manure analyses for three to five consecutive years of a given livestock operation are obtained, calculating the average nutrient values of the manure from that particular operation may provide reliable nutrient estimates of the operation. The nutrient estimates of the manure obtained as such can be used to calculate the application rates for the subsequent years as long as no significant changes occur in a given livestock production system that may alter the characteristics of the manure produced in that operation.

Average values of nutrients in manure from a given source obtained by analyses of the particular manure are usually more accurate than “book” values. Comparison of the average values of nutrients present in the manure from a given operation to “book” values of nutrients in similar type of manure can be useful in determining the degree of deviation and consideration of possible reasons for the deviation, including problems in manure sampling and sample handling.

The collection of representative samples of manure from a given source is vital to obtain an accurate reflection of its nutrient forms and content that enables accurate prediction of the manure’s nutrient credit. Due to the fact that only a very small proportion of the total manure in storage would be sent to the laboratory for analysis, collection of several samples from different parts of the storage unit is crucial. The representative (composite) sample can then be obtained by mixing sub-samples. Thorough mixing prior to sampling/application and collection of a large number of sub-samples is necessary for obtaining samples that can be considered representative of the manure from a given storage system. Collection of representative samples will greatly contribute to the reliability and interpretation of nutrient contents obtained from analysis of the samples in the laboratory. It is estimated that about ninety percent of the accuracy associated with achieving the desired rates of manure application depends on how well the manure samples are collected (Tri-Provincial Manure Application and Use Guidelines, 2002).

Sampling of both liquid and solid manure can be done either from the storage unit/pile or during field application. Since solids in liquid manure tend to start to settle out within 30 minutes of cessation of agitation, manures should be well agitated in the storage unit before taking samples and it is important to continue the agitation during pumping and application time (VanDevender et al., 2002). Complete agitation of manure contained in very large storages may be difficult to achieve. In such cases, taking several samples at the time of emptying the storage is helpful to get an estimate of nutrient variability within the storage units. Whether sampling is done from the storage unit or the manure application equipment, it is recommended that the composite sample be prepared by sub-sampling of the thoroughly mixed samples that were initially collected. The manure samples should be kept cool and transported immediately for analysis in the lab. If immediate transport is not possible, however, the samples should be kept frozen until shipped.

The continual change in the characteristics of manure from the time of excretion to land application and variability in the accuracy of manure analysis procedures coupled with the challenges of obtaining representative samples, calls for a better way of achieving the nutrient value of manures. To this end Dagnew (2002) suggested that a robust nutrient estimation method that is suitable for on-line sensing of manure nutrients on-the-

go would be of great value. In her study that investigated the feasibility of reflectance spectroscopy technology for sensing hog manure nutrients, she concluded that such a technique holds promise for prediction of total solids (TS), total Kjeldhal nitrogen (TKN), total phosphorus (TP), and available phosphorus (AP) in liquid manure, and could, with further development, potentially be adapted for in-field or on-line sensing.

Previous work in the field of on-line nutrient sensing system is reported in the scientific literature. For example, Scotford et al. (1998) developed a prototype sensing system that consists of a network of sensors to determine redox potential, pH, temperature, EC, and concentrations of ammonium ions in liquid manure. The system uses the correlations between the characteristics of manure such as EC and its nutrient concentrations. Fitting a similar prototype to a manure tanker of 7-m<sup>3</sup> capacity, it was possible to estimate the nutrient content of each tanker-load manure within a period of 2 minutes during transportation of the manure from the storage to the application site (Scotford et al., 1999). The estimates were comparable with other sample-based techniques. Crowe and Maule (2000) reported a system fitted with an in-line mounted EC sensor that was used to test eleven manure samples collected from Saskatchewan farms that showed good correlation between the sensor readings and ammonium concentrations in the manures ( $R^2 = 0.97$ ). Further development of satisfactory on-line manure nutrient sensing systems that can be used to accurately quantify the nutrients in manures in the field should be encouraged. It will greatly contribute towards the efforts being made to apply appropriate rates of manure and keep field records and is consistent with the philosophy of precision nutrient management, especially for liquid manures.

Solid manure is usually stored in piles and, perhaps owing to the high variability in the moisture content and bedding material content, it tends to exhibit more variability than liquid manure. When sampling from manure piles, samples should be taken from several depths and locations in the pile if manure from the whole pile is going to be land applied. If only a portion of the stockpile is to be spread, samples should be collected only from that portion. If the manure is to be sampled from manure spreader at the time of application, samples should be collected from each of the several spreader loads after which they will be composited to represent manure applied at the beginning, middle and end of the application process. It is important to take as many samples as necessary and possible to obtain representative samples. It may be difficult to get a single composite sample from a solid manure pile that can provide an accurate estimate of the nutrients contained in it if there is large variability in the composition. Therefore, it is recommended to make a number of composite samples that can systematically account for the variability due to factors such as depth, age, bedding material etc.

It tends to be more difficult to mix and sub-sample solid manure than liquid manure, however, the following procedure is recommended to obtain representative samples:

1. Combine all of the solid manure samples on a plastic sheet or cement pad and mix thoroughly.
2. Divide the well-mixed manure into four portions.
3. Discard two of the four portions and combine the remaining two portions and mix.
4. Repeat steps 2 and 3 until the remaining sample is small enough to send for analysis.

As in the case for liquid manure, samples from solid manure also need to be kept cool and sent to the lab for analysis as soon as possible.

### **2.1.2. Soil sampling**

Crop uptake of applied manure nutrients in the field can be reduced by several environmental, soil, and physiological factors such as dry weather, soil compaction, or disease. This may lead to elevated levels of nutrient in the soil following application and crop growth even at recommended rates. Losses of nutrient can also occur especially in the case of too wet conditions. As a result, there can be a wide range of nutrient contents in the soil and it is imperative to know how much available nutrients are present in a given soil at the start of each growing season. This requirement lends itself to the need for implementation of a site-specific nutrient management program to maintain optimum level of soil fertility for crop growth and protection of environmental quality. A soil sampling strategy is needed that enables one to obtain representative soil samples for laboratory analysis and is an integral component of sustainable manure management practices.

Soil sampling strategies vary depending on the intended objective such as improved crop response across the field in the year of application, identification of deficiencies and problem areas, or monitoring of soil conditions over several years. It is recommended that fields be soil sampled at 0-15 cm and 15-60 cm (0-6 and 6-24 in) depths regardless of the method of soil sampling employed. This is to account for nutrients that may have moved from the surface to greater depths by leaching. Common soil sampling strategies include: 1) traditional composite soil sampling, 2) benchmark soil sampling, 3) grid soil sampling, and 4) landscape-directed soil sampling. These strategies are described in detail in the Tri-Provincial Manure Application and Use Guidelines (2002) and also provided as fact sheets by many soil-testing laboratories.

Of these various methods, owing to its convenience, traditional composite soil sampling is the most commonly used sampling strategy in agricultural fertility programs that include manure management practices. In this method, core samples are collected at random from the whole field, bulked, thoroughly mixed, and composited for laboratory analysis. However, it does not allow accounting for field variability, site-specific soil management, and variable-rate fertilizer/manure application. Benchmarking is most appropriate for monitoring changes in soil properties over time. Grid sampling is appropriate for determining “hot spots” where excessive nutrients may reside in the field and for mapping purposes. Directed sampling involves separation of a field into individual units (polygons) according to landscape or some other identifiable attribute and these areas are sampled and managed separately.

Depth of sampling is an important aspect of soil sampling plan that can influence the validity of soil test results. The following soil sampling depth guidelines are suggested for routine soil tests on which to base nutrient recommendations.

1. Nitrate-N analysis should be conducted on both 0-15 and 15-60 cm depth samples.
2. Nitrate-N analysis should be conducted on deeper samples to determine if nitrate-N is leaching.
3. P and K analyses should be conducted on the 0-15 cm depth samples.

4. If desired, sulfur and salinity analyses should be conducted on the 0-15 and 15-60 cm depth samples.
5. If desired, pH, organic matter, and micronutrient analyses should be conducted on the 0-15 cm depth samples.

## **2.2. Application Rates**

Unlike inorganic fertilizers, determination of application rates of manure is complicated for many reasons. Firstly, manure is a multi-nutrient mixture that consists of variable amounts of macro and micronutrients along with organic material and sometimes minerals as well. Secondly, although manure contains all of the nutrients that are contained in inorganic fertilizers, the nutrients usually do not exist in the ideal balance or proportion to satisfy the crops' relative requirements. Thirdly, plant roots can only assimilate nutrients in the inorganic form whereas nutrients in manure exist in both organic and inorganic forms and the organic forms must be mineralized by microbial activity (at variable rates) to be rendered plant available. Nonetheless, as for inorganic fertilizers, rates of manure application should be determined based on soil test recommendation, crop nutrient requirement, manure history of the field, and the nutrient forms and contents of the manure to be applied.

Manure application rates are usually determined based on the crop's nitrogen requirements with lesser considerations to the phosphorus content of the manure and nitrogen-based requirements are often used to regulate the amount of manure that can be applied to farmlands. However, especially for solid manures such as feedlot cattle manure, the ratio of nitrogen to phosphorus in manure is narrower than that required by crops. As a result, application of manure based on the practice of satisfying crops' nitrogen requirement may lead to accumulation of phosphorus in the soil. For example, Daniel et al. (1994) reported that the average N:P ratio of animal manures is 3:1 whereas major grain and hay crops use N and P at a ratio of about 8:1, suggesting excessive supply of P when manure is land-applied in the interest of meeting all of the N needs of the crop. The application of swine lagoon effluent to satisfy the nitrogen requirement of bermudagrass pasture in North Carolina resulted in an approximately fourfold increase in the phosphorus level of the soil to a depth of 91 cm over a 3-year period of manure application (Mueller et al., (1994). Some countries, for example, The Netherlands, are reported to use P accumulation to regulate the amounts of manure additions to farmlands (Kornegay and Verstegen, 2001). Such practices, however, may not provide sufficient nitrogen for crops if the source of fertilizer would solely be animal manure.

To alleviate the problem of P accumulation, which has the potential for pollution of water bodies, nutrient management plans that are used to determine application rates of manure should include both nitrogen and phosphorus. Applying manure based on crops' phosphorus requirement and supplementing nitrogen fertilizers to compensate for the discrepancy between available nitrogen from applied manure and nitrogen demand of the crop grown can do this.

### 2.3. Decision Support Systems (Rate Calculators)

Decision support systems, as related to manure management, are computer models that are developed to assist producers in planning manure and nutrient management programs. The models are used for calculating manure application rates based on information such as nutrient content in manure, availability of the manure nutrients for crops, and loss factors in different storage and application methods. An example is the Manure Application Rate Calculator (MARC98) developed by Manitoba Agriculture (Tessier, 1999). Calculation of the application rate of manure from a particular source using MARC98 requires consideration of two major variables, namely, nutrient value of the manure and the nutrient requirement of the crop intended to be grown. The inputs for the variables are supposedly obtained from the users; however, in the absence of laboratory analysis of manure or soil, average values can be obtained from the large databases of MARC98.

Manure Application Rate Calculator (MARC98) is considered a powerful tool for manure management planning for the following reasons:

1. It simplifies the process of calculating rates for manure application.
2. It illustrates the true value of agronomically sound manure use.
3. It allows the user to experiment with different scenarios of commercial fertilizer and manure application to quickly find the best course of action for each particular field.
4. It provides average values from its large databases in the absence of laboratory analysis of manure or soil sampling results.

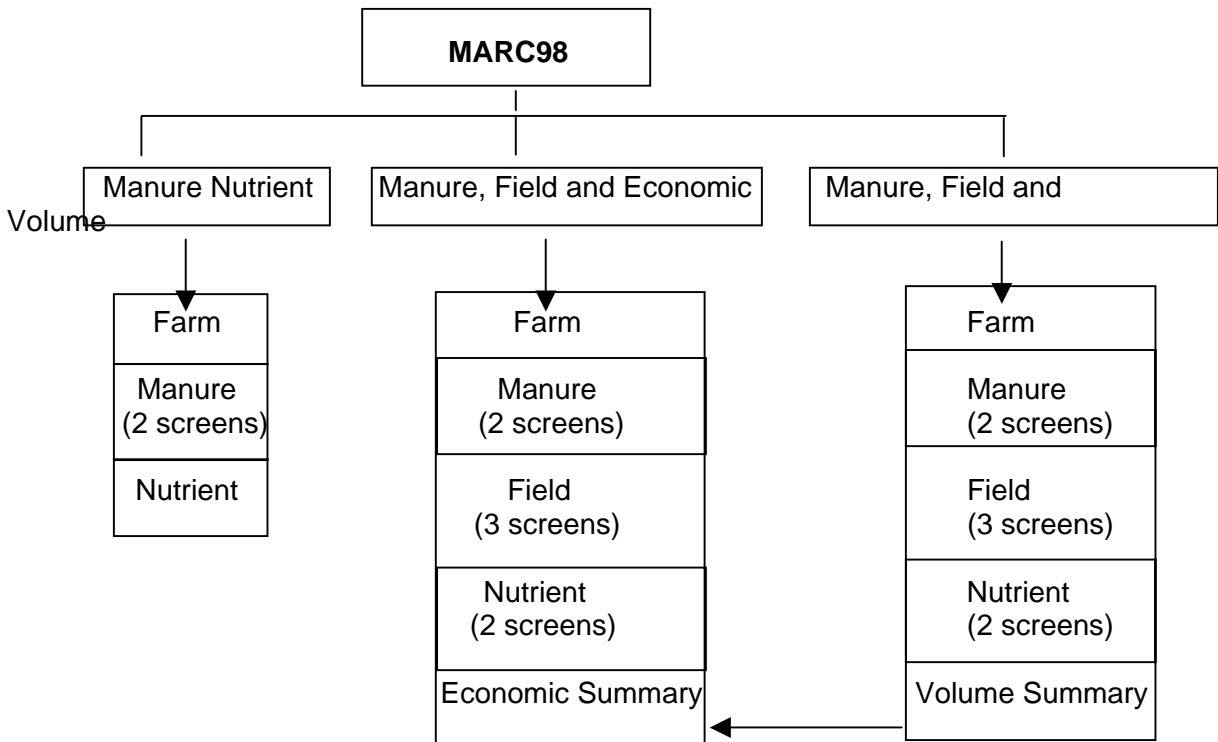
It consists of three different modules: manure nutrient module, manure, field, and economic module, and manure, field, and volume module. The manure nutrient module is used to calculate the availability of the nutrients in the manure. The economic module is used to calculate the economic value of the applied manure by using information from one field. The volume module is used to produce a table that illustrates the distribution of manure on various fields. The flow of each module in the program is shown in Figure 5.

Bolton et al. (2001) reported on an updated and expanded Manure Application Rate Calculator (MARC 2000), which offers greater flexibility in the management of entered data and generation of reports, and developed through the combined efforts of the prairie provinces of Saskatchewan, Manitoba and Alberta. They suggested that MARC 2000:

- is a user-friendly software that allows producers to plan their nutrient application field by field on an annual basis.
- enables farmers with multiple operations to plan for each type of livestock facility.
- allows custom applicators to track land applications of manure for a large number of clients.
- offers the possibility of electronic submission of data and the option of incorporating the information in a GIS environment.

- includes record keeping for detailed soil and manure analysis and a net economic return calculation.

There are also other programs that have been developed to help producers in making decisions with regard to rates of manure application. Examples include: Manure Nutrient Management: A Balancing Act developed in Alberta (Olson and McKenzie, 2000) and NMAN2001– Comprehensive Nutrient Management Planning Software developed in Ontario (DeBruyn et al., 2001).



**Figure 5.** Program flow of the three modules in MARC98 (After Tessier, 1999).

#### 2.4. Application Technology

Manure application technology has been advancing in step with the development of manure management programs. There are several equipment configurations used to field apply manure, that may be employed in one or more of the following ways: broadcast without incorporation, broadcast with incorporation, injection, and irrigation. Any form of manure may be land-applied by the method of broadcast either with or without incorporation, but only liquid manure is suited for application by injection or irrigation. In western Canada it is a common practice to handle hog manure in liquid form and, as a result, injection is the most commonly used method of applying liquid hog manure with the exception of some incidences of irrigation.

In her review of the existing methods and equipment for liquid manure application, Chen (2001) discussed the following methods: broadcasting, surface banding, incorporation, infiltration enhancement, and injection. Broadcasting is commonly performed using a tank wagon with a sprayer boom or gun where the soil surface is fully covered by the manure, resulting in maximum manure exposure. The tank discharges the manure through a deflector or splash plate that creates a fan spreading pattern. Surface banding is another method of applying manure on the surface with less manure exposure on the surface that can be done using dribble bars. In the method of incorporation, manure is spread on the surface by either of the above methods and followed by incorporation using a tillage operation either simultaneously, with or separately, from the manure spreading operation. This method provides even less manure exposure than surface banding method.

Infiltration enhancement is a method whereby manure is broadcast on the surface of a perforated ground. An aerator is used to create the perforations or indents in the top 5 to 15 cm of the soil layer. Infiltration enhancement may be used as pre-plant or post-emergent manure application method in annual crop systems such as in no-till fields or grasslands, however, Chen and Samson (2001) caution that it might present a potential for substantial nitrogen leaching to groundwater. Injection of manure into the soil is a method by which manure is placed below the soil surface using sweep, chisel or disc openers and covered with a layer of soil immediately following the placement. Perhaps owing to the superiority of injection (Table 1) as a method of manure application, considerable work has been done in the design and use of different injection equipment.

The Prairie Agricultural Machinery Institute (PAMI), for example, has been extensively involved in the development and introduction of technology for manure application that provides lower odour and sustainable manure management. Some of PAMI's achievements include: pipeline manure injection systems; Figure 6-a&b (PAMI, 1997), low and high disturbance liquid manure injection systems; Figure 7, (PAMI, 1999 and 2002), and manure injection research truck fitted with low disturbance disc openers developed by Bourgault Industries Ltd., St. Brieux, SK; Figure 8 (PAMI, 2002). Most of the recent equipment developed for liquid manure application have similar basic design elements and performance, and are based on injecting the manure into the soil and immediately covering the injection channel with soil with limited soil disturbance and leaving a good quality seedbed. An example is the custom injector machine (Figure 9) that was built by Sher-Dan Enterprises™ and used by Assefa (2002) in his field study in the Peace River Region of north-western Alberta.

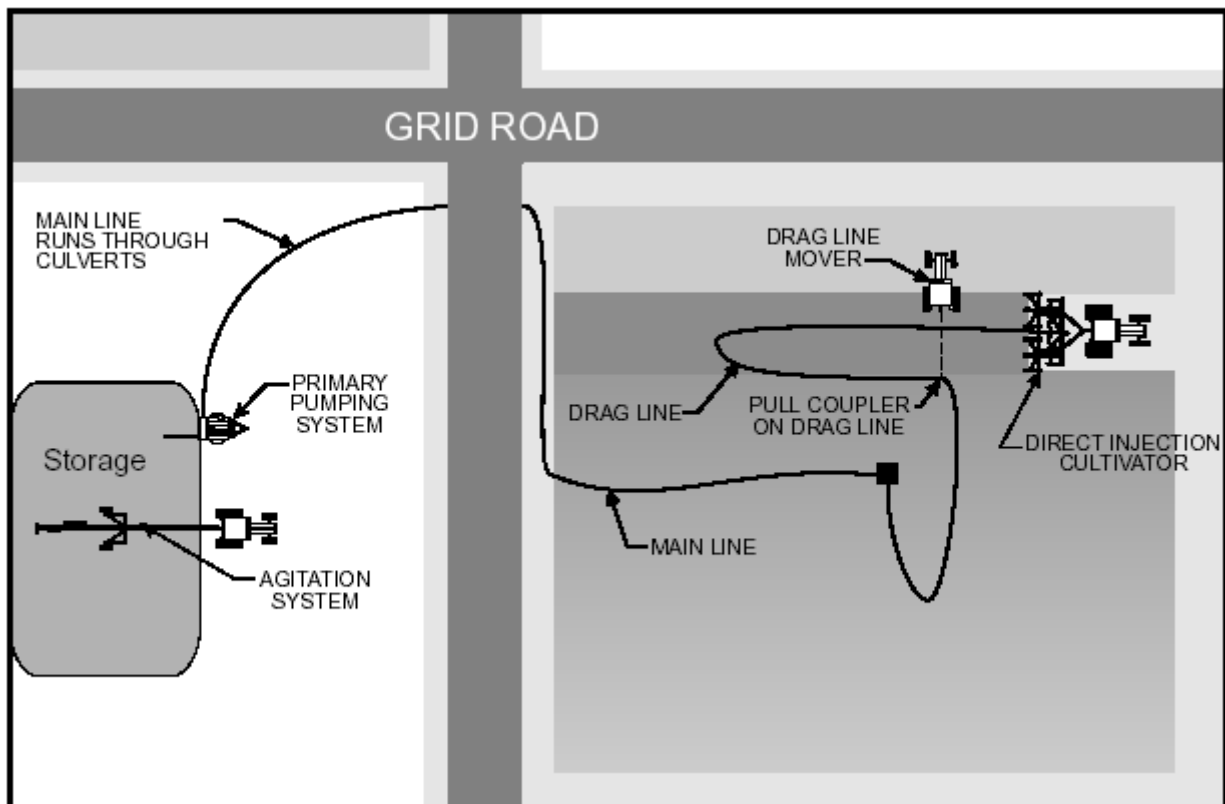
**Table 1.** Comparison of manure application methods with respect to N loss (PAMI, 1997).

Application method	Nitrogen Loss (%)	Comments
Sprinkler irrigation	30	Fine particles increase ammonia-N loss by volatilization. Loss will be greater in hot weather or with poor infiltration (clay soils) and lower with cool, wet weather and good infiltration (sandy soils).
Slurry wagon with splash plate and no incorporation	25	Larger particles and lower trajectory reduce loss somewhat.
Slurry wagon with splash and immediate incorporation	3	Timely incorporation reduces loss dramatically.

Injection	1	Very little loss due to lack of contact with the atmosphere.
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**Figure 6-a.** Pipeline manure injection system using drag hose connected to manifold distributor on chisel plow-based tool bar (Source: PAMI, 1997a).



**Figure 6-b.** Pipeline liquid manure injection system, a typical set-up (Source: PAMI, 1997a).



**Figure 7.** Low or high disturbance liquid manure injection system using a tool bar mounted on a tanker (Source: PAMI, 2002).



**Figure 8.** PAMI manure research truck fitted with low disturbance disc openers for liquid manure injection (Source: PAMI, 2002).



**Figure 9.** Custom injector machine built by Sher-Dan Enterprises™; a) side view, b) rear view showing the shanks (Source: Assefa, 2002).

The equipment used for application of solid manure are usually truck fitted with or tractor pulled rectangular shaped boxes and the manure is generally broadcast with or without incorporation. Owing to the rather inconsistent nature of most solid manures, homogeneity is even more difficult to achieve as compared to liquid manures. Contrary to liquid manure, incorporation of solid manure always involves an additional tillage pass, which increases the amount of time and operations required for spreading the manure and may affect soil compaction. However, besides conserving the ammonium, incorporation of the solid manure is important for increasing the manure-to-soil contact for decomposition and to prepare a suitable seedbed. Solid manure spreaders have struck-load or heaped-load depending on how the manure is loaded. A struck-load is a load that is level with the top of the box whereas a heaped-load is a load that is heaped as high as the box can hold.

Although spreaders for both liquid and solid manures have volumetric ratings, application rates of the manures are expressed in different units: litres per hectare (metric) or gallons per acre (imperial) for liquid manure and Mega grams per hectare (metric) or tons per acre (imperial) for solid manure. Detailed procedures of how to calibrate liquid and solid cattle manure spreaders are provided in the Tri-Provincial Manure Application and Use Guidelines (2002).

## **2.5. Gaps**

Some of the gaps identified in this section are as follows:

- For precision manure application in the field and for documentation of nutrient loading rates, there is a need for continued development of technologies for “on-the-go” sensing of nutrient content and forms in manure during application. This should be coupled with technology to permit accurate metering of the manure based on the nutrient contents of the manure being sensed.
- To ensure that producers, applicators and recipients of manure are aware and capable of using the knowledge and tools (i.e. rate recommendation software) available for sound manure management, it would be desirable to package this information into a course or program that would result in “manure management certification” upon successful completion.

There is a need to establish agronomic and environmentally realistic thresholds for nutrient loads in the soil that account for the many facets (soils, vegetation, climate, topography, tillage system etc) that may make one threshold value appropriate for one

area but not another. One approach might be to use geographic information systems to subdivide regions and establish suitable threshold values for each region. The accumulated database may then be used as part of regional or provincial nutrient management strategies, and permit extrapolation of research results and recommendations obtained from specific sites to other similar areas.