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LAND APPLICATION OF HOG MANURE: AGRONOMIC AND ENVIRONMENTAL CONSIDERATIONS THE CANADIAN PERSPECTIVE

by

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Introduction

Hog manure is not a waste product it is a valuable plant nutrient resource with the added benefit of improving soil quality. However, because of the complex nature of the material it can produce negative environmental impact on the environment when it is mis managed. In 1996, the Canadian hog population stood at approximately 12.2 million and was increasing in all provinces. Predictions are that not only will the number of hogs increase but the size of the production units will continue to increase. For example, from 1991 to 1996, the number of farms reporting hogs declined from 29,600 to 21,100, while the proportion of farms with more than 4,700 hogs increased from 10.9 to 23.3 percent. This rapid growth is fueled by an increasing international market demand for pork and pork products, particularly in Asia; environmental degradation and limited land base for manure disposal experienced by traditional competitors; and relatively low grain prices as a consequence of the demise of the Western Grain Transportation Act. For example in 1995, under the subsidized shipping cost of the WGTA, it cost a Manitoba producer $15.00 to ship one tonne of grain to the west coast, in 1997 the cost was $47.00 per tonne. Thus, rather than paying the high transportation cost to ship grain to foreign markets, producers are choosing to ship it to livestock producers within Western Canada. In 1997, all regions of Canada, from the Maritimes to British Columbia, reported increases in hog production. Capital and organizational expertise for the expansion appears to be readily available from feed companies, urban and foreign investors, but environmental issues appear to be the most important factor challenging expansion - odour, air pollution, soil and water quality. This paper will address only issues dealing with the management of land application of manure to enhance its agronomic effectiveness and to reduce the risk of environmental pollution.

Hog manure can be an asset to a pork producer and to agriculture when properly managed and utilized in a sustainable food production system. The increase in Canadian hog production has a positive impact on local economy, by increasing employment, and by providing alternative markets for feedstuffs (Larson 1991). However, hog operations generate large amounts of animal waste hence, manure storage and utilization have become important management considerations because of the potential for environmental pollution (Sutton et al. 1984a). On average, a hog produces 2 tons of manure each year (Larson 1991). Based on the 1996 Canadian hog population of 12.2 million hogs, about 24.4 million tonnes of manure is produced annually. In the past, disposal of manure was an economic liability because disposal costs exceeded the value of nutrients in the manure (McEachron et al. 1969; McKenna and Clark 1970). Because of the increasing cost of chemical fertilizer, the value of hog manure as a fertilizer has increased, although it is still not economically feasible to transport this dilute nutrient mixture more than a few kilometres. The value of hog manure nutrients spread close to the source of production has been estimated to be equal to the cost of field application (Saskatchewan Pork Industry Manure Management Recommendations, 1991).

In the Maritimes and British Columbia land availability for the use/disposal of hog manure and the threat of contaminating agricultural soil and surface and ground water supplies limits expansion. Similarly, expansion within Quebec is limited partly because of accumulation of very large quantities of phosphates in the soil and the risk of pollution of water supplies as a consequence of previous “overloading” of soil with hog manure (Simard 1996, Simard et al. 1996). Ontario and the prairie provinces are the regions with the potential for the greatest expansion because they have access to large supplies of relatively cheap feed grain and are perceived to have an “unlimited” soil resource for manure use/disposal. But, in these regions mismanagement of manure can increase the risk of soil and water pollution. Because of the large amount of hog manure produced by even modest operations, the risk of soil and water pollution is ever present with any hog operation in any part of Canada. Therefore, it is imperative that Best Management Practices (BMP) be tailored to minimize the impact of industry expansion in each of the eco-regions.

The objective of this paper will be to present a summary of the available information, Canadian and foreign, that can be used to develop BMP for hog manure management, and to identify the research and development gaps that must be addressed to enhance the process, in the shortest possible time frame, to ensure the economic and environmental sustainability of the hog industry in Canada.

Composition of Hog Manure

Hog manure is a valuable plant nutrient resource that poses environmental risks only when it is mismanaged. Therefore, land application is generally the most economical and environmentally acceptable means of disposal. However, if hog manure is applied in excess some of its components such as nitrogen, phosphorus, soluble salts and micro nutrients can cause environmental pollution. Sutton et al. (1984a) reported that hog manure contains essential plant nutrients that can be utilised for efficient crop production and to enhance soil properties. Plant nutrients are removed from the soil in the harvested product fed to the animals and returned to the soil as manure. There are wide variations in manure composition from livestock and also within different lots of a particular domestic animal. Azevedo and Stout (1974) reported that characteristic digestion processes and feed preferences of different species of animals are responsible for some differences in manure nutrient concentrations. For example, P is generally lower in ruminant manure than poultry and hog manure because of the ability of ruminants to extract organically-bound P from plant feeds. In general, on a compositional basis, hog manure contains higher total N and lower dry matter than beef manure (Table 1) (Evans et al. 1977). Similar values and large variation for hog manure (Table 1) composition are reported for all regions of Canada (Campbell et al. 1997, Goss et al. 1994, Bailey et al. 1997). The factors affecting the composition of manure are housing system, method of manure collection, storage, and handling (Azevedo and Stout 1974; Menzies and Chaney 1974; Powers et al. 1975; Vanderholm 1975; Gilberston et al. 1979). Generally 50% of N in the hog manure slurry is present in the ammonium N form and the remaining 50% in organic N form (Sutton et al. 1978; Sutton et al.1982; Sutton et al.1984a; Sutton et al. 1984b; Burns et al. 1987), although Kachanoski et al. (1997) reported levels of 65 to 90% ammonium N depending on water use of the piggery. The organic N consists of microbial N, labile organic N and stable organic N (Burton et al. 1994). Beauchamp (1983) determined that during a growing season approximately 20% of the organic N will be mineralized and become available, and that 25% of ammoniacal N will be volatilized resulting in a net availability of about 50% applied N for crop growth (Fig. 1). Vanderholm (1975) summarized research indicating NH_4-N losses of 10-99% from manure depending on the type of storage and system of treatment. The least loss was from aerated storage and the highest from feed lot surfaces and anaerobic lagoons. Al-Kanani et al. (1992) reported that use of sphagnum peat moss for lagoon cover reduced NH_3 losses by 75%. In general, losses of P and K are minimal (5% to 15%) except from open lot or from lagoon handling system where 40 to 50% of the P can be lost to run-off and leaching (Sutton et al. 1984a). Increasing levels of dietary salt (NaCl) and/or other mineral additives (Cu, As and other minerals) in hog rations directly affect the concentration of these elements in the manure (Sutton et al. 1976; Sutton et al. 1984a; Brumm and Sutton 1979). Thus, heavy application of manure from such sources may affect plant growth and may affect soil productivity.

Application: Methods, Time, Rate

The method, rate, and time of manure application depends on numerous factors including climatic conditions, soil properties, type of crop, and rate of mineralization of nutrients. Manure must be applied uniformly to minimize localized salt concentration, especially Na which can reduce germination and crop yields.

Methods: There are two principal methods of applying hog manure to arable land. The first is surface application (broadcast) using irrigation guns, dribble banding or splash-plate distribution from a tanker. The second system is direct injection or “banded” or “knifed-in”. In this latter system the manure is placed in the soil using a hollow tine preceded by a coulter to cut through the residue. The availability of nutrients, particularly nitrogen, differs between the two systems, principally because of differences in the potential for gaseous losses (Table 2). Knifing the manure into the soil not only enhances the recovery of nutrients by the crop but is recommended when there are severe odour problems. However, this procedure reduces the rate that can be applied. Vanderholm (1975) reported 5%, 15%, and 30-90% losses of NH_3-N from manure with ploughing down, discing, and surface applied systems, respectively. Hoeff et al. (1981) reported 0-2.5% NH_3-N losses with injection method of liquid hog manure compared with 10-16% from surface broadcast. The gaseous loss of nitrogen from manure after injection is mainly from denitrification (Thompson et al. 1987) (Table 3), while ammonia is the volatile product loss from surface application (Beauchamp et al. (1982). Paul (1991), reported that the total nitrogen available to crop is generally greater after injection than after surface application. Thus, in a BMP system for annual crops the injection technique should be used and when the manure is broadcast it should be incorporated within 24 hours to maximize its agronomic benefits (Sutton et al. 1984a; Alberta Agriculture 1984; Vanderholm 1975; Hoeff et al. 1981).

On forage crops and permanent pastures the injection method of manure application is slow and energy inefficient. The system uses a large amount of power and fuel. The broadcast method is generally preferred because of the relatively low power requirements. Bailey et al. (1997) and

Bittman (1998, personal communication) reported that manure nutrient use by the forage crop was good. Odour was reduced when the forage was about 15 cm to 20 cm high and the manure was applied through a hose that dragged on the bottom of the crop canopy.

Time: The timing of manure application is critical both for the availability of nitrogen to crops, and on the potential for environmental impacts. In most provinces application of hog manure is restricted to spring and fall. In Ontario and B.C., where winter temperature are moderate, winter application of manure is permitted, although in B.C. only 40% of the annual allowable rate is recommended for grassland or fall-seeded crops between the September to December periods . In Quebec, working with forage crops and grain corn on a silt loam soil Pesant et al. (1993) reported annual over winter losses of 160.8 kg NO_3-N for fall application of hog manure to grain corn compared to 94.5 kg NO_3-N for spring application. Losses of NH^+-N were also larger for fall than for spring application (Gangbazo et al. 1995). The authors also reported larger losses for phosphorus as a consequence of winter runoff and drainage compared to spring application (Fig. 2). The data also showed that phosphorus losses were greater for the fall applied manure to forages compared to application to corn even though the rates of applied phosphorus were smaller. On annual crops, spring application may be as a pre-plant or as a side- or top-dressing. Simard et al. (1998, personal communication) found that in Quebec on clay soil, hog manure was more efficient than dairy manure and composted dairy manure in suppling nitrogen to a corn crop, but time of application had no effect on nitrogen use efficiency (Fig. 3). In trials conducted in the Red River Valley of Manitoba, Schulte et al. (1979) reported that the amount of TKN and Ortho-P transported in surface runoff from plots receiving winter manure applications was equivalent to 12.0 and 7.9%, respectively, of the N and P applied in manure. Applying manure close to planting will maximize nutrient availability to the crop, especially in areas of high rainfall and highly permeable soils (Sutton et al. 1984a; Alberta Agriculture 1984). However, reduced germination and seedling growth could occur if planting is done immediately after heavy manure application because of salt accumulation. Thus, even though fall-winter application may cause 25-30% loss of N from manure, a longer field duration will allow soil microorganisms to decompose the manure and make the nutrient more available to spring seeded crops. In temperate climates, early spring application of manure may not be possible since it may be frozen in the pit particularly when stored in open lagoons (Bailey et al. 1997) . The loss of N from fall-winter application of manure can be minimized either by injecting it into the soil or by addition of a nitrification inhibitor (Thompson et al. 1987) (Table 3). To obtain the most efficient use of manure, the rate of application should be such that the amount of available nutrients is equal to the amount required by the crop. This is difficult to accomplish since the concentration of plant nutrient is not “balanced” to meet plant requirement. For example the average N:P ratio for hog manure is 4:1, but the amount of these two nutrient taken up by the major grain and hay crops are in the ratio of 7:1. Similar problems of “balance” ratio exist between N:S ratio in the manure and the requirements of crops. Further, the N in manure is present in organic and ammonium forms and in the first year of application only 45% of the manure N is mineralized. Larson (1991) reported that it takes about 5 years to mineralise 80% of the N from manure. On the other hand, almost all the P and K present in manure are available at the time of application. Bailey (1997), working on a permanent pasture, reported that when the nutrient content of hog manure (N, P, K and S) was balanced with inorganic fertilizer nutrient use efficiency increased producing greater yield of high quality forage (Fig. 4).

Rate: Traditional application rates of manure application is based on the nitrogen needs of the crop. In Quebec, B.C. and Ontario, because of this practice, bioavailable soil phosphorus levels are high in areas of intense hog production and has become an environmental problem. High levels of bioavailable phosphorus in the soil increased the risk of phosphorus migration and thus contamination of surface and ground water Sims et al. (1997). High levels of soil phosphorus also interferes with proper crop nutrition by restricting micronutrients (zinc) uptake (Grant and Bailey 1993a, 1993b). Simard et al (1996) reported that phosphorus migration from manure was crop dependent, migration was found to be greater for forage crops than for corn because the absence of tillage allows P to move through the network of soil biopores. The problem of phosphorus accumulation and migration in soils is exacerbated in Quebec and B.C. because of the limited land base for manure application. On the Prairies, the land base is sufficient to accommodate the current level of manure production in an environmentally acceptable manner, . Further, the soils are considered deficient in nitrogen and phosphorus (in many instances potassium and sulphur) and thus require annual application of nutrients for optimal crop production. The calcareous nature of the prairie soils restricts inorganic phosphorus mobility, thus inorganic phosphorus mineralized from manure rapidly combines with calcium and magnesium to form relatively insoluble and immobile products. But inadequate hog manure management, such as application of excessive rates of manure or applying rates to meet the nitrogen requirements of the crop, may create a risk to surface water contamination by runoff and erosion and the risk of downward movement of organic phosphorus to shallow aquifers. Heavy textured soils have low permeability and promote low rates of decomposition, hence the rate of manure application should be lower compared with coarse textured soils which are highly permeable and promote rapid decomposition of manure (Xie and MacKenzie 1986). On the other hand, high application rates of manure to coarse textured soils, in particular to annual crops, may contaminate ground water due to leaching of nutrients, in particular nitrates, phosphates and other soluble salts, while high application rates of manure on heavy textured soil may be beneficial because of the high nutrient holding capacity of these soils. On a course textured soil in Manitoba, Bailey et al. (1997) found no downward migration of nutrients out of the root biomass region when manure was applied to a permanent pasture at rates of up to 132,000 l ha^{-1}. To reduce surface migration of nutrients manure should not be applied on snow or frozen ground, particularly when the land is subject to rapid spring run-off (Larson 1991). Further, heavily manured fields should not be summer-fallowed to avoid leaching of N and the possibility of contamination of ground water.

Crop Yield and Quality

Numerous studies have been conducted on the effect of application of cattle and poultry manure on crop land (Powers et al. 1975). However, limited research has been done on crop responses, or on changes in soil chemical composition and ground water quality resulting from application of hog manure (Sutton et al. 1978).

Crop Yield: Manure is most frequently used for annual crop production because it can be applied before planting or after harvest. In Canada, manure is applied to a wide variety of annual and perennial crops. However, grasses and cereal grains because of their extensive root systems and relatively high nutrient requirements provide the best opportunity for large volume of manure application (Bailey et al. 1997). Also, grasses derive more benefit from manure than do legumes because of their higher nitrogen requirements, but legumes, because of their deeper rooting habits, are best at removing leached nutrient from the soil environment. Campbell and MacLeod (1997, personal communication) found greater leaching of NO_3 from manure applied to barley compared to soybean.

Hog manure application resulted in similar or higher crop and pasture yields than inorganic fertilizers (Fig. 4); Evans et al. 1977; Sutton et al. 1978; Sutton et al. 1982; Sutton et al. 1984b; Xie and MacKenzie 1986; Burns et al. 1987; Chase et al. 1991; Bailey et al. 1997). However, due to limited availability of N from manure at the time of application, the rate of manure in most tests was higher than inorganic fertilizers. On an equal N basis, Miller and MacKenzie (1978) reported lower corn grain yield and lower plant N recovery in the first year of manure application compared with inorganic fertilizer. However, because of the slow release of N from manures, residual N recovery from manure was twice that from inorganic fertilizer. In other studies, Xie and MacKenzie (1986) reported that 1 to 4 kg of manure-N had the same effect as 1-kg of urea-N on corn dry matter yield and N uptake. Long term studies with hog manure often do not show consistent year to year responses of crop yield to applied manure because of significant treatment x year interactions. Differences as high as 3500 kg dry matter/ha were reported between normal weather and dry weather and years when droughty soil conditions stressed corn plants during pollination (Sutton et al. 1984b). Increasing the rate of hog manure application increased crop yields, but yields varied depending on actual rate and method of application, type of soil and growing conditions. For example, Sutton et al. (1978) reported increases in corn yield with increasing rate of surface application of liquid hog manure varying from 0 to 134 t ha^{-1} on a silt loam soil. Chase et al. (1991) obtained increased corn yields with liquid hog manure surface applied or injected at 2000 gallons to 12000 gallons ha^{-1} on a fine loamy soil. On a silty loam soil, the injection of liquid hog manure increased corn grain yield an average of 2130 kg ha^{-1} compared with the broadcast method at similar rates (Sutton et al. 1982). The authors attributed the lower yield to NH_3-N volatilization from the broadcast manure. Similar findings were reported by Beauchamp et al. (1982). On the other hand, on a sandy loam soil, Xie and MacKenzie (1986) found no significant difference in corn yields between surface spreading and incorporation of manures.

Crop Quality: Hog manure has been shown to increase crop quality by increasing plant nutrient concentration not only in the year of application but also in succeeding years (Sutton et al. 1982). The authors reported higher corn leaf-N content from injected manure compared to broadcast. They attributed this result to losses of nitrogen from the surface application due to volatilization. In other studies, liquid hog manure was reported to increase leaf or seed nitrogen, phosphorus and potassium concentrations in grains (Sutton et al. 1982; Evans et al. 1977) or forages (Burns et al. 1987, Bailey et al. 1997) compared with inorganic fertilizers. Burns et al. (1985), working on nutrient recovery by Coastal bermudagrass, reported N, P, and K recoveries of (applied vs. removed) 73%, 41%, and 74% for low (13.7 cm), 57%, 28%, and 56% for medium (27.2 cm), and 34%, 17%, and 32% for the highest (53.6 cm) effluent loading rates. They concluded that nutrients in excess of quantities removed by crops were potential pollutants in surface and ground water, or soil. Excessively high rates of hog manure application to pastures may result in high levels of NO_3^--N in the forage making it unsafe for ruminants (Burns at al. 1990). Dietary salt or manure handling system had no consistent effect on plant composition in studies by Sutton et al. (1978) and Sutton et al. (1984b).

In contrast, Kornegay et al. (1976) reported increased corn leaf Cu, Zn, P, and K with hog manure from pigs fed high Cu diets (250 to 370 mg Cu kg^{-1}). In other studies, Zhu et al. (1991) reported increased plant growth and Cu uptake from Cu-amended hog manure compared to non amended manure.

Soil and Water Quality

Soil Quality: There is little to no information available on the effect of hog manure on soil physical properties. However, the effects of hog manure may be similar to those reported for cattle manure. Cattle manure has been reported to improve soil aggregation (Elson 1941; Williams and Cooke 1961; Hafez 1974), to lower bulk density (Hafez 1974; Tiarks et al. 1974), and to improve structure and water holding capacity of soils due to increased organic matter (Unger and Stewart 1974; Weil and Kroontje 1979). Sommerfeldt and Chang (1985), working on Chernozemic soil with three different tillage systems, reported increased soil organic matter and decreased bulk density, spring soil temperature, and drawbar draft on tillage implements with increasing rate of cattle manure. In general, soil structure is not a problem on soils with a history of manure application (Goss et al. 1994). On these soils, continued application would maintain but not further improve soil physical properties. However, manure application could result in significant improvement in soil physical properties of soils which had been cropped without manure application. The magnitude of this improvement would be site specific depending on the soil texture and the degree of structural degradation.

Changes in soil chemical composition due to application of liquid hog manure are variable and highly influenced by factors such as soil texture, rate, time and method of manure application, amount of precipitation, crops grown and time of sampling. Heavy application of manure increased NO_3^--N, available P and exchangeable K and Na more than did inorganic fertilizer (Evans et al. 1977). King et al. (1985) reported accumulation of NO_3^--N, Mehlich I extractable P and Na in subsoil from manure effluent application, the level of accumulation increased with increasing rate of manure application. Manures have lower N:P ratios than crop plants, we have seen that this can lead to sequestering of bioavailable soil phosphorus with subsequent mobilization leading to pollution of surface and ground water (Sims et al. 1997; Simard et al. 1996). At high rates of manure application, Ca and Mg may be displaced from exchange sites by competing ions present in the manure, such as Na^+, K^+, and NH_4^+, and may be leached from the top soil with some accumulation in deeper layers. Also, the H^+ produced during conversion of NH_4^+ to NO_3^- may successfully compete for Ca and Mg sites on the soil colloids and thus lower the surface soil pH (King et al. 1985). Bailey et al. (1997) reported a change of one pH unit in the top 45 cm soil from hog manure application to a pasture. Addition of salt or additives to the hog feed can change the hog manure composition and can accumulate in the soil. Manure from pigs fed high dietary Cu increased soil Cu, Zn, P, Ca and Mg levels slightly compared to a control (Kornegay et al. 1976). Similarly, increasing dietary salt levels increased Na levels in manure and Na loading of the soil (Sutton et al. 1984b). Bernal and Kirchmann (1992) reported that addition of hog manure in arid and semiarid areas could cause salinization.

Water Quality: Heavy application of manure may result in leaching of NO_3^--N, P, and K (Fig 2, King et al. 1990). The leaching of NO_3^--N depends on factors such as the rate of manure application, soil type, type and duration of crops grown and rate and amount of precipitation. In temperate regions, the soil solution NO_3^--N concentrations are generally highest in May and declined during the growing season due to crop N uptake and leaching. Burton et al. (1994) found that the application of liquid cattle manure to a Humic Luvic Gleysol resulted in higher NO_3^--N concentration in the soil solution at 75 cm depth with high precipitation compared to the years when precipitation was low. The concentration of NO_3^--N was higher when the manure was applied in the fall compared to a spring application. They concluded that the fate of manure nitrogen is influenced by the carbon content of the manure and they speculated that increased carbon associated with manure may increase the extent of denitrification in the soil profile and can reduce the potential for nitrate contamination of groundwater.

Although nitrogen and phosphorus and other nutrients accumulated in soil with increasing manure application rate on southeastern United States coastal plains and Piedmont, no significant downward movement of phosphate has been observed (Humenik et al. 1972). In contrast, under subtropical grassland vegetation, increasing the rate of hog manure application from 335 to 1340 kg N ha^{-1} significantly increased leaching of NO_3^--N, P, K and Mg (King et al. 1985; King et al. 1990) and NO_3^--N and P concentrations in rainfall runoff (Westerman et al. 1985). Sutton et al. (1978) also found evidence of downward movement of Na, K, and NO_3^--N in soil profile of plots receiving hog manure, but downward movement of NO_3^--N from inorganic fertilizer application was greater than from the manure application. Evans et al. (1977) observed higher NO_3^--N leaching from cow manure than from liquid hog manure. Increasing the application rate of manure increased NO_3^--N in the soil profile down to a 122 cm depth (Sutton et al. 1984b). However, in earlier studies, the authors did not find any effect of rate of application of hog manure on NO_3^--N leaching (Sutton et al. 1982). They concluded that leaching of soluble nutrients, especially NO_3^--N, to lower portions of the soil profile (62 to 122 cm depth) may be of greater concern when manure is applied by the injection method than when broadcast on the soil surface.

Economics

It is very difficult to analyse the overall economic impact of hog manure application to arable lands. In a BMP system, the economist must consider the impact to the producer and that to the public - the socio-economic factor. To date economists have worked with very poor estimates of both off-farm benefits and off-farm costs (Goss et al. 1994). Producers are concerned about the economic impact of any government or scientific recommended practice on their operations. The scientific/technical advisory community must assist producers by establishing the net positive or negative effects of degradation, or stewardship of the environment due to alternative farming systems and management practices (Goss et al. 1994).

Sommerfeldt et al. (1988) and Chang et al. (1991) reported on the economic benefit of manure used as a soil amendment. They included in their estimates loading, hauling and spreading costs and potential pollution costs (leaching of salts and pathogens) to ground water. They concluded that the economics of manure as a soil amendment depended on its benefits and costs, as well as specifics related to the location and nature of the application site (e.g. distance from manure source (Freeze and Sommerfeldt (1985)), extent of soil erosion, crop grown). In addition they found that the economics changed as prices of commercial fertilizer, crop prices, energy prices, labour costs and interest rates changes. Chase et al. (1991) reported that, in Iowa in a study involving various application rates of liquid manure, the highest economic return (US \$ 379 ha^{-1}) was from lands treated with manure applied at 2000 gallons ha^{-1} compared to commercial fertilizer (US \$ 337 ha^{-1}) at recommended rate for the region and crop. They concluded that with increasing cost of fertilizer, the profitability of hog manure as a nutrient source will increase.

Technological/Research and Development Gaps To Developing Best Management Practices

The economic and environmental sustainability of the Canadian hog industry will depend on the development of Best Management Practices for manure management. Because of the great variation in climate, soils and cropping systems across Canada one BMP system will not be adequate for the country as is evident from the information presented. Therefore, it is appropriate to expect that several systems will be developed each directed to a specific set of circumstances but always addressing the economic and environmental well-being of the industry. Further BMP will require long term commitment of government and private organizations and resource support for a multidisciplinary team of scientists working in harmony with socio-economic researchers, producers and producer organisations and environmentalists. It is also evident from the information presented that there are critical technological/research and developments gaps that must be addressed in order to develop BMP systems.

Planning Maps/Data Base: The most obvious gap is the lack of practical soil and water information on which to make decisions for the effective management of hog manure. It is critical that the best available soil, geological and hydrological information be available to the hog industry to ensure that operations are located in low environmental risk regions within an ecological zone. Most of this information for the prairies and for most of Canada is now (or shortly will be) in digital format from the Canadian Soil Inventory Data and can be used to develop GIS “Planning Maps/Data Base” for manure (nutrient) management and for use by the industry in the planning and siting of intensive livestock units. The objective will be to provide information on soil type, landscape position and cropping system in an easy to use format. Information on the appropriate manure nutrient loading and best time of application will be included. The development of such information system will parallel developing/importing new soil and agronomic technology to determine the impact of manure on crop production, soil organic matter, microbiology including pathology, fertility, aggregate stability, trace element and heavy metal chemistry, and moisture retention. Information collected will be used to develop practical guidelines for modifying manure management/hog operation in an environmentally sustainable manner.

Nutrient Management: There is little knowledge regarding the efficient management of hog manure nutrients. The nutrient composition is known to be unbalanced and incomplete as a plant food. Further, valuable components such as nitrogen are rapidly transformed to volatile and leachable compounds while others such as phosphorus and other non-nutrient salts (heavy metals) may accumulate in the soil and may interfere with the proper nutrition of crops. An unbalanced nutrient source, whether organic or inorganic, is an economic liability and threat to environmental sustainability. As a general rule if the constituents remain within the soil and become only bioavailable when they are required by plants there is a reduced risk of polluting the environment. New technology should be developed to balance the nutrient composition of hog manure to improve its value as a plant nutrient source, this may involve the use of inorganic fertilizers and the use of microbial and enzyme inhibitors such as elemental sulphur, N-Serve (Dow Chemical), urease inhibitors (NBPT, CHPT, PPDA) to slow down the rate of transformation of organic constituents to volatile and leachable inorganic constituents. These efforts should result in more efficient plant nutrition and a reduced risk of soil, water and air contamination.

Nutrient Cycling: Hog manure is a very complex source of plant nutrient. To make efficient use of its nutrients it is necessary to determine (a) the soil and environmental factors that control the rate and time of nutrient release in various soil types and ecological zones, (b) its impact on soil microbial population, pathological organisms and weed dynamics, and © to understand its impact on plant growth and crop diseases suppression.

Economics: The size for the land base to support a given number of animal units has to be determined for the various ecological regions of Canada. Good manure management might require low application rates which in turn necessitates expensive application equipment, long distance transportation of manure or a large land base. It is necessary to evaluate the fixed and variable costs of the various manure use technologies. For example, what is the value (to the producer) of manure as a soil conditioner and fertilizer ie. remediation of saline and low-fertility soils, and the cost of manure nutrient(s) per tonne grain (input $ vs output $)? Cost estimates are needed to determine the feasibility of treatment methods (composting and polymer addition) to concentrate nutrients for recycling so liquids can be applied and solids can be transported/applied more inexpensively to remote locations. Economic considerations often lead to the selection of sites for intensive livestock operations in areas of poorer soil quality, for example, the fringe areas in terms of the prairie ecozone. These areas generally have shallow soils or sandy soils or may be located over shallow aquifers raising the potential for seepage of contaminated water into dugouts and stream channels when manure is spread in inappropriate areas. Some levels of government may find some level of leaching acceptable especially if it affects economic competitiveness of the industry. Other levels of government may want a closed system with zero tolerance to leaching. The questions are: a) what is the economic penalty for these decisions and (b) what approach can be used to determine how much leaching or how much excess nitrogen in a soil is acceptable?

Communication and Socio-economic Impacts: There is a need to develop the means to facilitate communication, eg. E-mail, Internet discussion group, a Webpage which could be updated with new information. The various media should be available to producers, researchers and public and private agents, etc. Improved communication would increase the acceptance of the industry and prevent it from been driven to non-sustainable regions. It would also identify groups or individuals who will take responsibility to fill knowledge gaps and develop new technology, and list on-site manure management demonstration projects to increase acceptability and funding of the new technology. It can also be used to make science a stronger component of Green-house Gas policy than it was at the Kyoto meeting. Improved communication should reduce duplication of research and develop more complementary activities, it will also provide an opportunity to examine and disseminate information that distinguishes those communities that accept hog expansion compared to those that do not, eg. what determines acceptance of hog expansion in a community? It would be a vehicle for technology transfer to producers and a link between researchers and extension/demonstration persons.

SUMMARY AND CONCLUSION

Hog manure is a valuable plant nutrient resource and land application can be an efficient method for recycling nutrients through the soil-plant system. But it is only of value when it is managed properly, otherwise it is an economic and environmental liability. Hog manure can improve soil fertility, soil productivity and soil quality. Significant loss of nutrients occurs when manure is applied to frozen soils. Leaching of NO_3^--N and other soluble nutrients also increases in areas of high precipitation. Research has shown that nutrients accumulate or were leached only when manure application exceeded crop requirements and the environmentally safe loading capacity of the soil. Hence, manure should be applied at levels to match the crop nutrient demand and the soil natural loading limit. Research on hog manure is limited compared to that available for cattle and poultry manures. However, with the increase in hog population in temperate countries, pressure will be placed on researchers to develop Best management Practices that will greatly enhance the economic and environmentally sustainable use of hog manure in crop production and reduce its environmental risk.

References

Al-Kanani, T., Akochi, E., MacKenzie, A. F., Alli, I. & Barrington, S. 1992. Organic and inorganic amendments to reduce ammonia losses from liquid hog manure. J. Environ. Qual. 21, 709-715.

Alberta Agriculture 1984. Swine manure as fertilizer. Agdex-440/27-1. Alberta Agriculture, Edmonton, Canada.

Azevedo, J. & Stout, P. R. 1974. Farm animal manures: an overview of their role in the agricultural environment. Manual 44. California Agricultural Experiment Station Extension Service. p. 109.

Bailey, L.D., C.A. Grant and M. Choudhary. 1997. Use of lagoon stored manure for pasture production. Western Canada Agronomy Conference. Proceedings. Saskatoon, SK. July 9-11. Canadian fertilizer Institute, Ottawa, ON. p 111-115.

Beauchamp, E. G. 1983. Response of corn to nitrogen in preplant and sidedress applications of liquid dairy cattle manure. Canadian Journal of Soil Science 63, 377-386.

Beauchamp, E. G., Kidd, G. E. & Thurtell, G. 1982. Ammonia volatilization from liquid dairy cattle manure in the field. Canadian Journal of Soil Science 62, 11-19.

Bernal, M. P. & Kirchmann, H. (1992) Carbon and nitrogen mineralization and ammonia volatilization from fresh, aerobically and anaerobically treated pig manure during incubation with soil. Biology and Fertility of Soils 13, 135-141.

Brumm, M. C. & Sutton, A. L. 1979. Effect of copper in swine diets on fresh waste composition and anaerobic decomposition. Journal of Animal Science 49, 20-25.

Burns, J. C., Westerman, P. W., King, L. D., Overcash, M. R. & Cummings, G. A. 1987. Swine manure and lagoon effluent applied to a temperate forage mixture: I. Persistence, yield, quality, and elemental removal. Journal of Environmental Quality 16, 99-105.

Burton, D. L., Younie, M. F., Beauchamp, E. G., Kachanoski, R. G. & Loro, P. 1994. Impact of manure application on nitrate leaching to groundwater. In Proceedings of 37th Annual Manitoba Soc. of Soil Sci. Meeting. Dept. of Soil Sci., University of Manitoba, Winnipeg. Canada. p. 190-201.

Campbell A,J., MacLeod, J.A. and Stewart, C. 1997. Nutrient characterization of stored liquid hog manure. Canadian Agricultural Engineering Vol. 39: 43-48.

Chase, C., Duffy, M. & Lotz, W. 1991. Economic impact of varying swine manure application rates on continuous corn. Journal of Soil and Water Conservation 46, 460-464.

Chang, C., Sommerfeldt, T.G., and Entz, T. 1991. Soil chemistry after eleven annual applications of feedlot manure. Journal of Environmental Quality 20: 475-480.

Freeze, B. S. & Sommerfeldt, T. G. 1985. Breakeven hauling distances for beef feedlot manure in southern Alberta. Canadian Journal of Soil Science 65, 687-693.

Evans, S. D., Goodrich, P. R., Munter, R. C. & Smith, R. E. 1977. Effects of solid and liquid beef manure and liquid hog manure on soil characteristics and on growth, yield, and composition of corn. Journal of Environmental Quality 4, 361-368.

Gangbazo, G. Peasant, A.R, Barnett, G.M., Charuest, J.P., and Cluis, D. 1995. Water contamination by ammonium nitrogen following the spreading of hog manure and mineral fertilizers. Journal of Environmental Quality 24: 420-425.

Grant, C.A. and L.D. Bailey, 1993a. The interaction of zinc with banded and broadcast phosphorus fertilizer on the drymatter and seed yield of oilseed flax. Can. J. Plant Sci. 73:1-15.

Grant, C.A. and L.D. Bailey, 1993b. The interaction of zinc with banded and broadcast phosphorus fertilizer on the concentration and uptake of Zn, P, Ca and Mg in plant tissue of oilseed flax. Can.J.Plant Sci. 73:17-19.

Goss, M.J., Ogilvie, J.R., Beauchamp, E.G.,Stonehouse, D.P., Miller, M.H., and Parris, K. 1994. Current state of the art on manure/nutrient management. Final Report to Agriculture Canada on Contract No. 01689-2-3920/01-XSE. September 30, 1993.

Gilbertson, C. B., Van Dyne, D. L., Clanton, C. J. & White, R. K. 1979. Estimating quantity and constituents in livestock and poultry manure residue as reflected by management systems. Transactions of the ASAE 22, 602-611.

Hafez, A. A. R. (1974) Comparative changes in soil-physical properties induced by admixtures of manures from various domestic animals. Soil Science 118, 53-59.

Hoeff, J. D., Nelson, D. W. & Sutton, A. L. 1981. Ammonia volatilization from liquid swine manure applied to cropland. Journal of Environmental Quality 10, 90-95.

Humenik, F. J., Skaggs, R. W., Willey, C. R. & Huisingh, D. 1972. Evaluation of swine waste treatment alternatives. In Waste Management Research. Graphics Corporation, Washington, D. C. p. 341-352.

Kachanoski, G, Barry D.A.J. and. Stonehouse D.P. 1997. Nitrogen and carbon transformations in conventionally-handled livestock manure. COESA Report No.: RES/MAN-002/97.

King, L. D., Westerman, P. W., Cummings, G. A., Overcash, M. R. & Burns, J. C. 1985 Swine lagoon effluent applied to 'Costal' Bermudagrass: II. Effects on soil. J. Environ. Qual.14, 14-21.

King, L. D., Burns, J. C., & Westerman, P. W. 1990. Long-term swine lagoon effluent applications on `Costal' bermudagrass: II. Effect on nutrient accumulation in soil. J. Environ. Qual. 19, 756-760.

Kornegay, E.T., Hedges, J.D., Martens, D.C., and Kramer, C.Y.1976. Effect on soil and plant mineral levels following application of manures of different copper contents. Plant and Soil 45,151-162.

Larson, B. G. 1991. Saskatchewan pork industry manure management recommendations. Saskatchewan Pork Producers' Marketing Board, Saskatoon, SK. pp. 30.

McEachron, L. W., Zwerman, P. J., Kearl, C. D. and Musgrave, R. B. 1969. Economic return from various land disposal systems for dairy cattle manure. In Animal Waste Management. Proceedings Cornell University Waste Management Conference 13-15 Jan. 1969. Syracuse N. Y. Cornell University Press, Ithaca, N. Y. p. 393-400.

McKenna, M. F. & Clark, J. H. 1970. The economics of storing, handling and spreading of liquid hog manure for confined feeder hog enterprises. In Relationship of agriculture to soil and water pollution. Proceedings Cornell University Agricultural Waste Management Conference 19-21 Jan. 1970. Rochester, N. Y. Cornell University Press, Ithaca, N. Y. p. 98-110.

Menzies, J. D. & Chaney, R. L. 1974. Waste Characteristics. In Factors Involved in Land Application of Agricultural and Municipal Wastes. USDA, ARS.

Miller, P. L. & MacKenzie, A. F. (1978) Effects of manures, ammonium nitrate and S-coated urea on yield and uptake of N by corn and on subsequent inorganic N levels in soils in southern Quebec. Canadian Journal of Soil Science 58, 153-158.

Paul, J.W. 1991. Corn yields and potential for nitrate leaching from manures and inorganic N fertilizer. Ph.D. Thesis. University of Guelph, Guelph, Ontario, Canada.

Peasant, A.R, Gangbazo, G., Cluis, D, Barnett, G.M., and Charuest, J.P. 1993. Effect of hog manure and fertilizer application on runoff and drainage water quality. Pages 513-524 in S. Wicherek ed. proc. Int. Symp. On farm land erosion. St-Cloud, Fra. Catena, Elsevier, Amsterdam.

Powers, W. K., Wallingford, G. W. & Murphy, L. S. 1975. Research status on effects of land application on animal wastes. Environmental Protection Technology Series, EPA 660/2-75-010. U. S. Government Printing Office, Washington, D. C. p. 44-46.

Saskatchewan Pork Industry Manure Management Recommendations. 1991. Prepared by G.B. Larson, in cooperation with Environmental Issues Committee and the Saskatchewan Pork Producer's Marketing Board.

Schulte, D.D., M.B. Tokarz and G.E. Laliberte. 1979. Nitrogen and phosphorus transport from swine-manured fields during snowmelt runoff events in the Red River Valley. ASAE Papers 79-2116.

Simard, R.R. 1996. Manure management in Quebec: the urgent need for solutions. Pages 65-80 in C. Chang ed. Proc. Can. Soc. Soil Sci. Waste Management Workshop, July 7th, 1996, Lethbridge, Alberta.

Simard, R.R. Drury, C.F. and Lafond, J. 1996. Cropping effects on phosphorus leaching in clay soils. Better Crops and Plant Food 80: 24-27.

Simard, R.R. 1998. Land application of manure: agronomic and environmental considerations. AAFC-Research Centre, Ste-Foy, Quebec. Personal communication.

Sommerfeldt, T. G. and Chang, C. 1985. Changes in soil properties under annual applications of feedlot manure and different tillage practices. Soil Science Society of America Journal 49, 983-987.

Sommerfeldt, T.G, Chang, C, and Entz, T. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, decrease carbon to nitrogen ratio. Soil Sci. Amer. Proc. 38: 826-830.

Sutton, A. L., Mayrose, V. B., Nye, J. C. & Nelson, D. W. 1976. Effect of dietary salt level and liquid handling systems on swine waste composition. Journal of Animal Science 43, 1129-1134.

Sutton, A. L., Nelson, D. W., Mayrose, V. B. & Nye, J. C. 1978. Effects of liquid swine waste applications on corn yield and soil chemical composition. J. Environ. Qual. 7, 325-333.

Sutton, A. L., Nelson, D. W., Hoff, J. D. & Mayrose, V. B. 1982. Effects of injection and surface applications of liquid swine manure on corn yield and soil composition. J. Environ. Qual.11, 468-472.

Sutton, A. L., Melvin, S. W. & Vanderholm, D. H. 1984a. Fertilizer value of swine manure. AS-453. Iowa State Cooperative Extension Service, Ames, Iowa. p. 6.

Sutton, A. L, Nelson, D. W., Mayrose, V. B., Nye, J. C. & Kelly, D. T. 1984b. Effects of varying salt levels in liquid swine manure on soil composition and corn yield. J. Environ.Qual.13, 49-59.

Thompson, R.B. Ryden, J.C. and Lockyer, D.R. 1987. Fate of nitrogen in cattle slurry following surface application or injection to grassland. Journal of Soil Science 38: 689-700.

Unger, P. W. & Stewart, B. A. 1974. Feedlot waste effects on soil conditions and water evaporation. Soil Science Society of American Proceedings 38, 954-957.

Vanderholm, D. H. 1975. Nutrient losses from livestock waste during storage, treatment and handling. In Managing livestock wastes. Proceedings of 3rd Inter. Symp.on Livestock Wastes, Urbana-Champaign, Ill. 21-24 Apr. 1975. Am. Soc. Agric. Eng., St. Joseph, Mich. p. 282-285

Warman, P. R. 1986. Effects of fertilizer, pig manure, and sewage sludge on timothy and soils. Journal of Environmental Quality 15, 95-100.

Weil, R. R. & Kroontje, W. 1979. Physical condition of a Davidson clay loam after five years of heavy poultry manure applications. Journal of Environmental Quality 8, 387-392.

Williams, R. J. B. & Cooke, G. W. 1961. Some effects of farmyard manure and of grass residues on soil structure. Soil Science 92, 30-39.

Xie, R. & MacKenzie, A. F. 1986. Urea and manure effects on soil nitrogen and corn dry matter yields. Soil Science Society of America Journal 50, 1504-1509.

Zhu, Y. M., Berry, D. F. & Martens, D. C. 1991. Copper availability in two soils amended with eleven annual applications of copper-enriched hog manure. Communications in Soil Science & Plant Analysis 22, 769-783.

Table 1. Composition of liquid beef and liquid swine manure[z].

Measurement	Liquid beef[1]	Liquid swine[1]	Liquid swine[2]
pH	7.6-8.1	7.8-8.1	6.3-6.5
Dry matter (%)	10.4-10.7	2.33-5.04	5.25-6.58
Total N (%)	7.3-7.9	8.1-11.6	6.3-9.1
NH_4-N (%)	4.1-5.6	5.7-8.9	3.3-5.7
Total P (%)	2.31-4.04	2.58-4.38	1.7-3.0
K (%)	1.32-5.89	2.81-5.50	2.2-3.8
Ca (%)	1.22-5.79	3.12-6.33	-
Mg (%)	0.52-2.18	0.93-2.66	-
Na (%)	0.80-4.25	1.61-3.66	-
Reference	[1]Evans et al. 1977		[2]Sutton et al. 1984b

[z]All data expressed on dry weight basis.

Table *2:* Comparison of different methods of manure application on the losses by volatilization of ammonia (% of applied nitrogen).

Method of Application	Type of Waste	% Nitrogen Lost 0-7 days
Broadcast	Solid Liquid	15-30 10-27
Broadcast with immediate cultivation	Solid Liquid	1-5 1-8
Injection	Liquid	1-5
Sprinkler irrigation	Liquid	14-37

Source: Fleming, 1988; Meisinger and Randall 1991; Van der Molen 1990a.

Table 3: Sinks for N following application of slurry in three treatments to grassland in winter and spring in the UK results corrected for the appropriate control plots.
Values in parentheses are the amounts of N expressed as % of the total N applied. (Thompson *et al.* (1987)).

	Nitrogen Sinks*			
Application	Apparent Recovery in Herbage	NH_3 Volatiliz. Loss	Denitrific. Loss	∑ Sinks
Winter Experiment	------------------------kg N ha^{-1} (%)----------------------------			
Surface spread slurry	49.0 (19.8)	77.1 (30.8)	29.9 (12.1)	156.1 (62.9)
Injected slurry	82.7 (33.4)	2.1 (0.9)	52.7 (21.3)	137.5 (55.4)
Injected slurry* nitrapyrin	90.1 (36.3)	2.1 (0.9)	22.7 (9.2)	114.9 (46.3)
CV**	17.0% -	*25.3%* -	98.2% (42.6%)	—
Spring Experiment				
Surface spread slurry	66.9 *(25.5)*	*53.0* (20.2)	*4.5* (1.7)	124.4 *(47.5)*
Injected slurry	93.9 *(35.5)*	2.4 (0.9)	17.7 (6.8)	114.0 *(43.5)*
Injected slurry nitrapyrin~	109.9 (42.0)	2.4 (0.9)	14.0 (5.3)	126.3 (48.2
CV**	13.8% -	21.1% -	182% (74.8%)	--

*****In both experiments leaching losses from all treatments were negligible

**Coefficients of variation determined as follows:

Apparent recovery: from the total apparent recoveries for each of the four plots for the three treatments in each experiment.

NH_3 volatilization: from the total NH_3 loss determined for each of the three tunnels used for the surface application treatment.

Denitrification: the average coefficient of variation for all denitrification measurements in each experiment. In parenthesis the average for values greater than 0. 10 kg N ha^{-1} d^{-1}.

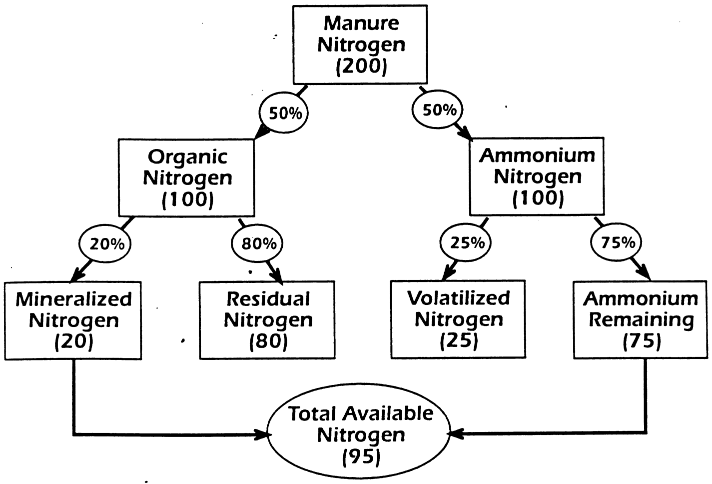

Figure 1. Relative contribution of manure N applied to soil compared to N available to the crop (derived from Beauchamp, 1983).

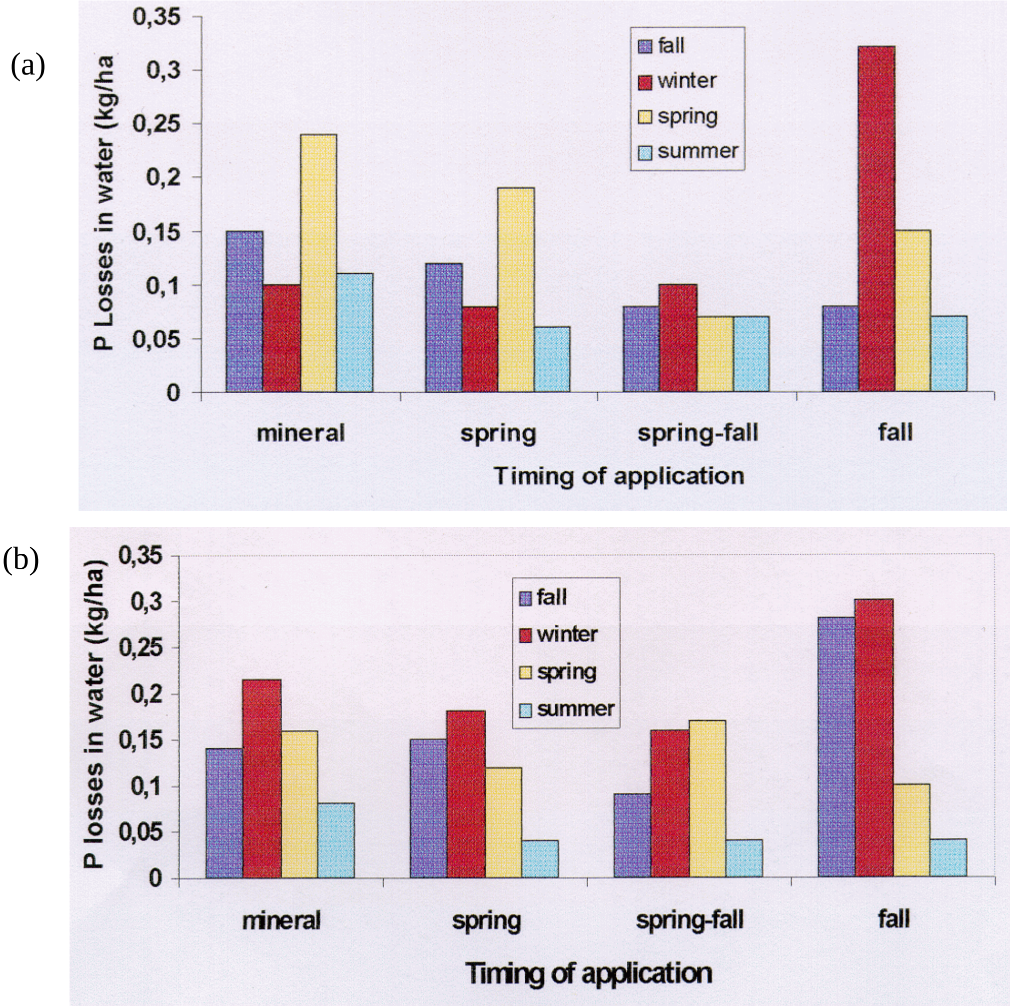

Figure 2. Effect of timing of hog manure application on seasonal P losses (1989-1992) in grain corn production (a) and forage (b) at Lennoxville (Gangbazo et al. 1997).

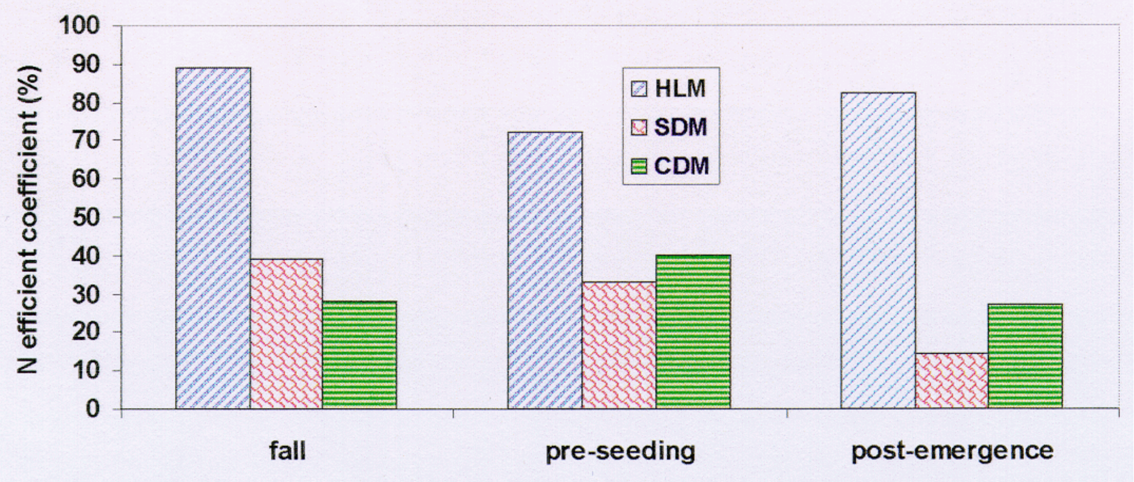

Figure 3. Fertilizer N efficiency coefficients of hog liquid manure (HLM), solid dairy manure (SDM) and composted dairy manure (CDM) as affected by timing of application in spring wheat production (Simard et al., 1998).

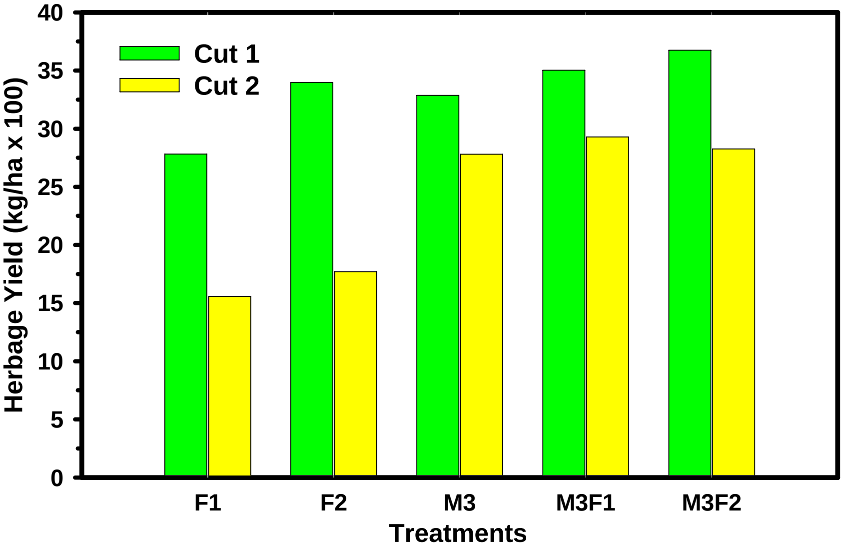

Figure 4. Effect of fertilizer (F1, F2), manure (M3) and combinations of fertilizer and manure on forage yield (Bailey et al., 1997).