Land Application and Handling of Manure

J.J. Schoenau and B. Assefa
Department of Soil Science
University of Saskatchewan

Science to
Social Issues

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1

Effects of Manure on Soil and Crops

Manure is a useful soil amendment that can serve as a low-cost source of organic fertilizer for crop production and as a soil conditioner that may improve the chemical and physical conditions of the soil (Campbell et al., 1986; Freeze and Sommerfeldt, 1985; Sommerfeldt et al., 1988; Hillel, 1980). However, this remains realistic only as long as manure is managed properly. Unrestricted repeated applications of large volumes of manure might deteriorate the quality of soils and reduce crop production (Chang et al., 1990; Larson, 1991).

1.1 Soils

The effect of manure on soils is manifold. It can increase nutrient availability, and alter chemical properties of the soil such as salinity, sodicity, pH, and organic matter as well as physical properties of the soil such as bulk density, aggregation, aggregate stability, crust strength, and water infiltration.

1.1.1 Nutrient availability, loading and losses

The use of manure or compost results in qualitative and quantitative differences in the transformation of nutrients in the soil. This affects nutrient availability to crops, either directly by contributing to the nutrient pool or indirectly by influencing the soil chemical and physical environment (Egrinya et al., 2001). If manure is applied according to soil tests and crop nutrient requirement, it can optimize the availability of the nutrients in the soil. Manure application also needs to be done using the appropriate method. Unnecessary nutrient loading and losses can occur following over-application and not using the appropriate method of manure application. For example, Meek et al. (1982) reported that high rates (180 $t \cdot ha^{-1}$ every two years over a nine-year period of time) of cattle manure applications to field plots of a calcareous Holtville silty clay soil in an irrigated desert region in California led to large losses of N, increased levels of K and increased availability of P.

Nutrient availability

The availability to plants of nutrients, particularly N, from applied manure can be influenced by the forms of the nutrients contained in the manure, and methods and times of application. For example, studies in Saskatchewan have shown that the total N content of hog manure from earthen storage units ranges from 15 to 50 pounds per 1000 gallons (7 to 23 kg per 4540 liters) of which 30 to 90% is ammonium (Schoenau et al., 2000). Ammonium is a form of inorganic nitrogen that is immediately available for crop use. Of the N contained in the organic form about 20 to 30% is estimated to be mineralized and become a plant-available inorganic form of N in the year of application. The same studies (Schoenau et al., 2000) reported that solid manure from cattle pens had only 10 to 20% of the total N present in the inorganic (ammonium) form. Beauchamp (1983) suggested from studies conducted in Ontario that the proportions of ammoniacal N are around 50, 75, and 10% of the total N for liquid dairy cattle, liquid poultry, and solid farmyard manures, respectively. As such the forms of N present in manure affect N availability to plants; manure with a higher content of immediately available ammonium offers greater short-term crop response.

Method and time of application may influence nutrient availability due to the varying levels of losses associated with different methods and times of application. In a study that compared liquid dairy cattle manure and N fertilizer, Beauchamp (1983) found that the availability of N from liquid dairy cattle manure that was side-dressed and not incorporated was about 33% of that from anhydrous ammonia. The N availability from liquid dairy cattle manure applied before planting and incorporated 4-5 days later was 50% of that from urea; and injected liquid dairy cattle manure at either planting or sidedress times resulted in increasing the availability of manure N to 60% of fertilizer N. This variability in N availability from the manure is attributed to different degrees of ammonia volatilization, with surface applications having high volatilization loss and leading to lower N availability (Beauchamp, 1983, Safley et al., 1980).

Based on his findings, Beauchamp (1983) developed a flow chart showing the contribution of liquid dairy cattle manure N when applied to soil to N available to a crop (Figure 1). With the assumption that manure would be applied and only incorporated after 1 week in the spring, he suggested that approximately one-half of the total N in the manure would be available to the crop in the year of application. He also reported that the availability of the N in liquid dairy cattle manure was about one-half that of the fertilizer N.

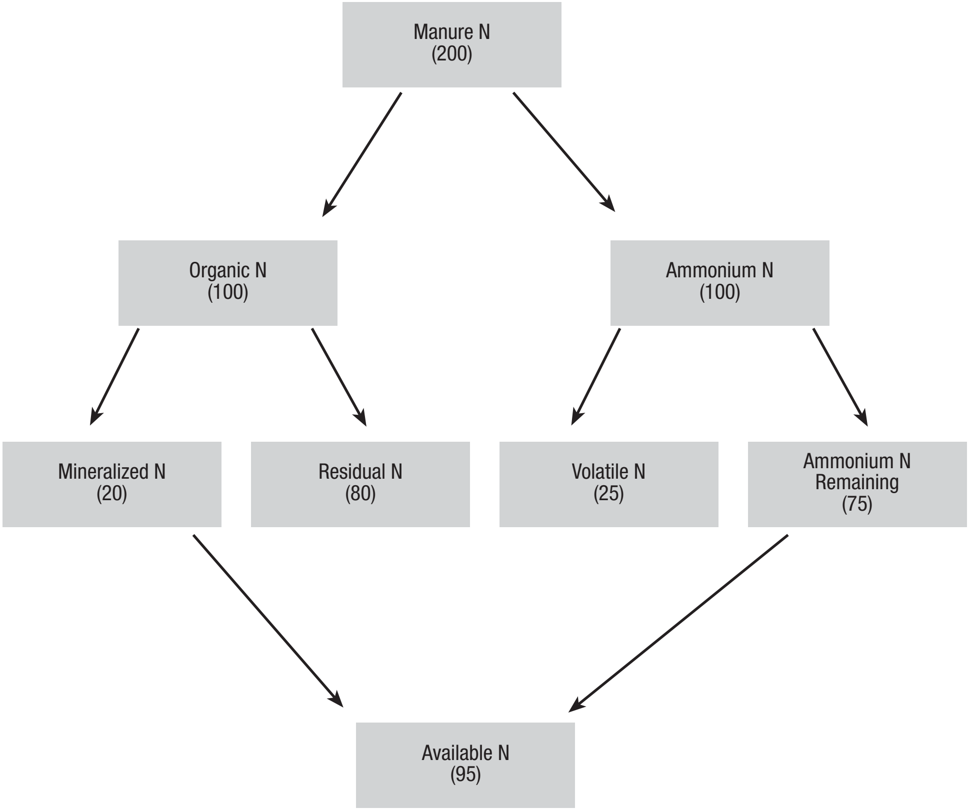


Figure 1. Flow chart showing the contribution of manure N when applied to soil to N available to a crop. The numbers in parenthesis indicate units of N. Source: After Beauchamp, 1983.

Likewise, Schoenau et al. (2000) reported the availability of N from liquid hog manure effluent (of which about 50% of the N was present as ammonium) was in the range of 60 to 70% of that observed for urea applied at equivalent rates of added N in the field in east-central Saskatchewan.

Aarnink (1997) developed another example of nitrogen flow as related to pigs, starting in the feed up until land application (Figure 2). It is evident from Figure 2 that some of the volatile compounds are emitted immediately and others are emitted within varying times after excretion. For example, the immediately emitted compounds could come from some odorous volatile components, short-chain volatile fatty acids, and other volatile carbon-nitrogen and sulfur-containing compounds from microbial fermentation in the gastrointestinal tract (Kornegay and Verstegen, 2001). Assuming 50% efficiency of N availability to the crop from soil-applied manure N (Beauchamp, 1983), only about 11 g N of the 21 g N applied in the slurry in Figure 2 would be used by the crop in the first year.

Soil analysis is one of the various techniques by which nutrient availability in soils can be determined (Mengel et al., 2001). Cooper et al. (1984) reported the presence of a considerable amount of residual N in a study involving average dry weights (32, 61, and 121 $Mg \cdot ha^{-1}$) of dairy cattle manure applied annually to a Davidson clay loam soil in Virginia for five years. They found that the total N remaining in the soil profile 7 years after the initiation of the experiment ranged from 42 to 63% of the total N applied as manure during the 5-year period. Chang et al. (1991) observed increased levels of soil total N due to 11 annual applications of solid cattle feedlot manure in southern Alberta. The rates included: 30, 60, and 90 $Mg \cdot ha^{-1}$ and 60, 120, and 180 $Mg \cdot ha^{-1}$ (wet wt.) to non-irrigated and irrigated clay loam soil, respectively. In the 0-30 cm depth, the total N content of the soil was increased from about 6 Mg·ha^{-1} to 8.2 Mg·ha^{-1} by the 90 Mg·ha^{-1} manure application to the non-irrigated soil, and from 6 to 12 Mg·ha^{-1} by the 180 Mg·ha^{-1} manure application to the irrigated soil.

Three annual applications of dairy cattle manure at varying rates of 22.5, 45, 90, 180 and 270 Mg·ha^{-1} (dry wt.) to a silty clay loam soil in Huntsville, Alabama increased the total N and NO_3 in the top 0-15 cm (Mugwira, 1979). By the fourth year, the total N content of the soil was increased by about 100% and 400% and the NO_3-N content was increased by 30% and 200% by the 45 and 270 Mg·ha^{-1} manure applications, respectively.

Several authors have reported increases in surface soil P levels following repeated feedlot and dairy cattle manure applications (Meek et al., 1982; Sutton et al., 1986; Chang et al., 1991; Tran and N'dayegamiye, 1995; Dormaar and Chang, 1995; and Eghball, 1999). In contrast, no significant increases in extractable inorganic phosphorus levels in the soil following a single manure application were observed in two study sites in east-central Saskatchewan (Schoenau et al., 1999). In a 16-week incubation experiment, soil total P was increased from 708 mg P·kg^{-1} soil to 738 mg P·kg^{-1} soil by a single liquid hog manure addition at the rate of 40 mg of total P·kg^{-1} of soil (corresponding to 400 mg of total N·kg$_{-1}$ of soil) (Qian and Schoenau, 2000a). In a separate plot experiment conducted over 12 weeks, the cumulative supply rates of available P were found to be about 15 and 20 µg·cm^{-2} higher at the rate of 40 mg P·kg^{-1} hog manure application than in the control, in a sandy loam and clay loam soil, respectively (Qian and Schoenau, 2000b).

Increased soil K supply rates due to single hog and cattle manure applications were reported in east-central Saskatchewan (Schoenau et al., 1999). Olson et al. (1998) reported that the potassium content in the top 15 cm of a medium-textured soil amended with cattle feedlot manure (four annual applications at the rate of 120 Mg·ha^{-1}) was 11 times higher than the soil with no manure addition. After four years of manure application, Pratt and Laag (1977) reported that K had moved to a depth of 90 to 120 cm below the surface in an irrigated soil.

Chang et al. (1991) reported that the accumulation in the soil of soluble SO_4 due to repeated annual cattle feedlot manure applications was variable and was smaller as compared to the effect on other parameters such as organic matter, pH and total nitrogen. They attributed this occurrence to high SO_4 content of the soil and the relatively low SO_4 content of the manure applied. Similarly, soil sulfate levels were not significantly affected by a single application of hog and cattle manure in two soils of east-central Saskatchewan (Schoenau et al., 1999). In contrast, Castellano and Dick (1988) reported increases in total S in the range of 7 to 41% in manured soils over unmanured soils.

Owing to its nature of being a source of multi nutrients, manure can also increase availability of other macro and micronutrients and contribute to plant nutrition when soil-applied. For example, Chang et al. (1991) observed increased levels of soluble Ca, Mg, Na, Cl, and Zn following 11 annual cattle feedlot manure applications. In their study, however, they did not find any changes in the copper content of the soil.

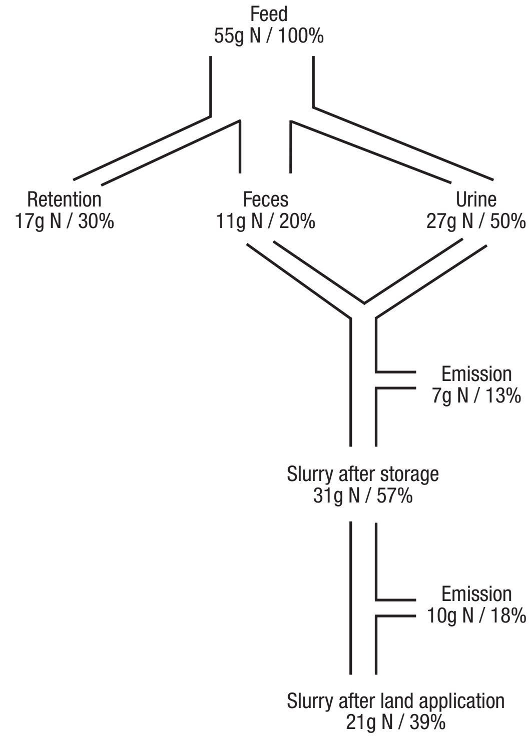


Figure 2. Nitrogen chain for growing-finishing pigs in housing with partially slatted floor and with surface land application of the slurry. The N intake is assumed to be 55 g/pig/day. Source: Adapted from Aarnink, 1997.

Loading and losses

Due to the inherent high variability in the nutrient contents and forms of manure (Schoenau, et al., 2000), there is a wide range of nutrient loading at a given rate of manure application. Also, although manure contains many nutrients, it may not provide the appropriate balance according to the relative requirements of different crops for different nutrients, and this contributes to the variability in the loading of nutrients from manure. A good example would be cattle feedlot manure that has a lower N to P ratio (4:1 to 5:1) than crops (6:1 to 8:1) (Intensive Livestock Operations Committee, 1995). Under these conditions, manure applications based on crop N requirements tend to provide P in excess of crop P requirements. If such management continues over a long time, it could result in P loading in soils and lead to an increased risk of P movement into water bodies via processes such as erosion, runoff, and leaching (Lennox et al., 1997; Sharpley et al., 1994.)

Losses of nutrients following manure application seem unavoidable but the degree varies depending on the form and method of manure application. Studies have shown manure N to be the nutrient most susceptible to loss to the atmosphere, mainly via ammonia volatilization followed by denitrification, as illustrated in Figure 3 (Bouldin et al., 1984; SAF, 1999). N can also be lost in the form of nitrate via leaching.

Stevenson et al. (1998) cited Vitosh et al. (1988) and reported that 15-30% of the N from surface applied solid feedlot manure could be lost via ammonia volatilization within a period of four days after the manure application. Sutton (1994) suggested that as much as 5% of the N, possibly even higher with high temperature, wind, and pH, could be lost through volatilization when liquid manure is broadcast and incorporated within three days after application. According to his study, this nitrogen loss would be only 0-2% if the manure was injected. Hoff et al. (1981), from a field experiment, reported that soil injection of hog manure reduced the N loss through ammonia volatilization of the proportion of NH_4-N applied to 2.5% from 12.5% when the manure was broadcast on the soil. They also observed that ammonia loss would be greater at warmer temperatures, lower humidity, higher air movement, and higher pH.

Beauchamp et al. (1982) reported that up to 33% of the surface applied ammoniacal-N in liquid dairy cattle manure was lost during a 7-day period following the time of manure application. As a result, injection is recommended to be the best method of applying liquid hog manure for the purpose of reducing odor and surface runoff while minimizing the loss of nitrogen and other valuable nutrients (Hoff et al., 1981). If manure has to be surface applied, incorporation as soon as possible after application is recommended to avoid the potentially large losses of ammoniacal-N from applied manure (Beauchamp et al.,1982). Taking several sources of information together, Beauchamp et al. (1982) generalized that 10 to 75% of the ammoniacal-N might be lost from applied manure if not incorporated within a week or so following application. They also suggested that the amount to be lost depends on factors such as ammoniacal-N concentration, rainfall, temperature, manure pH, water content and rate of application.

Increases in temperature result in greater volatile losses of N from hog manure as shown by Hoff et al. (1981). They measured NH_3-N loss at the rate of 0.1 $kg \cdot ha^{-1} \cdot h^{-1}$ when the temperature was about 0°C and 1.6 $kg \cdot ha^{-1} \cdot h^{-1}$ when the temperature was 30°C. They also found that soil and manure pH affected the rate of NH_3-N loss. In their greenhouse experiment they found that nearly 65% of the applied NH_4^+-N was lost via volatilization during a 3.5-day period following manure (pH = 7.8) application to a soil with a pH of 7.0. In their field experiment only 14% of the applied NH_4^+-N was volatilized following manure (pH = 6.4) application to a soil with a pH of 6.4 during the same amount of time. Manure application rate did not have an effect on the proportion of NH_3-N loss, but the total amount of NH_3-N loss increased with increasing rates of application. Such a potential for ammonia volatilization associated with surface application of manure without immediate incorporation puts a challenge on the utilization of manure as a nutrient source in zero till systems.

As suggested by Bouldin et al. (1984) denitrification, the reduction of nitrate to molecular N or oxides of N by microbial activity, is the other major pathway of manure N loss. Kimble et al. (1972), from laboratory studies conducted on soil profile samples, observed that potential denitrification was greater in soils from manure treated plots as compared to those that received inorganic N or no source of N. Similarly, Guenzi et al. (1978), from results of a greenhouse experiment, suggested that N loss by denitrification could occur following large amounts of manure

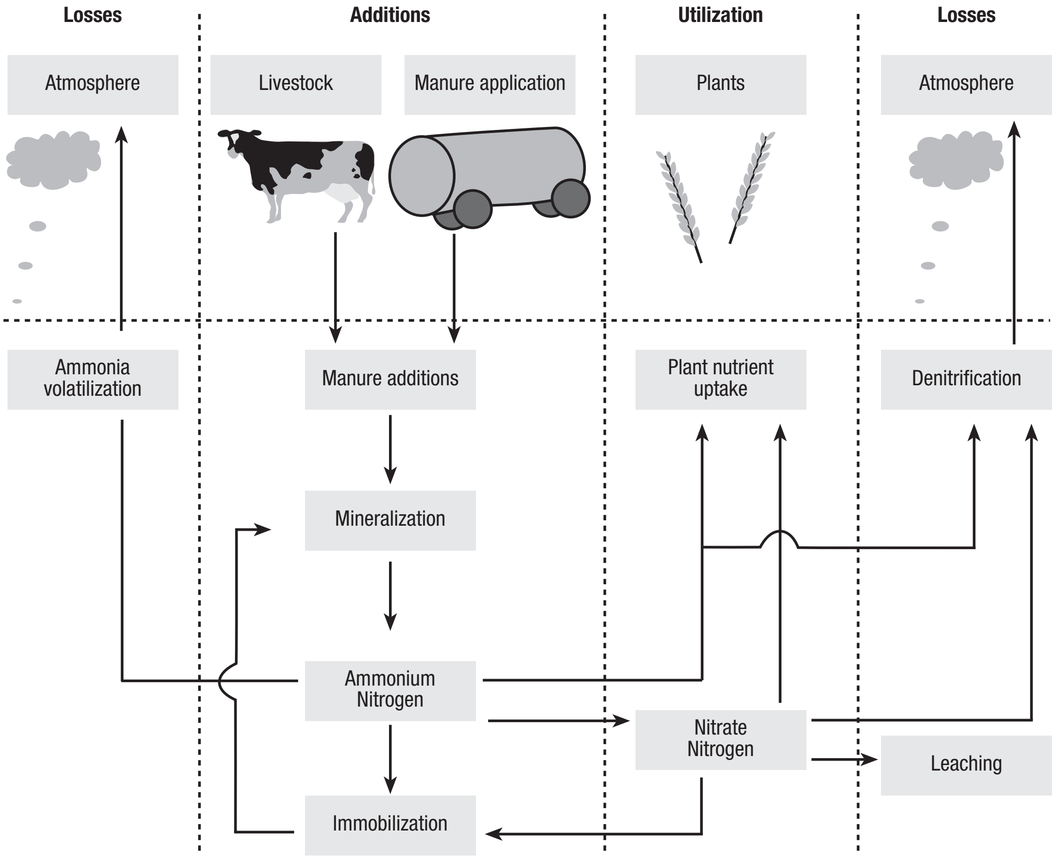


Figure 3. Nitrogen cycle. Source: Adapted from SAF, 1999.

applications to field soils and the amount of denitrification could be raised by wet weather and warm temperatures. Loro et al. (1997) investigated the intensity and duration of denitrification following manure application in the field as well as in the laboratory. From the results of their study, they indicated that both solid beef and liquid dairy cattle manure enhanced denitrification as compared to fertilizer N. The rate of denitrification was closely related to air-filled soil porosity, CO_2 production, NH_4^+ concentration, season of manure application, and soil water content. The liquid dairy cattle manure stimulated immediate denitrification whereas the solid cattle manure provided for a slower and sustained rate of denitrification.

Denitrification is a process that is controlled by O_2 supply, concentration of NO_3^- and availability of C (Tiedje, 1988). Low O_2 supply along with the presence of NO_3^- as an electron acceptor plus C substrate favour denitrifiers. Manure provides available C that stimulates respiration in nitrifying and denitrifying soil microbes. Ammonium applied with the manure would rapidly be nitrified into nitrates and becomes susceptible for denitrification. Following nitrification, the C from manure continues to stimulate microbial respiration while water from manure and perhaps from rainfall limits diffusion of O_2 in soils. Increased consumption coupled with the limited diffusion of O_2 could create the suitable conditions (anaerobic environment) required for denitrification (Loro et al., 1997). The denitrified nitrogen is eventually lost to the atmosphere as a molecular N gas or oxides of nitrogen.

Losses of N from applied manure can also occur through nitrate leaching. Although there are only small amounts of nitrate in most manures, significant amounts of nitrates can be produced from the added ammonium as well as from mineralization of organic forms of N to ammonium which is subsequently nitrified to nitrate if not used by plants. Such nitrogen in the form of nitrate is highly mobile and could be leached into the ground water, particularly under irrigated or high precipitation environments. For example, in southern Alberta, Chang and Entz (1996) investigated the long-term effects in Dark Brown Chernozemic clay loam soils of annual applications of cattle manure on nitrate N accumulation and movement. Annual applications of feedlot manure at 0, 30, 60, and 90 $Mg \cdot ha^{-1}$ and 0, 60, 120, and 180 $Mg \cdot ha^{-1}$ to nonirrigated and irrigated fields, respectively, represented zero, one, two and three times the maximum recommended rates. The results of the study indicated accumulations of nitrate in the root zone and minimal leaching loss below 1.5 m with the exception of a year under unusually high precipitation, under the nonirrigated conditions. In contrast, in the irrigated soils, significant leaching of nitrate and contamination of groundwater was observed at all rates of manure application. This led to a conclusion that even the maximum recommended rate of manure application would be too high for annual applications over the long term under the greater leaching environment in the irrigated fields.

In the prairies, owing to the generally low precipitation, infiltration into the groundwater occurs slowly. Thus, contamination of groundwater may not be observed until after many years of manure application at maximum rates. The incidence of nitrate leaching following manure application under dry land conditions on the prairies should be verified on other soils as well.

Levels of P in animal manure vary greatly and may exist both in the organic form (unavailable to plants before mineralization) and inorganic forms, a portion of which is immediately plant-available. As is the case with nitrogen, P cycles between the two forms in the soil via mineralization and immobilization processes. However, unlike nitrogen, which is highly mobile in the soil, phosphorus ions react quickly with other ions in the soil solution resulting in precipitation and adsorption to mineral colloids (Foth, 1990). Similarly, Schoenau et al. (2000) reported that in Saskatchewan, manure P tends to be readily fixed to soils by sorption and precipitation. As a result, P leaching is not a critical problem in most soils; however, P losses can occur through runoff from manured fields leading to eutrophication of nearby water bodies and the P content of surface soils directly influences the loss of P in runoff (Daniel et al., 1994).

Manures contain plant functional nutrient metals such as copper, zinc, manganese and iron, and may contain trace amounts of non-functional elements such as cadmium. Another element of interest that is non-functional to plants but required by animals is selenium. The effect of manure addition on bioavailability of metals in the soil may be direct and/or indirect. Direct effects would include increases in the amount of an element in soil due to that element being present in the manure added. An example of this is copper and zinc. The natural presence of these micronutrients in feed as well as their use as dietary supplements results in variable concentrations in manure and when added to the soil, can increase the total and bioavailable concentrations. A recent study in Saskatchewan (Qian et al., 2003) showed that three to five years of annual swine and cattle manure applications at low (~100 kg N/ha) and high (~400 kg N /ha) rates resulted in only small increases in total and bioavailable copper and zinc in surface soils at three study sites. As with phosphorus, prairie soils have a high capacity to fix metals like copper and zinc into relatively insoluble forms due to high pH, high content of calcium carbonate and high clay content. However, as fixation sites become saturated with repeated additions, more of the metal will remain in a soluble form.

Manure, like commercial fertilizer, can indirectly influence the bioavailability of a metal already present in soil in trace amounts by influencing soil pH, salinity, ion concentrations, microbial activity, root growth and mineral weathering. For example, it has been reported that as soil salinity increases, plant availability of cadmium also increases (McLaughlin et al., 1994), especially if a high level of chloride ions are present (Weggler-Beaton et al. 2000). Interactions can be complex and no published research on effects of manure addition on cadmium, arsenic and mercury on the prairies has been reported. However, studies are currently underway in Manitoba and the University of Saskatchewan on these metals as well as selenium.

Selenium is of interest because it is an element required by animals and commonly added to livestock rations but is not essential to plants. Manure would directly add selenium to the soil and is anticipated to influence the selenium content of plants grown on the soil. However, little or no information on this relationship currently exists. Plants such as canola are known to accumulate selenium, possibly because they cannot discriminate between absorbing selenium and sulfur ions (Ajwa et al., 1998).

Investigations into the impact of manure on metals in the soil-plant system have recently been initiated in Western Canada and abroad. Although some analogies and understanding can be borrowed from the many published studies on effects of municipal sewage, it is important to note that sewage contains different (usually higher) contents of heavy metals than animal manure as well as different chemical forms due to treatment processes. New approaches such as synchrotron spectroscopy show promise in providing more insight into the different chemical forms of metals in manure and their behavior in the soil.

1.1.2 Chemical composition

Several studies have been conducted to understand the effects of manure applications on soil chemical properties.

Salinity and sodicity

Eleven annual applications of cattle feedlot manure at the rate of 90 Mg·ha^{-1}· yr^{-1} increased the electrical conductivity of a soil in southern Alberta by about 6 dS·m^{-1} and the sodium adsorption ratio by about 3 mmol$^{0.5}$ (Chang et al., 1990 & 1991). Horton et al. (1981) cited by Chang et al. (1991) and Wallingford et al. (1975) reported that repeated annual applications of manure, which had high salt content, caused a build-up of soluble salts in the soils to the extent of lowering crop productivity. Pratt (1984) reported that four annual applications of solid dairy manure at an average rate of 158 Mg·ha^{-1} reduced the yields of sudangrass due to salinity. Similarly, Mathers et al. (1977) attributed the low yield of sorghum observed, following three annual solid feedlot manure applications at the rate of 67 Mg·ha^{-1}, to increased salinity resulting from the relatively higher rate as compared to 22 Mg·ha^{-1}.

In a study that was conducted in the Peace River region of Alberta, single manure application to Gray Luvisolic soils at rates as high as 176 kL·ha^{-1} (15500 gal·acre^{-1}) of hog or 185 Mg·ha^{-1} (81 tn·acre^{-1}) of cattle manure (wet basis) did not pose any significant problem of salinity (Assefa, 2002). In the same study, however, in east-central Saskatchewan, four annual applications of cattle manure at the rate of 15 Mg·ha^{-1} (7 tn·acre^{-1}) (dry basis) increased the salinity (electrical conductivity, EC) of the soil from 0.3 dS·m^{-1} to 1.6 dS·m^{-1} and increased the sodicity (sodium adsorption ratio, SAR) from 0.7 to 1.7 at one site and from 0.3 to 0.8 at another site. Similarly, four annual applications of hog manure at the rate of 75 kL·ha^{-1} (6600 gal·acre^{-1}) raised the SAR of the soil from 0.4 to 1.3.

pH and organic matter

Whalen et al. (2000), in an 8-week study conducted in the laboratory, reported an immediate increase in the pH of two acid soils (Hazelmere silt loam from Beaverlodge and Davis silt loam from Fort Vermilion, Alberta) following fresh cattle manure application. An application of 40 g (oven dry basis) manure ·kg^{-1} of soil and manure mixture increased the pH of the Beaverlodge soil from 4.8 to 6 and that of Fort Vermilion from 5.5 to 6.3. Fresh or composted animal manure applications were shown to have a similar effect of increasing soil pH in previous studies (Iyamuremye et al., 1996; Eghball, 1999).

In contrast, Chang et al. (1990 and 1991) reported a 0.3 to 0.7 units decline in pH of calcareous soils (pH 7.8) in the top 15 cm following 11 years of cattle manure applications, attributable to the nitrification of NH_4 as well as the organic acid produced during the decomposition of the organic fraction of the manure. In another study, annual applications of hog lagoon effluent for 11 years resulted in an increase or a decrease of the surface (15 cm) soil pH (5.4) depending on the application rate (King et al., 1990). The lagoon effluent was applied weekly via sprinkler irrigation to Coastal bermudagrass at low (335), medium (670), and high (1340) rates (kg N·ha^{-1}·yr^{-1}). The low and medium applications of the hog lagoon effluent increased the soil pH by 0.4 to 0.5 units whereas the high annual manure application decreased the pH of the soil by 0.3 units. Eghball (1999) proposed that changes in the pH of soils amended with cattle manure could be due to buffering from $CaCO_3$ originating from $CaCO_3$ added to cattle diets and excreted in the manure.

Whalen et al. (2000) suggested that the increase in pH of an acid soil following manure addition was only partially due to buffering from bicarbonates since they did not detect carbonate in either the manure or soils examined in their study. They proposed that compounds other than carbonates and bicarbonates, such as organic acids with carboxyl and phenolic hydroxyl groups, have important roles in buffering soil acidity and increasing the pH of acid soils amended with manure. Their conclusion was that the effects of manure on soil pH would depend on the manure source and soil characteristics.

Over the years, the organic matter content of many prairie soils has been significantly reduced by cultivation and erosion (Tiessen, et al., 1982). Since organic matter plays the role of supplying nutrients required for crop growth and production, its decline would lead to a reduced level of soil fertility and a resulting low crop production. The need for more production coupled with improvements in technology enabled the use of commercial fertilizers to make up for the discrepancy between the reduced level of nutrients in the soil and crop requirement. Commercial fertilizers, however, are only inorganic compounds targeted to supply specific nutrients, usually N, P, K, and S, which do not offer direct contribution to the restoration of organic matter content. On the other hand, organic matter from manure, besides supplying multiple nutrients to the soil, affects soil organic matter and tilth in favor of crop emergence and growth (Schoenau et al., 2000; Assefa, 2002; Campbell et al, 1986; Hoyt and Rice, 1977; Stewart, 1982; Unger and Stewart, 1974; Meek et al, 1982; Allison, 1973).

Larney et al. (2000) compared the effects of three amendments: N + P fertilizer, 5 cm top soil, and 75 $Mg \cdot ha^{-1}$ (wet wt.) cattle feedlot manure. They concluded that the manure was the best amendment for restoring eroded soils with low organic matter content. Similarly, in a long-term (18-yr) study that compared the effects of applications of cattle manure (20 $Mg \cdot ha^{-1} yr^{-1}$ wet wt.) and NPK fertilizers on the labile organic matter and its protection in water-stable aggregates in a Le Bras silt loam (Humic Gleysol) soil, Aoyama et al. (1999) found that the manure application contributed to the accumulation of macroaggregate-protected C and N, but the mineral fertilizers increased the protected-N pool only. They observed that manure application resulted in up to threefold and fourfold increases in the protected pools of C and N in the small macroaggregates (250-1000 μm) whereas the NPK fertilizers increased the pool of the macroaggregate-protected N by 2.5-fold but had no effect on the protected C. Accordingly it was concluded that long-term manure application enhances the mechanism for the protection of the labile soil organic matter provided by macroaggregates (Aoyama et al., 1999).

Sommerfeldt et al. (1988) reported that annual cattle feedlot manure applications over 11 years in southern Alberta increased the organic matter in the surface (0-15 cm) of nonirrigated and irrigated soils. In the first year, the organic matter (OM) increased from 1.83% OM to 1.9% OM at 30 $Mg \cdot ha^{-1}$ level of manure application and from 1.83% OM to 2.4% OM at 180 $Mg \cdot ha^{-1}$ of manure. In the 11th year the organic matter content had increased from 1.83% to about 2.8% in the 30 $Mg \cdot ha^{-1}$ manure treatment and to 5.43% in the 180 $Mg \cdot ha^{-1}$ manure treatment. Mathers and Stewart (1974) reported that three annual applications of cattle feedlot manure at the rate of 224 $Mg \cdot ha^{-1}$ raised the soil organic matter content from 1.5% to 3.5%.

King (2002) found in Saskatchewan that 3 years of hog manure application to forage stands (brome grass, Russian wildrye grass, alfalfa) increased the labile soil carbon levels in the top 15 cm, but not the total soil organic carbon. In another study in east-central Saskatchewan, Assefa (2002) also did not find significant increases in the total organic carbon content of Black Chernozemic soils (0-30 cm) that had received four annual applications of hog and cattle manure. The lack of significance in this case was attributed to the large sampling depth and the inherently high level of indigenous organic carbon in the Black soils.

1.1.3 Physical properties

Manure not only affects the chemical properties of soils but also the physical properties. For example, Campbell et al. (1986) reported that soils that received repeated applications of cattle manure were more friable to the feel and less compact under the foot than those of the unmanured plots. Hoyt and Rice (1977) suggested that barnyard manure, when applied to farmland, could improve soil structure. Stewart (1982) has shown that cattle manure increased soil porosity. Unger and Stewart (1974) and Meek et al. (1982) had also shown that manure increased water-holding capacity and decreased evaporation rate with increased applications.

Mathers et al. (1977) reported that cattle feedlot manure applications to soils increased water infiltration into the soils. Mathers and Stewart (1980) observed a decrease in soil bulk density and an increase in the saturated hydraulic conductivity of the soil following repeated cattle manure applications over an 11-year period. Nuttall (1970) found from a plot experiment that additions of manure decreased crust strength and increased the emergence of rapeseed *(Brassica napus L.)*.

In his study that involved two field sites in the Peace River region of Alberta and two field sites in east-central Saskatchewan, Assefa (2002) examined the effects of manure application on some selected physical properties of Gray Luvisolic and Black Chernozemic soils, respectively. His findings indicated that a single application of hog manure to the Gray Luvisolic soil at a rate of 146 $kL \cdot ha^{-1}$ (12800 $gal \cdot acre^{-1}$) increased the aggregate size of the soil from 13.3 to 20.4 mm at one site and increased the aggregate stability of the soil from 0.4 to 0.5 at the other site. Single application of cattle manure to the same soils at a rate of 103 Mg·ha^{-1} (45 tn·acre^{-1}) and 185 Mg·ha^{-1}(81 tn·acre^{-1}) (wet basis) decreased the crust strength of the soil from 820 to 390 kPa at one site and increased the aggregate size of the soil from 12.0 to 18.7 mm at the other site, respectively. Moreover, the 185 Mg·ha^{-1} cattle manure application increased the cumulative water infiltration as indicated in Figure 4.

In the same study, Assefa (2002) reported that four annual applications of hog and cattle manure to the Black Chernozemic soils decreased the bulk density and aggregate size of a sandy loam textured soil. This is in contrast to the effects of manure application to the Luvisolic soils, where a single application of manure increased the aggregate size of the soil. The decrease in aggregate size in the Black soils following the repeated manure application was attributed to some possible dispersive effects from accumulated sodium.

In addition to slow entry and movement of water through soil pores, water may flow rapidly through certain pathways such as cracks and biochannels in the soil. This process is termed preferential flow (Brady and Weil, 1999) and can allow for rapid movement of water and its constituents deep into the soil profile. As well, with preferential flow there is less contact between the soil and water, giving less opportunity for adsorption and immobilization of components contained in the water. Preferential flow can therefore increase the risk for entry of nutrients and pathogens into aquifers. Manure that is surface applied may be at greater risk of movement by preferential flow than when incorporated into the soil, as the surface components may be readily washed into the large cracks. On the Canadian prairies, large cracks develop in glacio-lacustrine (heavy clay) soils upon drying due to the shrink-swell nature of the clay minerals. When intact, these cracks can act as a conduit for rapid movement deeper into the profile. However, destruction of cracks and macropores during manure application and incorporation would be anticipated to reduce the risk of deep migration of manure constituents via preferential flow.

1.1.4 Microbial activity

Microbial activity and its associated factors are important in systems where organic materials are used as sources of fertilizer nutrients because it is the microbial turnover of soil organic matter that determines nutrient flow to crops (Cooper and Warman, 1997). Manure additions to soils also affect microbial activity in the soil. For example, Ndayegamiye and Côté (1989) reported increases in microbial activity following farmyard manure and pig slurry additions to an acidic silty loam soil. They observed that the farmyard manure had a larger effect in increasing the microbial activity than the pig slurry, which was attributed to the higher level of organic carbon in the farmyard manure than that in the pig slurry. Charles (1999) found more rapid initial decomposition of hog manure C than the cattle manure C per unit C but cattle manure sustained the increase in microbial activity over a longer time period. In general, larger pools of microbial biomass are associated with soils of higher levels of organic

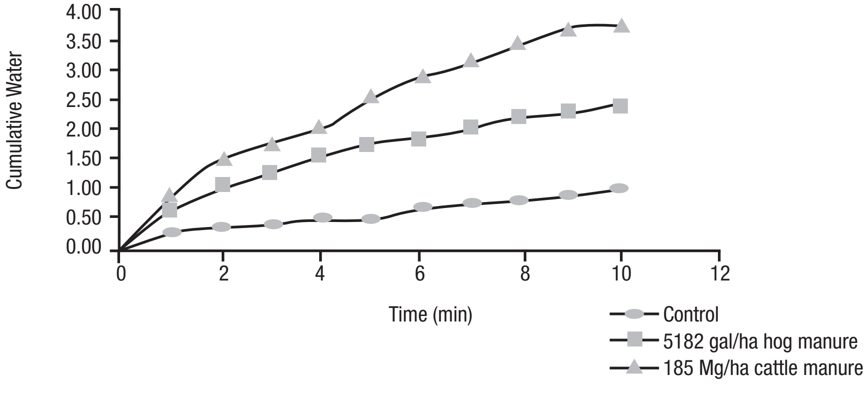


Figure 4. Plot of cumulative water infiltration versus time at the Fairview site. Source: After Assefa, 2002.

C and this, in turn, influences the size of the plant nutrient pool as well as the flux of nutrients into plants (Goyal et al., 1993).

1.2 Crop Growth and Production

Manure has been recognized throughout recorded history as an excellent soil amendment that can be used as an organic fertilizer, providing plant macro and micronutrients to improve crop production (James et al., 1996; Dormaar and Chang, 1995). Major fertilizer and trace nutrients contained in manure as well as the benefits to the soil as a conditioner, by raising the organic matter content of the soil, comprise the main value of manure for crop production (White and Safley, 1984). However, there is a major difference between animal manure and commercial fertilizers in terms of nutrient availability, in that some of the nutrients in animal manure exist in the organic form and need to be converted to inorganic forms through mineralization before being available for plant use. Hence animal manure, particularly cattle manure, is a slowly available source of plant nutrients as compared to inorganic fertilizers. Nonetheless, manure has the advantage over inorganic fertilizers of adding organic matter and multiple nutrients to the soil (Schoenau et al., 2000).

1.2.1 Nutrient concentration/uptake

Plant tissue analysis is a commonly used technique in determining nutrient availability in soils, which is based on the perception that the content of a particular nutrient in the plant is greater the higher its availability in the soil (Mengel et al., 2001). Contrary to soil analysis, tissue analysis also reflects nutrient uptake conditions. Nutrient concentrations in plant materials do not depend only on nutrient availability in the soil, but also on other factors, such as the kind of plant organ or tissue, the age of the plant, the supply of the plant with other nutrients, and the mobility of the particular nutrient within the plant. It is imperative, in light of this, that the age of the plant part under investigation be considered for the purpose of making comparisons between samples and eventual fertilizer recommendations. Chang et al. (1994) suggested higher nutrient concentrations in plant tissues might arise from yield suppression associated with high manure rates.

Several researchers have used plant material analysis to account for nutrient availability in soils as affected by the applications of different sources of fertilizer. Mataruka et al. (1993) conducted a two-year field study on a Kendaia-Lima silt loam soil in New York that included manure and fertilizer applications. They reported that the N concentration in the whole-plant of corn at the V6 growth stage (Ritchie and Hanway, 1982) ranged from 24.7 to 33.3 $g \cdot kg^{-1}$. This range is lower than the critical range (35-50 $g \cdot kg^{-1}$) for that stage of development (Jones and Eck, 1973). They attributed the unexpectedly low concentration of N in the plant to denitrification favored by wet soil conditions. Moreover, comparison of manure and fertilizer treatments revealed lower plant N status in the manure treatment that might be associated with the potential for higher denitrification rates of manure N compared to the inorganic fertilizer N. Similarly, Sawyer et al. (1991) found lower concentrations of N in corn plants at the V5 stage under a disk-incorporated manure treatment than a fertilizer treatment during year 1 of a 3-year study. The lower plant N concentration of the manure treatment in that study was attributed to NH_4-N volatilization losses due to a 2-week delay in manure incorporation.

In contrast, a single land application of hog and cattle manure in Gray Luvisolic soils in north-western Alberta increased nutrient concentrations over the control in the whole mid-season (flowering stage) canola plant tissue (Assefa, 2002). The rates used were: 40, 42, 49, 88, 146 and 176 $kL \cdot ha^{-1}$ for the hog manure and 16, 32, 66, and 103 $Mg \cdot ha^{-1}$ (on wet wt. basis) for the cattle manure. Most of the cattle manure treatments did not significantly increase the N concentration in the plant, probably owing to the relatively slow N mineralization and available N release from cattle manure as compared to the hog manure. Both the hog and cattle manure increased P concentrations in the plant tissue and the influence of manure application on P concentration was of greater magnitude than N concentration. This might be attributed to the crop's high demand for P during early stages of growth and that canola is a very effective crop in extracting fertilizer (manure) P (Grant et al., 2001). Similarly, Qian and Schoenau (2000b) reported that additions of hog manure and urea significantly increased canola P accumulation and resulted in a higher proportion of P in the seed. They also observed higher supply rates of available P in the soil, and hence higher P accumulation in the manure treatment than the urea treatment, attributable to the contribution of readily available inorganic P as well as some mineralization of organic P contained in the manure.

Assefa (2002), from the study in north-western Alberta, reported that only the hog manure increased the concentrations of K and only the cattle manure increased the concentrations of S in the plant. Increases in tissue concentrations of Fe, Mn, and Zn were also observed, but only with hog manure application, suggesting that hog manure has a relatively larger effect than cattle manure in increasing availability of micronutrients for plants in the first year of manure application. Charles (1999), from a study that involved two sites in Saskatchewan, observed that both hog and cattle manure increased K availability, leading to increased plant K uptake and K concentration in the tissue. He found no effect of manure on canola S uptake at one site, but observed increased canola S uptake at the second site at high rates of hog and cattle manure additions. The study was continued and from a summary of results over four growing seasons Mooleki et al. (2001) reported that crop N uptake was enhanced by both hog and cattle manure annual applications. The crop N uptake in the hog manure treated plots was observed to be comparable to that of the urea treated plots.

Chang et al. (1994) examined the influence of long-term (18 years) manure application on nutrient uptake by barley at field sites in Lethbridge, Alberta. They used feedlot manure from an open, unpaved commercial feedlot and stored for 1-2 yr prior to application and all plots had been continuously cropped to barley throughout the experiment. The results revealed that concentrations of N, P, K, Mg, Na, Cu, and Zn in the barley tissue at the heading stage were significantly higher in the manured plots than in the control plots. Moreover, the concentrations of these nutrients were observed to have increased with rate of manure. In contrast, Ca concentration was generally inversely related to rate of manure application and found to be significantly lower in the manured plots at the rate of 180 $Mg \cdot ha^{-1}$ as compared to the control. This phenomenon was attributed to increased salinity associated with the repeated manure application. Janzen and Chang (1987) attributed the occurrence of Ca deficiency resulting from salinity stress to reduced activity of calcium in the soil solution because of precipitation with sulfate and high ionic strength.

1.2.2 Yield

Sutton et al. (1986) compared the effect of solid vs. liquid annual dairy manure applications for five years on corn yield grown on a Crosby silt loam soil. The treatments (on wet basis) were: 34, 67, and 101 $Mg \cdot ha^{-1}$ for the solid manure and 112, 224, and 336 $Mg \cdot ha^{-1}$ for the liquid manure. Except in the first and the residual (6th) year, all the manure treatments increased the corn yield over the control. The three liquid manure applications increased the yield above all the other treatments in the first year and only the 244 and 336 $kg \cdot ha^{-1}$ liquid manure applications increased the yield in the residual year. From this they concluded for both solid and liquid dairy manure that the residual N, even with five successive years of high rates of application, was not sufficient to support maximum crop growth in the 6th year and that supplemental N would be required. The effect of differing rates of application of the solid manure became apparent in terms of yields only in the 4th and 5th year. The percentage of the total N that was plant available was higher in the liquid than in the solid manure. They suggested that the release of the N from the solid manure might not have been at the proper time for the maximum crop utilization and could have been leached beyond the root zone.

In east-central Saskatchewan, Charles (1999) found that a single application of liquid hog manure increased the yield of canola over the control in a sandy loam soil but the yield decreased with increasing rates of hog manure. The lowest rate (204 $kg\ N \cdot ha^{-1}$) gave the maximum yield (1271 $kg \cdot ha^{-1}$) whereas the highest rate (790 $kg\ N \cdot ha^{-1}$) gave the lowest yield (587 $kg \cdot ha^{-1}$) among the manure treatments. This decrease in yield with increasing rate of hog manure was attributed to ammonium toxicity. In contrast to the hog manure, an increasing trend in yield was evident with increasing cattle manure rate. In the same study, a single application of both hog and cattle manure to another soil of loamy surface texture increased canola yield. For the hog manure, the medium rate (147 $kg\ N \cdot ha^{-1}$) gave the maximum yield (1743 $kg \cdot ha^{-1}$). For the cattle manure, the highest rate (484 $kg\ N \cdot ha^{-1}$) was required to produce the maximum yield (1019 $kg \cdot ha^{-1}$). Eghball and Power (1999) reported that corn yields were increased by annual or biennial beef cattle feedlot manure and compost applications over four years (1992-1995) as compared to the yield from the check. The manure and compost treatments were applied based on N or P removal of corn and the expected yield level. Accordingly, the rates used were 151 kg N·ha^{-1} and 25.8 kg P·ha^{-1} for an expected corn yield of 9.4Mg·ha^{-1}.

Olson et al. (1998) in a four-year study in Lethbridge, Alberta, found that barley silage yield on a coarse-textured soil and on a medium-textured soil was increased by cattle feedlot manure application as compared to the control. There were no significant differences in yield between the manure treatments (20, 40, 60, and 120 Mg·ha^{-1}). They recommended that repeated (3-5 years) annual cattle manure applications should be limited to less than 60 Mg·ha^{-1} on coarse-textured irrigated soils and 20 Mg·ha^{-1} or less over longer term (5-10 years). Similarly Mathers and Stewart (1980), from results of 10 years of manure application on Pullman clay loam soil, in Bushland, TX, reported that annual applications of 22 Mg·ha^{-1} beef feedlot manure supplied sufficient plant nutrients for maximum yields of sorghum, corn silage, and wheat.

1.2.3 Quality

As a viable source of fertilizers, manure not only maximizes crop production but also enables the user to attain the required quality of crops. Besides maximizing yield, Mooleki et al. (2001) reported that hog and cattle manure had similar effects of increasing grain protein concentrations in the three test crops used: canola, wheat and barley. The increase in the protein content of crops following manure application could be attributed to mineralization of N later in the growing season. Moreover, the presence and availability of other nutrients in manure such as P might contribute to increased plant N uptake by stimulating plant root growth and access to N in the soil. Qian and Schoenau (2000c) reported, from a greenhouse experiment, increased total N uptake of canola plants in treatments that received hog manure and urea as compared to the control treatment. They also observed that there was a higher percentage of N stored in the canola seed in the manure treatment than in the urea treatment for plants grown on a Blaine Lake soil.

1.3 Best Management Practices

Expansion in the size and intensity of livestock operations generates increased amounts of manure that leads to a disposal problem. This, coupled with the increasing cost and energy required to produce commercial fertilizers, makes the management and use of manure as a source of fertilizer a feasible option to solving two problems in one package. The goals of manure application to farmlands should be provision of a sustainable means of utilizing the manure to maintain soil fertility and nutrient balance for optimum crop production and environmental quality. Achieving this may depend on several factors such as agronomic, manure composition, environmental and social factors. Thus studies that take such factors into consideration are important to develop Beneficial Manure Management Practices (BMMP).

1.3.1 Rates

In the past most farmers didn't have the tools to effectively use manure for crop production. Consequently, it was a common practice to supply commercial fertilizer even to fields that had received large quantities of manure (White and Safley, 1984; Beegle et al., 2000; Huber et al., 1993). This could be due to the critical requirement of nitrogen for efficient crop production and the difficulty in predicting nitrogen availability from manure that might have led to the application of excess nitrogen in the interest of ensuring nutritional sufficiency throughout the growing season. In recent years, several researchers have attempted to characterize animal manure and study nutrient losses from the manure at different stages, from collection to land application for crop production (Barth, 1985; Safley et al., 1985; Converse and Holmes, 1985, Schulte et al., 1985; Welty et al., 1985; Westerman et al., 1985; Chang, et al., 1993; and Eghball and Power, 1999).

Considerations such as appropriate rate, timing, and method of application, and expected crop response are important when using manure as a source of plant nutrients (Schoenau, 1997). Under-application or over-application should be avoided. Crops may suffer from deficiency and injury as a result of under-application and over-application, respectively, both leading to reduced yield. For example, Mathers and Stewart (1974) reported that high rates (224 Mg·ha^{-1} or more) of cattle feedlot manure applied annually on Pullman clay loam soils over three years reduced corn yields by about 15% in the second and third year. The yield reduction was not as much in the first year as in the second and third years owing to the lower analysis of the manure applied in the first year. When the cattle manure was applied at the rate of 896 Mg·ha^{-1}

the yield decreased to 0. They concluded that annual application rates of 22 Mg·ha^{-1} cattle feedlot manure would be adequate to give maximum yields of good quality on Pullman clay loam soils.

In Alberta the maximum recommended rates of cattle feedlot manure were: 30 and 60 Mg·ha^{-1} (wet wt.) on nonirrigated and irrigated land, respectively (Alberta Agric., 1980). Similar recommendations were made in a recent study that was conducted in the Gray Luvisolic soil of the Peace River Region, north-western Alberta (Assefa, 2002). The fields of the study were nonirrigated. The results revealed that application rates in the range of 16 to 30 Mg·ha^{-1} (wet wt.) for cattle manure and 35 to 40 kL·ha^{-1} for hog manure were required for optimal crop production. In the first year of an ongoing experiment at two field sites in Saskatchewan, Charles (1999) recommended hog manure applications in the range of 38 to 76 kL·ha^{-1} for maximum crop production. Mooleki, et al. (2001) reported consistent findings after four annual applications of manure at the two sites. However, Assefa (2002) cautioned that salinity and sodicity could be potential problems and should be monitored if manure is going to be applied over a longer period of time. The manure nutrients and forms, nutrients available in the soil, crop nutrient requirement, environmental conditions, and effects on soil quality should be considered when determining application rates. Manure and soil analysis, and forecasting of crop nutrient requirements before application are essential tools in managing manure for optimum agronomic and environmental benefit.

1.3.2 Placement

Placement of manure, as with inorganic fertilizers, is an important issue that needs consideration for the purpose of optimizing the accessibility and utilization of nutrients for plants. It can affect the ability and efficiency of crops to use the manure nutrients and the likelihood of their loss from the point of application. For example, under dry conditions, surface-applied manure nutrients may become inaccessible by remaining on the soil surface or by being blown away by wind. In conditions of heavy rain, on the other hand, they are subject to loss by water erosion. Also, surface applications of liquid manures that are characterized by the presence in them of more ammonium-N than in solid manures are accompanied by inevitable losses of ammonia gas that reduce N availability to crops and hence result in poor productivity. Therefore, injection of liquid manure, such as hog and dairy cattle, has been reported to be a superior method whereby the manure is placed at approximately 4-5 in (10-12.5 cm) below the surface (Hoff et al., 1981; Charles, 1999; Schoenau et al., 2000; Assefa, 2002). For solid manures broadcast and incorporation by tillage to a depth of about 4-5 in (10-12.5 cm) below the surface is the customary method of applying solid manure such as that from beef cattle (Mathers and Stewart, 1980; Charles, 1999; Schoenau et al., 2000; Assefa, 2002).

1.4 Gaps

There needs to be an optimum and balanced utilization of the nutrients used in any farming system if sustainable agricultural practices are to be established. Long-term studies are needed involving manure from different sources and in different forms, different soil types, different crops (as would be common in certain rotation practices), and variable environmental conditions. Such studies could include treatments with supplemental commercial fertilizer to achieve the desired balance or ratio of nutrients required by the crop. Producers may have been initially reluctant to manage manure as a fertilizer source for crop production due to lack of confidence in the value and nutrient content of manure, or the unavailability of sufficient labor and methods for effective manure application (Huber et al., 1993). This needs to be addressed by way of creating awareness among producers and developing suitable equipment and methods for manure application. The precision application of a variable product, manure, to variable soils is a daunting task, but Ess et al. (1996) suggested precision management of animal manure. Precision manure management is believed to have the potential to further improve production efficiency with reduced farmer exposure to potentially devastating legal action resulting from unintentional, but inappropriate manure applications.

Some specific gaps identified in this section may include:

Studies to evaluate the long-term effects of repeated manure applications on various aspects of soil quality. This would include examining the effect of several manure applications on soil microbial populations, soil physical properties such as structure, chemical properties including nutrient load, salinity, sodicity as well as hydrological properties such as water infiltration. Some research towards this has already been conducted, for example, with cattle manure in southern Alberta, or is underway, such as with swine manure in Saskatchewan. However, more is needed with all types of manure, including composted products, to cover the variety of soil-environmental conditions present in Western Canada.

There is a need to take physical response data (i.e. yield, protein increases) associated with application of manure nutrients observed in field trials, and apply economic analyses to determine the net benefits of manure application and economic transportation distance. Such economic analyses should be applied to new approaches to manure handling and transportation as well.

Technologies for handling and applying solid manure with increased uniformity and precision in rate of application and placement are needed to ensure maximum benefit is obtained from the nutrients and organic matter contained in the manure. For example, new engineering approaches to manure spreading, possibilities for in-soil placement versus broadcasting could be examined.

Further process studies to obtain more accurate, site-specific estimates of rates of nutrient losses from manured fields, including per annum losses by leaching, runoff, volatilization, and denitrification, that can be used in nutrient budgeting. Research is also needed that would contribute to more accurate estimates of rate of release of available nutrients from organic forms contained in manure.

2 Manure Management Strategies

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

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

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

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

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

a. variability in nutrient content and form which makes it difficult to determine appropriate rates of application to meet crop nutrient requirements;

b. that manure is not an "off-the-shelf" source of nutrients and may not match the crop's relative requirement (example: manure with more phosphorus relative to nitrogen than the crop can use); and

c. low nutrient content per unit volume limits the distance to which manure can be transported economically.

They, however, suggested that through the use of sound nutrient management practices, the risk of manure nutrient accumulation and loss could be minimized while realizing the maximum agronomic benefit from the nutrients. Similarly, Huber, et al. (1993) suggested that managing manure as a fertilizer resource for crop production can increase the return to the producer, minimize the pollution potential of manure, and enhance overall production efficiency of an animal-crop farming system.

2.1 Manure Sampling and Soil Sampling

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

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

2.1.1 Manure sampling

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

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

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

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

The field test methods are reported to give better estimates of manure nutrient contents than using average values by allowing for accounting of the variability in manures that exist on a farm as well as between farms. Besides, they offer the advantages of:

1. detecting changes in manure characteristics as the storage facility is unloaded, and
2. allowing mixing of the stored manure slurry before sampling.

Similarly, Fleming et al. (1993), from results of their evaluation of on-farm manure test procedures that involved 106 manure samples from pig, beef, dairy, and poultry farms, reported that nitrogen and electrical conductivity methods yielded reasonably accurate results that were far superior to those obtained using standard tables. However, Barker (1996) cautions that “field quick test” methods should not substitute for laboratory analysis of well mixed manure samples.

Lack of information on nutrient value of manure to be land-applied is more of a problem for producers applying manure for the first time and it is in such cases that the use of "book" or published average nutrient values of typical manure may be best. It may be possible to do the manure analysis at an early enough time to allow completion of the analysis prior to the land application in order to obtain estimates of the manure nutrients for the purpose of determining the rates of application. However, results from a single manure nutrient analysis can be unreliable owing to the variability both in the manure and analyses procedures, and it may best to refer to published average values of nutrients in different types of manure to start out with. Once results of manure analyses for three to five consecutive years of a given livestock operation are obtained, calculating the average nutrient values of the manure from that particular operation may provide reliable nutrient estimates of the operation. The nutrient estimates of the manure obtained as such can be used to calculate the application rates for the subsequent years as long as no significant changes occur in a given livestock production system that may alter the characteristics of the manure produced in that operation.

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

The collection of representative samples of manure from a given source is vital to obtain an accurate reflection of its nutrient forms and content that enables accurate prediction of the manure’s nutrient credit. Due to the fact that only a very small proportion of the total manure in storage would be sent to the laboratory for analysis, collection of several samples from different parts of the storage unit is crucial.

The representative (composite) sample can then be obtained by mixing sub-samples. Thorough mixing prior to sampling/application and collection of a large number of sub-samples is necessary for obtaining samples that can be considered representative of the manure from a given storage system. Collection of representative samples will greatly contribute to the reliability and interpretation of nutrient contents obtained from analysis of the samples in the laboratory. It is estimated that about 90% of the accuracy associated with achieving the desired rates of manure application depends on how well the manure samples are collected (Tri-Provincial Initiative, 2003).

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

The continual change in the characteristics of manure from the time of excretion to land application and variability in the accuracy of manure analysis procedures coupled with the challenges of obtaining representative samples, call for a better way of achieving the nutrient value of manures. To this end Dagnew (2002) suggested that a robust nutrient estimation method that is suitable for on-line sensing of manure nutrients on-the-go would be of great value. In her study that investigated the feasibility of reflectance spectroscopy technology for sensing hog manure nutrients, she concluded that such a technique holds promise for prediction of total solids (TS), total Kjeldhal nitrogen (TKN), total phosphorus (TP), and available phosphorus (AP) in liquid manure, and could, with further development, potentially be adapted for in-field or on-line sensing.

Previous work in the field of on-line nutrient sensing systems is reported in the scientific literature. For example, Scotford et al. (1998) developed a prototype sensing system that consists of a network of sensors to determine redox potential, pH, temperature, EC, and concentrations of ammonium ions in liquid manure. The system uses the correlations between the characteristics of manure such as EC and its nutrient concentrations. Fitting a similar prototype to a manure tanker of 7-m^3 capacity, it was possible to estimate the nutrient content of each tanker-load of manure within a period of 2 minutes during transportation of the manure from the storage tothe application site (Scotford et al., 1999). The estimates were comparable with other sample-based techniques. Crowe and Maule (2000) reported a system fitted with an on-line mounted EC sensor that was used to test 11 manure samples collected from Saskatchewan farms that showed good correlation between the sensor readings and ammonium concentrations in the manures ($R^2 = 0.97$). Further development of satisfactory on-line manure nutrient sensing systems that can be used to accurately quantify the nutrients in manures in the field should be encouraged. It will greatly contribute towards the efforts being made to apply appropriate rates of manure and keep field records and is consistent with the philosophy of precision nutrient management, especially for liquid manures.

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

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

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

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

2.1.2 Soil sampling

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

Soil sampling strategies vary depending on the intended objective such as improved crop response across the field in the year of application, identification of deficiencies and problem areas, or monitoring of soil conditions over several years. It is recommended that fields be soil sampled at 0-15 cm and 15-60 cm (0-6 and 6-24 in) depths regardless of the method of soil sampling employed. This is to account for nutrients that may have moved from the surface to greater depths by leaching. Common soil sampling strategies include: 1) traditional composite soil sampling, 2) benchmark soil sampling, 3) grid soil sampling, and 4) landscape-directed soil sampling. These strategies are described in detail in the Tri-Provincial Manure Application and Use Guidelines (2003) and also provided as fact sheets by many soil-testing laboratories.

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

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

- Nitrate-N analysis should be conducted on both 0-15 and 15-60 cm depth samples.
- Nitrate-N analysis should be conducted on deeper samples to determine if nitrate-N is leaching.
- P and K analyses should be conducted on the 0-15 cm depth samples.
- If desired, sulfur and salinity analyses should be conducted on the 0-15 and 15-60 cm depth samples.
- If desired, pH, organic matter, and micronutrient analyses should be conducted on the 0-15 cm depth samples.

2.2 Application Rates

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

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

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

2.3 Decision Support Systems (Rate Calculators)

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

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

- It simplifies the process of calculating rates for manure application.
- It illustrates the true value of agronomically sound manure use.
- It allows the user to experiment with different scenarios of commercial fertilizer and manure application to quickly find the best course of action for each particular field.
- It provides average values from its large databases in the absence of laboratory analysis of manure or soil sampling results.
- It consists of three different modules: manure nutrient module; manure, field, and economic module; and manure, field, and volume module. The manure nutrient module is used to calculate the availability of the nutrients in the manure.

The economic module is used to calculate the economic value of the applied manure by using information from one field. The volume module is used to produce a table that illustrates the distribution of manure on various fields. The flow of each module in the program is shown in Figure 5.

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

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

There are also other programs that have been developed to help producers in making decisions with regard to rates of manure application. Examples include: Manure Nutrient Management: A Balancing Act developed in Alberta (Olson and McKenzie, 2000) and NMAN2001– Comprehensive Nutrient Management Planning Software developed in Ontario (DeBruyn et al., 2001). Private laboratories offering manure analyses, soil testing and nutrient recommendation services have manure - specific recommendation systems as well.

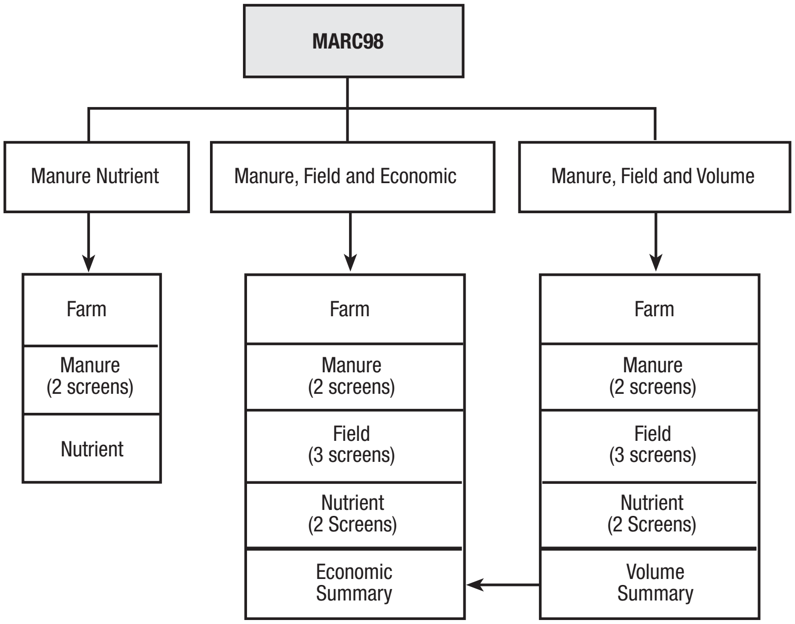


Figure 5. Program flow of the three modules in MARC 98 Source: After Tessier, 1999.

2.4 Application Technology

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

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

Infiltration enhancement is a method whereby manure is broadcast on the surface of a perforated ground. An aerator is used to create the perforations or indents in the top 5 to 15 cm of the soil layer. Infiltration enhancement may be used as pre-plant or post-emergent manure application method in annual crop systems such as in no-till fields or grasslands; however, Chen and Samson (2001) caution that it might present a potential for substantial nitrogen leaching to groundwater.

Injection of manure into the soil is a method by which manure is placed below the soil surface using sweep, chisel or disc openers and covered with a layer of soil immediately following the placement. Perhaps owing to the superiority of injection (Table 1) as a method of manure application, considerable work has been done in the design and use of different injection equipment.

The Prairie Agricultural Machinery Institute (PAMI), for example, has been extensively involved in the development and introduction of technology for manure application that provides lower odor and sustainable manure management. Some of PAMI's achievements include: pipeline manure injection systems; Figure 6-a&b (PAMI, 1997), low and high disturbance liquid manure injection systems; Figure 7, (PAMI, 1999 and 2002), and manure injection research truck fitted with low disturbance disc openers developed by Bourgault Industries Ltd., St. Brieux, SK; Figure 8 (PAMI, 2002). Most of the recent equipment

Table 1. Comparison of manure application methods with respect to N loss Source: PAMI, 1997.

Application method	Nitrogen Loss (%)	Comments
Sprinkler irrigation	30	Fine particles increase ammonia-N loss by volatilization. Loss will be greater in hot weather or with poor infiltration (clay soils), and lower with cool, wet weather and good infiltration (sandy soils).
Slurry wagon with splash plate and no incorporation	25	Larger particles and lower trajectory reduce loss somewhat.
Slurry wagon with splash and immediate incorporation	3	Timely incorporation reduces loss dramatically.
Injection	1	Very little loss due to lack of contact with the atmosphere.

Figure 6-a. Pipeline manure injection system using drag hose connected to manifold distributor on chisel plow-based tool bar Source: AAFRD.

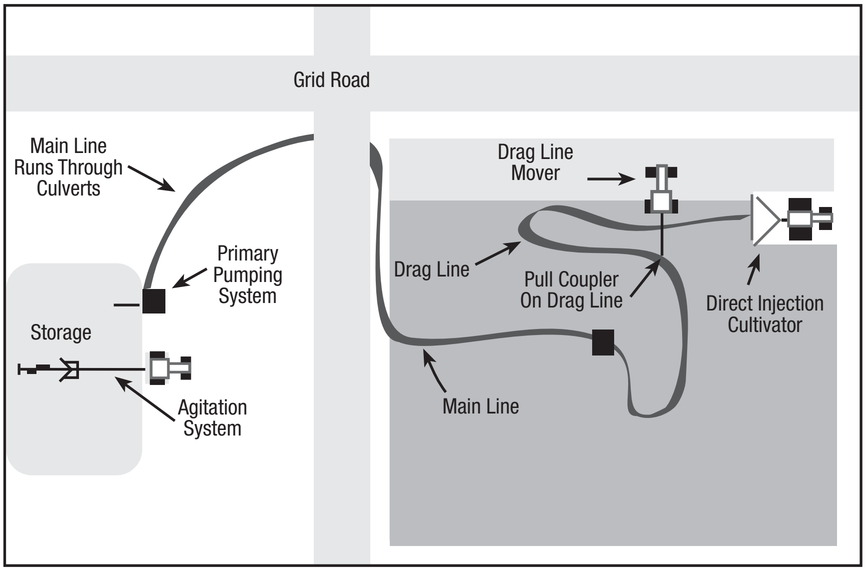


Figure 6-b. Pipeline liquid manure injection system, a typical set-up Source: PAMI, 1997a.

Figure 7. *Liquid manure injection system using a tool bar mounted on a tanker* *Source: PAMI, 2003 (Carol Jackson person.comm.).*

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

Figure 9. *Sample of custom injector machine* *Source: Matt Oryschak AAFRD*

developed for liquid manure application have similar basic design elements and performance, and are based on injecting the manure into the soil and immediately covering the injection channel with soil with limited soil disturbance and leaving a good quality seedbed (Figure 9).

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

Although spreaders for both liquid and solid manures have volumetric ratings, application rates of the manures are expressed in different units: litres per hectare (metric) or gallons per acre (imperial) for liquid manure and Mega grams per hectare (metric) or tons per acre (imperial) for solid manure. Detailed procedures of how to calibrate liquid and solid cattle manure spreaders are provided in the Tri-Provincial Manure Application and Use Guidelines (2003).

2.5 Gaps

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

For precision manure application in the field and for documentation of nutrient loading rates, there is a need for continued development of technologies for "on-the-go" sensing of nutrient content and forms in manure during application. This should be coupled with technology to permit accurate metering of the manure based on the nutrient contents of the manure being sensed.

To ensure that producers, applicators and recipients of manure are aware and capable of using the knowledge and tools (i.e. rate recommendation software) available for sound manure management, it would be desirable to package this information into a course or program that would provide manure management training.

There is a need to establish thresholds for nutrient loads in the soil based on identified risk or threat to environmental quality that account for the many facets (soils, vegetation, climate, topography, tillage system, etc.) that may make one threshold value appropriate for one area but not another. One approach might be to use geographic information systems to subdivide regions and establish suitable threshold values for each region. The accumulated database may then be used as part of regional or provincial nutrient management strategies, and permit extrapolation of research results and recommendations obtained from specific sites to other similar areas.

3 Manure Handling and Composition

The nutrient forms and composition of manures vary greatly. There are several factors, some of which are discussed in section 3.2, that are responsible for the variation between manures. Manure handling is one of the several factors that greatly contributes to the variation in manure composition, particularly following excretion.

3.1 Handling Systems

Manure handling systems vary among producers but, generally, they consist of four main components that include: collection, storage, treatment, and use/disposal (Smith, 1996). A similar summary of the components of manure handling systems for livestock production is given in Table 2. Manure collection systems are those components of manure handling systems that are used to collect and remove manure from confinement facilities. Manure storage structures are components of manure handling systems that are used to store the collected manure from confinement facilities, and include structures such as deep pits, earthen structures, and above ground or below ground concrete tanks. Manure treatment can be perceived as the component of manure handling systems that is used to alter the original condition of the manure. An example is solid-liquid separation, mechanically or chemically, for the purpose of improving manure handling properties, producing manure solids for animal feeding, energy generation (for example, biogas) and compost production as well as reduction of odor and pollution potential of the manure (Zhang and Westerman, 1997). Currently, application of manure to cropland is the most common and practical method of manure utilization whereby benefits to the soil and plants of the organic matter and nutrients that are contained in manure can be derived. It is considered disposal when manure is applied at a rate greater than which the soil and crops can use (Smith, 1996). Although it seems like a cheap manure handling system, it is a system in which producers use their fields as landfill sites, and is unlikely to be sustainable.

The major difference in manure handling systems is the use of solid or liquid systems (Schmidt et al., 1996). It is possible that producers may use solid manure handling systems or liquid manure handling systems exclusively, or both solid and liquid systems. However, selection between these two systems is not simple, but challenging to producers because of the consideration that has to be given to two important issues: cost effectiveness and environmental safety (Barrington and Cap, 1991; Schmitt et al., 1996; Harrigan et al., 1996). Both solid and liquid manures have to be managed properly for the protection of the environment and optimum level of crop production. This may be achieved by the use of manure application management decisions. According to Schmitt et al. (1996), the form (solid or liquid) in which manure is handled and stored is implicitly related to some manure application decisions. The quantity of manure that has to be handled and the type of soil (due to compaction and leaching properties, etc.) on which manure would be applied also greatly determine the profitability of manure handling systems (Brundin and Rodhe, 1993).

A manure management survey of Minnesota swine producers, for example, indicated that the form in which manure was applied to fields was statistically ($P < 0.001$) linked to the size of the farms (Schmitt et al., 1996). They reported that, 52%, 21%, and 4% of the small, medium, and large farms, respectively, handled their swine manure exclusively as a solid whereas 15%, 23%, and 43% of the small, medium, and large farms handled their manure as liquid. The correlation of small farms and solid manure and large farms and liquid manure was attributed to financial

Table 2. Components of a manure handling system.

Operation	Solids	Semi-Solid/Liquids
Collection	Gutter cleaners Front end loaders	Slotted floors (complete with gutters) Scrapers cable hydraulic tractor
Transfer	Manure wagons Open tank spreaders Dump trucks Earth moving equipment	Pumps submerged, open impeller piston pneumatic Augers Vacuum tank wagon Pipeline Gravity Continuous flow gutters Large diameter pipes
Storage	Stock pile Bunk silo	Glass-lined steel Concrete Earthen
Treatment	Aerobic compost dry incinerate Anaerobic	Aerobic pre-storage partial total Anaerobic Solid/Liquid separation
Utilize/Disposal	Land application Energy production (i.e. biogas)	Land application Irrigation Energy production

Source: MAF, 2001.

considerations. The justification was that liquid manure handling and storage systems generally require more initial capital investment than solid manure handling and storage systems, which smaller farms could not justify but the larger farms could by allocating the set-up costs over more hogs. Similarly, in a study that compared manure-handling systems under Swedish conditions, Brundin and Rodhe (1993) reported that solid manure handling systems appeared to be more profitable than slurry systems for small dairy farms of about 20 cows. In another study, conducted in Quebec, it was indicated that solid manure storage facilities that were accepted by environmental authorities were more expensive and less practical systems for dairy farmers as compared to the liquid alternatives (Barrington and Cap, 1991).

3.1.1 Liquid

Liquid manure can be defined as a mixture of excreta (urine and fecal matter) that is handled mostly by pumps, pipelines and closed tankers, and it typically has a total solids content of 3-6% (Turnbull, 1984; Fleming, 1986). Owing to ease of mechanization and low labor requirement, liquid manure handling systems are popular in various types of confinement animal operations including swine, dairy, beef, and poultry (Zhang and Westerman, 1997). Liquid manure handling equipment varies more than that used for solid manure due to the many different styles of liquid manure storages (Fleming, 1985).

Barrington and Cap (1991) listed several advantages that liquid manure handling systems offer over solid manure handling systems and indicated that there was a justifiable trend towards adopting liquid manure systems for dairy producers in Quebec. For example, use of gravity flow systems may allow eliminating all handling equipment and minimizing bedding (Midwest Plan Service, 1983). In spite of the consequently limited use of bedding material, adaptation of liquid manure handling systems in tie and stanchion barns can be made possible by installing grates over gutters to keep the cows clean. The manures can then be transferred to a liquid storage facility, which can be built entirely of compacted soil at 25% of the cost that is needed to build a concrete tank (Barrington and Cap, 1991). When required, it is possible to remove the manure from the storage by using only one type of equipment and pumping it out from the reservoir with little problem.

On the other hand, however, Barrington and Cap (1991) caution that, from an ecological point of view, liquid manures tend to be more susceptible to causing problems of odors, soil compaction during land application, and nutrient leaching after soil incorporation. For example, they cited Sobel et al. (1988) to have reported that liquid dairy manure produced more offensive odors than solid manures during disposal. Liquid manure handling systems are causes for much environmental concern due to their inherent odor generation potential. In a study that investigated the presence, concentrations and distribution of manure gases in livestock housing in Sweden, Skarp (1975) found that liquid manure set in motion by pumping, mixing or cleaning-out released large amounts of gases, particularly H_2S which sometimes appeared in lethal concentrations, whereas solid manure did not release gases in quantities injurious to animals or humans. Similarly, Klarenbeek (1985) reported a 10 times greater odor emission from liquid poultry manure than the same manure handled in the solid form.

There are several types of liquid manure storage systems. Some examples include: circular concrete storage, rectangular concrete storage, above ground concrete silos, circular glass-lined steel storage, earthen storage, and multiple storage systems (Hilborn, 1997). The round concrete structure in the circular concrete storage provides the most efficient use of concrete and reinforcing steel whereby the steel bars resist the outward force of the manure when the tank is full and the concrete wall resists the inward pressure of the earth when the tank is empty. This type of storage can be built completely below ground, partly below ground or fully above ground. Rectangular storages are suitable for conditions when constructing barns over top, the storages are roofed, or when the available area may not fit for a circular structure. The straight walls of rectangular storages must be supported so that they withstand the large stress on them, and the most common ways of doing so are constructing a roof or a slat support and designing the walls as retaining walls; i.e. using a cantilever or buttress design. Above ground concrete silos are smaller diameter limited capacity (about 200 kgal.) storages. Circular glass-lined steel storages are large diameter glass-lined steel storages that are typically sold as part of a complete system including transfer, pumping, and agitation equipment. Earthen storages are usually rectangular in shape and possess 1:2 (rise:run) side slopes which increase the surface area of the storage as well as the liquid volume by allowing more precipitation to land in it. The resulting dilution makes it easier to handle the manure as liquid; however, added water increases the cost of application. Seepage loss is a potential problem associated with such storages, and adequate testing and proper construction techniques must be used to ensure that sealing of the surface of the structures would take place to protect the environment. Figures 10 and 11 indicate different types of liquid manure storages that can be built of concrete, Figure 12 shows an example of earthen manure storage, and Figure 13 shows one way of surface covering of liquid manure in an earthen storage to control odor nuisance.

Emissions of gases such as ammonia, methane, and nitrous oxide are potential problems associated with manure production and storages, particularly with liquid manures. Emissions of such gases can be detrimental to the environment and a source of odor nuisance to the community around livestock operations, and may translate to economical loss due to the loss of important nutrients that could have been used for crop production (Hörnig et al., 1999). They reported that research has been conducted to examine the effect of reducing emissions while considering cost and durability. A study in Germany revealed that rigid covers over large lagoons are impractical and prohibitively expensive, however, indicated the existence of alternative versatile and low-cost covers (floating layers) such as straw, granule, swelled clay, oils, peat, foams, foils, mesh, leka rock, etc. (Hörnig et al., 1999).

Similarly, PAMI (1993) conducted a serious of studies on the effectiveness of the use of supported and unsupported floating covers on hog manure lagoons, with emphasis on cover durability, straw type, odor reduction period, and management problems in Saskatchewan. The result of these studies indicated that barley straw of good quality (i.e. fresh,

Figure 10. Above ground concrete liquid manure storage that can be used in places where soil conditions would pose risk to drinking water if earthen storages were used. Source: Kai Ma, NRCB.

Figure 11. A concrete liquid manure storage tank with chain link safety fence. Source: Matt Oryschak, AAFRD.

Figure 12. Earthen manure storage
Source: Brian Sexton, AAFRD.

Figure 13. Straw being applied to an earthen manure storage. Source: AAFRD.

unweathered, relatively dry, with as many whole stalks as possible) can give effective odor control over the entire season with only one or two reapplications to small areas of the lagoon surface to recover areas of straw sinkage. Moreover, it was reported that any type of cereal straw and even poor quality straw might work effectively when float systems are used to support the cover. In the same studies polystyrene sheets, 1 in (25 mm) thick, and plastic engine oil bottles were used as straw floatation devices, and the polystyrene floats were reported to have kept the straw cover supported and dry for nearly the entire season, and resulted in excellent odor control. Figure 14 shows unsupported and supported straw covers applied over hog manure lagoons as demonstrated by PAMI (1993).

Removal of the manure from long-term storages is reported to be the operation that usually presents most of the problems; however, if the manure has proper moisture content and if correct equipment is used to complete agitation of manure within the storage, it can be done quickly and with little difficulty (Fleming, 1985). Gravity flow systems are a very common and effective way of removing liquid manure from above ground storages as well as transferring it from the animal confinement to the storage. For example, in North Carolina, Vanotti and Hunt (1999) indicated that flushing systems are preferably utilized in many modern swine production systems for their simplicity and economy. In Ontario, Fleming (1985) reported a gravity system (Figure 15) to be a very

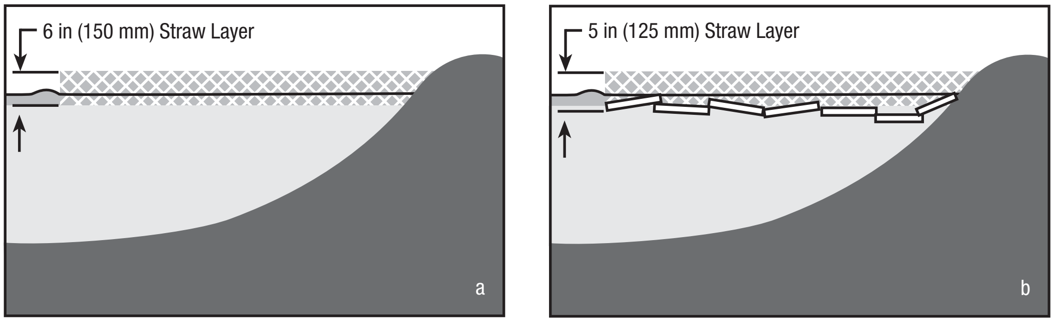


Figure 14. Straw cover over surface of a hog manure lagoon; a) unsupported, b) supported
Source: PAMI, 1993.

simple and maintenance-free approach to liquid manure removal from storage, and Hilborn (1997) suggested a gravity flow pipe system to be the simplest and most common approach of transferring manure from barns to storages.

Other methods of removal of manure from liquid storages include: use of vertical pumps, side mounted pumps, and earthen manure storage pumps (Fleming, 1985). Vertical pumps are used to remove manure from storages under barns or in outside storages where the storage is below the level of the tractor that is used to power the pump. Side mounted pumps are used to remove manure from storages that have vertical walls and are above ground or partly above ground. Earthen manure storage pumps are used to remove manure from storages with earth wall and/or sloped concrete ramps.

Most liquid manure storages on the prairies are earthen structures because of the advantages they offer such as cost per animal unit, ability to store large amounts of manure and/or runoff, and potential to handle manure with conventional pumping and irrigating equipment. However, some disadvantages, such as lack of appropriate soil materials for construction, the need for solid separation or sludge removal equipment if bedding or other nonbiodegradable materials are present, aesthetic appearance and/or public perception, may be associated with them (Manure Management Curriculum, 2002).

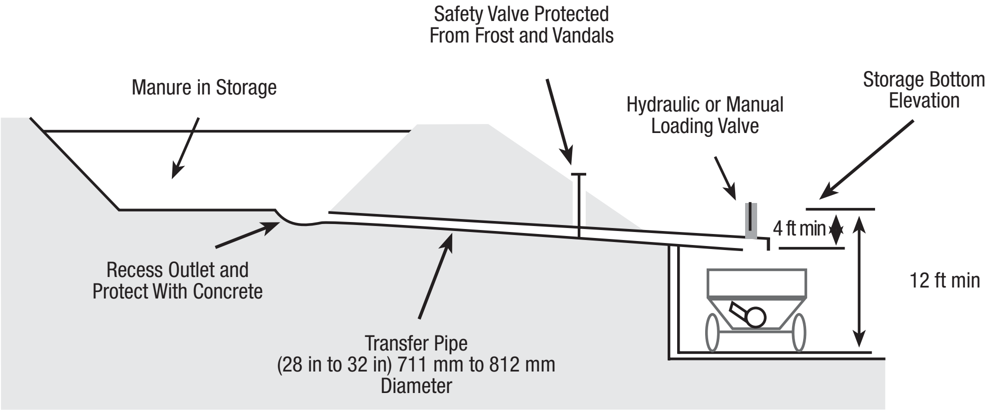


Figure 15. Gravity load out of manure from storage. Source: After Fleming, 1985.

3.1.2 Solid

Solid manure can be defined as manure that contains a mixture of feces, urine, and bedding material with little or no water added to it and is handled mostly by mechanical conveyers, tractor-mounted fork or bucket loaders, and open box-type manure spreaders (Turnbull, 1984). According to Barrington and Cap (1991), handling of solid manure would require mechanization, a system which is not only costly but also subject to wear and breakage. They indicated other factors that contribute towards the costliness of solid manure handling systems. For example, the storage facilities require a hard concrete floor for the purpose of removal by means of a front-end loader on a farm tractor, and the concrete floor makes the storage facility extremely expensive when compared to an earthen reservoir. Furthermore, solid manure storage facilities must be designed to store liquids originating mostly from the contaminated rainfall washing off the manure pile, and this necessitates two types (a liquid system for the contaminated rainfall and a solid system for the solid manure) of handling equipment when removing the manure.

Solid manures, on the other hand, represent a lesser volume of lower density (650 $kg \cdot m^3$) to handle at disposal than liquid manures (reaching 1000 $kg \cdot m^3$), and they are less likely to cause soil compaction problems during transportation as well as field application (Barrington and Cap, 1991; Midwest Plan Service, 1983). Barrington and Cap (1991) suggested that the use of manure pile covers made of an impermeable geotextile could be as economical and practical as liquid manure systems provided that enough bedding material can be used to curtail all seepage from the manure during storage. According to their design, the cover lies on the floor of the platform as well as the pile and this eliminates all structural components, and the manure would be introduced under the cover by means of a pneumatic system.

Solid manure handling systems are usually used with cattle operations in feedlots and barns, and these systems normally allow manure to accumulate over the entire area of the animal confinement until the time of cleaning (SAF, 1997). Bedding material, usually straw, is used to keep the animals warm and dry until the time of cleaning the barns or mounding the manure, which is a common way of storing solid manure until the time of use/disposal. In feedlots, pens may be scraped and manure piled in the back for partial composting, or in the center as part of the bedding pile during the year. Figure 16 shows examples of (a) piled solid manure that allows pens to dry and (b) how manure stored as such can be spread on the field. When solid manure is to be piled on coarse granular material such as gravel or sand, it may be required to construct impervious slab from materials such as compacted clay, concrete or asphalt to contain seepage. It may also be necessary to construct a perimeter curb to contain liquid runoff and sloping the slab to a corner opposite to the entrance ramp would enable collection of the liquid runoff for removal by vacuum tanker or transfer to a separate storage (MAF, 2000).

Handling manure in solid form has advantages such as less volume (high solids content), less odor (because of reduced bacterial action producing odorous compounds at lower moisture contents), less runoff potential, and relatively high nutrient retention. On the other hand, solid manure handling systems pose some disadvantages such as more labor requirement for manure collection and handling (i.e. mechanical handling as compared to hydraulic handling), runoff management from storage areas,

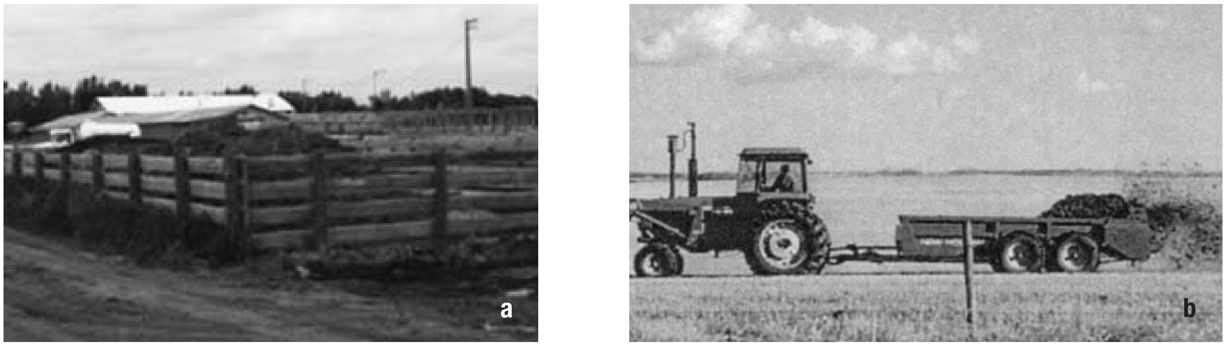


Figure 16. Solid manure a) piled to allow pen drying b) how it is spread

Source: AAFRD *Source: SAF*

and labor/equipment requirements (due to the number of loads required to haul and spread the manure) for land application (Manure Management Curriculum, 2002).

3.1.3 Separation

Solid-liquid separation is one of the several manure treatment methods that can be used to improve manure handling properties and produce manure solids for animal feeding, energy generation, and compost production (Zhang and Westerman, 1997). They suggested that "effective solid-liquid separation that is capable of removing a substantial amount of organic solids from fresh liquid or slurry manure will potentially offer the benefits of production of nutrient-rich organic solids, odor reduction, in subsequent liquid storage pits (or tanks) and anaerobic lagoons, and improvement in the economics of subsequent liquid manure treatment processes due to reduced organic loading rates on an annual basis." They also indicated that the separated solids may be used on farms near animal operations or may be economically exported to other areas as fertilizer and soil conditioning products.

Typically, liquid manure has a total solids concentration of around 5%; however, in some cases it may be handled with over 10% solids. Fleming (1986) attributes this range of moisture content in liquid manure to such factors as method of storage, type of livestock, feeding program, and type and amount of bedding used (if any). High solids content can make manure difficult to pump. One way of reducing the ratio of solids to liquids is adding more diluting liquid, which, however, only increases the volume of the material to be handled, but does not reduce the size of the particles. For example, Vanotti and Hunt (1999) reported that such high dilution results in wastewaters that have very low solids concentrations, which are often in the range of 0.2 to 1.5% total solids content. According to Fleming (1986), if the size of particles can also be reduced, this helps avoid plugging of transfer pipes from build-up on rough surfaces inside a piping system due to larger solid particles. Reduction in size of particles in manure can be achieved by a solid-liquid separator. He listed several advantages and disadvantages to reducing the amount of solids in manure and reducing the particle size of the solids, as well. The advantages include: 1) less possibility of plugging transfer pipes, 2) less power needed to pump the same volume of material, 3) much easier to irrigate, 4) reduced agitation time, 5) other uses for the solids, such as recycling for bedding material, 6) other uses for the liquid, such as for in-barn flushing systems, and 7) odor control. The disadvantages include: 1) relatively high cost when considered on its own, 2) regular maintenance is required to avoid breakdowns on mechanical systems, 3) extra space is needed to accommodate the system, 4) two separate manure handling systems are needed, one for liquid and one for solids, 5) some systems have high energy costs to operate, and 6) there is an increased management requirement.

Hill and Tollner (1980) reported that most of the organic nutrients in swine wastewater effluents are contained in fine suspended particles that are not separated by available mechanical separators. Similarly, Sievers et al., (1994) indicated that separation of suspended solids from animal wastewater using screens and presses is very inefficient, and requires chemical coagulation to bind together the small particles of solids in manure into larger clumps. For example, in a study conducted in North Carolina, Vanotti and Hunt (1999) reported that only 5-13% of the total suspended solids (TSS) was removed with 1-mm opening screen. However, when they used polyacrylamides (PAM, high molecular weight, long chain, water-soluble polymers), higher (>90%) TSS removal efficiency was obtained. As a result, they suggested that use of PAM polymers has a potential for efficient separation of manure solids and nutrients and such technology can provide an attractive alternative to existing liquid manure management methods, promoting the transportation of nutrients from nutrient-rich to nutrient-deficient areas.

The design and selection of proper solid-liquid separation equipment requires understanding of the particle size distribution of manure solids and distribution of various chemical constituents among the particles of different sizes in different types of animal manure (Zhang and Westerman, 1997). After reviewing previous research findings, they concluded that fine particles in animal manure decompose faster than coarse particles and most of the reduced carbon compounds, protein, and nutrient elements (especially nitrogen and phosphorus) are contained in the fine particles. Having considered such compounds to be the precursors for odor generation, they suggested that solid-liquid separation processes should be designed to remove fine particles (smaller than 0.250 mm) effectively, as well as coarse particles, to cause a significant impact on reducing odor generation potential.

Solid-liquid separation techniques involve physical separation with sedimentation basins (by using the effects of gravity) and mechanical devices and chemical treatment to facilitate the physical separation process (Fleming, 1986; Zhang and Westerman, 1997). While the separation processes include sedimentation, screening, centrifugation, and filtration (pressing), sedimentation and screening are the most commonly used techniques for solid-liquid separation of liquid animal manure. Sedimentation (gravity separation) involves a settling pond or basin whereby the flow of the liquid is slowed down to a point where solid particles settle and is considered a fairly simple and most effective means of separating the solids from liquid manure (flushed manure or feedlot runoff). Figure 17 shows an example of liquid-solid separation using sedimentation in 2-stage storage.

Solid-liquid separation can be performed mechanically in two ways: a) size separation by screening, and b) size separation by centrifugation. The use of mechanical separators has the following advantages (Fleming, 1986):

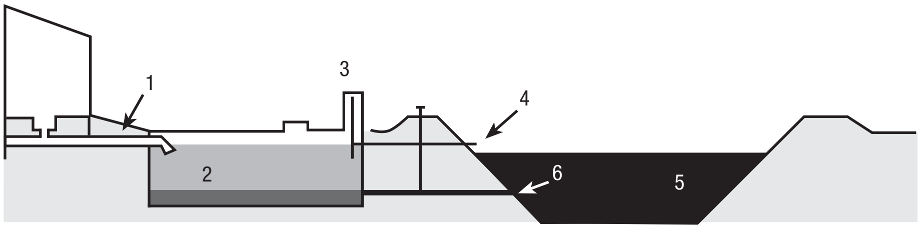
- The separated solids portion has lower moisture content and can usually be handled as solid manure.
- Most systems are better equipped to remove large floating or suspended particles.
- Less space is needed.

It is expected that the amount of solids removed by such mechanisms varies from about 40 to 80%. Both Fleming (1986) and Zhang and Westerman (1997) presented detailed discussions of the solid-liquid separation techniques and equipment. Following is a brief description of the different types of techniques and equipment taken from their work.

The mechanical separators used for solid-liquid separation include: stationary screen, vibrating screen, rotating screen, and centrifuge separators. The stationary rundown (inclined) screen (Figure 18) is considered the least expensive mechanical separator which uses slow relative motion between the manure and the screen whereby the liquid manure flows (pumped) onto an inclined screen by a force of gravity. The separation process takes place by the liquid passing through the holes of the screen whereas the solids move down the inclined face of the screen to a collection area. Absence of moving parts and the resulting low maintenance and no power requirement are the most attractive features of the stationary screen separator.

As opposed to the stationary screen, vibrating (Figure 19) and rotating (Figure 20) screens employ continuous motion of the screens to aid in the separation. As the names imply, the vibrating screen separator uses a rapid vibrating motion whereas the rotating screen uses a rotating motion of the screen to facilitate the movement of the separated solids across the screens and reduce clogging of the screens. There is a power requirement involved with these separators.

Centrifuges as well as hydrocyclones employ centrifugal forces (forces that help to speed up the gravitational separation) resulting from spinning the manure to cause separation. Figure 21 shows an



1. 8-inch main sewer from barns, gas-trap elbow at outlet
2. Concrete sedimentation tank, 1/5 of total storage volume
3. Hand-cranked stopper valve in ABS pipe tee, opens 300 mm below liquid surface
4. 6-inch pipe drain to #5
5. Clay lined storage pond, 4/5 of total storage volume
6. Return pipe and gate valve

Figure 17. *Solid-liquid separation using sedimentation in 2-stage swine manure storage.*

Source: Fleming, 1986.

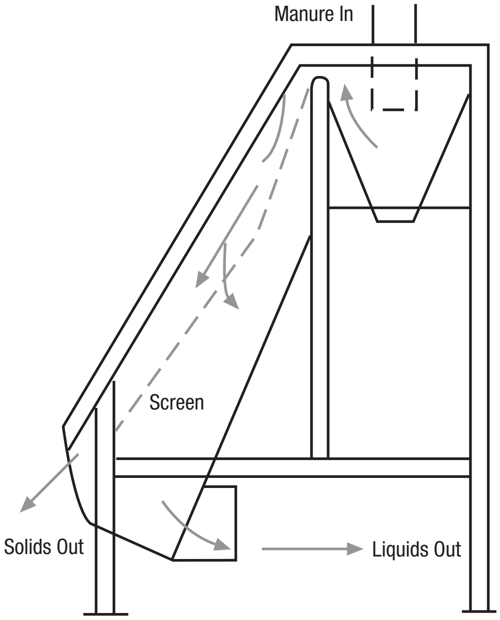


Figure 18. *Stationary rundown separator*

Source: Fleming, 1986

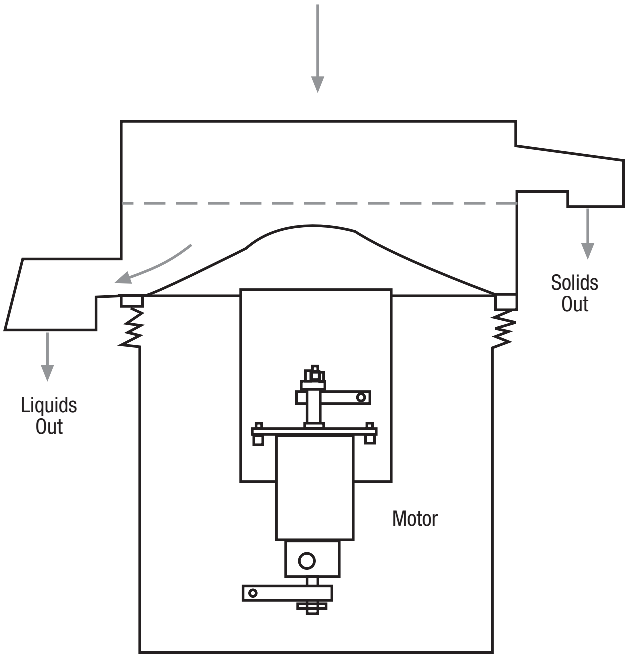


Figure 19. *Vibrating screen separator*

Source: Fleming, 1986

example of a centrifuge that uses a closed cylinder of continuous motion in which an auger turning at a slightly higher speed than the cylinder moves the solids to the conic part where they are discharged. Contrary to centrifuges, hydrocyclones do not have moving parts and the liquid itself performs the required vortex motion. Figure 22 depicts a hydrocyclone that consists of a cone tangentially to the circle near the top. These systems can be very effective in separating the solids form the liquids; however, they require high initial cost and energy as compared to other systems. Several other mechanical separators, such as vibrating screen with screw press, cyclone, roller press, brushed screen, rotary screw press, and porous belt press, are available on the market, and individual assessment of the merits of each of these separators is imperative when making selection and use of any particular separator. In their conclusion, Zhang and Westerman (1997) suggested the need for chemical treatment of manure prior to physical solid-liquid separation due to the relatively low efficiencies of the available equipment. According to them, the purpose of the solid-liquid separation and the intended use of the separated solids are the main factors to be considered when selecting a

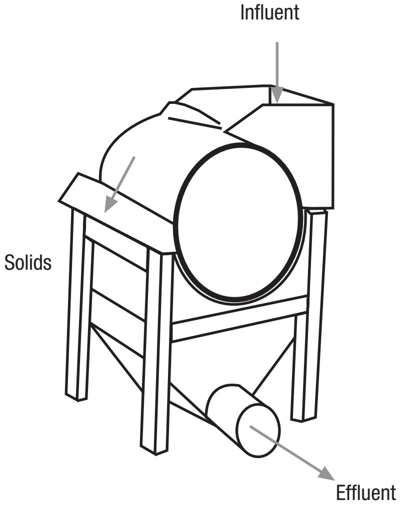


Figure 20. *Rotating screen separator*

Source: Hegg et al., 1981.

separation unit. The screens alone may be sufficient for the purpose of removing coarse particles for easier manure handling. For the purpose of odor control and nutrient removal, separators that are capable of removing fine particles, perhaps coupled with chemical treatment, are needed.

3.1.4 Composting

Composting is a biological manure treatment in which organic materials such as fresh manure, sludge, leaves, paper, and food wastes are converted to a more stable soil-like material called compost by the action of micro-organisms (Rynk et al., 1992; Larney, 1999). Composting involves aerobic decomposition of the organic material to produce the humus-like material known as compost (SAF, 2002), which is relatively resistant to further decomposition (Foth, 1990). The process of composting animal manure results in conversion of the manure into an easily manageable, nutrient-rich soil conditioner and soil amendment (Chaw and Abiola, 1999). Implementation of composting in manure management tends to shift the focus from disposal to resource management. Eghball (2000) indicated that composting is a useful method of manure treatment whereby a stabilized product is produced that can be stored or spread with little odor or fly breeding potential. Therefore, composted manure can be applied to the soil as an odorless and relatively dry source of nutrients compared to non-composted manures (Eghball et al., 1997). Well-finished compost has been reported to have a pleasant, earthly odor and a colour that generally varies from dark brown to black (SAF, 2002).

Haug (1980) stated three main goals of composting:

1. to serve as a source of organic matter for maintaining or building supplies of soil humus, which are necessary for proper soil structure, moisture holding capacity and fertility,
2. to improve the growth and vigor of crops in commercial agriculture or home related uses, and
3. to reclaim and replace certain valuable nutrients in the soil including nitrogen, phosphorus, and a wide variety of essential trace elements.

Other more recent studies have shown that composted manure can be effectively used for crop production. For example, in a study conducted in south-central Nebraska, application of composted beef feedlot manure resulted in corn silage yield that was similar to the yield from commercial fertilizer application (Ferguson and Nienaber, 1995). Schlegel (1992) reported that application of composted manure plus fertilizer resulted in greater sorghum grain yield than either source applied alone.

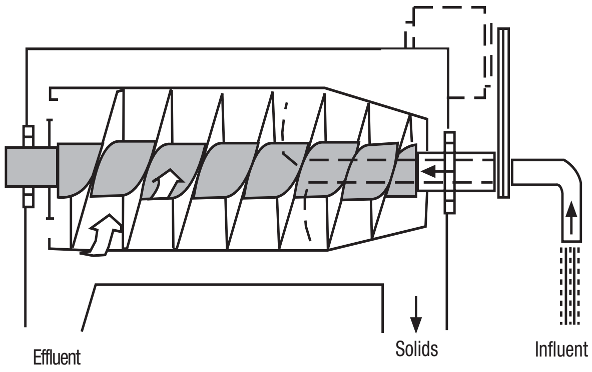


Figure 21. Horizontal decanter centrifuge

Source: Glerum et al., 1971.

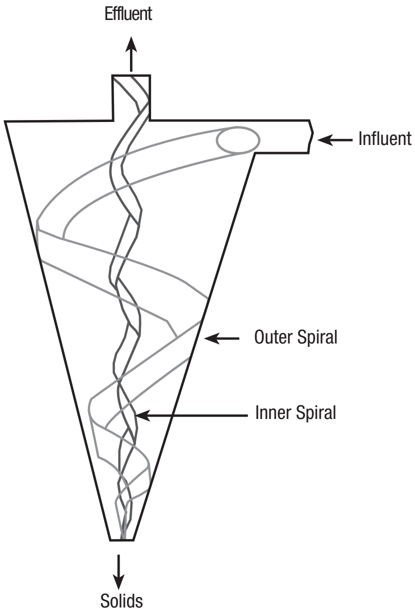


Figure 22. Hydrocyclone

Source: Shutt et al., 1975.

Composting manure occurs through biological activity and chemical reactions that provide the heat required for composting the manure (Eghball and Power, 1994). Normally, composting begins as soon as appropriate materials are piled together whereby initial mixing of the raw materials introduces enough air to start the process (Rynk et al., 1992), the same way as decay of leaves and other organic debris take place in nature. When it occurs naturally, the process of composting takes a very long time; however, with the development of new technologies it has been made easier and faster and it is possible to do on a much larger scale. Artificially, this can be achieved either by passive air exchange (natural convection and diffusion) or by active (forced) aeration (blowers/fans) that provide aeration continually to recharge the oxygen supply required (Rynk et al., 1992). Thus purposeful composting as such is merely controlling the conditions that favour faster decomposition of the raw materials of compost. The composting process, as illustrated in Figure 23, is most rapid when conditions that encourage the growth of the micro-organisms are established and maintained (Rynk et al., 1992) and does not stop until the material is completely consumed. However, because the compost becomes relatively stable and ready for use before complete consumption of the material, it should be judged to be "done" based on the characteristics related to its use and handling such as C:N ratio, oxygen demand, temperature and odor.

In a study that compared active vs. passive composting of feedlot manure in Alberta, Larney (1999) reported that active composting performed better than passive composting. When cutting the passive windrows, he found that a large portion of the centre of the windrow had the appearance of fresh manure indicating that the manure was only partially composted, perhaps due to limited supply of oxygen. Besides forced aeration, the use of mechanical equipment to agitate or turn the composting material on a regular basis in the active composting secures the necessary amount of oxygen for complete composting. However, active composting involves large overhead cost and may be justified only for large operations.

The physical changes that occur during composting include reduction in volume, moisture content, concentration of nutrients and carbon/nitrogen ratio (Larney, 1999). This allows for storing and transporting the composted manure with greater ease and lesser negative impact on the environment as compared to fresh manure. Moreover, the lower C/N ratio reduces immobilization of N in the soil following land application of the composted manure. A summary of some of the benefits and drawbacks of composting is presented in Table 3.

There are several methods of composting. Rynk et al. (1992) generalized them into four groups: passive composting, windrows, aerated piles, and in-vessel composting. Passive composting is done by simply stacking the raw materials of compost in piles to decompose over long time of period with little agitation and management. In contrast, windrow composting involves placing the mixture of the

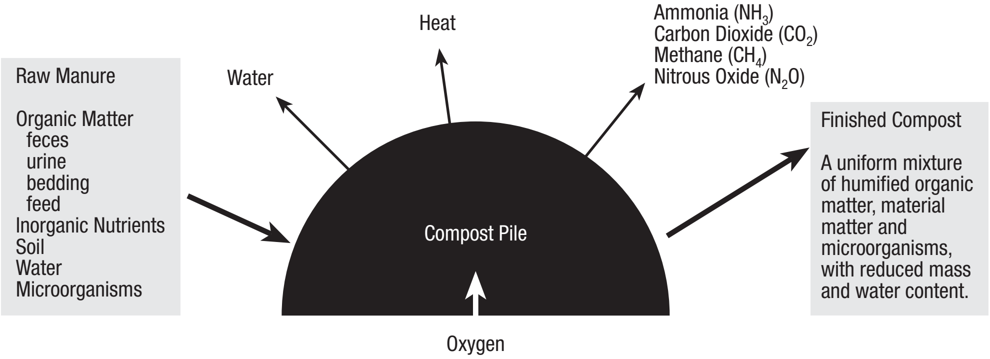


Figure 23. The composting process *Source: SAF, 2002.*

raw materials in long narrow piles (windrows) and agitating or turning them regularly. In passively aerated windrow methods, the need for turning is eliminated by supplying air to the composting materials via perforated pipes embedded in each windrow. In aerated static pile methods, blowers are used to supply air to the composting material, which is a step beyond the piped aeration system. In-vessel composting methods consist of a group of methods that confine the composting materials within a building, container, or vessel and they rely on a variety of forced aeration and mechanical turning techniques to speed up the composting process. A summary of the advantages and disadvantages of three composting methods are given in Table 4.

3.2 Composition

Manure is a natural by-product of animals that contains complex organic compounds originating from the undigested and wasted feed as well as simple organic and inorganic compounds produced in the gastric intestinal track of animals (Zhang and Westerman, 1997). Manure varies highly in its chemical and physical properties. There are several factors responsible for the high variability in properties of animal manure such as the physiology of the animal, the feed ration, and the environment (Hermanson and Kalita, 1994). The type of animal (ruminant versus monogastric) and age are important physiological factors. Sex, breed, age and activity of the animal also affect the manure properties by way of partially determining the feed conversion efficiency under a given environment. Manure quality also varies with handling and storage systems (Lindley et al., 1988), and temperature plays an important role in such systems. For example, up to 66% losses of N from hog manure during collection and 15% losses of N from dairy manure during storage have been reported (Schulte et al., 1985; Welty et al., 1985).

The feed ration is an important factor in determining the characteristics of manure. Variability in feed digestibility, protein content, fiber content and other feed elements affect the composition of manure (Hermanson and Kalita, 1994). Highly digestible feedstuffs in rations can effectively reduce excretion of nitrogen and other nutrients whereas low quality protein sources (such as hydrolyzed hog hair meal) and high levels of crude fiber can increase nitrogen excretion (Kornegay and Verstegen, 2001; Kornegay, 1978a; Kornegay, 1978b). For example, in Australia, the starch content of the manure produced by cattle fed on dry-rolled sorghum rations was five times that of manure produced by cattle fed on steam-flaked sorghum, dry-rolled barley and steam-flaked barley rations (Tucker and Watts, 1993). The average ash content of the manure from cattle fed on barley and steam-flaked sorghum rations was about 32% greater than the ash content in the manure from the cattle fed on the dry-rolled sorghum ration. The average volatile solids content of the manure from the cattle fed on the dry-rolled sorghum rations was about 40% higher than the manure from the cattle fed on the barley and steam-flaked sorghum. The average pH of the manure

Table 3. *Benefits and drawbacks of manure composting*

Benefits of composting	Drawbacks of composting
• Destroys weed seeds and pathogens • Decreases bulk of raw inputs (estimated shrink factor 50 – 75 per cent) • Finished compost has a consistent soil like quality that makes it easier to handle and apply • Stabilizes nutrients as organic compounds • Stable organic nutrients release more slowly, providing plants with a more sustained source of nutrient for growth • Results in an odorless, potentially marketable product	• Emissions of ammonia, carbon dioxide, methane, nitrous oxide and volatile compounds, especially in the early stages • Runoff from the compost piles must be controlled to prevent movement of nutrients to ground or surface waters • Aeration and moisture must be managed throughout the composting process • Time, equipment and land required • Some additional fertilizer may be needed to meet crop requirements

Source: SAF, 2002.

Table 4. Advantages and disadvantages of three composting methods.

Method	Advantages	Disadvantages
Windrow	Able to handle large volumes. Low capital investment. Rapid drying with high temperatures. High degrees of pathogen and weed seed kill. Drier product, resulting in easier handling of material. Good product stabilization.	Not space-efficient. Equipment (varies greatly in price) and labor is required for turning and monitoring. Vulnerable to weather changes (rain, snow, and drought). Odors released with turning. Bulking agents might be required.
Aerated Windrow or Static Pile	Able to handle large volumes. Low capital costs. Relatively space-efficient. High degree of pathogen and weed seed kill. Good odor control. Good product stabilization.	Not space-efficient. Operation and maintenance costs for blowers and fans. Loading and unloading equipment required. Placement of aeration system may present operational difficulties. Vulnerable to weather changes (rain, snow, drought, and cold).
In-vessel	Space-efficient. Good control of composting process with confinement and automation. Predictable, uniform product. High degree of pathogen and weed seed kill. Potentially good odor control. Protection from climate. Potentially not visible. Can be designed as a continuous process rather than a batch process.	High capital cost for sophisticated units with automated tuners, forced air and monitoring systems. Careful management required. Less flexibility in operation than other methods.

Source: SAF, 2002.

produced by the cattle fed on the barley rations was about 21% higher than that of the manure produced by the cattle fed on sorghum rations.

Feed waste is another potential factor that may greatly contribute to the variation among manure properties. For example, 5% feed waste can bring about an increase of up to 40% total solids in manure (Barth, 1985).

Kornegay and Verstegen (2001) reported that much of the phosphorus contained in corn-soybean meal diet is excreted because two thirds of the phosphorus in the meal is bound as phytic acid and is poorly available to pigs (Cromwell and Coffey, 1991). Lindley et al. (1988) reported that large differences in phosphorus concentrations occurred between samples of animal manure (hog and cattle) that were the results of different rations of feed. Feed rations containing barley and soybean oil meal resulted in the highest phosphorus concentration (4.3 $kg \cdot m^{-3}$ P_2O_5) in the manure as compared to an overall mean of 1.6 $kg \cdot m^{-3}$ P_2O_5; and feed rations containing barley and sweet clover gave the lowest phosphorus concentration (0.6 $kg \cdot m^{-3}$ P_2O_5). They did not observe any differences in total solids, nitrogen concentrations and potassium concentrations. There is currently research on low phytate barley and use of phytase enzyme in pig diets in order to reduce the amount of phosphorus concentrations in excreted manure.

Characteristics of manure from various animals have been reported in different publications (ASAE Standards, 1999; Midwest Plan Service, 1985; SAF, 1999; Schoenau et al., 2000). Generally liquid hog manure and solid cattle manure differ in their dry matter, nitrogen and carbon content as well as in their influences on microbial activity and physical and chemical changes in the soil (Ndayegamiye and Côté, 1989).

The characteristics and composition of cattle (dairy and beef) and hog manure are shown in Table 5. Such values could be used for estimating nutrients in a given manure. However, owing to the variation among manures, it is suggested that site-specific data are preferred to "average value" data. According to the values in Table 5, generally per unit weight of animal, hogs void greater amounts of fecal and urine nutrients (for most of the nutrient elements) as compared to dairy and beef cattle manure. This could be due to the differences in digestibility of the feedstuffs fed to the animals because it influences the excretion of nutrients. For instance, reduced excretion of nitrogen and other nutrients is expected from the use of highly digestible feedstuffs (Kornegay and Verstegen, 2001).

3.2.1 Physical

In terms of physical composition, liquid manure such as hog manure is a mixture of excreta (urine and fecal matter), which is composed of undigested and wasted feed components, endogenous components, and products from the activity of indigenous microorganisms along with the biomass of those microorganisms (Kornegay and Verstegen, 2001). In addition to these components, water is added to the manure following excretion in systems that use some type of water conveyance such as flushing for collection of the manure. Solid manure such as cattle manure is composed of both fecal matter and bedding material, such as straw, and hence has a higher dry matter content than liquid manure. Manure can be classified into three types, as shown in Table 6, based on its physical state (moisture content).

3.2.2 Chemical

Suspended solids (SS) and dissolved solids (DS), the sum of which makes the total solids (TS), constitute the chemical composition of manure (Zhang and Westerman, 1997). Each solids fraction is in turn composed of a volatile solids (VS) fraction, that is a measure of the amount of organic matter present in that solids fraction, and a fixed solids (FS) fraction, a measure of the amount of inorganic matter present (ash content). Accordingly, there are corresponding volatile solids fractions and fixed solids fractions of the TS, SS, and DS.

Zhang and Westerman (1997) indicated that the amount of organic matter that is present in manure could also be determined by two other means: chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Chemical oxygen demand is the quantity of oxygen required to chemically oxidize the organic matter in the manure whereas biochemical oxygen demand is the quantity of oxygen required to biochemically oxidize the organic matter in the manure, which is the measure of the amount of biodegradable organic matter. It is typical to do five-day biochemical oxygen demand measurement (BOD_5); however, COD is usually preferred to BOD_5 due to a lesser time requirement for the laboratory analysis procedure for COD.

3.2.3 Salts

Salts are among the chemical constituents of manure. Some of the soluble salts include: Na, Ca, Mg, SO_4-S, Cl, K, NH_4-N, and NO_3-N (Chang et al., 1991). As is the case with other constituents of manure, the levels of these salts in manure varies depending on factors such as the type of feed the animals are fed. Manure from animals fed on feedstuff with higher salt concentration would have higher levels of salts and vice versa. For example, Sutton et al. (1984) reported that dietary salt (NaCl) levels of hog rations directly affect Na concentrations in manure. Increases in salt levels of soils that received manure have been reported in several studies (Chang et al., 1991; Assefa, 2002).

3.2.4 pH

Manure also exhibits variation in its pH value. For example, Malley et al. (1999) reported the pH value of the hog manure from various types of hog operations in south-eastern Manitoba ranged from 6.8 to 8.1. The pH of the cattle manure Assefa (2002) used in the Peace River Region of Alberta was around 9 whereas Chang et al. (1991) reported an average pH value of 7.2 for the cattle feedlot manure they applied annually for 11 years in southern Alberta. The pH of manures used in a study conducted over a four-year period in east-central Saskatchewan, were in the range of 7.7-8.1 for cattle manure and 7.6-8.1 for hog manure (unpublished data). Bate et al (1988) reported that pH values in liquid hog manure would be affected by the loading rate during collection and temperature. Under high loading rates or low temperature, manure tends to be more alkaline due to inhibition of metabolism of the microflora under conditions in which populations of nitrifiers would be less and hence the mineralized nitrogen remains in the form of ammonia.

Table 5. *Characteristics of different types of fresh animal manure per 1000-kg live animal mass per day (wet basis). Typical live animal masses are: dairy, 640 kg; beef, 360 kg; and hog, 61 kg.*

		Animal type		
Parameter	**Units**	**Dairy**	**Beef**	**Hog**
Density	$Mg\cdot m^{-3}$	0.99	1.00	0.99
Total manure†	kg	86	58	84
Urine	kg	26	18	39
Total solids	kg	12	8.5	11
Volatile solids	kg	10	7.2	8.5
pH		7.0	7.0	7.5
Total N	g	450	340	520
NH_4-N	g	79	86	290
Total P	g	94	92	180
Orthophosphorus	g	61	30	120
Potassium	g	290	210	290
Calcium	g	160	140	330
Magnesium	g	71	49	70
Sulfur	g	51	45	76
Sodium	g	52	30	67
Chloride	g	130	NA	260
Iron	g	12	7.8	0.33
Manganese	g	1.9	1.2	1.9
Boron	mg	710	880	3100
Molybdenum	mg	74	42	28
Zinc	mg	1800	1100	5000
Copper	mg	450	310	1200
Cadmium	mg	003	NA	27
Nickel	mg	280	NA	NA
Lead	mg	NA	NA	84

Source: ASAE Standards (1999).

† Feces and urine as voided.

NA denotes data not available.

Table 6. *Classification of manure by moisture content.*

Type of manure	**Moisture content**	**Ease of pumping**
Liquid manure	>90%	Easy to pump
Semi-solid manure	80-90%	May be difficult to pump
Solid manure	<80%	Cannot be pumped

Source: SAF (1999).

3.2.5 Nutrients

The nutrient contents and forms of animal manure vary considerably depending on the type of livestock, manure handling systems and type of ration used to feed the animals. For this reason, although tables of typical manure nutrient contents (such as Table 5) are available, to date only a laboratory analysis of a representative sample of manure from a given source will give the best indication of the nutrient value of the manure. In general, animal manure contains macro and micronutrients required by plants, such as nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, copper, manganese, zinc, boron, iron, etc., as indicated in Table 5. However, some of the nutrients in manure exist in the organic form and need to decompose or mineralize into inorganic form to be rendered plant available and as such animal manure is a more slowly available source of plant nutrients as compared to commercial fertilizers.

Typical nutrient contents in liquid hog manure and fresh cattle pen manure as studied in Saskatchewan are shown in Table 7. The studies have revealed that 30% to 90% of the total N contained in the liquid hog manures existed as ammonium whereas the rest of the N existed in organic form of which 20% to 30% would be mineralized to plant-available form in the year of application (Schoenau et al., 2000). In cattle manure, in contrast, only 10% to 20% of the nitrogen is present as ammonium while the rest of the N is present in the organic form. The study also indicated that 10% to 50% of the total P in the liquid hog manure was present as readily soluble inorganic phosphate, and of solid manures poultry manure had the highest P content. Potassium in manure is present in a readily plant-available form, and hence manures are effective sources of potassium for plant growth. Some manures also contain a considerable amount of sulfur; however, manures like liquid hog manure tend to be low in their sulfur content.

Due to the complexity of micronutrient chemistry in manures, there is limited information on the forms and availability of micronutrients in manure; however, it is well known that manures also contain micronutrients. Schoenau et al. (2000) indicated that micronutrient metals may be present in manures as soluble free and complexed cations as well as insoluble inorganic and organically bound forms.

3.2.6 Other Constituents

In response to public concerns about antibiotic resistant bacteria and hormones in the environment, a new field of manure research has been initiated to determine the content of anti-microbials and hormones in manure and their associated persistence when land-applied. Very little published information exists regarding this issue and studies are currently underway in Western Canada to address these issues.

Table 7. Typical nutrient contents in liquid hog manure and fresh cattle pen manure samples in Saskatchewan.

Nutrient	Liquid hog manure (feeder hogs) Pounds per thousand gallons	Fresh cattle penning manure (with straw bedding) % on dry weight basis
Nitrogen (N)	15-50	0.5-1.5
Phosphorus (P)	1-20	0.5-1.5
Potassium (K)	8-20	0.8-1.5
Sulfur (S)	0.1-3	0.08-0.15
Copper (Cu)	0.05-0.5	0.01
Manganese (Mn)	0.05-0.5	0.02
Zinc (Zn)	0.05-1.0	0.02
Boron (B)	0.01	0.005

Source: Schoenau et al. (2000).

3.3 Gaps

Some gaps identified are as follows:

There are opportunities for adding value to manure through various treatment methods to increase the nutrient concentration and ease of handing and application. Technologies associated with composting, nutrient amendment and biochemical treatments should be further explored to make manure an economically exportable commodity to farther locations. Furthermore, the agronomic, environmental and economic performance of such value added manure products should be rigorously investigated.

Further work is required in animal feed formulation aimed at reducing nutrient excretion and producing desirable proportions of each nutrient contained in manure to meet crop requirements. Undesirable constituents of manure such as high content of sodium in relation to calcium and magnesium could be addressed through feed management or manure treatment.

There is limited information on appropriate rehabilitation practices for decommissioned manure storage, handling systems. While this is not a current concern, such issues may arise in the future and there is a need to have best management practices established for such aspects as excavation and fill of old storage units. This may also impact on the design of new storage units that should have decommissioning consideration as part of the overall design and construction criteria.

4

Sound Management Practices for Land Application and Handling of Manure: A Summary

4.1 How Much Manure Should Be Applied?

The goals of manure application to farmland should strive towards sustainable use of manure as a nutrient resource that maintains soil nutrient balance for optimum crop production and environmental quality, now and in the future. In the past, it was common practice to continue to apply commercial fertilizer to manured fields, even to fields that had received large quantities of manure. Past difficulties in predicting nutrient availability from manure might have led to the application of excess nutrients in the interest of ensuring nutritional sufficiency throughout the growing season. However, excess nutrients that accumulate in the soil are susceptible to loss from the soil by leaching, runoff and gaseous evolution. This not only represents a waste of the nutrients, but entry of lost nutrients into water bodies and the atmosphere poses an environmental threat. Ensuring that the amounts of manure and commercial fertilizer nutrient that are applied to a land area over time are in balance with the removal of nutrients from the system in crop harvest is key to preventing excessive accumulations of nutrients in the system.

As manures do not usually have the appropriate balance of available nutrients to meet the crop's relative nutrient requirements, application of manure to meet the requirement for one nutrient element can invariably result in the over- or under-application of other nutrients. As manures are not "off-the-shelf" fertilizers, nutrient management in manured fields requires consideration of nutrient balances as well as rates of individual nutrients. Therefore, when applying manure at rates according to a nitrogen or phosphorus based requirement, the availability of other nutrients should be considered and supplemented with commercial fertilizer if necessary. Research in the last decade has contributed to the development of tools to better predict the appropriate rate of manure and commercial fertilizer to achieve the crop nutrient requirements without loading of the soil with excessive amounts of nutrient. Such tools include manure rate recommendation software offered by private labs and government agencies that, based on manure analysis and soil testing, provide recommendations for the appropriate rate of manure to apply. Included in the software are predictions of availability of nutrients in the manure source added, which is a major step forward in managing manure as a fertilizer.

Consideration of the expected crop response to applied nutrients must be part of the rate selection process. The application rate of nutrient as manure and fertilizer should be in line with the anticipated crop nutrient demand. This consideration is built in to the recommendation systems and recommendations generated by the soil-manure testing/fertilizer recommendation agencies. Under-application or over-application should be avoided. Crops can suffer from deficiency and injury as a result of under-application and over-application, respectively, both of which lead to reduced yield. When manure application rates are at such a level that they are producing problems in the crop like delayed germination, lodging and haying-off, these same high rates are usually also associated with accumulation of excessive amounts of nutrient in the soil and subsequent nutrient loss. Under-application of a nutrient in a manured soil can also result in less efficient use of other manure nutrients. For example, application of manure with high available phosphorus content relative to available nitrogen can result in inefficient use of the applied manure phosphorus if additional nitrogen is not added to promote high crop yield and uptake of the phosphorus.

Because manures contain varying levels of salts and minerals, long-term monitoring of soil salinity, sodicity and micronutrient content should be conducted along with macro-nutrient levels over time, especially in fields receiving repeated applications of manure over a number of years. Particularly, soils that already have limited downward leaching and percolation due to restricted drainage and/or dry conditions should be watched closely for accumulation of salt and the development of a sodic (sodium affected) layer near the soil surface that may interfere with germination and emergence due to surface soil crusting. Salinity and sodicity thresholds vary depending on the salt-sensitivity of the crop, but some crops such as fruit trees and some vegetables have very low tolerances to salinity and sodicity.

The amounts, forms and availability of nutrients in manure, nutrients available in the soil, the crop nutrient requirement, environmental conditions, and long-term effects on soil quality should be considered when determining application rates. Manure and soil analysis, and forecasting of crop nutrient requirements before application are essential tools in managing manure for optimum agronomic and environmental benefit.

4.2 How Should the Manure Be Placed in the Field?

Placement of manure, as with inorganic fertilizers, is an important management issue that affects the accessibility and utilization of the manure nutrients by plants and the likelihood of loss before the plant has a chance to use them. For example, under dry conditions, surface-applied manure nutrients may be stranded from crop roots by remaining in the dry, surface layer or in the case of low density solid manures, re-distributed by wind. With heavy rain and high runoff, surface-applied manures are subject to loss by water erosion. Surface applications of manure of high ammonia and ammonium content are accompanied by inevitable losses of ammonia gas that reduces N availability to crops and represents a form of atmospheric N pollution.

Manure application equipment for in-soil placement that injects liquid manures such as hog and dairy cattle slurries in bands is now readily available and has been widely adopted on the Canadian prairies. Injection of liquid manure in bands about 3-4 inches deep has been reported to result in superior crop yield and nutrient recovery over broadcast and broadcast-incorporation applications for a variety of crops and conditions in Western Canada. For solid manures, broadcast and incorporation by operations such as discing to a depth of about 4-5 inches below the surface is the customary method of applying solid manure such as that from beef cattle. Lack of uniformity in distribution of solid manures and the requirement for extensive soil disturbance to incorporate solid manures, especially those of low density, continues to be a challenge in application and use of solid manures.

4.3 Recommendations

- *Long-term nutrient management:* A nutrient budget should be constructed for land areas receiving manure in which rates of nutrient application as manure and commercial fertilizer should be balanced with crop nutrient uptake and removal from that area over a period of several years. Records should be kept, and benchmark sites should be established in these fields from which soil samples are taken periodically to monitor the effects of long-term manure use on soil nutrient levels, organic matter, pH, salinity and sodicity.
- *Short-term nutrient management:* Annual testing of manure composition and soil nutrient levels should be conducted for manured fields and, using manure rate recommendation systems, an appropriate rate of manure nutrient and/or commercial fertilizer selected to meet the crop nutrient demands. Manures should be placed in-soil, rather than surface-applied, to increase crop root access to the manure nutrients and to reduce potential losses by runoff and volatilization.

4.4 How Should the Manure Be Handled?

Manure handling systems consist of four main components that include

1. collection,
2. storage,
3. treatment, and
4. use.

Manure application and use has been covered previously, but collection, storage and treatment considerations are another important part of manure management. The composition of manure is variable, depending on animal species, feeds, and feed additives, and it is also affected by the manure handling system employed. A unifying feature among manures is their low nutrient content per unit weight or volume. The low nutrient content restricts the distance they can economically be transported for land application to usually only a few kilometers away from the site of production, based on the value of the yield increase they produce when applied to the land relative to transport and application costs.

An important consideration in a livestock operation is the best form in which to handle the manure. This may be broken down into two categories: solid and liquid. Solid manures may be defined as those with less than 80% moisture content by weight, semi-solids with 80-90% moisture, and liquids with greater than 90% moisture content. Semi-solids may be difficult to pump and liquids are generally easy to pump. Many considerations affect the form the manure will be handled in, including capital cost and labor availability. It is possible that producers may use solid manure handling systems or liquid systems exclusively, or both solid and liquid systems, depending on the type of operation and size. It is a challenging task to select between the two systems because of the consideration that has to be given to two important issues: cost effectiveness and environmental safety. Generally, small livestock operations tend to favor low capital cost solid systems while large operations will utilize higher capital cost mechanized systems, which are more suited to handling manure in liquid form. Some operations such as feedlots, due to their nature, are restricted to handling manure only in the solid form.

Advantages of handling manure in liquid form include ease of mechanization and low labor requirements, and the ability to apply manure in the field more uniformly and precisely. Disadvantages to liquid manures can be a greater susceptibility to odor problems during storage and application. In the prairies, earthen storage units are commonly used to store liquid manure because of advantages in low cost per animal unit, large storage capacity and ability to handle manure with conventional pumping and irrigating equipment. Odor issues surrounding the storage may be addressed by covering the storage with good quality cereal straw. Advantages of solid manure handling systems include lower complexity, less offensive odors produced during storage and application, greater nutrient retention, and a lesser volume of lower density to handle. Disadvantages of solid manures are the need for impervious pads or concrete for storage and the need for a containment pond to store liquids originating from the rainfall washing off the manure pile. Furthermore, solid manures must be trucked to the field, rather than pumped, which adds to labor requirements.

Solid-liquid separation and composting are two approaches that may be used to overcome some of the limitations associated with straight solid or liquid manure handling systems. Production of nutrient-rich organic solids through separation, odor reduction and improvement in economics of subsequent liquid manure treatment processes due to reduced organic load are reported to be advantages of these treatment strategies. Use of the manure solids for energy generation (biogas) is another treatment option that is more widely used in Europe and in early stages of development in Western Canada. Composting of solids involves aerobic decomposition of the organic material to produce humus-like stabilized material that can be stored or spread more uniformly with little odor and contributes to soil quality by improving fertility and tilth. Approaches to composting of solid manures can be simple as in passive stockpiling, or complex as in active aeration or in-vessel systems. Proper aeration is the key to achieving good compost, whether this is achieved through windrow turning or supplying oxygen through a forced air system. Active composting can involve large overhead costs and may be justified only for large operations. Producing good compost is a blend of art and science, and bad composting can produce as many potential problems with odor and nuisance as fresh manure.

4.5 Requirements for Additional Information

There must be balanced application and recovery of the nutrients applied in any farming system if that system is to be deemed “sustainable” over the long-term. Balancing of the system requires “fine-tuning” to ensure that nutrient requirements of crops are met. This can be accomplished through use of manure and commercial fertilizers together. Future manure research trials should include treatments with supplemental commercial fertilizer to determine which combinations are optimal in maximizing crop yield and nutrient recovery. These combinations should be built into future nutrient recommendation systems.

Producers are sometimes reluctant to manage manure as a nutrient source for crop production due to failure to recognize or have confidence in the value and nutrient content of manure, or the lack of sufficient labor and methods for effective manure application. This needs to be addressed by creating awareness among producers and further development of suitable equipment and methods for manure application. The precision application of a variable product like manure to soils is a daunting task. However, precision manure management is believed to have the potential to further improve production efficiencies.

Selection of the best manure handling system involves a myriad of factors that must be considered. The best system in terms of collection, storage, and treatment will be affected by available capital and size of operation to spread the cost across, regulations and requirements for storage and transport, and the market for the manure product produced. The marketability of the manure product is an important consideration in Western Canada that deserves further study, since most soils can benefit from the added organic matter and nutrients, particularly around new livestock operations. As adjacent land-owners have come to realize the value of manure and compost in enhancing soil quality and crop production, a market has developed for the manure, often in the form of a farmer covering part or all of the application costs. Future manure handling systems should be designed around the concept that the manure is a resource and should enable both the livestock operation and manure recipients to reap the most benefit from the manure as a soil amendment and fertilizer.

Some specific gaps identified in this review that need to be addressed are listed below:

- Further studies are needed to evaluate the long-term effects of repeated manure applications on various aspects of soil and environmental quality. This is necessary in part to satisfy concerns raised by the general public as to whether land application of manure is a "safe" practice environmentally, as well as ensuring sustainability of the agricultural resource. This would include examining the effect of repeated manure applications on soil microbial populations, soil physical properties such as structure, chemical properties including nutrient load, salinity, and sodicity, and hydrological properties such as water infiltration. Questions are also raised about the potential entry into the environment of hormones, antibiotics and viruses from manured lands. More field research is needed with all types of manure, including composted products, to cover the variety of soil-environmental conditions present in Western Canada.
- There is a need to take physical response data (i.e. yield, protein increases) associated with application of manure nutrients observed in field trials, and apply economic analyses to determine the net benefits of manure application and economic transportation distance. Such economic analyses should be applied to new approaches to manure handling and transportation as well.

- Technologies for handling and applying solid manure with increased uniformity and precision in rate of application and placement are needed to ensure maximum benefit is obtained from the nutrients and organic matter contained in the manure. For example, new engineering approaches to solid manure spreading and possibilities for in-soil placement could be examined.
- Process studies to obtain more accurate, site-specific estimates of rates of nutrient losses from manured fields, including per annum losses by leaching, runoff, volatilization, and denitrification that can be used in nutrient budgeting are needed. Research is also needed that would contribute to more accurate estimates of rate of release of available nutrients from organic forms contained in manure.
- For precision manure application in the field and for documentation of nutrient loading rates, there is a need for continued development of technologies for "on-the-go" sensing of nutrient content and forms in manure during application. This should be coupled with technology to permit accurate metering of the manure based on the nutrient contents of the manure being sensed.
- To ensure that producers, applicators and recipients of manure are aware and capable of using the latest knowledge and tools (e.g. rate recommendation software) available for sound manure management, it is desirable to routinely update on a regular basis and deliver this information in the form of manure management training sessions or courses.
- There is a need to establish thresholds for nutrient loads in the soil based on identified risk or threat to environmental quality that account for the many facets (soils, vegetation, climate, topography, tillage system, etc.) that may make one threshold value appropriate for one area but not another. One approach might be to use geographic information systems to subdivide regions and establish suitable threshold values for each region. The accumulated database may then be used as part of regional or provincial nutrient management strategies, and permit extrapolation of research results and recommendations obtained from specific sites to other similar areas.
- There are opportunities for adding value to manure through various treatment methods to increase the nutrient concentration and ease of handing and application. Technologies associated with composting, nutrient amendment and biochemical treatments should be further explored to make manure an economically exportable commodity to farther locations. Furthermore, the agronomic, environmental and economic performance of such value added manure products should be rigorously investigated. The feasibility of biogas production and electricity generation from manure deserves further attention as well.
- Further work is required in animal feed formulation aimed at reducing nutrient excretion and producing desirable proportions of each nutrient contained in manure to meet crop requirements. Undesirable constituents of manure such as high content of sodium in relation to calcium and magnesium could be addressed through feed management or manure treatment.
- There is limited information on appropriate rehabilitation practices for decommissioned manure storage and handling systems. While this is not a large current concern, such issues may arise in the future and there is a need to have best management practices established for such aspects as excavation and fill of old storage units.

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