Tri-Provincial

Manure Application and Use Guidelines

Prepared by: The Prairie Provinces' Committee on Livestock Development and Manure Management

Manitoba Version

Alberta Agriculture, Food and Rural Development

Saskatchewan Agriculture, Food and Rural Revitalization

Manitoba

Tri-Provincial Manure Application and Use Guidelines

The information contained in this document is based on research and experience from the Western Canadian prairie provinces including Alberta, Manitoba and Saskatchewan, and draws on research and experience from other jurisdictions. This document is the combined effort of a team of scientists and other professionals from across the Prairie region. Acknowledgement and thanks go to the following organizations:

Saskatchewan Agriculture, Food and Rural Revitalization
Manitoba Agriculture, Food and Rural Initiatives
Alberta Agriculture, Food and Rural Development
University of Saskatchewan
University of Manitoba
Prairie Agricultural Machinery Institute

TOC Table of Contents

1 Introduction

1.1 Goal of the Tri-Provincial Manure Application and Use Guidelines

The goal of the Tri-Provincial Manure Application and Use Guidelines is to provide a set of recommended practices supported by science-based information to help ensure the sustainable use of manure as a fertilizer across the Prairie region.

1.2 Manure Management Principles

The following principles are accepted by the three Departments of Agriculture across the Prairie Provinces as the basis for sustainable manure management.

- Sound manure management requires annual planning and proper record keeping.
- Manure application rates will depend on the type of manure and nutrient availability, and should be calculated using results from annual soil and manure analysis to meet crop nutrient requirements.
- Manure application should account for the season, weather conditions and site-specific conditions relating to soil, topography and water.
- Manure application equipment should be calibrated to ensure consistent and appropriate delivery rates of manure.
- Manure should be managed in a way that maximizes crop nutrient utilization and minimizes negative impacts to soil, water and air resources.

1.3 Benefits of Manure

Livestock manure is a valuable resource. It is an effective source of plant nutrients and organic matter, which can be used to improve crop production and soil quality.

Using manure as a fertilizer returns nutrients to the land for crop production. Applying manure correctly:

- increases crop productivity and yield
- supplies macronutrients and micronutrients required for crops
- provides nitrogen (N) throughout the season, potentially increasing the protein content in the crop
- increases microbial activity, which can increase the availability of nutrients
- increases the organic matter content of the soil, which provides the following benefits:
    - improved soil structure
    - increased water infiltration and water holding capacity, resulting in reduced water loss from runoff and increased water availability to the crop
    - increased cation exchange capacity (the ability of the soil to hold nutrients)
    - reduced wind and water erosion

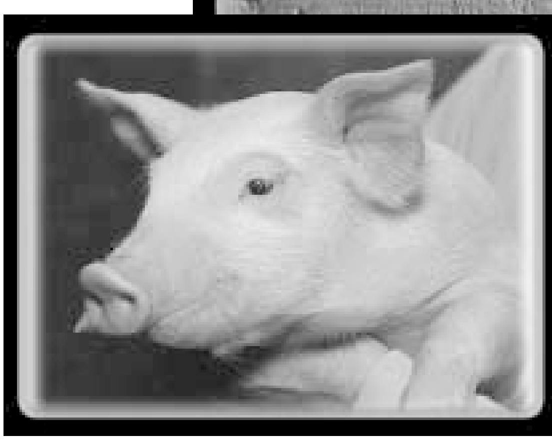
1.4 Manure Management Challenges

All nutrient sources, whether commercial chemical fertilizer or livestock manure, must be managed to ensure that soil, water and air quality are not degraded. However, there are additional challenges to using manure effectively as a fertilizer. These challenges include:

- The moisture and nutrient contents of manure are highly variable, making it difficult to estimate nutrient availability without a representative manure analysis.
- The nutrients in manure are rarely “balanced” to meet all of the crop’s nutrient

requirements. For example, when manure is applied to meet the crop's N requirement, other nutrients such as phosphorus (P) and potassium (K) are simultaneously applied at rates that, in many cases, do not match the crop's requirements.

- The low nutrient content per unit weight or volume of manure limits the distance that manure can be transported economically.
- Manure can be a considerable source of odour during land application.
- Because manure may contain pathogens, added care must be taken to ensure it does not enter surface and ground water.
- Manure storage, handling and application practices will be affected by weather.



2 Understanding Manure

In order to properly use manure as a fertilizer, producers need to understand moisture content, nutrient forms, nutrient transformations and nutrient availability.

2.1 Moisture Content

The moisture content of manure is influenced by livestock production practices and the manure handling and storage technology used on the farm. In liquid systems, bedding is not added to the manure but water, from a variety of sources, may be added to the manure. Within the barn, the choice of feeding equipment (such as wet-dry feeders) can significantly reduce the amount of water that enters the manure storage. Wash water will also enter the manure storage. The design of the liquid manure storage structure will also affect the quantity of rainwater that is added to the manure.

In solid systems, the type and amount of bedding and the amount of precipitation entering the manure pack or pile is exposed to (such as in open-lot situations) greatly affect the moisture content of the manure. The way in which manure is stored will also affect the moisture content. Diverting rainwater from the manure pile, with roof and eaves will reduce the moisture content. Covering the manure pile will also reduce the moisture content.

In general, livestock manure can be classified as solid, semi-solid or liquid. Solid and semi-solid manures have a higher organic matter content than liquid manure because of the added bedding. Manure types can be differentiated on the following basis:

- Solid <80% moisture content
- Semi-solid 80% to 90% moisture content
- Liquid >90% moisture content

2.2 Nutrients in Manure and Soil

Livestock manure contains most of the nutrients that crops require, including nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), copper (Cu), manganese (Mn), zinc (Zn), boron (B) and iron (Fe). Nitrogen, P and K are macronutrients because they are required in large amounts for optimal plant growth. They are also called primary nutrients because they are typically the nutrients limiting crop production and the most commonly applied as fertilizer. Sulphur, Ca and Mg are also macronutrients but are considered secondary nutrients because they are normally present in soil in sufficient amounts for crop growth. Copper, Mn, Zn, B and Fe are all called micronutrients because they are required in very small quantities by plants.

The nutrient content of manure is highly variable. The actual nutrient content of a manure will depend on the type of operation, moisture content of the manure, 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. The manure nutrient analysis results can also be greatly affected by how the manure sample is taken. Table 2.1 illustrates the wide range in manure nutrient concentrations from manure samples analyzed at commercial laboratories (data from the Manure Application Rate Calculator software for Manitoba).

Table 2.1: Manure Nutrient Analysis Ranges for Total Nitrogen, Ammonium, Phosphorus and Potassium for Swine, Dairy, Beef and Poultry Manures

	Nutrient Concentrations								
	Lab Units [2]			Metric			Imperial		
Liquid Swine n=133[1]	% for all except ppm for NH_4^+-N			kg/1,000 L			lb/1,000 gal		
	avg	min	max	avg	min	max	avg	min	max
Total N	0.31	0.04	0.68	3.1	0.4	6.8	31	4	68
NH_4^+-N	1,946	230	5,150	1.9	0.2	5.2	19	2	52
Total P	0.10	0.00	0.51	1.0	0.0	5.1	10	0	51
Total K	0.14	0.03	0.37	1.4	0.3	3.7	14	3	37
Dry Matter (1 - 10%) [3]	3.4	1.0	9.0						
Liquid Dairy n=252	% for all except ppm for NH_4^+-N			kg/1,000 L			lb/1,000 gal		
	avg	min	max	avg	min	max	avg	min	max
Total N	0.34	0.07	0.76	3.4	0.7	7.6	34	7	76
NH_4^+-N	1,463	21	7,168	1.5	0.0	7.2	15	0	72
Total P	0.09	0.01	0.85	0.9	0.1	8.5	9	1	85
Total K	0.32	0.02	0.98	3.2	0.2	9.8	32	2	98
Dry Matter (1 - 20%)	8.9	1.0	19.9						
Solid Beef n=45	% for all except ppm for NH_4^+-N			kg/tonne			lb/ton		
	avg	min	max	avg	min	max	avg	min	max
Total N	0.60	0.14	2.02	6.0	1.4	20.2	12	2.8	40.4
NH_4^+-N	564	11	2,656	0.6	0.0	2.7	1.1	0.0	5.3
Total P	0.14	0.03	0.64	1.4	0.3	6.4	2.8	0.6	12.8
Total K	0.59	0.16	2.54	5.9	1.6	25.4	11.8	3.2	50.8
Dry Matter (20 - 40%)	26.4	20.1	38.4						
Liquid Poultry n=35	% for all except ppm for NH_4^+-N			kg/1,000 L			lb/1,000 gal		
	avg	min	max	avg	min	max	avg	min	max
Total N	0.80	0.30	1.42	8.0	3.0	14.2	80	30	142
NH_4^+-N	5,751	107	1,051	5.8	0.11	10.5	58	1	105
Total P	0.28	0.06	0.51	2.8	0.6	5.1	28	6	51
Total K	0.33	0.16	0.53	3.3	1.6	5.3	33	16	53
Dry Matter (1 - 20%)	9.10	2.60	18.70						

[1]number of samples in the dataset for each manure type
[2]all analyses in this column are in % except for NH_4^+-N
[3]dry matter ranges for typical manure analyses (dry matter contents < 1.0% not included as these manures are considered to be highly dilute)

Reference: Manure Application Rate Calculator (MARC98) for Manitoba

In Alberta, Schedule 3, Table 5 of the Standards and Administration Regulation under the *Agricultural Operation Practices Act* contains specific manure nutrient values of typical agricultural livestock manures for the purpose of calculating land-base requirements for livestock operations. *Agricultural Operation Practices Act.* Regulation 267/2001. Queens Printer for the Province of Alberta.

Table 2.2: Boron, Sulphur, Copper, Zinc and Manganese Manure Analysis Results for Various Swine Operations with Liquid Manure and Beef Feedlots with Solid Manure										
			Nutrient Concentrations [1]							
Manure/Operation Type			Lab Units (ppm)			Metric (kg/1,000 L)			Imperial (lb/1,000 gal)	
Liquid Swine Manure [2]		n	avg	min	max	avg	min	max	avg	min	max
B	Nursery	11	4.27	3.15	7.34	0.004	0.003	0.007	0.04	0.03	0.07
	Feeder	92	1.98	0.32	11.20	0.002	0.000	0.011	0.02	0.00	0.11
	Sow	37	1.57	0.36	5.63	0.002	0.000	0.006	0.02	0.00	0.06
	Farrow-Finish	5	1.87	0.52	2.75	0.002	0.001	0.003	0.02	0.01	0.03
S	Nursery	11	266.0	34.1	727	0.266	0.034	0.727	2.66	0.34	7.27
	Feeder	92	271.3	42.8	1,220	0.271	0.043	1.220	2.71	0.43	12.20
	Sow	37	143.1	23.2	606	0.143	0.023	0.606	1.43	0.23	6.06
	Farrow-Finish	5	162.0	39.2	313	0.162	0.039	0.313	1.62	0.39	3.13
Cu	Nursery	11	57.9	1.2	169.0	0.058	0.001	0.169	0.58	0.01	1.69
	Feeder	92	37.2	1.6	177.0	0.037	0.002	0.177	0.37	0.02	1.77
	Sow	37	13.4	0.6	152.0	0.013	0.001	0.152	0.13	0.01	1.52
	Farrow-Finish	5	20.4	2.5	45.2	0.020	0.003	0.045	0.20	0.03	0.45
Zn	Nursery	11	131.0	1.58	541.0	0.131	0.002	0.541	1.31	0.02	5.41
	Feeder	92	53.98	1.18	239.0	0.054	0.001	0.239	0.54	0.01	2.39
	Sow	37	50.34	1.27	338.0	0.050	0.001	0.338	0.50	0.01	3.38
	Farrow-Finish	5	35.95	5.77	95.8	0.036	0.006	0.096	0.36	0.06	0.96
Manure/Operation Type			Lab Units (ppm)			Metric (kg/tonne)			Imperial (lb/ton)		
Solid Beef Manure [3]		n	avg	min	max	avg	min	max	avg	min	max
B	Feedlot	173	6.9	1.7	16.5	0.007	0.002	0.017	0.014	0.003	0.033
S	Feedlot	173	2,458	679	6,042	2.46	0.68	6.04	4.92	1.36	12.08
Cu	Feedlot	173	22.6	0.84	49.9	0.023	0.001	0.050	0.045	0.002	0.100
Zn	Feedlot	173	152	21.6	589	0.152	0.022	0.589	0.304	0.043	1.178
Mn	Feedlot	173	157	28.4	372	0.157	0.028	0.372	0.314	0.057	0.744

[1] All nutrient values expressed on a wet-weight basis.
[2] Data adapted from: Fitzgerald, M.M. and G.J. Racz. 2001. Long-term effects of hog manure on soil quality and productivity. Final Report presented to the Agri-Food Research and Development Initiative.
[3] Unpublished Data (B. Olson, Alberta Agriculture, Food and Rural Development, 2002).

2.2.1 Nitrogen Forms in Manure

Manure is an excellent source of N. The N found in manure is primarily made up of two forms: ammonium N and organic N. Manure contains very little nitrate N.

Total Nitrogen (N) is a measure of all of the N contained in the manure. In general, it includes the ammonium N, the organic N and any nitrate N that may be present. Not all of the nitrogen in manure is available for crop production. As well, the concentrations of total N in manures are highly variable both between and within all livestock types. Table 2.1 demonstrates the broad range of total N contents of manure.

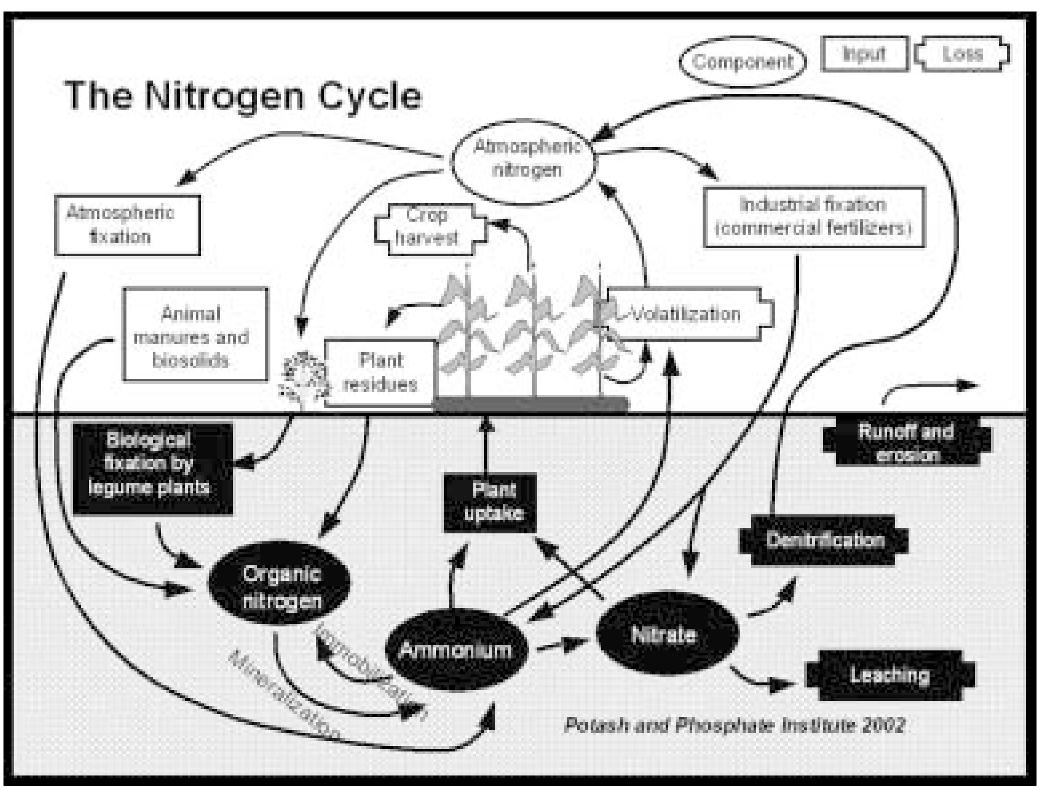
Ammonium N (NH_4^+-N) is an inorganic form of N in manure. The quantity of ammonium N in manure is of particular importance because it is immediately available for crop uptake. The amount of ammonium N in manure varies widely, even within livestock types (Table 2.1). Despite the existence of exceptions, there are observed trends in the relative ammonium N contents of solid versus liquid manure. For example, although liquid swine manure analyses have shown that the ammonium N content can be anywhere from 30 to 90 % of the total N, typically, liquid swine manure has more than half of the total N in the plant-available ammonium form. As well, although some solid beef manure analyses have shown the ammonium N content to be up to 60% of the total N, solid beef manure often contains most of the N in the organic form, with only 5 to 10% of the total N in the ammonium form.

Nitrate N (NO_3^--N) is another inorganic form of N. Although soil can contain significant quantities of nitrate N, most manures contain low amounts.

Organic N is not measured directly but is calculated from the total N and ammonium N measures, as follows:

Organic N = Total N – ammonium N

The organic N must be decomposed (mineralized) to inorganic N to be made plant available.



2.2.2 Nitrogen Processes in Soil

Differences in the forms of N present in manure, application techniques, and soil and weather conditions all influence the availability of the manure N to plants. For example, manure with a high ammonium N content will provide more plant-available N than manure with low ammonium N content. However, if manure is not applied using techniques that conserve N, it may be lost to air or water and rendered unavailable to plants.

Mineralization: When using manure as a fertilizer, it is important to understand that only a portion of the total manure N is immediately available. Some of the N in manure is in the organic form and must go through a decomposition process known as mineralization. Specifically, mineralization is the conversion of organic N to ammonium N. Mineralization can be slow and, as a result, the N is released throughout the growing season rather than at the time of application, as is the case with commercial inorganic fertilizer.

Nitrification: Although manure contains low amounts of nitrate, nitrate can be found in manured soils in significant quantities. This is because ammonium is converted to nitrate by microorganisms in the soil through a process called nitrification.

Immobilization: Many solid manure systems use large amounts of bedding materials that are high in carbon (C). This can raise the C:N ratio of the manure significantly. A high C:N ratio in manure can delay the availability of N to the crop in the year of application. Soil organisms use the added C as a source of food. As they consume C, they also consume N, thereby making it temporarily unavailable to plants. This process is called immobilization (conversion of inorganic N to organic N). When the organisms die, N and other nutrients are released back into the soil.

Volatilization: Nitrogen can be lost to the atmosphere by the conversion of ammonium to ammonia gas through a process called volatilization. Nitrogen losses through this process can occur during storage as well as during field application. The amount of N lost through volatilization during land application of manure is a function of the amount of ammonium in the manure, exposure of the manure to the atmosphere and weather conditions.

Canola Field

Nitrate Leaching: Nitrate is highly soluble in water. As excess water moves down through the soil profile, such as after snowmelt or heavy rainfall, it can carry any nitrate present with it. Nitrate is more prone to leaching from coarse textured soils and at times of the year when the crop is not actively growing (pre-seeding and post harvest).

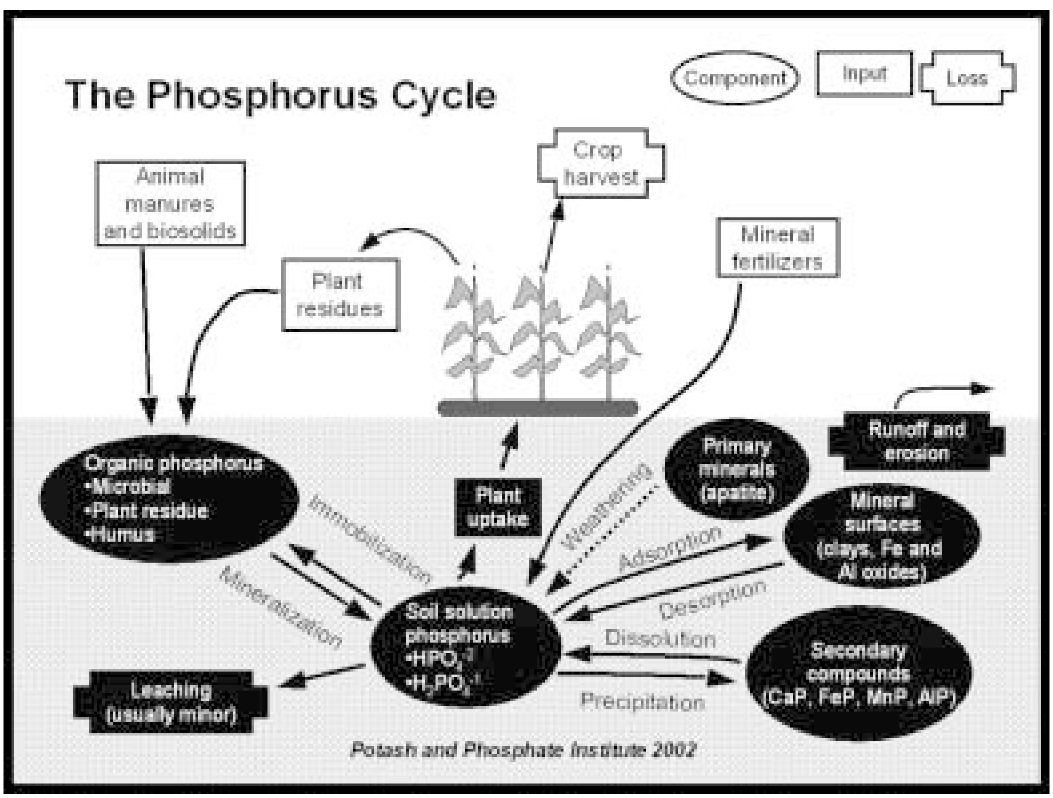
Denitrification: Soils become anaerobic (lack oxygen) when saturated or during periods of high microbial activity. When soils are anaerobic, the soil bacteria can continue to breathe using nitrate instead of oxygen. During this process, nitrate is consumed and N gases (such as N_2 and N_2O) are released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

2.2.3 Phosphorus Forms in Manure

When excreted, manure contains primarily organic P within the solid portion of the manure. Over time, some of the organic P is converted to soluble inorganic P. By the time of application, manure contains significant amounts of P in both inorganic and organic forms.

Total Phosphorus: As with N, the total P content of manure is highly variable for all livestock types. Table 2.1 illustrates the range in P contents for various manure types. In addition to the variability between operations and livestock types, there can be significant variability in total P concentrations within a given liquid manure storage. 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.

Organic and Inorganic P: Research in Saskatchewan found that from 10% to 50% of the total P in liquid swine manure could be present as soluble inorganic phosphate, which is considered to be immediately available to plants. However, because inorganic P in manure is not routinely measured, the availability of P in



manure in the year of application is estimated to be 50% of the total P measured in manure.

2.2.4 Phosphorus Processes in Soil

Differences in the concentrations and forms of P in manure will influence P availability. For example, manure with a high inorganic P content will provide more plant-available P immediately after application than manure with a low inorganic P content. Soil properties will also influence the availability of P.

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 soil through adsorption and precipitation reactions. It can be bound to soil organic matter or to Fe, Al, Mg and Ca through the development of mineral complexes. Fine textured (clayey) soils are able to bind considerably more P than coarse textured (sandy) soils.

In general, inorganic P that is retained in neutral to alkaline (high pH) soils will be predominantly associated with Ca and Mg while P that is retained in neutral to acidic (low pH) soils will be primarily associated with iron (Fe) and aluminum (Al). A large amount of P can be retained by a soil that is rich in Ca, Mg, Fe or Al.

Solubilization: Soil has a large, but not infinite, capacity to bind P. As soil test P levels increase, there is often a concurrent increase in soluble P. Soluble P can occur in both organic and inorganic forms.

2.2.5 Potassium in Manure

Manure is a good source of potassium (K) for plant growth. The K in manure is inorganic. Unlike some of the other manure nutrients, there are no transformations required by soil microorganisms to make potassium readily available for plant uptake. K is relatively mobile in coarse textured or organic soils and less mobile in fine textured soils. As with the other macronutrients, there is a broad range of K contents in manure (Table 2.1).

2.2.6 Sulphur in Manure

Manure contains sulphur in both organic and inorganic forms. A portion of the sulphur in manure will be readily available as sulphate ($SO_4^{=}$-). That portion of the manure that exists as organic sulphur cannot be used directly by plants, it must first be converted (mineralized) to sulphate-S by soil microorganisms. The sulphur in the form of sulfide must be oxidized to sulphate.

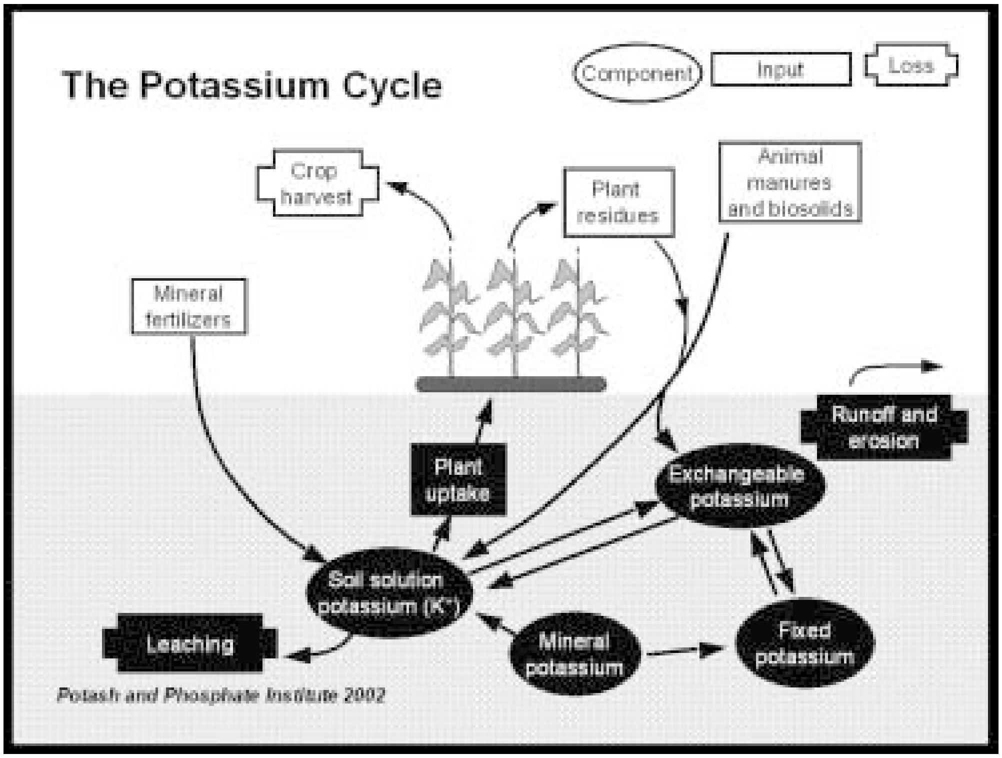
Some animal manure, such as liquid swine manure, can be low in S relative to N. This is a management consideration when fertilizing high-S-demanding crops like canola.

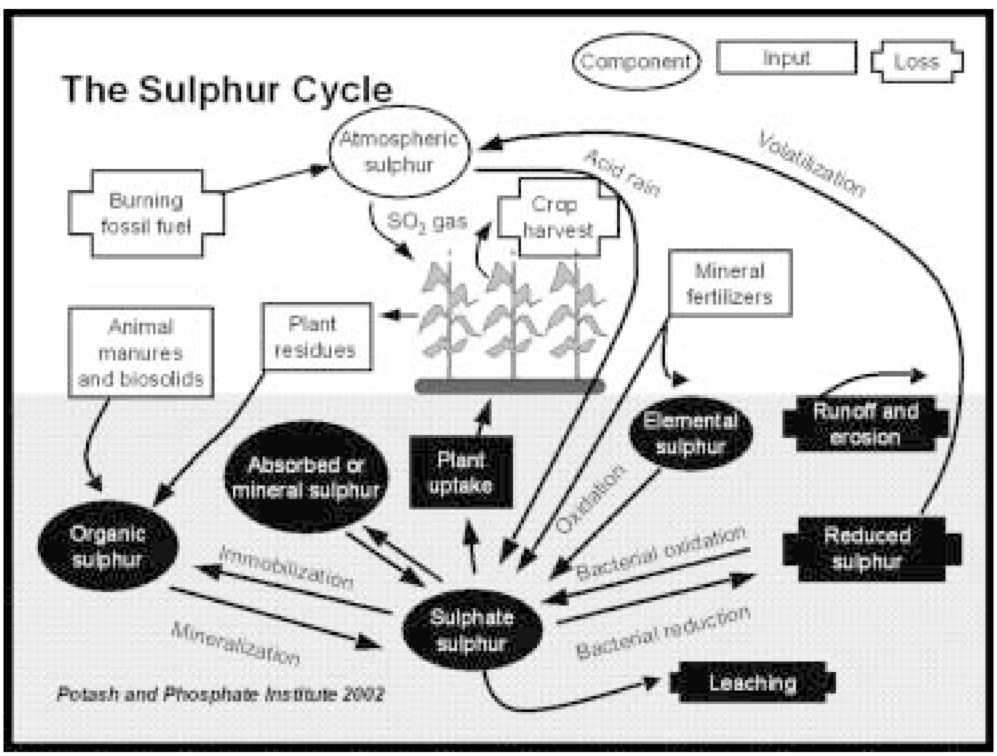
Table 2.2 shows the ranges of S found in liquid swine manure and solid cattle-pen manure.

2.2.7 Micronutrients in Manure and Soil

Manure contains micronutrients such as copper (Cu), manganese (Mn), zinc (Zn), cobalt (Co), molybdenum (Mo) and boron (B). Table 2.2 contains liquid swine and solid beef manure analysis results for B, Cu and Zn from research conducted in Manitoba and Alberta.

Crops require relatively small quantities of micronutrients. Manured soils often provide sufficient quantities of micronutrients for crop production. Crops that are grown on soils that are deficient in micronutrients normally exhibit physiological symptoms. Micronutrient deficiencies can be verified through plant tissue testing.





3 Soil Sampling and Analysis

3.1 Principles of Soil Sampling

Soil sampling and analysis is the only way to determine the available nutrient status of a field and to receive field-specific fertilizer recommendations. To be fully effective, an on-farm soil testing program should properly sample and test every field every year. In order to use manure as a fertilizer, soil sampling principles should be incorporated into sustainable manure management practices.

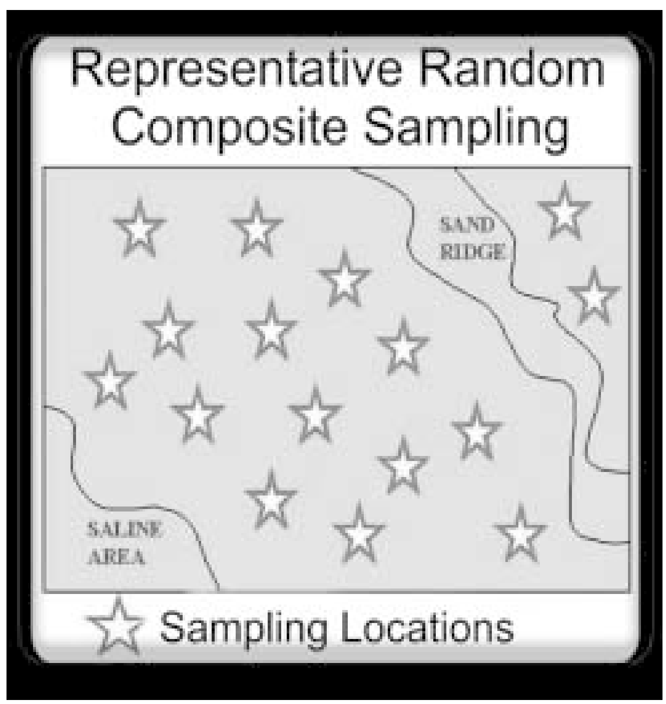
There are a variety of ways to take a soil sample. Before deciding on a soil sampling strategy, the objective(s) of the sampling program must be considered (e.g. improved crop response, identification of micronutrient deficiencies and problem areas, or monitoring of soil nutrient levels). A good sampling strategy will provide information that can be used to support or adjust manure application practices, given the site characteristics and application equipment.

Most manure management programs are based on “Representative Random Composite Sampling”. Details on other possible soil sampling strategies are also provided.

Whichever method of soil sampling is employed, all fields should be sampled at the 0 to 15 cm and 15 to 60 cm depths (0 to 6 and 6 to 24 inch), and the composite samples for each depth should be kept separate for analysis.

3.2 Representative Random Composite Soil Sampling

Representative random composite soil sampling (commonly referred to as Traditional Composite Sampling) is the most common soil sampling strategy. It involves taking random core samples throughout a field, bulking and thoroughly mixing them, and submitting a single, representative sub-sample to the soil-testing laboratory for analysis.



Before sampling, evaluate the field to determine representative areas for sampling. Level fields are relatively easy to sample. For hilly fields with knolls, slopes or depressions, take samples from mid-slope positions to get “average” results.

Avoid sampling obvious sources of unusual variability, such as saline areas, eroded knolls, old manure piles, burn piles, haystacks, corals, fencerows or old farmstead sites, headlands, areas within 15 metres (50 feet) of field borders and shelterbelts, or areas within 45 metres (150 feet) of built-up roads.

A composite soil sample should come from at least 15 to 20 sample sites per field, with a minimum of one sampling site for every 3 – 4 hectares (8 to 10 acres). Sample at 0 to 15 cm and 15 to 60 cm depths (0 to 6 and 6 to 24 inch), and separate the samples according to depth.

Features

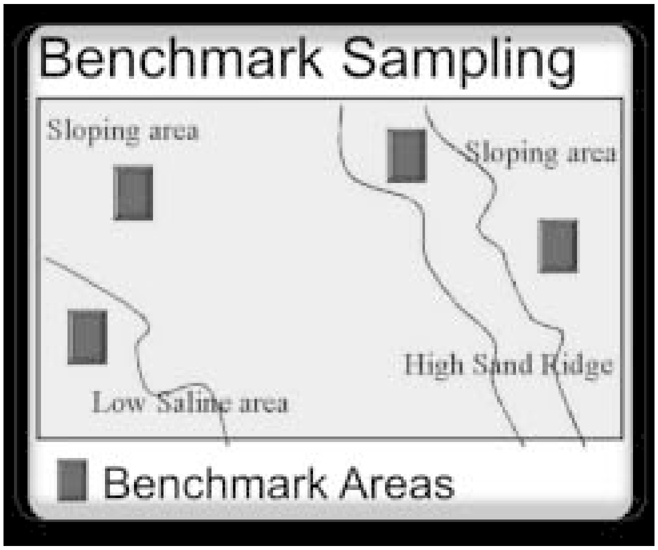
- Reduced analytical costs as single sub-samples are submitted as “representative” of an area.
- Supportive data for agricultural fertility programs.
- Level fields are relatively easy to sample.

Limitations

- Does not provide any indication of field variability. Small areas of very high nutrient levels that are probed and included in composite samples may artificially raise the “average” reported value, resulting in much of the field being under-fertilized. This frequently occurs in sulphur sampling, but may occur with other nutrients as well.
- Minimizes the potential for site-specific soil management and does not support variable-rate fertilizer application as whole fields are represented by a single composite sample. University, government and industry soil-sampling guidelines have indicated for some time that major areas within fields having distinctly different soil properties (such as texture) should be sampled and fertilized separately because of differences in nutrient requirements. This was rarely done in the past, since farmers had limited options for variable rate fertilization.

3.3 Site-Specific Soil Sampling

Site-specific soil management focuses on managing the variability that occurs within fields. Understanding the pattern of variability allows the field to be divided into relatively uniform units, which can be managed individually.



More detailed soil sampling strategies have been developed to support site-specific management techniques. These techniques often incorporate Global Positioning System (GPS) technology so that soil sampling locations can be geo-referenced and these areas can be revisited in the future for fertilizer application, scouting or re-sampling.

3.3.1 Benchmark Soil Sampling

The basic principle of benchmark sampling is continued sampling at the same location from year to year. A benchmark is an area of approximately 1/10 ha or 30 by 30 metres (1/4 acre or 100 by 100 feet) that is chosen as being typical of the field or a dominant soil type within the field. In this benchmark area, 15 to 20 samples are randomly collected and mixed together as a composite. This technique assumes that the benchmark area is less variable than the entire field, because it is much smaller. By using the same benchmark location and method year after year, sampling error should be minimized, provided the benchmark is representative of the field or management unit. It is treated as a reference area on which all fertilizer recommendations for that field are based. More than one benchmark site per field may be chosen if complex soil types or variable landscapes occur, or if variable-rate fertilization is an option.

The critical part of this method is the selection of the benchmark site. Representative sites can be selected by close observation of the crop (particularly during early growth stages when fertility differences are most evident), past grower experience, yield maps, soil surveys and remotely sensed images.

Features

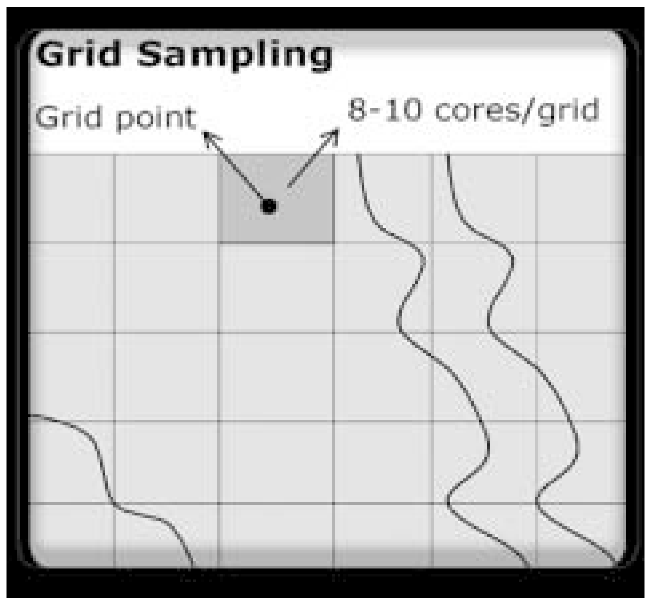
- Less expensive and time-consuming than grid soil sampling (see 3.3.2).
- Year-to-year variations better reflect actual nutrient changes.
- May provide information for variable-rate application when different benchmark sites are selected to represent different areas of the field.

Limitations

- Does not provide a full indication of field variability, but assumes that the rest of the field will respond similarly to the benchmark area.

3.3.2 Grid Soil Sampling

The grid sampling system uses a systematic method to reveal fertility patterns and assumes fertility patterns do not vary within a field.



The first step in grid sampling is to divide the field into small cells called grids. The second step is to identify a sample location within the grid. The point at the centre of the grid cell is usually referred to as the grid point. From this centre point, approximately 10 sample cores are collected in a 3 to 6 metre (10 to 20 foot) radius to form a composite sample. Generally, as sampling intensity increases, the identification of fertility patterns becomes more accurate. Some jurisdictions recommend a sampling density of one sample per half hectare (1 acre) in order to obtain representative soil N, P, K and pH data. Less intensive sampling may still provide useful information on the magnitude of field variability, but may be too inaccurate for variable-rate management.

Features

- Grid sampling is well integrated into commercial GPS-based soil sampling and nutrient-mapping GIS programs.

Limitations

- Grid point sampling may result in bias because of the regular row and column sample alignment. Other regularly spaced patterns, such as tillage, drainage tiles and ditches, or fertilizer spreading may cause a repeating pattern that, if aligned with the sample rows, will seriously bias results. Modifications to the sampling pattern, such as staggering of sample points or random placement within the grid, may be used to overcome this problem.

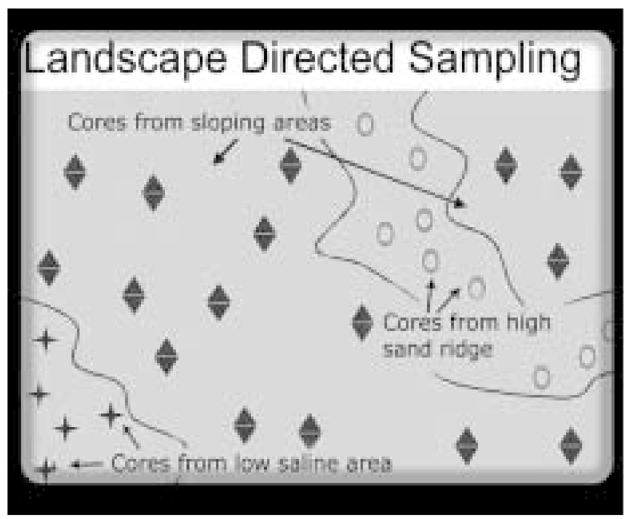
- The intensive grid sampling required to effectively reveal fertility patterns can be quite expensive, especially for the lower-value grain and oilseed crops grown on the Prairies.
- There is no soil-landscape rationale for grid size. In fields with complex landscapes, there is a risk of missing some soil units with a large grid size, and commercial grid spacing is often too large.

A field may be suitable for grid sampling if the field history is unknown or its natural fertility patterns have been masked because:

- The field has a history of manure application.
- Smaller fields have been merged into a larger one.
- High rates of fertilizers or lime have recently been used.

3.3.3 Landscape-Directed Soil Sampling

Landscape-directed sampling is based on spatial patterns defined using some prior knowledge or observation of a field, and assumes that fertility patterns exist for logical reasons. Patterns in soil and crop variation can often be observed by reviewing the management history and consulting soil survey information, detailed elevation mapping, aerial photographs, satellite imagery, yield monitor maps, and the land owner. This type of variation is called “systematic variation” because it follows a system or pattern and is predictable and manageable if that pattern is understood. The recent use of yield monitors has shown that yield variation is often related to topography, although this variation may be due more to differences in drainage or available water and weed pressure than to nutrient variation.



Soil development and productivity are largely a function of water flow, which is in turn controlled by landscape properties such as slope gradient and length, slope curvature and relative elevation. The combination of these factors determines the location of soil types in the landscape and their inherent productivity. Nutrient levels, particularly for the mobile nutrients, N and S, have shown consistent relationships with landscape or topography in recent studies. Soil/moisture relationships largely control N availability in the landscape through processes of denitrification, leaching, mineralization of organic matter and crop uptake. Elevation measurements may be used to initially develop topographical management zones, but it is actually landscape features or slope position that influences nutrient relationships.

This system requires the identification of areas (polygons) with similar soil and hydrological conditions. Properly identified, there will be less variability within each polygon than among polygons.

Research has not firmly established the required sampling density or pattern for landscape sampling. If landscape units were totally homogeneous, one sample would characterize the entire unit, but in reality these units are not homogeneous.

Options are to take several point cores per landscape unit or to take a composite sample of 10 to 20 cores for each area. Within a field, various management zones, based on topographic variation, can generally be delineated with the aid of elevation maps, yield maps or remotely sensed images. Boundaries may be adjusted with further data and experience with the system.

Features

- Potentially fewer soil samples required than intensive grid sampling.
- Nutrient distribution and management-unit boundary delineation are often superior to grid sampling, especially for N.

Limitations

- Requires previous knowledge of crop performance within the field and an ability to discern slight topographic and soil changes within the field.
- Crop growth and yield relationships with topography may be completely reversed in years of extreme wetness versus years of extreme dryness.
- For fields with subtle changes in topography, a digital elevation map may be needed to select sample sites. Such elevation mapping is available as a commercial service.
- Past management, such as heavy fertilization or manure application, may mask the landscape-nutrient relationships and reduce the usefulness of this method.

Research and field experience suggests a field may be suitable for landscape-directed soil sampling if:

- Remote sensing or yield mapping reveals some relationship between crop growth and landscape properties.
- The field does not have a history of manure application.
- Relatively low rates of nutrients have been applied.

3.4 Soil Analysis

It is recommended that the soil-testing laboratory be consulted regarding specific requirements for sample size and shipping, turn-around times, analytical options, costs and any additional instructions they may have. As well, some labs provide bags, labels and submission forms for soil samples.

Although a variety of analytical packages are available, a package that includes nitrate-N, exchangeable K and available P should be selected. There are a number of analytical methods for determining P, including Modified-Kelowna, Olsen (sodium bicarbonate) or Mehlich-lll. These analytical methods can yield considerably different results. The soil-testing laboratory will calculate the crop nutrient recommendations for the region based on the analytical method used.

In areas where salinity or sodicity is a concern, electrical conductivity (EC) and sodium adsorption ratio (SAR) should be considered. Electrical conductivity is used as an indicator of salt accumulation in the soil (i.e. salinity). Sodium adsorption ratio is a measure of sodium (Na^+) in relation to calcium (Ca^{2+}) and magnesium (Mg^{2+}) in soil. For the purpose of manure management planning, it is also useful to have an estimate of the amount of potentially mineralizable N in soils that have received solid manure applications. Some labs offer a test intended to determine potentially mineralizable N.

3.4.1 Depth of Sampling

The type of information that is required from the soil analysis will determine the depth of soil sampling:

- At a minimum, nitrate-N analysis should be conducted on both the 0 to 15 cm (0 to 6 inch) and 15 to 60 cm (6 to 24 inch) depth samples because nitrate is a mobile nutrient in soil water.
- If the fields have received heavy or unknown N application rates or if the soil is susceptible to leaching, nitrate-N analysis should be conducted on deeper samples (greater than 60 cm or 24 inches) to determine if leaching is occurring.
- At a minimum, P and K analysis should be conducted on the 0 to 15 cm (0 to 6 inch) depth sample.
- Sulphur and salinity analysis should be conducted on the 0 to 15 (0 to 6 inch) and 15 to 60 cm (6 to 24 inch) depth samples, if this information is required.
- pH, organic matter or micronutrient analysis should be conducted on the 0 to 15 cm (0 to 6 inches) depth sample, if this information is required.

4 Manure Sampling and Analysis

To calculate manure application rates, an estimate of the nutrient content of the manure must be known. Because manure nutrient concentrations are highly variable (see Section 2), actual manure nutrient analyses are strongly recommended. The only way to determine the level of each nutrient being applied to a field is to submit a representative manure sample for analysis.
Field kits are also available that can provide estimates of N and P contents in manure.

When a manure analysis is not available, published average values ("book" values) for a given region are available. Book values can be obtained from the various provincial departments of agriculture.

The biggest challenges in manure sampling are:

- getting a representative sample from a manure pile or liquid manure storage structure;
- getting a laboratory analysis that can be used to calculate this year's manure application rate.

4.1 When to Sample Manure

It is recommended that manure be sampled just prior to the actual application. If manure is applied in different seasons (such as in spring and in fall), a manure sample should be taken during each application period. Sampling at the time of application will account for changes in nutrient concentrations due to nutrient transformations, atmospheric losses, evaporation and dilution during storage.

Unfortunately, sampling at the time of application does not provide enough time for the nutrient analysis to be completed prior to application. This presents a problem for producers who are in the early stages of manure management planning. Book values do provide estimates that can be used in the absence of laboratory values. However, as shown in previous sections, manure nutrient concentrations are variable. As a result, book values may not represent actual manure nutrient concentrations for a given operation. Therefore, although it poses several challenges, sampling prior to application should be considered when the first manure sample is taken for an operation.

Due to the variability in manure, a single manure nutrient analysis can be unreliable. Manure samples should be taken over a number of sampling seasons to provide more reliable nutrient estimates for an operation. The greater the number of samples in a farm's database, the more accurate the information will be to calculate the annual manure application rates. Once established a farm's database can be used to calculate application rates if significant changes in the livestock production system have not been made. The current year's analysis can then be used to refine the manure nutrient estimates for the coming years.

4.2 How to Sample Liquid Manure

Because the solids tend to settle out of liquid manure over time (stratification), the manure in the storage should be well agitated before samples are taken. Samples of well-agitated manure will contain both liquid and solid fractions and, therefore, will provide a better average nutrient estimate for the entire manure storage. If the nutrient analysis represents all of the manure in the storage, then only one application rate is required per field to satisfy crop nutrient requirements.

Liquid manure samples should be representative of the manure being applied, or about to be applied, to the field. A one-litre (one quart) plastic sample bottle, no more than three-quarters full, is normally adequate for nutrient analysis. The plastic bottle should be clearly labelled, placed in a plastic bag and sealed with a twist tie. All manure samples should be kept cool and transported immediately to the lab for processing. If immediate transport is not possible, the manure samples should be frozen until transport is possible.

4.2.1 Sampling from the Liquid Manure Storage

The most convenient time to take manure samples is when the manure is being pumped from the manure storage for land application. Several samples should be taken from the manure outlet over a period of several hours, mixed and sub-sampled to create one representative, composite sample. If micronutrient analysis is desired, the manure samples should be mixed using plastic equipment, as galvanized steel contains zinc and can interfere with the results.

Very large manure storages are difficult to fully agitate. In order to get an estimate of the nutrient variability within the storage, several samples can be taken while the storage is being emptied, and samples from the top, middle and bottom of the storage can be sent to the lab for separate analysis.

It is also possible to sample the manure storage prior to land application. However, if the manure has not been agitated, much more care must be taken to obtain a representative sample. Sampling equipment is available that can take samples at various depths within the storage. These samples should be thoroughly mixed, sub-sampled and transported to the lab for analysis.

There are safety issues related to sampling liquid manure. Liquid manure contains dangerous manure gases, such as hydrogen sulphide (H_2S). **Never enter an enclosed area that contains manure without wearing proper respiratory equipment.** Respiratory equipment is also recommended in the vicinity of all manure storages during agitation, as manure gases will be released in higher concentrations at this time.

4.2.2 Sampling Liquid Manure During Field Application

It is also possible to take manure samples directly from the manure application equipment. If a manure tanker is being used, single samples can be taken from each of several tanker loads, mixed and sub-sampled in order to obtain a representative sample. A clean, plastic pail should be used to collect the sample from the unloading port or the opening near the bottom of the tank.

Catch Sample from Injector

If applying with a drag hose system, several samples can be taken from the tap near the pump or from the injectors when they are lifted out of the ground.

Manure samples can also be taken during manure irrigation. Catch cans, such as aluminum roasting pans or clean plastic buckets, can be placed randomly in the field to catch the liquid manure. Although messy, this method of collection provides a real estimate of the N lost through volatilization during irrigation. Therefore, additional volatilization losses during irrigation (Table 6.2) do not need to be factored into the manure application calculation.

4.3 How to Sample Solid Manure

Obtaining a representative solid manure sample can be very difficult. A single composite sample from a manure pile may not provide an accurate estimate of the nutrient content. Therefore, a number of composite samples are recommended to get an estimate of the variability. For each solid manure sample that is taken, visible variations in moisture and bedding content should be taken into account.

Sampling Solid Manure from a Truck

For mixing and sub-sampling solid manure, the following method is recommended:

1. Combine all of the solid manure samples on a plastic sheet or cement pad and mix thoroughly. Large clumps should be chopped with a fork or spade.
2. Divide the well-mixed manure into four portions.
3. Discard two of the four portions.
4. Combine the remaining two portions and mix.
5. Repeat steps 2, 3 and 4 until the remaining sample is small enough to send for analysis.

A well-mixed sample (approximately one litre) should be placed in a freezer bag or tightly sealed plastic container. The sample should be placed in an outer bag that can be sealed to prevent leaks and kept cool or frozen until transported to the lab for analysis.

4.3.1 Sampling from Manure Piles or Housing Areas

Manure can be sampled directly from manure piles, packs or housing areas. In order to get an estimate of the variability, more than one composite sample should be sent for analysis. Manure should be taken from several depths and locations throughout the pile or pack using a fork or spade. If only a portion of the stockpile is to be spread, only that portion of the pile requires sampling. The objective is to take as many samples as necessary to obtain a reasonably representative sub-sample for analysis. It is often difficult to obtain samples from the middle of a large solid manure pile. It may be necessary to access the centre of the pile using a front-end loader. A sample should then be obtained from the bucket of the loader. All of the manure samples can be mixed and sub-sampled for analysis.

Solid Manure Pile

4.3.2 Sampling Solid Manure During Field Application

Solid manure can be sampled directly from the manure spreader just prior to field application. Single samples can be taken from each of several spreader loads using a fork or spade. The number of spreader loads that must be sampled in order to obtain a representative sample will depend on the total amount of manure that is to be spread. The spreader loads which are sampled should represent the beginning, middle and end of the application process. As the samples are being collected, they should be placed in a bucket and, if possible, temporarily stored where it is relatively cool (such as in the shade). The samples must be well mixed in order to obtain a representative sub-sample for analysis.

4.4 Handling and Shipping Samples

It is recommended that the manure-testing laboratory be consulted regarding specific requirements for sample size and shipping, turn-around times, analytical options, costs and any additional instructions it may have. As well, some labs provide containers, labels and submission forms for manure samples.

When handling and shipping samples, leakage, nutrient loss to the air (volatilization), moisture loss and nutrient transformations must be prevented as much as possible. To accomplish this:

- Liquid manure containers should be no more than three-quarters full in order to provide air space in the container for manure gases.
- All samples should be kept cool, either by refrigeration or by placing on ice, until they are transported to the lab. Cool conditions will reduce nutrient transformation and minimize odours.
- If the samples cannot be transported within a day, they should be frozen until shipping is possible. If liquid manure is to be frozen, plastic containers should be used and should be no more than three-quarters full to leave room for the liquid to expand while freezing.
- Samples should spend no more than two days in transit. Shipping should be arranged to ensure that samples are not held over weekends or holidays or in warm locations.
- Manure samples should be tightly sealed to prevent leakage. Secondary containment, such as double bagging, should be used as an added precaution.

Sampling Liquid Manure

4.5 Laboratory Analysis for Manure

Laboratories that offer manure analysis often provide a variety of tests and analysis packages. Costs can vary, depending on the laboratory and the extent of the analysis.

The following manure analyses are recommended:

- moisture content or dry matter content
- total N
- ammonium N
- total P
- total K
- EC (required in Alberta)

Optional tests could include: electrical conductivity (total salts), pH, chloride (Cl), sulphur (S), sodium (Na), calcium (Ca), magnesium (Mg) and micronutrients, such as copper (Cu), manganese (Mn), zinc (Zn) and iron (Fe).

4.6 Estimating Manure Nutrients in the Field

Sampling manure for laboratory analysis at the time of application provides the most accurate measurement of the nutrient content. However, due to the delay between sample collection and return of the lab analysis results, this information cannot be used in the calculation of the current application rate.

Estimates of manure nutrient concentrations can be obtained quickly and inexpensively in the field using rapid-test kits. Although not as accurate as laboratory results, these estimates can be used to calculate approximate application rates prior to application. Laboratory analysis of a representative sample can then be used to confirm the result obtained from the rapid-test kit. Although adjustments can sometimes be made to the testing procedure, rapid-test field kits are designed mainly for manure with relatively low solids content (i.e. liquid or semi-solid manure).

Caution: Rapid field-testing of manure can only provide rough estimates of nutrient concentrations. It should not replace regular laboratory analysis.

Most rapid tests provide estimates, through either direct or indirect measurement, of ammonium N in manure. Tests kits that provide ammonium N estimates include:

- Agros N meter
- ammonia electrode
- conductivity meter
- conductivity pen
- Quantofix-N-volumeter
- Reflectometer

These rapid analytical methods are useful since manure is typically applied to meet the crop's requirements for N, and ammonium N is the most readily available form of N in manure.

Some rapid testing procedures, such as those of the conductivity meter and conductivity pen, can also provide indirect estimates of potassium ion (K^+) concentrations in solution. However, because these methods involve only indirect determinations of K^+ levels, interference by other ions in solution can reduce the accuracy of results.

Estimates of total N and total P in manure can be determined using a hydrometer, an instrument that measures the specific gravity, or density, of a liquid. This method is based on two premises: that the density of manure varies with its dry matter, or solids, content; and that total N and total P concentrations vary with dry matter content.

The accuracy of rapid test kits in the field can be reduced due to a number of factors, including manure variability and inconsistent operation of equipment. Consequently, on-farm calibration over multiple manure applications is recommended. Calibration is the adjustment of field test kit readings to improve their accuracy. The adjustment is typically based on laboratory results. Keeping complete records of field and laboratory results over time is critical to effective calibration. Calibration of the rapid-test equipment for certain nutrients can also be done on a regular basis (even prior to each use) using standard solutions, each of known concentration.

5 Understanding the Soil Test & Manure Test Reports

5.1 The Soil Test Report and the Fertilizer Recommendation

The purpose of soil testing is to measure the amount of available nutrients in the soil in order to establish the amounts of additional nutrients that should be applied to meet the crop nutrient requirements. Soil testing and fertilizer recommendations have been used to enhance crop production, maximize economic return and minimize environmental impact on soil, water and air.

Most laboratories provide fertilizer recommendations on the soil test reports. The fertilizer recommendations are based on crop nutrient requirements, available soil nutrients and target yields for specific crops. In addition to the soil test results, there are several other factors that can be used to refine the fertilizer recommendation. These include: soil type, soil zone (Saskatchewan and Alberta), soil moisture, crop type, target yield, crop and fertilizer prices, whether the crop system is irrigated or dryland, and previous manure applications.

> The accuracy of the fertilizer recommendation relies on target yields that are realistic and based on expected moisture availability. In order to generate an accurate fertilizer recommendation, the laboratory must know which crop type will be grown and be given a realistic target yield. Target yields can be provided by customers based on recent yield data from their operations (such as a five-year average plus 10%). If the customer does not specify a target yield, most laboratories will base their fertilizer recommendations on regional average and optimum yield goals, which may not be representative of the operation's expected yield.

5.1.1 Why Fertilizer Recommendations May Differ

In developing fertilizer recommendations, each laboratory may consider several factors that will predict a targeted crop response at the most economic rate of fertilizer application. Factors such as target yield, soil moisture, crop price and the cost of fertilizer may be considered when developing a fertilizer recommendation. Laboratories may differ in their recommendations because they weigh the importance of the various factors differently. It is important to be confident in the recommendations of the laboratory. If a recommendation is given that does not appear reasonable, an explanation should be requested or a qualified agronomist consulted.

Some laboratories may give different recommendations for manure than for commercial fertilizer. This can occur if the laboratory considers the cost of fertilizer as a factor limiting the amount of fertilizer to be applied. Manure is often given free of charge to neighbouring landowners or sold at a fraction of its equivalent fertilizer value. As a result, the cost of manure is assumed to be lower and less limiting, and the recommendation may be less conservative.

5.2 Manure Test Reports: Unit Conversions

Laboratory reports use a variety of units to express the nutrient content of manure. In some instances, the results must be converted before they can be used to calculate a manure application rate.

Different laboratories report manure test results in different units. Scientists generally use metric units, but many producers are more comfortable using the imperial system of measurement.

Appendix A contains most of the conversion factors used for nutrient management planning. However, when there is no conversion table at hand, it is helpful to understand how the conversions are calculated. Below are various examples of conversion calculations that can be used with the manure test report results.

5.2.1 Conversions for Solid Manure Samples

The figures contained in table 5.1 are used in the following examples of solid manure conversions.

Table 5.1 Example of a Solid Beef Manure Test Report

Parameter	Lab Units[1] % and ppm		Metric Units kg/tonne
	Dry Basis	Wet Basis ("as received")	Wet Basis ("as received")
Moisture Content		69.5	
Total N	1.7	0.52	5.2
Ammonium N	2,243	684	0.684
Phosphorus	0.20	0.06	0.6
Potassium	1.08	0.33	3.3

[1] all analyses in this column are in % except for Ammonium N which is in ppm

Converting From a Dry-Weight to a Wet-Weight Basis

The nutrient content of the manure may be provided on a wet-weight (as-received) basis or a dry-weight basis. Since the manure is being land-applied "as-received", it is the wet-weight basis nutrient concentrations that are required. Laboratories report the manure analysis on a dry-weight basis simply because the sample is dried in the lab before many of the nutrient contents are determined.

If the results are expressed on a dry-weight basis, they must be converted to wet-weight in order to calculate a manure application rate. To convert back to a wet-weight or as-received value, the moisture content (%) must be known. This is usually provided in the manure test report. The conversion from a wet-weight value to a dry-weight value is as follows:

wet-weight value = dry-weight value x (1 – (% moisture/100))

Using total N as an example:
1.7% total N (on a dry-weight basis)
69.5% moisture content

To convert the total N value to a wet-weight basis:
wet-weight value = dry-weight value x (1 – (% moisture/100))
wet-weight value = 1.7 x (1 - (69.5/100))
wet-weight value = 1.7 x (1- 0.695)
wet-weight value = 1.7 x 0.305
wet-weight value = 0.52% total N

Converting From Percentage to kg/tonne

In the above example, the total N content of the solid beef manure is 0.52% total N on a wet-weight, or as-received, basis. This means that there is 0.52 kg of total N in every 100 kg of manure. There are 1,000 kg in a tonne. Therefore, there are 5.2 kg total N in 1,000 kg of manure.

kg/tonne = value (%) x 10

kg total N/tonne = 0.52 x 10
kg total N/tonne = 5.2

Converting From Percentage to lb/ton

In the above example, the total N content of the solid beef manure is 0.52% total N on a wet-weight, or as-received, basis. This means that there is 0.52 lbs of total N in every 100 lbs of manure. There are 2,000 lbs in a ton. Therefore the conversion factor from percentage to lb/ton is 20, as follows:

lb/ton = value (%) x 20

lb total N/ton = % Total N (wet-weight basis) x 20

For the solid beef manure:
lb total N/ton = % Total N (wet-weight basis) x 20
lb total N/ton = 0.52 x 20
lb total N/ton = 10.4

Therefore, the solid beef manure contains 10.4 lb total N in every ton.

Converting From kg/tonne to lb/ton

Some manure test reports list the nutrient contents of manure in kg/tonne, whereas many producers work in lb/ton. There are 2.2 lb per kg and there are 1.1 tons in a tonne. This means that there are 2 lb/ton for every kg/tonne.

lb/ton = value (kg/tonne) x 2

lb/ton = kg/tonne x 2.2 lb/kg x tonne/1.1 ton

In the above example, the solid beef manure contained 5.2 kg/tonne, or 10.4 lbs total N/ton manure.
5.2 kg total N/tonne x 2 = 10.4 lb/ton

Table 5.2 Example of a Liquid Swine Manure Test Report

Parameter	Lab Units[1] % and ppm		Metric Units kg/1,000 L
	Dry Basis	Wet Basis ("as received")	Wet Basis ("as received")
Moisture Content		96	
Total N	9.25	0.37	3.7
Ammonium N	58,375	2,335	2.3
Phosphorus	2.75	0.11	1.1
Potassium	3.75	0.15	1.5

[1] all analyses in this column are in % except for Ammonium N which is in ppm

5.2.2 Conversions for Liquid Manure Samples

The figures contained in table 5.2 are used in the following examples of liquid manure conversions.

- **Converting From a Dry-Weight to a Wet-Weight Basis**

  The conversion of nutrient concentrations in a liquid manure sample from a dry-weight basis to a wet-weight basis is the same as that for a solid manure sample (see Section 5.2.1)

- **Converting From Percentage to kg/m^3**

  In the above example, the total N content of the liquid manure is 0.37% total N on a wet-weight, or as-received, basis. This means that there is 0.37 kg of total N in every 100 kg of manure; or 3.7 kg total N in 1,000 kg.

  To convert liquid manure from a weight to a volume, you must estimate the density.

  Density = mass/volume

  The density of water is 1,000 kg/m^3. However, the higher the dry matter content of the manure, the lower the density of the manure.

  Since the liquid swine manure has a very low solids content, we can assume that the density of the liquid swine manure is very close to the density of water. For the purpose of this calculation, assume the density of the liquid swine manure is 1,000 kg/m^3.

  To calculate the volume of 1,000 kg of manure:
  Density = Mass/Volume
  1,000 kg/m^3 = 1,000 kg/Volume (m^3)
  Volume = 1,000/1,000 m^3
  Volume = 1.0 m^3

  Since there are 3.7 kg total N in 1,000 kg of manure and 1,000 kg equals 1.0 m^3 of manure, then there are 3.7 kg total N/m^3 of manure.

  Therefore, the simple factor from percentage to kg/m^3 is 10, as follows:
  kg/m^3 = value (%) x 10

- **Converting From kg/m^3 to kg/1,000 litres**

  In the above example, we calculated that the liquid swine manure contained 3.7 kg total N per m^3 of manure. There are 1,000 litres in a m^3.

  Therefore, the total N content in the manure in kg/1,000 litres is:
  3.7 kg total N/1,000 litres

  Therefore,
  kg/m^3 = kg/1,000 litres

Converting From Percentage to lb/1,000 gallons

In the above example, the total N content of the liquid swine manure is 0.37% total N on a wet-weight, or as-received, basis. This means that there is 0.37 lb of total N in every 100 lb of manure. The density of water is 10 lb/imperial gallon. The density of the liquid swine manure is assumed to be very close to the density of water.

Therefore, in 100 lb of manure there are 10 imperial gallons as follows:

Density = Mass/Volume

10 = 100/ Volume

Volume = 10 gallons

This means that there is 0.37 lb total N in 10 gallons of manure; and 37 lb total N in 1,000 gallons of manure. The simple conversion from percentage to lb/1,000 gallons can be summarized as follows:

lb/1,000 gal = value (%) x 100

Converting From kg/1,000 litres to lb/1,000 gallons

Some manure test reports provide the nutrient contents of manure in kg/1,000 litres, whereas many producers work in lb/1,000 gallons. There are 2.2 lb per kg and there are 4.55 litres in an imperial gallon.

kg/1,000 litres x 2.2 lb/kg x 4.55 litres/gallon

kg/1,000 litres x 10 = lb/1,000 gallons

lb/1,000 gallons = value (kg/1,000 litres) x 10

Therefore, a lab analysis of 1.5 kg/1,000 L of K would represent

1.5 kg K/1,000 L x 10 = 15 lbs/1,000 gal

5.2.3 What is ppm (parts per million)?

Ammonium-N may be reported in parts per million (ppm), or mg/kg (equal to µg/g) for solid manure and mg/L for liquid manure.

ppm = mg/kg = µg/g

ppm = mg/L assuming the density of water (1,000 kg/m^3)

Converting mg/kg to kg/tonne for Solid Manure

There are 1,000,000 mg in a kg.

There are 1,000 kg in a tonne.

kg/tonne = mg/kg x kg/1,000,000 mg x 1,000 kg/tonne

kg/tonne = mg/kg / 1,000

kg/tonne = value (mg/kg) / 1,000

In the above example, the ammonium N content of the solid beef manure is 684 mg/kg on a wet-weight, or as-received, basis.

kg NH_4-N/tonne = 684 / 1000

kg NH_4-N /tonne = 0.7

Converting mg/kg to lb/ton for Solid Manure

There are 453,600 mg in a lb.
There are 907.2 kg in a ton.

lb/ton = mg/kg x lb/453,600 mg x 907.2 kg/ton
lb/ton = mg/kg / 500

lb/ton = value (mg/kg) / 500

In the above example, the ammonium N content of the solid beef manure is 684 mg/kg on a wet-weight, or as-received, basis.

lb NH_4-N /ton = 684/500
lb NH_4-N /ton = 1.4

The result can then be converted to imperial units using the conversion for kg/tonne to lb/ton as provided above (see Section 5.2.1).

Converting mg/L to kg/1,000 L for Liquid Manure

Since the density of liquid manure can be assumed to be the same as that of water, then mg/kg can also be reported as mg/L.

In one litre there is:
kg/L = mg/L x kg/1,000,000 mg

In 1,000 litres there are :
kg/1,000 L = mg/L x kg/1,000,000 mg x 1,000

kg/1,000 L = value (mg/kg) / 1,000

In the above example, the ammonium N content of the liquid swine manure is 2,335 mg/kg on a wet-weight, or as-received, basis.

kg NH_4-N/1,000 L = 2,335 / 1000
kg NH_4-N/1,000 L = 2.3

Converting mg/L to lb/1,000 gallons for Liquid Manure

There are 453,600 mg in a lb.
There are 4.55 L in an Imperial gallon.

In one gallon there is:
lb/gal = mg/L x lb/453,600 mg x 4.55 L/gal

In 1,000 gallons there are:
lb/1,000 gal = mg/L x lb/453,600 mg x 4.55 L/gal x 1,000

lb/1,000 gal = value (mg/kg) / 100

In the above example, the ammonium N content of the liquid swine manure is 2,335 mg/kg on a wet-weight, or as-received, basis.

lb NH_4-N/1,000 gal = 2,335 / 100
lb NH_4-N/1,000 gal = 23.4

5.2.4 Phosphorus versus P_2O_5

The manure test results may be expressed as total elemental P or P_2O_5.

To be consistent with the reporting of the P content of commercial inorganic fertilizers, P fertilizer recommendations are provided on the soil test report as P_2O_5. For this reason, it is helpful to be able to convert between the two.

To convert from P to P_2O_5 simply multiply the value for P by 2.3

Example:
Liquid swine manure contains 0.11% P
The manure will provide 1.1 kg P/1,000 L (see Section 5.2.2)
P_2O_5= 2.3 x P
P_2O_5 = 2.3 x 1.1 kg P/1,000 L
Therefore, the liquid swine manure will provide 2.53 kg P_2O_5/1,000 L

5.2.5 Potassium versus K_2O

The manure test results may be expressed as total elemental K or K_2O.

To convert from K to K_2O, simply multiply the value for K by 1.2

To be consistent with the reporting of the K content of commercial inorganic fertilizers, K fertilizer recommendations are provided on the soil test report as K_2O. For this reason, it is helpful to be able to convert between the two.

Example:
Liquid swine manure contains 0.15% K
The manure will provide 1.5 kg K/1,000 L (see Sections 5.2.2)
K_2O = 1.2 x K
K_2O = 1.2 x 1.5 kg K/1,000 L
Therefore, the liquid swine manure will provide 1.8 kg K_2O/1,000 L

6 Calculating Manure Application Rates

Manure is a fertilizer and can be used to meet the fertilizer recommendations on the soil test reports. This is often referred to as manure/nutrient management planning. The end result of a manure/nutrient management plan is the calculation of a manure application rate that will meet the nutrient requirements of the crop.

Worksheets for calculating manure application rates are in **Appendices B and C.** Notes for the worksheets are in **Appendix D**.

6.1 Development of the Manure Application Rate Recommendations

Observations from field trials across the Prairies have been used to develop the recommendation system that is used to determine manure application rates that will meet the nutrient requirements of a crop. The recommended manure application rates vary according to manure nutrient content (manure test), predicted manure nutrient availability (field trials and research data), available soil nutrient content (soil test) and the anticipated crop nutrient requirement (field trials, research and climate data). Crops with high nutrient-demand and -removal potential, such as forage grasses and potentially high-yielding cereals and oilseeds, have shown good yield response to the nutrients provided by manure. Protein content in cereals has also been shown to significantly increase with manure use because the organic manure N mineralizes later in the growing season.

6.1.1 Using Nitrogen as the Basis for Manure Application Rates

Unlike manufactured fertilizer, the nutrients in manure are not balanced for optimal crop growth; therefore, it is difficult to apply manure to meet exact crop requirements for two or more nutrients. When manure is applied based on one nutrient, other nutrients are usually either over- or under-applied. In the Prairie region, nitrogen-based application rates are the accepted practice. If manure is applied to meet nitrogen requirements, then phosphorus and potassium may be applied in excess of crop requirements. If manure is applied to meet P requirements, additional N may be required.

Agronomic Impacts of Over-applying Nutrients: Although many crops have shown significant yield responses to the nutrients provided by manure, it is important not to over-apply nutrients. The over application of nutrients, from any source, can have a negative effect on crop growth and yield (Table 6.1). Lodging is perhaps the most apparent response to high nitrogen applications.

In low moisture areas of the Prairies, high nitrogen applications can produce a large amount of vegetative growth, especially in cereals, but with subsequent poor grain-fill and yield if the weather turns dry later in the season (“haying off”).

Forage grasses that receive excess rates of N can have elevated nitrate concentrations. This may be even more prevalent if forage growth is limited by some factor such as drought. Feed testing of forages grown on manured soils is recommended to determine nitrate levels.

Table 6.1 Yield Comparison Showing Crop Response to Various Rates of Injected Liquid Hog Manure in East-Central Saskatchewan

Rate	Canola Yield		Barley Yield		Crested Wheat Grass	
	tonne/ha	bu/ac	tonne/ha	bu/ac	tonne/ha	tons/ac
0	0.56	10	2.04	38	0.96	0.43
84 kg N/ha (75 lb N/ac)	1.29	23	4.03	75	2.46	1.11
168 kg N/ha (150 lb N/ac)	1.74	31	4.30	80	4.52	2.03
337 kg N/ha (300 lb N/ac)	1.62	29	3.98	74	4.43	2.00

Adapted from Schoenau, J.J., P. Mooleki, P. Qian. 2001. Maximizing the Economic and Environmental Benefit of Land Application of Animal Manure. AFIF/Sask Pork Final Report # 96000131. Saskatchewan Agriculture, Food and Rural Revitalization. (Yield Tables modified by Barry Olson, Alberta Agriculture, Food and Rural Affairs, Nov 2001.)

In general, a shift in soil test values should initiate a review of the manure management plan. The review should determine why there is an excess or deficiency of any one, or combination of nutrients, so that decisions can be made on applications for the coming crop year.

6.2 Nutrient Availability to Crops

In order to determine an appropriate manure application rate, estimates of the nutrients that are available in the manure are necessary. The first step in estimating manure nutrient availability is determining the nutrient content of the manure through laboratory manure analysis.

The total amount of the various nutrients provided on the manure test report does not necessarily reflect the amount of nutrients that will be available for crop growth when the manure is added to the soil as fertilizer. Generally, the nutrients in commercial (inorganic) fertilizers are available to plants at the time of application. The nutrients in manure, however, are in both organic and inorganic forms, which differ in their availability for plant uptake. It is important to understand the processes involved in nutrient availability when calculating manure application rates.

6.2.1 Nitrogen

The manure test report should include results for total N and ammonium N.

Available Ammonium N: The amount of ammonium N available to the crop will depend on the spreading method, season and weather conditions. Ammonium can be readily lost to the atmosphere as ammonia through volatilization. The amount of ammonium N lost will depend on how long the manure is exposed to the air. To maximize the economic benefit of the manure N, an application method that minimizes volatilization should be chosen.

Table 6.2 provides estimated % loss of ammonium under varying weather conditions when the manure is surface broadcast (with and without incorporation) or injected. In general, injection and incorporation immediately after application will significantly reduce volatilization losses. Research on N loss from ammonia volatilization shows that losses are highly variable. The values provided in Table 6.2 are estimates for manure application rate calculation purposes.

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

Table 6.2 Volatilization losses (%) associated with different application methods and weather conditions

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

Adapted from MARC 1998. Manitoba Agriculture and Food.

Available Organic N: Organic N is not measured in the laboratory. Organic N is calculated as follows:

Organic N = Total N – Ammonium N

The amount of organic N that will be available to the crop is estimated to be 25% to 30% in the first year after application.

Available Organic N = Organic N x 0.25 Year 1

Organic N will continue to be released in the years following application. The amount of organic N mineralized in the second and third years after application is significantly less than in the first year.

The amount of N that is available at the beginning of the second and third cropping years following manure application will be determined by the soil nitrate test. If a soil nitrate test is not available, the amount of organic N available in the second and third years following application can be roughly estimated. As a “rule of thumb”, about 25% of manure organic N will be available in the crop year following application, 12% will be available two years later, and 6% will be available three years later. Annual manure application, particularly in the case of solid manure, can result in a significant organic N pool, which can provide a considerable amount of available N. Use of the soil nitrate test to estimate the available N is strongly recommended.

Total Available N: The total N available to the crop is the amount of N that will be mineralized from the organic N plus the ammonium N remaining after volatilization losses.

Total Available N = Available Organic N + Available Ammonium N

6.2.2 Phosphorus

The manure test report will generally provide a total P analysis. Manure P can be in both inorganic and organic forms, but the organic P must be mineralized before it can be used. Inorganic P is considered to be available to the crop. Approximately 50% of the total P is considered to be available to the crop in the year of application.

> In general, P does not move much in soil. This is because P can be strongly bound by Al, Fe, Ca and Mg. Of the total amount of P applied, the crop will only take up a fraction. A large portion of the P applied will be bound by the soil and become unavailable for plant uptake. For chemical fertilizer P, placement with the seed has increased the probability of the crop accessing the P before it is bound by the soil. In the case of manure, both broadcasting or injection are less effective than seed-placed fertilizer P.

Manure application rates are often based on N. Depending on the manure nutrient analysis, this may result in applications of P above crop nutrient requirements. Alternatively, manure application rates can be calculated based on the P content of the manure and the crop requirement for P.

6.2.3 Potassium

The manure test report will provide a total K analysis. Manure K is considered to be as available as fertilizer K with estimates ranging from 90 – 100%.

Repeated yearly applications of manure can result in elevated soil K levels. Although this is not considered to be of environmental concern, high soil K can produce elevated levels of K in forages, which is of particular concern to dairy producers. High K levels in dry cow diets predispose cows to several metabolic disorders including milk fever and udder edema. The feeding of forages with less than 1.5% K (dry matter basis) is therefore recommended for dairy cows prior to calving.

6.3 Soil Suitability and Establishing Land-base Requirements

Manure nutrient management is based on the premise that an adequate amount of suitable land is available for long-term application of manure at agronomic rates. The land-base must be comprised of soils that are productive and that minimize the risk of nutrient losses via leaching, denitrification, runoff and erosion.

Soils with low agricultural capability, according to the Canada Land Inventory (CLI), have lower yield potential and, therefore, limited nutrient uptake by plants. When these soils are located in landscapes where there is high risk of nutrient loss to surface and/or groundwater, manure applications should be controlled according to Beneficial Management Practices specific to that region. In extreme situations, these lands may have to be excluded from the land-base that is to receive manure applications.

Sometimes not all of the lands within a planned spreading area will be suitable for manure application, and some of the land may have to be removed as part of setback distances outlined in local guidelines and regulations (wetland, bush, saline areas). All of these factors should be considered when determining the actual area suitable for spreading.

The suitability of the land-base for manure spreading is based on a number of criteria in addition to the soil test information. Individual provinces evaluate soil suitability in the context of detailed soil survey information and other defined criteria. These criteria can vary, but may include soil type, slope, topography, nutrient levels, erosion risk, climate, management practices, distance to surface water, and depth to ground water or bedrock. Crop productivity data according to soil type can be obtained from provincial crop insurance agencies and used as a starting point in determining whether a specified target yield is attainable or reasonable for a given situation.

7 Manure Application Equipment

The manure application method has considerable impact on nutrient retention and loss. Liquid manure application technology has improved in the past few years. Newer systems can apply liquid manure in a way that maximizes nutrient recovery, minimizes odour, and reduces the risk of runoff, compaction and soil disturbance.

Drag hose injector applying into stubble

The development of manifold distribution systems has allowed liquid manure to be delivered to a toolbar that can apply the manure close to the ground or through direct injection into the soil. Low-level application reduces odour and ammonia volatilization compared to traditional broadcast systems or irrigation. Injection reduces odour, volatilization and runoff risk and maximizes nutrient utilization. If the manure is supplied with a drag hose, soil compaction can also be significantly reduced.

Openers commonly employed to inject liquid manure include sweeps and low-disturbance systems using chisel or disc openers. The low-disturbance openers are suitable for liquid manure application into post-emergent forage and annual crops as well as pasture, zero tillage or reduced tillage systems. One disadvantage of injection is the potential for nutrient stripping if row spacing is wide (e.g. 60 cm/24 inches).

Solid manure application generally involves broadcasting with or without incorporation. Due to the rather inconsistent nature of most solid manure, uniformity is often an issue. Incorporation of solid manure helps to reduce odour, conserve ammonium, increase the manure-to-soil contact for decomposition, and to prepare a suitable seed-bed. However, incorporation of solid manure may require an additional tillage pass. This would increase the amount of time required for manure spreading and may increase soil compaction.

7.1 Calibrating Manure Application Equipment

"Calibration" refers to the combination of settings needed to deliver manure at a particular rate. The only way to know how much manure is actually being applied to the field, and to meet the calculated manure application rate, is through calibration of the manure application equipment. The calculation of manure application rates is of little value if the equipment is not properly calibrated to deliver the required application rate.

Loading a Manure Tanker

Solid, semi-solid and liquid manure spreaders can discharge manure at various rates, depending on speed of travel, PTO speed, gear-box setting, discharge openings, width of spreader, overlap patterns and other parameters.

Whenever possible, data from the manufacturer should be used to calibrate application equipment.

The following equations (metric) are used to calibrate liquid and solid manure application equipment. Imperial calculations can be found in **Appendices E and F**.

7.1.1 Calibrating Liquid Manure Applicators

Liquid Manure Tankers

The actual volume of manure that is contained in a liquid manure tanker is often less than the manufacturer's rated volume due to foaming and splashing. Ninety per cent of the manufacturer's rated volume is a reasonable approximation of the actual volume in a full load.

- **Calculate an application rate, using the actual tanker volume, emptying time, ground speed and spread width.**

$$\text{Application Rate (L/ha)} = \frac{\text{Actual Tanker Volume (L)} \times 36{,}000}{\text{Emptying Time (s)} \times \text{Ground Speed (km/h)} \times \text{Spread Width (m)}}$$

Example: If the manufacturer's rated volume for a tanker is 20,000 L, emptying time is 7 minutes (420 s), ground speed is 5.5 km/h and the spread width is 7 m, the application rate is calculated to be:

$$\text{Application Rate} = \frac{(20{,}000 \times 90\%) \times 36{,}000}{420 \times 5.5 \times 7} = 40{,}100 \text{ L/ha}$$

- **Adjust the ground speed to achieve a target application rate using the actual tanker volume, emptying time, target application rate and spread width.**

$$\text{Ground Speed (km/h)} = \frac{\text{Actual Tanker Volume (L)} \times 36{,}000}{\text{Emptying Time (s)} \times \text{Application Rate (L/ha)} \times \text{Spread Width (m)}}$$

Example: If the manufacturer's rated volume for a tanker is 20,000 L, emptying time is 7 minutes and the spread width is 7 m, to achieve a target application ate of 60,000 L/ha the appropriate ground speed is calculated to be:

$$\text{Ground Speed} = \frac{(20{,}000 \times 90\%) \times 36{,}000}{420 \times 60{,}000 \times 7} = 3.7 \text{ km/h}$$

- **Calculate an application rate, using the actual tanker volume, spread width and spread length.**

$$\text{Application Rate (L/ha)} = \frac{\text{Actual Tanker Volume (L)} \times 10{,}000}{\text{Spread Width (m)} \times \text{Spread Length (m)}}$$

Example: If it takes two loads with a 20,000 L tanker (manufacturer's rating) to cover an 800 m length of field with a 7 m width of spread, the calculated application rate is:

$$\text{Application Rate} = \frac{(20{,}000 \times 90\%) \times 2 \times 10{,}000}{800 \times 7} = 64{,}300 \text{ L/ha}$$

Drag Hose System

Drag hose systems pump manure through flexible hoses or umbilical pipe from the storage to a tractor powered injector. This system combines the time savings features of an irrigation system with the benefits of direct injection.

- **Calculate an application rate using the flow rate, ground speed and spread width**

$$\text{Application Rate (L/ha)} = \frac{\text{Flow rate (L/h)} \times 10}{\text{Ground Speed (km/h)} \times \text{Spread Width (m)}}$$

Example: If the flow meter indicates a pumping rate of 225,000 L/h, the ground speed is 3.5 km/h and the spread width is 5.5 m, the application rate is calculated to be:

$$\text{Application Rate} = \frac{225{,}000 \times 10}{3.5 \times 5.5} = 116{,}900 \text{ L/ha}$$

- **Adjust the ground speed to achieve a target application rate using the flow rate, target application rate and spread width**

$$\text{Ground Speed (km/h)} = \frac{\text{Flow Rate (L/h)} \times 10}{\text{Application Rate (L/ha)} \times \text{Spread Width (m)}}$$

Example: If the flow meter indicates a pumping rate of 225,000 L/h and the spread width is 5.5 m, a target application rate of 80,000 L/ha is achieved with a ground speed calculated to be:

$$\text{Ground Speed} = \frac{225{,}000 \times 10}{80{,}000 \times 5.5} = 5 \text{ km/h}$$

7.1.2 Calibrating Solid Manure Spreaders


Truck mounted solid manure spreader

Solid manure spreaders usually are rated in cubic feet or bushels for struck-load and heaped-load capacities. A struck-load is a load that is level with the top of the box, and a heaped-load is heaped as high as the box will hold. Since the box will probably be heaped as much as possible when hauling manure, the heaped load capacity is the most useful value.

Although the spreader boxes have a volume rating, application rates are usually expressed as mass (i.e. in tonnes) per unit area (i.e. hectare). If truck scales are available, determine the mass of manure in a full load by finding the mass of the manure spreader empty and then full. The mass of the manure is the difference between the two.

- **Calculate an application rate using the net mass per load, the spread width and the spread length for a given load**

$$\text{Application Rate (t/ha)} = \frac{\text{Net Mass per Load (t)} \times 10{,}000}{\text{Spread Width (m)} \times \text{Spread Length (m)}}$$

Example: If the net mass per load is 3.5 t, the spread width is 3 m and the spread length is 300 m, the application rate is calculated to be:

$$\text{Application Rate} = \frac{3.5 \times 10{,}000}{3 \times 300} = 39 \text{ t/ha}$$

If truck scales are not available, the mass of the manure in a full load must be calculated from the known volume and an estimated density because:

Density = Mass/Volume
and therefore
Mass = Density x Volume

To determine the density of the manure:

1. Get a pail of known volume in cubic meters (m^3). If the volume of the pail is in litres, use the conversion table in **Appendix A** to convert to cubic metres.
2. Fill the pail with a typical sample of manure, and pack it in the pail to a density similar to that in the spreader box.
3. Weigh the pail full and then empty the manure and weigh the pail empty.
4. For the mass of the manure, take the difference between the full pail mass and the empty pail mass. [Manure Mass = Full Pail Mass – Empty Pail Mass]
5. Repeat steps 2 to 4 three times to obtain three manure masses.
6. Take the average of the three manure masses.
7. Take the average manure mass (in kg) and divide by the pail volume (in m^3) to get the density of the manure. [Density = Mass/Volume]

- **Calculate the manure density**

Density = Mass/Volume

Example: If a 0.02 cu.m pail weighed 1 kg empty and 8 kg (on average) full, the density would be:

$$\text{Density} = \text{Mass/Volume} = \frac{(8-1)\text{ kg}}{0.02\text{ cu.m}} = 350\text{ kg/cu.m}$$

- **Calculate an application rate using the spreader box volume, manure density, spread width and spread length**

$$\text{Application Rate (t/ha)} = \frac{\text{Box Volume (cu.m) x Manure Density (kg/cu.m) x 10}}{\text{Spread Width (m) x Spread Length (m)}}$$

Example: If the box volume of a spreader is 8 cu.m, the manure density is 350 kg/cu.m, the spread width is 3 m and the spread length is 175 m, the application rate is calculated to be:

$$\text{Application Rate} = \frac{8 \text{ x } 350 \text{ x } 10}{3 \text{ x } 175} = 53\text{ t/ha}$$

- **Calculate an application rate using the spreader box volume, manure density, emptying time, ground speed and spread width**

$$\text{Application Rate (t/ha)} = \frac{\text{Box Volume (cu.m)} \times \text{Manure Density (kg/cu.m)} \times 36}{\text{Emptying Time (s)} \times \text{Ground Speed (km/h)} \times \text{Spread Width (m)}}$$

Example: If the box volume of a spreader is 8 cu.m, the manure density is 350 kg/cu.m, the emptying time is 70 s, the ground speed is 8 km/h and the spread width is 3 m, the application rate is calculated to be:

$$\text{Application Rate} = \frac{8 \times 350 \times 36}{70 \times 8 \times 3} = 60 \text{ t/ha}$$

- **Adjust the ground speed to achieve a target application rate using the spreader box volume, manure density, emptying time, target application rate and spread width**

$$\text{Ground Speed (km/h)} = \frac{\text{Box Volume (cu.m)} \times \text{Manure Density (kg/cu.m)} \times 36}{\text{Emptying Time (s)} \times \text{Application Rate (t/ha)} \times \text{Spread Width (m)}}$$

Example: If the box volume of a spreader is 8 cu.m, the manure density is 350 kg/cu.m, the emptying time is 70 s and the spread width is 3 m, to achieve a target application rate of 50 t/ha the required ground speed is calculated to be:

$$\text{Ground Speed} = \frac{8 \times 350 \times 36}{70 \times 50 \times 3} = 9.6 \text{ km/h}$$

Alternatively, an application rate can be calculated without knowing the manure density. Instead, the rate is estimated based on the measured mass of manure spread over a small, known area. In the field, the manure spreader passes over a sheet of plastic cut to specific dimensions (eg. 1 m x 1 m). The manure on the plastic sheet is picked up with the sheet and its mass determined using a scale. These steps are repeated several times so that an average application rate can be determined.

- **Calculate an application rate using the mass of manure and sheet area.**

$$\text{Application Rate (t/ha)} = \frac{\text{Net Mass of Manure (kg)} \times 10}{\text{Sheet Area } (m^2)}$$

Example: If the net mass of manure on a 1 m x 1 m plastic sheet is 5 kg, the application rate is calculated to be:

$$\text{Application Rate} = \frac{5 \times 10}{1} = 50 \text{ t/ha}$$

7.2 Uniformity of Application

Uniformity of application is also important for optimum crop response. Uniformity is important because the manure nutrients need to be applied to the entire crop to avoid stripping or overlapping. Uniform application requires that the manure application equipment delivers nutrients evenly across the spreading width, and that the driving pattern avoids gaps and overlaps in application.

Tractor pulled solid manure spreader

8 Manure and the Protection of Water, Air & Soil

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

This chapter provides an overview of the potential risks associated with manure application and use, including:

- nutrient and pathogen transport to water sources;
- odour generation; and
- impacts on soil quality.

Various beneficial management practices (BMPs) that producers can use as part of their manure management program to reduce these risks are also provided.

8.1 Provincial Legislation

Each of the three provincial governments on the Prairies has legislation that applies to manure management. Producers should be familiar with all of the legislation that could affect their manure management practices.

Alberta:
Agricultural Operation Practices Act. Regulation 267/2001. Queens Printer for the Province of Alberta.

Manitoba:
Manitoba Livestock Manure and Mortalities Management Regulation. *The Environment Act.* Regulation 42/98. Chapter E125 of the *Continuing Consolidation of the Statutes of Manitoba*. Queens Printer for the Province of Manitoba.

Manure Regulation. *The Pesticide and Fertilizers Control Act*. Chapter P40 of the *Continuing Consolidation of the Statutes of Manitoba.* Queens Printer for the Province of Manitoba.

The Farm Practices Protection Act. Chapter F45 of the *Continuing Consolidation of the Statutes of Manitoba*. Queens Printer for the Province of Manitoba.

Saskatchewan:
Agricultural Operations Act 1995. The Agricultural Operations Regulations: Intensive Livestock Provisions. The Queens Printer, Regina, Saskatchewan.

8.2 Surface and Groundwater Quality

Surface water and groundwater are integral to ecosystems and have multiple uses, including water for drinking as well as other agricultural, industrial and municipal demands. Surface water is also relied upon for fishing and recreation. Manure management should incorporate the application of practices that minimize the risk of nutrient and pathogen contamination of surface and groundwater.

8.2.1 Nutrient Loss to Surface Water

The nutrients of primary concern to surface water quality are nitrogen and phosphorus due to ammonia toxicity and eutrophication.

Ammonia/Ammonium
Although surface waters naturally contain very low levels of both ammonium (NH_4^+) and ammonia (NH_3), they are toxic to fish at higher concentrations. The

concentration of each depends on the pH and temperature of the water. As pH and temperature of the water increase, the ammonium converts to the more toxic ammonia form. Ammonia is very toxic to fish at relatively low concentrations.

Relative to surface water, manure can contain very high concentrations of nitrogen in the form of ammonium. It is essential that manure management practices minimize the risk of manure entering surface water. The greatest risk of ammonium from manure entering surface water is through direct runoff or erosion soon after application. When manure is properly applied to the soil, the ammonium enters the soil N cycle. It can be converted to nitrate, held on the soil's cation exchange sites or taken up directly by plants.

Phosphorus

Eutrophication is the enrichment of water bodies by nutrients, particularly nitrogen (N) and phosphorus (P). Phosphorus 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, thereby affecting the quality of water and the diversity of organisms present.

Large colonies of algae, commonly referred to as blooms, can significantly deplete oxygen levels when they die and decompose, which can result in fish-kills. Blooms of cyanobacteria (blue-green algae) can also release toxins that are harmful to aquatic life, livestock and humans if they ingest the water.

How does P enter surface water?

Three conditions are necessary for P to enter surface water, as follows:

- there must be a supply of P **(source)**;
- a mechanism to carry the P from the field **(transport)**; and
- there must be a connection between the source of P and the water body **(connection)**.

Source: Manure, chemical P fertilizer and soil P are the most significant non-point sources of P. Both manure and chemical fertilizer P inputs contribute to the soil P pool.

Chemical fertilizer can be formulated to meet both the N and P requirements of the crop. Manure nutrients are often not in balance with the nutrient requirements of the crop. Therefore, manure application rates can be based on the requirements for only one of the primary macronutrients. On the Prairies, manure is most often applied to meet the N requirements of the crop. In these cases, manure P may be applied in excess of the crop's needs.

Repeated yearly applications of manure at rates that exceed crop requirements for P result in a buildup in soil test P. Increases in soil test P benefit crop yields until soil test P reaches a level adequate for crop production, after which there is no agronomic benefit. Unfortunately, as the fertility status of a field is improved for crop production, the source of P available for transport to surface water also increases. This is because as soil test P increases, the soluble forms of P also tend to increase. For this reason, it is very important that soil P levels be managed to optimize crop production and minimize risk to water quality.

Transport: Phosphorus can be transported by water from agricultural land in sediment (particulate) form via water erosion, and in soluble forms via runoff or erosion. In most watersheds, P transport from fields results from surface flow, although P loss via sub-surface flow can occur under certain conditions (e.g. sandy, acidic or peaty soils, or soils with tile drainage).

The form of P that is lost from the field will depend on the form of the nutrient that is applied, management practices, soil type and topography. Losses from cultivated land can take the form of either particulate or soluble P. Particulate P losses dominate when soil erosion rates are significant. When soil erosion rates are very low, such as in areas under permanent pasture, forage or forest, it is the soluble P that is predominantly released in runoff.

Connection: In order to impact surface water, the source of the P must be connected to the water body through transport mechanisms. In some fields, P is transported from one area of the field to another, but does not always reach surface watercourses.

Source, transport and connection should all be considered when developing effective on-farm management solutions that minimize the risk of P loss from agriculture to aquatic environments.

8.2.2 Nutrient Loss to Groundwater

The main nutrient concern to groundwater quality is nitrogen in the form of nitrate due to nitrate contamination of groundwater.

Nitrate

The maximum acceptable concentration of nitrate in drinking water is 10 mg/L nitrate-N (or 45 mg/L nitrate). This level has been set by Health Canada based on methemoglobinemia in human infants. Methemoglobinemia, or Blue Baby Syndrome, is currently the only health condition widely accepted as being directly related to high nitrate levels in drinking water. Ingestion of nitrate-contaminated water is not the only cause of this illness. While methemoglobinemia due to elevated nitrate levels in drinking water is recognized as a possible concern, to date, there are no reported incidences of this condition across the Prairies.

Although nitrate-N levels are very low in manure, the organic-N and ammonium-N can be converted to nitrate when manure is applied to soil. Nitrate is highly soluble in water and, unlike P, is not bound by soil particles. Therefore, as excess water moves down through the soil profile, such as after snowmelt or heavy rainfall, it can carry with it any nitrate present. The magnitude of nitrate leaching depends on the amount of nitrate in the soil, the amount of water moving through the soil, and the texture of the soil which influences the rate of percolation.

Monitoring Deep Nitrate Movement and Nitrate Recovery

In addition to routine, agronomic soil testing in the 0 to 60 cm (0 to 24 inch) range, which is used to determine fertilizer recommendations, deep soil nitrate testing can be used to determine if nitrate has leached below the root zone. Every three to five years, soil samples can be taken to a depth of 100 to 150 cm (40 to 60 inches) and tested for nitrate. This is particularly important for fields that have received manure applications that have exceeded the annual crop requirement.

If deep, leached nitrates are detected, producers should consider lowering application rates or discontinuing application, and establishing deep-rooting forage crops such as alfalfa. Such forages readily absorb nitrate-N and their deep root penetration allows them to reach greater depths than annual crops. Since manure can be applied to a standing forage crop, forages also offer an excellent opportunity to extend the window of manure application to include the summer months. Low-disturbance injectors further improve the options for liquid manure application on forage land.

Regulating Soil Nitrate Levels
Regulations in Manitoba and Alberta contain limits for nitrate levels in soils that receive manure.

- In Manitoba, the Livestock Manure and Mortalities Management Regulation includes nitrate-N limits for soils that receive manure. (*The Environment Act.* Regulation 42/98. Chapter E125 of the *Continuing Consolidation of the Statutes of Manitoba.* Queens Printer for the Province of Manitoba.)

- In Alberta, the Standards and Administration Regulation requires that a person have sufficient land for the application of manure so that the application limits for nitrate-nitrogen in Schedule 3, Table 3 are not exceeded. (*Agricultural Operation Practices Act.* Regulation 267/2001. Queens Printer for the Province of Alberta.).

8.2.3 Pathogen Loss to Surface and Groundwater

Livestock manure contains bacteria, viruses, protozoa and parasites, some of which may be pathogenic (cause disease) in humans. These pathogens can also be found in faeces from wildlife, birds, pets and humans and can enter surface water if animals have direct access to the water or through the discharge of sewage treatment systems. Manure can also enter surface water through runoff or erosion from agricultural fields or because of an accidental spill. For these reasons, drinking untreated surface water is never a recommended practice.

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 where the water table is shallow and overlain by coarsely textured material. Microbial transport to groundwater may also be a concern in areas where fractured bedrock is found at or near ground surface or in areas characterized by Karst features such as sinkholes. Manure can also reach groundwater directly through poorly constructed wells.

8.2.4 BMP's for Minimizing the Risk of Nutrient and Pathogen Loss to Surface and Groundwater

There are various practices that can be implemented to minimize the risk of nutrient and pathogen loss to surface and groundwater. These include:

Manure/Nutrient Management Planning
Develop a manure/nutrient management plan:
- test soils annually for nutrient concentrations;
- test manure for nutrient concentrations;
- match manure application rates to crop nutrient requirements;
- apply manure uniformly and at agronomic rates;
- optimize the N:P ratio of manure to more closely match the N:P ratio of crop requirements:
  - improve phosphorus use efficiency to minimize P excretion from livestock (eg. Phytase additive for swine and poultry)
  - minimize N losses during collection, handling and storage of manure
  - adopt application practices such as injection or incorporation to reduce the opportunity for ammonia volatilization

Soil Conservation
Implement practices to reduce runoff and soil erosion:

- adopt reduced tillage which allows for incorporation of manure;
- practice contour tillage; and
- maintain adequate cover on the soil surface using crop residue or cover crops.

Surface and Groundwater Protection

- establish appropriate setbacks and buffer strips between land application areas and streams, lakes, ponds and wells;
- establish settling basins where erosion rates are high;
- do not apply manure on frozen soil or snow-covered ground;
- avoid storing or applying manure in ground water recharge areas;
- establish deep rooted crops such as alfalfa to take up nitrate that is below the root zone of other crops; and
- restrict animal access to surface water.

It is also important to ensure that wells are properly protected and drinking water quality is routinely monitored. Everyone should:

- ensure proper well construction, including casing and caps; and
- test and treat, as necessary, surface and groundwater used for domestic purposes.

8.3 Odour

There are three primary sources of odour from a livestock operation:

- livestock housing;
- manure storages or treatment units; and
- lands that receive livestock manure.

Manure odours, defined by human response, are the compounded result of hundreds of different gases associated with manure decomposition and animal metabolic activities. The more offensive gases are by-products of anaerobic decomposition of manure. Liquid manure storage systems promote anaerobic decomposition, particularly deeper in the manure storage structure.

Sensitivity to odour varies greatly from one individual to another and can be affected by a number of factors. The FIDO(H) factors (Frequency, Intensity, Duration, Offensiveness and Hedonic Tone) will impact odour tolerances. Personal testimonials indicate that odour can be a source of psychological stress, and in some cases, is reported to be the source of physical symptoms including nasal irritations, headaches and nausea. To date, studies have not demonstrated significant health hazards to neighouring residents caused by manure odours; however, data from clinical and engineering studies suggest that further research is warranted.

Odours released during land application can cause nuisance. Odour emission is a function of the type and form of the manure, its exposure to the air and the length of time it is exposed. Fine manure droplets that spend more time exposed to the air will have the greatest opportunity to release manure gases.

The “big gun” manure irrigation system has the most potential for creating odour nuisance. The high-pressure spray nozzles form a fine mist of liquid manure that is projected into the air and can travel long distances with maximum air contact. For this reason, they are not recommended.

Minimizing the exposure of the manure to the air can greatly reduce odours. Injection or incorporation as soon as possible after application is very effective in reducing or eliminating odours during land application.

8.3.1 BMP's for Reducing Odour

There are various practices that can be implemented to minimize odour nuisance, including:

- considering neighbours when agitating, cleaning pens or applying manure;
- informing neighbours in advance of agitating and applying manure;
- avoiding land application on weekends if neighbours are located downwind where odour can be a nuisance;
- injecting manure into the soil whenever possible;
- using low-level application equipment if injection is not possible and incorporating the manure as soon as possible after application; and
- discontinuing the use of "big gun" manure irrigation systems;
- manure treatment options may be considered where nearby land uses may be sensitive to odours (eg. Composting).

8.4 Soil Quality

Manure plays an important role in improving soil quality, which has excellent short- and long-term benefits for agricultural crop production. The improvement in soil quality also has potential benefits for the environment such as:

- improving crop yields, thereby increasing nutrient uptake by plants; and
- improving soil structure, which increases infiltration and reduces runoff and erosion.

Manure should be properly managed to ensure that soil quality is maintained or improved. Improper manure management has the potential to negatively affect soil quality through:

- increased salinity and sodicity;
- micronutrient and metal buildup; and
- compaction.

8.4.1 Salinity and Sodicity

Salinity

Manure and soil contain the salts of ammonium, calcium, magnesium, potassium and sodium. When manure is applied to soil, varying quantities of salts are also applied depending on the characteristics of the manure. In areas of adequate precipitation and drainage, these salts are normally leached through the soil profile and do not create a problem for crop production. However, in areas with borderline saline soils and low annual precipitation, manure additions may cause a salt build-up in excess of crop tolerance.

Elevated soil salinity can impede the ability of a growing plant to absorb water from the soil, even in conditions of otherwise adequate soil moisture. Different crops have different tolerances to soil salinity. Therefore, salinization will reduce the types of crops that can be produced on salt-affected land. Crops such as peas, field beans, timothy and several clovers have a relatively low tolerance to saline conditions. Oats, flax, wheat, canola, yellow mustard, corn, crested wheat grass, intermediate wheat grass, meadow fescue and reed canary grass will tolerate moderately saline conditions.

Soil salinity can be measured in the laboratory and is expressed as electrical conductivity (EC). Manure management should take into account soil salinity, particularly in areas with borderline saline soils and low annual precipitation. The application rate of manure should not increase soil salinity to a level such that crop choices are limited.


Barley is a Moderately Salt Tolerant Crop

In Alberta, the Standards and Administration Regulation, under the Agricultural Operation Practices Act, states that the land application of manure must not increase the electrical conductivity of soil by more than one deciSeimen per metre (dS/m) and manure must not be applied to soil that has an electrical conductivity of more than 4 dS/m (Agricultural Operation Practices Act. Regulation 267/2001. Queens Printer for the Province of Alberta).

Sodicity

Soil sodicity occurs when the sodium content of the soil is too high relative to calcium and magnesium. It can adversely affect soil structure and, consequently, reduce crop yields. Soil sodicity is expressed by the Sodium Adsorption Ratio (SAR), which is calculated from the measured concentration of sodium relative to calcium and magnesium in a soil extract solution.

8.4.2 BMP's for Managing Salinity and Sodicity

In areas with borderline saline soils and low annual precipitation:

- soil salinity and sodicity should be monitored. If soil testing indicates that EC or SAR values are increasing, manure applications should be adjusted and a qualified agronomist should be consulted.

8.4.3 Micronutrients and Metals

Manure contains trace levels of micronutrients and other metals. These metals are naturally occurring in prairie soils and therefore may be present in trace levels in feeds as a result of plant uptake.

Micronutrients are required in relatively small amounts for crop and livestock production. These include cobalt (Co), copper (Cu), molybdenum (Mo) and zinc (Zn). Livestock operations that feed micronutrients (during certain phases of the production cycle) at rates that exceed nutritional requirements will produce manure that has elevated levels of those micronutrients. The level of micronutrients in the manure can be determined by manure testing.

Metals that are <u>not</u> micronutrients include cadmium (Cd), mercury (Hg), nickel (Ni) and lead (Pb). These metals are normally found in very low concentrations in manure and are generally not a concern. As with micronutrients the occurrence and concentrations of these metals can be measured through manure testing.

8.4.4 BMP's for Managing Micronutrients and Metals

Operations that feed micronutrients for growth promotion should test their manure for these metals.

8.4.5 Soil Compaction

Manure application can cause soil compaction due to the use of heavy equipment. Soil compaction takes place when soil particles are squeezed together, reducing the space available for air and water. This decrease in pore space results in reduced aeration, water availability and drainage, which inhibits root growth as well as increases the potential for surface runoff. At near-saturation moisture levels, the soil may be unable to support a load, resulting in rutting, smearing and soil mixing. These changes in the physical condition of the soil can reduce its productive capacity and sometimes require costly and difficult measures to rectify.

The degree to which soil is compacted by heavy equipment traffic depends on the size of the equipment, the tire configuration and the soil conditions at the time of application. Application equipment that can transport large amounts of manure may reduce the number of trips from the storage to the field, however a larger total axle weight can cause greater compaction with a single pass. Larger volume equipment can also cause compaction at greater depths – making remedial tillage more difficult. Soils are generally most susceptible to degradation through compaction and shearing when they are wet, such as in the spring after snowmelt or following heavy rainfall.

8.4.6 BMP's for Reducing Soil Compaction

To reduce compaction during manure application:

- Use drag-hose application systems for liquid manure to reduce traffic on the field;
- Restrict repeated vehicle traffic to specific areas of the field (e.g. designated pathways);
- Apply manure when field conditions are favourable and avoid conditions in which soils are more prone to compaction (e.g. high wetness following snowmelt or precipitation);
- Minimize the axle weight of application equipment;
- Maximize the 'footprint' (the area over which the downward pressure is exerted by the tires) through the use of:
  - Lower tire pressure
  - Larger tires
  - Radial tires
  - More tires (e.g. tandem axles)
  - Equipment with front-wheel assist, four-wheel drive
  - Track vehicles

These techniques should produce a long, narrow footprint, as opposed to a short, wide 'footprint' (e.g. dual tires).

8.5 Summary

Properly managed livestock manure provides many benefits such as improved soil quality, enhanced crop production and a reduced need for chemical fertilizer. There are numerous BMPs available to producers that optimize the benefits of manure application and, at the same time, minimize the potential for negative impacts on the environment. Producers using manure as a fertilizer and /or soil amendment should incorporate the appropriate BMPs into their farming activities in order to maintain the necessary balance between agricultural production and environmental protection.

9 Record Keeping

Manure management planning requires that the manure management information be organized and application practices well documented. This requires record keeping, which can serve a number of purposes. Proper record keeping can be used to demonstrate due diligence in manure management. In certain jurisdictions producers are required to keep on-farm records. For example, in Alberta these requirements are documented in the Agricultural Operation Practices Act (SA 2002). Queen's Printer for the Province of Alberta. Producers should check with their local departments of agriculture to determine if there are any requirements for mandatory record keeping.

Record keeping improves producers' ability to manage manure in a way that maximizes its economic benefit while minimizing the environmental risk. For example, soil test reports allow the nutrient status of a field to be tracked over time. If an unexpected shift in soil test values is noticed, the manure management plan can be reviewed to determine the cause. Once this is known, adjustments can be made to subsequent nutrient applications.

Records should be kept for all fields that receive manure, whether they are owned by the operation or leased under a manure-spreading agreement with a neighbouring producer. Below is a checklist of the information that should be documented annually for each field that will be receiving manure:

General Field Information
- field identification (in some provinces/municipalities the legal location and ownership may be required);
- land area available for manure application (total land area minus setbacks from watercourses and neighbours and unsuitable land, etc.);
- field sketches including labels, identification of setbacks, etc., and land area for manure application.

Soil Information
- soil texture
- soil test reports (including as a minimum Nitrate, P and K)

Manure Information
- manure test report or nutrient book values (including, as a minimum, moisture content, total N, ammonium N, P, K)

Cropping Information
- crop type and anticipated yield
- nutrient requirement (from the soil test report)

Nutrient Application Information
- amount of starter/commercial fertilizer used
- manure application rate
- manure application date
- manure application method
- custom applicator information, if applicable (name/company/contact)
- weather conditions during and immediately after application

Manure Equipment Calibration Information

- capacity of spreader/tanker
- application rate of a drag hose system, if applicable
- width of spread
- time to apply a single load, if applicable
- calibrated forward speed or rate of application

For complete annual record keeping, producers should keep a summary of manure applications for the entire operation. An example of the summary sheet can be found in **Appendix G.** The summary records the legal description, the field area, the manure application rate, and the total volume applied for each field.

A-G Appendices

Unit Conversion Table

Length	Approximate Conversion Factor	
centimetre (cm)	x 0.39	inches
metre (m)	x 3.28	feet
kilometre (km)	x 0.62	mile
Area		
square metre (m^2)	x 10.76	square feet (ft^2)
hectare (ha)	x 2.5	acres
hectare (ha)	x 10,000	square metres (m^2)
square kilometre	x 0.3861	square mile
acre	x 43,560	square feet (ft^2)
Volume		
US gallon	x 0.83	imperial gallon
litre (L)	x 0.035	cubic feet
	x 0.22	imperial gallon
cubic metre (m^3)	x 35.31	cubic feet
	x 1.31	cubic yard
	x 220	imperial gallon
	x 1,000	litres
cubic foot	x 6.24	imperial gallon
Weight		
kilogram (kg)	x 2.2	pound
tonne (t)	x 1,000	kilogram
short ton	x 0.91	tonne (t)
short ton	x 2,000	pound
Agricultural		
kilograms per hectare (kg/ha)	x 0.89	pounds per acre
kilograms per tonne (kg/t)	x 2	pounds per ton
kilograms per 1,000 litres (kg/1,000 L)	x 10	pounds per 1,000 gallons
tonnes per hectare (t/ha)	x 0.45	tons per acre
litres per hectare (L/ha)	x 0.089	imperial gallons per acre
litres per acre (L/ac)	x 0.22	imperial gallons per acre
Fertilizer		
Phosphorus (P)	x 2.3	P_20_5
Potassium (K)	x 1.2	K_20

Quick Look-up Conversion Table

Conversions for Solid Manure Samples

Dry weight to:	Wet weight	dry-weight value x (1 - (% moisture/100))
Percentage to:	kg/tonne	value (%) x 10
Percentage to:	lb/ton	value (%) x 20
kg/tonne to:	lb/ton	value (kg/tonne) x 2
mg/kg to:	kg/tonne	value (mg/kg)/1,000

Conversions for Liquid Manure Samples

Dry weight to:	Wet weight	dry-weight value x (1 - (% moisture/100))
Percentage to:	kg/m^3	value (%) x 10
kg/m^3 to:	kg/1,000 litres	kg/m^3 = kg/1,000 litres
Percentage to:	lb/1,000 gallons	value (%) x 100
kg/1,000 litres to:	lb/1,000 gallons	value (kg/1,000 litres) x 10
mg/L to:	kg/1,000 L	value (mg/kg)/1,000
What is ppm?	ppm = mg/kg = g/g ppm = mg/L (assuming the density of water)	
L/ha	gal/ac	value (L/ha) / 11.23

Worksheet for Calculating Manure Application Rates: Metric Calculations

- liquid manure application rates are expressed as litres per hectare (L/ha)
- solid and semi-solid manure application rates can be expressed in tonnes per hectare (tonne/ha)

Liquid Manure Application Rate Calculation Worksheet (Metric Units)					
Line #			***Notes in Appendix D**		
1	**Field ID:**		**Crop:**		
2			**Target Yield**		kg/ha
	Step 1 - Soil Test Data: See Laboratory Report				
	Recommended nutrient rate				
3	N	A			kg/ha
4	P_2O_5	B			kg/ha
	Step 2 - Manure Test Data				
5	Total Nitrogen	C			kg/1000L
6	Ammonium Nitrogen	D			kg/1000L
7	Organic Nitrogen (line 5 - line 6)				kg/1000L
8	Phosphorus	E			kg/1000L
9	P_2O_5 (line 8 x 2.3)				kg/1000L
	Step 3 - Amount of manure nutrient available to crop:				
10	Method of application	F			
11	Anticipated weather conditions during spreading	G			
12	Expected volatilization loss (%)	H			
13	Available organic N (line 7 x 25%)				kg/1000L
14	Ammonium nitrogen available (line 6 x [100 - line 12]%				kg/1000L
15	Total available nitrogen (line 13 + line 14)				kg/1000L
16	Total available P_2O_5 (line 9 x 50%)	I			kg/1000L
	Step 4 - Application rate based on N requirements				
17	Nitrogen based application rate (line 3 ÷ line 15 x 1000)	J			litres/ha
18	Amount of available P_2O_5 applied (line 17 ÷ 1000 x line 16)				kg/ha
20	P_2O_5 application check (line 18 ÷ line 4) x 100 (see notes)	K			%
21	Phosphorus based application rate (line 4 ÷ line 16 x 1000)	L			kg/ha
22	Amount of available N applied (line 21 ÷ 1000 x line 15)	M			kg/ha
23	Additional N required (line 3 - line 22)				kg/ha
24	**Step 5 - Select a rate: N or P based** (line 17 or 20)				litres/ha

Worksheet for Calculating Manure Application Rates: Metric Calculations Continued

Solid Manure Application Rate Calculation Worksheet (Metric Units)					
Line #			***Notes in Appendix D**		
1	**Field ID:**		**Crop:**		
2			**Target Yield**		kg/ha
	Step 1 - Soil Test Data: See Laboratory Report				
	Recommended nutrient rate				
3	N	A			kg/ha
4	P_2O_5	B			kg/ha
	Step 2 - Manure Test Data				
5	Total Nitrogen	C			kg/tonne
6	Ammonium Nitrogen	D			kg/tonne
7	Organic Nitrogen (line 5 - line 6)				kg/tonne
8	Phosphorus	E			kg/tonne
9	P_2O_5 (line 8 x 2.3)				kg/tonne
	Step 3 - Amount of manure nutrient available to crop				
10	Method of application	F			
11	Anticipated weather conditions during spreading	G			
12	Expected volatilization loss (%)	H			
13	Available organic N (line 7 x 25%)				kg/tonne
14	Ammonium nitrogen available (line 6 x [100 - line 12]%				kg/tonne
15	Total available nitrogen (line 13 + line 14)				kg/tonne
16	Total available P_2O_5 (line 9 x 50%)	I			kg/tonne
	Step 4 - Application rate based on N requirements				
17	Nitrogen based application rate (line 3 ÷ line 15)	J			tonnes/ha
18	Amount of available P_2O_5 applied (line 17 x line 16)				kg/ha
20	P_2O_5 application check (line 18 ÷ line 4) x 100 (see notes)	K			%
21	Phosphorus based application rate (line 4 ÷ line 16)	L			tonnes/ha
22	Amount of N applied (line 21 x line 15)	M			kg/ha
23	Additional N required (line 3 - line 22)				kg/ha
24	**Step 5 - Select a rate: N or P based** (line 17 or line 21)				tonnes/ha

Worksheet for Calculating Manure Application Rates: Imperial Calculations

Appendix C

- liquid manure application rates are expressed as gallons per acre (gal/ac)
- solid and semi-solid manure application rates can be expressed in ton per acre (ton/ac)

Liquid Manure Application Rate Calculation Worksheet (Imperial Units)					
Line #			***Notes in Appendix D**		
1	**Field ID:**		**Crop:**		
2			**Target Yield**		bu/ac
	Step 1 - Soil Test Data: See Laboratory Report				
	Recommended nutrient rate				
3	N	A			lb/ac
4	P_2O_5	B			lb/ac
	Step 2 - Manure Test Data				
5	Total Nitrogen	C			lb/1000 gal
6	Ammonium Nitrogen	D			lb/1000 gal
7	Organic Nitrogen (line 5 - line 6)				lb/1000 gal
8	Phosphorus	E			lb/1000 gal
9	P_2O_5 (line 8 x 2.3)				lb/1000 gal
	Step 3 - Amount of manure nutrient available to crop				
10	Method of application	F			
11	Anticipated weather conditions during spreading	G			
12	Expected volatilization loss (%)	H			
13	Available organic N (line 7 x 25%)				lb/1000 gal
14	Ammonium nitrogen available (line 6 x [100 - line 12]%				lb/1000 gal
15	Total available nitrogen (line 13 + line 14)				lb/1000 gal
16	Total available P_2O_5 (line 9 x 50%)	I			lb/1000 gal
	Step 4 - Application rate based on N requirements				
17	Nitrogen based application rate (line 3 ÷ line 15 x 1000)	J			gal/ac
18	Amount of available P_2O_5 applied (line 17 ÷ 1000 x line 16)				lb/ac
20	P_2O_5 application check (line 18 ÷ line 4) x 100 (see notes)	K			
21	Phosphorus based application rate (line 4 ÷ line 16 x 1000)	L			gal/ac
22	Amount of available N applied (line 21 ÷ 1000 x line 15)	M			lb/ac
23	Additional N required (line 3 - line 22)				lb/ac
24	**Step 5 - Select a rate: N or P based** (line 17 or 21)				gal/ac

Worksheet for Calculating Manure Application Rates: Imperial Calculations Continued

Solid Manure Application Rate Calculation Worksheet (Imperial Units)					
Line #			*Notes in Appendix D		
1	**Field ID:**		**Crop:**		
2			**Target Yield**		bu/ac
	Step 1 - Soil Test Data: See Laboratory Report				
	Recommended nutrient rate				
3	N	A			lb/ac
4	P_2O_5	B			lb/ac
	Step 2 - Manure Test Data				
5	Total Nitrogen	C			lb/ton
6	Ammonium Nitrogen	D			lb/ton
7	Organic Nitrogen (line 5 - line 6)				lb/ton
8	Phosphorus	E			lb/ton
9	P_2O_5 (line 8 x 2.3)				lb/ton
	Step 3 - Amount of manure nutrient available to crop				
10	Method of application	F			
11	Anticipated weather conditions during spreading	G			
12	Expected volatilization loss (%)	H			
13	Available organic N (line 7 x 25%)				lb/ton
14	Ammonium nitrogen available (line 6 x [100 - line 12]%				lb/ton
15	Total available nitrogen (line 13 + line 14)				lb/ton
16	Total available P_2O_5 (line 9 x 50%)	I			lb/ton
	Step 4 - Application rate based on N requirements				
17	Nitrogen based application rate (line 3 ÷ line 15)	J			ton/ac
18	Amount of available P_2O_5 applied (line 17 x line 16)				lb/ac
20	P_2O_5 application check (line 18 ÷ line 4) x 100 (see notes)	K			%
21	Phosphorus based application rate (line 4 ÷ line 16)	L			ton/ac
22	Amount of N applied (line 21 x line 15)	M			lb/ac
23	Additional N required (line 3 - line 22)				lb/ac
24	**Step 5 - Select a rate: N or P based** (line 17 or 21)				ton/ac

Notes for Liquid and Solid Manure Application Rate Calculation Worksheets

These notes are provided to assist in the completion of the Manure Application Rate Calculation Worksheets that appear on the previous pages. For help refer to the line number or letter in the worksheets.

A. [Line 3] Enter the amount of N to be applied as recommended by the soil test

B. [Line 4] Enter the amount of P_2O_5 to be applied as recommended by the soil test

C. [Line 5] Enter the total amount of total N in the manure from the manure analysis.
Total nitrogen is often measured as Total Kjeldahl Nitrogen (TKN)
For liquid manure: Example: lab test says total N = 0.30%
wet % x 100 = lbs/1,000 gallons N = 0.30 x 100 = 30 lb/1,000 gal
wet % x 10 = kg/1,000 liters N = 0.30 x 10 = 3.0 kg/1,000 L

For solid manure: Example: lab test says total N = 0.4%
wet % x 20 = lb/ton N = 0.40 x 20 = 8 lb/ton
wet % x 10 = kg/tonne N = 0.40 x 10 = 4 kg/tonne

D. [Line 6] Enter the amount of ammonium N (NH_4) from the manure analysis (this is the nitrogen that is immediately available).

E. [Line 8] Enter the total elemental P from the manure analysis
For liquid manure: Example: lab test says total P = 0.09%.
wet % x 100 = lbs/1,000 gallons P = 0.09 x 100 = 9 lb/1,000 gal
wet % x 10 = kg/1,000 liters P = 0.09 x 10 = 0.9 kg/1,000 L

For solid manure: Example: lab test says total P = 0.2%
wet % x 20 = lbs/ton P = 0.20 x 20 = 4 lb/ton
wet % x 10 = kg/tonne P = 0.20 x 10 = 2 kg/tonne
To convert Total P to P_20_5 Total P x 2.3

F. [Line 10] Volatilization occurs when ammonium is converted to ammonia gas. Losses vary with different application methods (e.g. injected, surface applied/incorporated, irrigated).

G. [Line 11] Indicate anticipated weather conditions.

H. [Line 12] Enter the estimated volatilization losses (%) based on the weather conditions at application and the time to incorporation.

Volatilization losses (%) associated with different application methods and weather conditions

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

Manitoba Agriculture and Food, 2000

Notes for Liquid and Solid Manure Application Rate Calculation Worksheets Continued

I. [Line 16] Phosphorus in manure comes in two forms: organic phosphorus (released after decomposition) and inorganic phosphorus (readily available). Approximately 50% of the equivalent P_2O_5 is considered to be available within a growing season.

J. **Liquid Manure**
[Line 17] The nitrogen-based application rate is calculated by taking the nitrogen requirement as recommended in the soil test (Line 3) and dividing by the total available nitrogen in the manure and multiplying by 1,000. This will give you the application rate in L/ha or imperial gal/acre.

Solid Manure
[Line 17] The nitrogen-based application rate is calculated by taking the nitrogen requirement as recommended in the soil test (Line 3) and dividing by the total available N in the manure (Line 15) will give you an application rate in tonne/ha or ton/ac.

K. [Line 20] Basing your application rate on nitrogen may result in an application of phosphorus that exceeds crop requirements. Phosphorus should be monitored annually.

a) If the application rate of P_2O_5 is less than the recommendation in the soil test, supplement with commercial fertilizer.

b) If the amount of P_2O_5 exceeds the crop removal of P_2O_5 and the soil test P levels are already very high, producers may wish to consider an application rate based on phosphorus instead of nitrogen.

c) An appropriate rate of starter commercial phosphorus placed with the seed is recommended.

L. **Liquid Manure**
[Line 21] The phosphorus-based application rate is calculated by taking the P_2O_5 requirement as recommended in the soil test (Line 4) and dividing by the total available P_2O_5 in the manure (Line 16) and multiplying by 1,000. This will give you an application rate in L/ha or gal/acre. When basing your application rate on phosphorus, you need to next calculate the applied available nitrogen (N) and determine the additional N requirement by subtracting the applied N from the crop requirement (Line 3).

Solid Manure
(Line 21) The phosphorus-based application rate is calculated by taking the P_2O_5 requirement as recommended in the soil test (Line 4) and dividing by the total available P_2O_5 in the manure (Line 16). This will give you an application rate in tonne/hectare or ton/acre. When basing your application rate on phosphorus, you need to next calculate the applied avaialble nitrogen (N) and determine the additional N requirement by subtracting the applied N from the crop requirement (Line 3).

M. [Line 22] A check is built into the calculation to determine if the amount of nitrogen applied is meeting crop requirements. If the amount of nitrogen is less than the recommendation in the soil test (Line 3), producers may wish to supplement with commercial fertilizer.

Below are Imperial equivalents of the metric calculations presented in Chapter 7.

Liquid Manure Tankers

To determine the volume that will be applied for each load of a liquid tanker, first obtain the manufacturer's rated volume. The actual volume will often be less than the rated volume due to foaming and splashing. Ninety per cent of the rated volume will be a good approximation of the actual volume in each load.

Note: Calculators with only eight digits may be unable to complete the calculations as they are presented. Dividing the top and bottom of the equation by 1,000 prior to doing the calculation will address this problem.

- **Calculate an application rate, using the actual tanker volume, emptying time, ground speed and spread width:**

$$\text{Application Rate (gal/ac)} = \frac{\text{Actual Tanker Volume (gal)} \times 29{,}700}{\text{Emptying Time (s)} \times \text{Ground Speed (mph)} \times \text{Spread Width (ft)}}$$

Example: If the manufacturer's rated volume for a tanker is 4,400 gal, emptying time is 7 minutes (420 s), ground speed is 3.5 mph and the spread width is 23 ft., the application rate is calculated to be:

$$\text{Application Rate} = \frac{(4{,}400 \times 90\%) \times 29.700}{420 \times 3.5 \times 23} = 3{,}480 \text{ gal/ac}$$

- **Adjust the ground speed to achieve a target application rate using the actual tanker volume, emptying time, target application rate and spread width.**

$$\text{Ground Speed (mph)} = \frac{\text{Actual Tanker Volume (gal)} \times 29{,}700}{\text{Emptying Time (s)} \times \text{Application Rate (gal/ac)} \times \text{Spread Width (ft)}}$$

Example: If the manufacturer's rated volume for a tanker is 4,400 gal, emptying time is 7 minutes and the spread width is 23 ft., to achieve a target application rate of 5,300 gal/ac the appropriate ground speed is calculated to be:

$$\text{Ground Speed} = \frac{(4{,}400 \times 90\%) \times 29{,}700}{420 \times 5{,}300 \times 23} = 2.3 \text{ mph}$$

- **Calculate an application rate, using the actual tanker volume, spread width and spread length.**

$$\text{Application Rate (gal/ac)} = \frac{\text{Actual Tanker Volume (gal)} \times 43{,}560}{\text{Spread Width (ft)} \times \text{Spread Length (ft)}}$$

Example: If it takes two loads with a 4,400 gal tanker (manufacturer's rating) to cover a 2,600 ft length of field with a 23 ft width of spread, the calculated application rate is:

$$\text{Application Rate} = \frac{(4{,}400 \times 90\%) \times 2 \times 43{,}560}{23 \times 2{,}600} = 5{,}770 \text{ gal/ac}$$

Drag Hose System

- **Calculate an application rate using the flow rate,g round speed and spread width:**

$$\text{Application Rate (gal/ac)} = \frac{\text{Flow Rate (gal/h)} \times 8.25}{\text{Ground Speed (mph)} \times \text{Spread Width (ft)}}$$

Example: If the flow meter indicates a pumping rate of 49,500 gal/h, the ground speed is 3.5 mph and the spread width is 18 ft, the application rate is calculated to be:

$$\text{Application Rate} = \frac{49{,}500 \times 8.25}{3.5 \times 18} = 6{,}480 \text{ gal/ac}$$

- **Adjust the ground speed to achieve a target application rate using the flow rate, target application rate and spread width.**

$$\text{Ground Speed (mph)} = \frac{\text{Flow Rate (gal/h)} \times 8.25}{\text{Application Rate (gal/ac)} \times \text{Spread Width (ft)}}$$

Example: If the flow meter indicates a pumping rate of 49,500 gal/h and the spread width is 18 ft, a target application rate of 9,100 gal/ac is achieved with a ground speed calculated to be:

$$\text{Ground Speed} = \frac{49{,}500 \times 8.25}{9{,}100 \times 18} = 2.5 \text{ mph}$$

Calibrating Liquid Manure Applicators: Imperial Calculations Continued

- **Calculate your application rate with a drag hose system**

$$\text{Application Rate (gal/acre)} = \frac{\text{Flow rate (gal/h)} \times 8.25}{\text{Ground Speed (mph)} \times \text{Spread Width (ft)}}$$

Example: If your flow meter said you were pumping 60,000 gallons per hour, you have a ground speed of 3.5 mph and a 12 ft spread width, your application width would be:

$$\text{Application Rate} = \frac{60{,}000 \times 8.25}{3.5 \times 12} = 11{,}790 \text{ gal/ac}$$

- **Calculate your ground speed for a drag hose system**

$$\text{Ground Speed (mph)} = \frac{\text{Flow rate (gal/h)} \times 8.25}{\text{Application Rate (gal/acre)} \times \text{Spread Width (ft)}}$$

Example: If your flow meter said you were pumping 60,000 gallons per hour, you had a 12 ft spread width, and you wanted an application rate of 7,000 gallons per acre, your desired ground speed would be:

$$\text{Ground Speed} = \frac{60{,}000 \times 8.25}{7{,}000 \times 12} = 5.9 \text{ mph}$$

Calibrating Solid Manure Spreaders: Imperial Calculations

Solid manure spreaders are usually rated in cubic feet or bushels, and there can be struck load and heaped load capacities. A struck load is a load that is level with the top of the box, and a heaped load is heaped as much as the box will hold. Since the box will probably be heaped as much as possible when hauling manure, the heaped capacity is the most useful value.

Although the spreader boxes have a volume rating, application rates are usually expressed as weight (i.e. in tons) per unit area (i.e. acre). If truck scales are available, determine the weight of manure in a full load by finding the weight of the manure spreader empty and then full. The weight of the manure is the difference between the two.

- **Calculate an application rate using the net weight per load, the spread width and the spread length for a given load.**

$$\text{Application Rate (tons/ac)} = \frac{\text{Net Weight per Load (tons)} \times 43{,}560}{\text{Spread Width (ft)} \times \text{Spread Length (ft)}}$$

Example: If the net weight per load is 4 tons, the spread width is 10 ft and the spread length is 1,000 ft, the application rate is calculated to be:

$$\text{Application Rate} = \frac{4 \times 43{,}560}{10 \times 1{,}000} = 17.4 \text{ tons/ac}$$

If truck scales are not available, the weight of the manure in a full load must be calculated from the known volume and an estimated density because:

Density = Weight/Volume
and therefore
Weight = Density x Volume

To determine the density of the manure:

1. Get a pail of known volume in feet (cu.ft). If the volume of the pail is in gallons, use the conversion table in **Appendix A** to convert to cubic feet.
2. Fill the pail with a typical sample of manure, and pack it in the pail to a density similar to that in the spreader box.
3. Weigh the pail full and then empty the manure and weigh the pail empty.
4. For the weight of the manure, take the difference between the full pail weight and the empty pail weight. [Manure Weight = Full Pail Weight – Empty Pail Weight]
5. Repeat steps 2 to 4 three times to obtain three manure weights.
6. Take the average of the three manure weights.
7. Take the average manure weight (in lb) and divide by the pail volume (in cu.ft) to get the density of the manure. [Density = Weight/Volume]

- **Calculate the manure density:**

Density = Weight/Volume

Example: If a 0.67 cu.ft pail weighed 2 lb empty and 18 lb (on average) full, the density would be:

$$\text{Density} = \text{Weight/Volume} = \frac{(18\text{-}2)\ \text{lb}}{0.67\ \text{cu. ft.}} = 24\ \text{lb/cu. ft}$$

- **Calculate an application rate using the spreader box volume, manure density, spread width and spread length.**

$$\text{Application Rate (tons/ac)} = \frac{\text{Box Volume (cu.ft) x Manure Density (lb/cu.ft) x 21.78}}{\text{Spread Width (ft) x Spread Length (ft)}}$$

Example: If the box volume of a spreader is 280 cu.ft, the manure density is 24 lb/cu.ft, the spread width is 10 ft and the spread length is 575 ft, the application rate is calculated to be:

$$\text{Application Rate} = \frac{280 \text{ x } 24 \text{ x } 21.78}{10 \text{ x } 575} = 25.5 \text{ tons/ac}$$

- **Calculate an application rate using the spreader box volume, manure density, emptying time, ground speed and spread width.**

$$\text{Application Rate (tons/ac)} = \frac{\text{Box Volume (cu.ft) x Manure Density (lb/cu.ft) x 14.85}}{\text{Emptying Time (s) x Ground Speed (mph) x Spread Width (ft)}}$$

Example: If the box volume of a spreader is 280 cu.ft, the manure density is 24 lb/cu.ft, the emptying time is 70 s, the ground speed is 5 mph and the spread width is 10 ft, the aplication rate is calculated to be:

$$\text{Application Rate} = \frac{280 \text{ x } 24 \text{ x } 14.85}{70 \text{ x } 5 \text{ x } 10} = 28.5 \text{ tons/ac}$$

- **Adjust the ground speed to achieve a target application rate using the spreader box volume, manure density, emptying time, target application rate and spread width.**

$$\text{Ground Speed (mph)} = \frac{\text{Box Volume (cu.ft)} \times \text{Manure Density (lb/cu.ft)} \times 14.85}{\text{Emptying Time (s)} \times \text{Application Rate (tons/ac)} \times \text{Spread Width (ft)}}$$

Example: If the box volume of a spreader is 280 cu.ft, the manure density is 24 lb/cu.ft, the emptying time is 70 s and the spread width is 10 ft, to achieve a target application rate of 24 tons/ac the required ground speed is calculated to be:

$$\text{Ground Speed} = \frac{280 \times 24 \times 14.85}{70 \times 24 \times 10} = 6 \text{ mph}$$

Alternatively, an application rate can be calculated without knowing the manure density. Instead, the rate is estimated based on the measured weight of manure spread over a small, known area. In the field, the manure spreader passes over a sheet of plastic cut to specific dimensions (eg. 3 ft x 3 ft). The manure on the plastic sheet is picked up with the sheet and its weight determined using a scale. These steps are repeated several times so that an average application rate can be determined.

- **Calculate an application rate using the weight of manure and sheet area.**

$$\text{Application Rate (tons/ac)} = \frac{\text{Net Weight of Manure (lb)} \times 21.78}{\text{Sheet Area (ft}^2\text{)}}$$

Example: If the net weight of manure on a 3 ft x 3 ft plastic sheet is 15 lb, the application rate is calculated to be:

$$\text{Application Rate} = \frac{15 \times 21.78}{9} = 36.3 \text{ tons/ac}$$

Annual Manure Management Summary					
Crop Year	Total volume or weight of manure on farm				
Field (legal description)	Hectares/ Acres	Crop	Manure Rate	Volume or Weight Required	Volume or Weight of Manure Remaining