RESEARCH STRATEGY
FOR
HOG MANURE MANAGEMENT IN CANADA

Research Branch
Agriculture and Agri-Food Canada

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FOREWORD

The hog industry is well established in Canada, and it looks toward expanding in the future. However, this sector of Canadian economy is facing a number of issues, mostly related to environment, regarding acceptance by the public and the impact on the environment.

In the spring of 1997, Agriculture and Agri-Food Canada created a multidisciplinary task force to develop effective and economically viable solutions to the environmental issues arising from hog production.

The contribution of the Research Branch to this activity has been to collate, through the expertise of a scientific focus group from research centres across the country, the available information from the international literature.

This report presents the available information and provides a research response to the environmental challenge. I hope that it will contribute to the development of solutions for the environmental issues related to the existing and future hog production in Canada.

Frank Claydon
Deputy Minister

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EXECUTIVE SUMMARY

The hog industry in Canada has grown more than 400% since 1982. The 12.2 million animals in Canada produce 24.4 million tons of manure annually. The present trend in hog production, i.e., toward a greater number of animals per farm, results in excessive manure production on a small land base and greater distances to utilize manure for crop production without causing pollution. This situation has led to environmental concerns with current hog manure management.

Environmental impacts of hog production are
- objectionable odors
- nitrogen and phosphorus pollution to water
- ammonia emission to the atmosphere.

Odors are an environmental concern throughout Canada, whereas nitrogen and phosphorus pollution to water are a concern in some geographical areas or as a result of improper management of the manure. Ammonia emission is a problem in British Columbia, and it may become a problem in other areas in the future.

Minimizing odor

Odors, the most obvious complaint, come from the animal-housing manure storages, especially during mixing or following land application of the manure. Usually considered as a nuisance, odors may have a negative impact on human health. Objectionable odors are produced by fresh manure, and the intensity of these odors increases during anaerobic decomposition of the liquid manure.

The first steps toward reducing odors is to keep animals and facilities clean and to minimize manure exposure to the air during storage and land application. The second step is to incorporate cost-effective technologies already available to reduce odor during manure storage and land application. The third step includes research on
- the impact of diet amendment and feeding practices on odor emissions
- improving pig genetics to better utilize nitrogen, phosphorus, and other precursors to odorous compounds
- developing pig production and manure management systems that reduce odor production and dispersion.

Minimizing ammonia emission

Ammonia is emitted from animal housing, during manure storage, and following land application. Up to 75% of the excreted nitrogen may be lost through ammonia emission with the current pig-production systems now being built in Canada, which include lagoon storage of manure and irrigation of the manure onto land. Ammonia emission increases with temperature and manure exposure to air. Ammonia redeposition cannot be predicted and may cause acidification and nutrient imbalance in sensitive ecosystems, including surface water.

There are four possible steps toward minimizing ammonia emissions:
- incorporate manure immediately into the soil following field application
- better balance the diet with pigs requirements, alter the diets by balancing amino acids, and/or incorporate other additives that may reduce ammonia emission

- reduce the exposure of the manure to air
- conduct research on improving diets and on developing pig production and manure management systems that minimize ammonia emission.

Determining soil suitability to receive manure

In some regions the soils, because of coarse texture or drainage characteristics, are not suitable for utilizing hog manure effectively as a nutrient resource, and this problem results in a risk of pollution of water by nitrogen and phosphorus. The presence of shallow unconfined aquifers used for drinking water or the presence of ecologically sensitive streams or lakes may also influence suitability for safe location of hog farms.

Steps in determining soil suitability for manure application are:
- develop manure application guidelines so that manure nutrients are applied at rates not exceeding the capability of specific crops to utilize these nutrients
- develop alternative manure utilization systems for hog farms that have excessive manure in areas that are at high risk of surface or groundwater pollution
- develop "risk" maps identifying which soils or areas are at greatest risk and determining safe rates of manure application. This also includes encouraging hog production to develop in areas of least risk.

Reducing the risk of phosphorus pollution

Manure application guidelines based on nitrogen lead to phosphorus accumulation in soil. Long-term application to soils in Quebec, Ontario, and British Columbia have increased soil phosphorus concentrations, which in turn increases the risk of polluting water through soil erosion. Manure application also increases the water-soluble phosphorus content.

Steps toward reducing the risk of phosphorus pollution are:
- apply manure based on the ability of crops to utilize the phosphorus and at times of the year which result in minimum pollution potential
- develop feeding systems that reduce manure P by using enzymes such as phytase, or by phase feeding
- develop alternative manure-utilization systems to produce value-added products to be exported from areas at risk of water pollution.

Toward sustainable pork production

Odors and risk of water pollution by nitrogen and phosphorus are immediate concerns in Canada. Ammonia emission during pork production does not represent a sustainable system. A system approach is required to encourage an economically viable and environmentally sustainable hog production industry in Canada. Recycling manure nutrients for crop production is at present the least-cost method of manure utilization, where the land base is large enough to utilize the manure effectively. This becomes more challenging as hog production intensifies.

Five major issues/considerations for sustainable pork production include:
- developing improved feeding systems, to reduce odor, phosphorus and nitrogen excretion, and ammonia emission from the manure
- improving manure storage and application methods, to effectively utilize manure as a nutrient source for crops
- establishing manure application guidelines for soil and soil suitability criteria that consider the risk of water pollution by N, P, biological oxygen demand (BOD), and bacteria, and of accumulation of metals in soil

- developing manure treatment systems that consider all environmental concerns; e.g., manure treatment systems designed to reduce odor or "remove" N and P often promote ammonia emissions
- establishing an economically viable and environmentally sustainable pork production, through development of alternative housing and manure management systems.

INTRODUCTION

Over the past 20 years, much of the animal production in Canada has evolved from diversified to specialized and intensive production systems. The changes occurred in response to market signals, especially an increase in the demand for a different product. In several areas, this intense productivity had an impact on the conservation of agroecosystems. Hog production, in particular, showed a significant increase. This industry is perceived often negatively by the public and the media because of the concentration of production units in some regions and the nuisance and pollution problems they generate, especially in relation to the manure slurry.

On average, one hog produces approximately one ton of manure per year. Therefore, on a year-round basis, the Canadian pig population produces some 24.4 million tons of manure annually. Hog manure contains major plant nutrients and organic matter that can be utilized for efficient crop production and to enhance soil properties. However, because many production units do not often have a sufficient land base or are located away from field crop production areas, the issue of disposing of the manure adequately and in an environmentally sound manner represents significant additional costs to the industry.

Most hogs in North America are housed and raised using similar technologies. As a result, issues are also similar everywhere: odor, surface water and groundwater pollution, and NH_3 volatilization. Hog production is therefore at the origin of potential environmental problems for air, water, and soil resources. The public has high expectations regarding:

- the odors that are released from the production units and the liquid manure storage facilities, and during field application
- the high concentrations of nutrients (especially phosphorus) and heavy metals building up in the soils as a result of field application of manure, especially in the areas with a large number of production facilities
- the contamination of water bodies by nutrients and bacteria.

The department's response is outlined in *Agriculture in Harmony with Nature*, the sustainable development strategy for Agriculture and Agri-Food Canada. The plan calls for actions along four strategic directions in order to address the environmental issues. Current management practices must be reconsidered, and improved ones developed, as well as new technologies for the treatment and economical utilization of the animal manure. A soil-based approach (manure utilization for crop production) will not really solve this industry's problems. A holistic approach that considers the entire production system, from housing to feed, to manure utilization in the fields, and uptake of nutrients by crops, must be adopted in order to address problems such as odor and water contamination. This approach, aiming at reducing animal wastes and improving its characteristics, will assist in determining which part of the production system is creating major environmental problems, and also where maximum gains are achievable. At the same time, research needs for the future will become more evident.

MAJOR ISSUES RELATED TO SWINE MANURE

An overview of the situation shows common and distinct issues in the different regions, very much in relation to the agricultural context.

Odors—the common major problem related to swine production units

Odor, a problem closely linked to housing and production of hogs, and also with land application, is the most important issue. Coverage by the media results in a negative public perception of the swine industry that further decreases the tolerance of people to odors' nuisance. In some regions, the odor problem is restricting the growth of the hog industry. Therefore, it is imperative to find solutions to control odors. Solutions will come from a concerted effort to improve the current agricultural practices regarding the handling of manure and its use as a fertilizer. Major technological needs are related to:

- odor control along the hog production line (e.g., closed systems, ventilation, feed, handling in the production unit, and storage, handling, and spreading of animal wastes)
- more efficient utilization and valorization of the animal wastes (composting, treatment, fractionation, equipment, application according to crop requirement, time and techniques of application, transportation, and new uses).

Regional concerns

Atlantic Provinces

- problems related to land application of manure in conformity with environmental regulations in each province.

Quebec

- problems related to land application of manure, especially the accumulation of P in the soil and the release of P and N into groundwater and runoff.

Ontario

- loss of N as ammonia
- problems related to land application of manure and the incorporation of nutrients in the soil before they are lost
- problems related to bacteria spread on the land along with the manure, which often enter tile drains or surface water.

Prairies

- storage of liquid manure
- hog production facilities established over shallow water tables
- land suitability to receive liquid manure, in relation to soil types and nature of the vegetation.

British Columbia

- impact of manure nutrients on surface and groundwater quality
- impact of swine production on air quality (NH_3 emissions).

These concerns reflect significant regional environmental questions. Issues that seem less important nowadays may become very important in the future. Strategies to solve environmental problems in the long-term need to identify solutions that solve rather than shift the environmental problems.

DEALING WITH ODORS

The problem

Industrialization of hog production and demographic changes in rural areas (substantial urban development onto agricultural land over the past decades) have resulted in sensitive cohabitation problems. Odors generated from pig housing, manure storage, and application in the field are major causes of conflicts between producers and their neighbors. In Quebec, for example, 10% of the complaints about odors involved farm buildings, 20% dealt with manure storages, and 70% involved land application activities. Management of manure slurry outside the production building was therefore responsible for 90% of the complaints.

Farming operations give rise to a variety of "naturally occurring" odor problems. Odorous gases are generated by the microbial breakdown of plant and animal proteins and when manure is stored under anaerobic conditions. The main sources of odors are associated with the production, handling, and processing of animal wastes, and the problem has become accentuated with the high-density, confined rearing of livestock.

Odor intensity varies with
- size and type of hog production facilities
- production practices
- location of the unit and local topography
- season and climate
- time of the day
- direction and speed of the wind
- turbulence of the air.

It is often difficult to determine which compounds, or combination of chemicals, give rise to the offense. Humans have a highly developed sense of smell, but not everyone smells the same thing. Thus the response to odor intensity is highly variable, influenced by factors like people's background, perception of hog production, and sensitivity of the olfactory system.

The complex nature of odors

- Odorous substances in animal housing are produced predominantly by volatile compounds and dust. Chemical analyses of the volatile chemicals arising from animal production have been attempted. More than 150 volatile compounds have been identified; not all compounds necessarily cause "bad" odors, and volatile compounds in the highest concentrations may not be the most unpleasant to humans. These volatile compounds originate mainly from manure slurry, wet floors, and dirty animals.

- Dust is composed of fine aerosol particles such as feed components, dried fecal material, hair, skin cells, mold, fungi, viruses, and bacteria. The dust associated with hog-production facilities amplifies the perceived odors. The concentration of some odorants may be 40,000,000 times greater on dust particles than in an equal volume of air. Dust particles are also capable of transporting odors over long distances.

- Odors from manure storage result from the anaerobic degradation of the organic fraction of the slurry. Odors are very intense during the homogenization of the content in the storage and the loading of the manure slurry spreader.

- Volatile compounds are released rapidly when manure is applied onto the land, and very strong odors are emitted in the field area. Odor emissions may reach levels that are sometimes unacceptable to the neighborhood for the serious discomfort they create.

- Another problem associated with odors is the low acceptability of manure slurry by some potential users, e.g. cash crop producers. This is a real constraint for hog farms that have to dispose of a surplus of manure. The lack of sufficient land for disposal of manure surplus often results in soil and water pollution. This issue will be addressed later.

- In some regions, the threat of odor emissions from hog operations has restricted the growth of the industry. Odor abatement is thus a major concern for hog producers. At present, there is no economical control technology available in Canada to solve the odor problems from hog operations.

- Until recently, odors were considered essentially as a nuisance problem. However, there is new evidence that odors can have also some negative effects on human health, causing nausea, headaches, sleep disturbances, upset stomach and loss of appetite, and depression. Health problems can be more serious for farm workers who are exposed continuously to odors, dust, and toxic gases. Some farm workers have developed respiratory problems such as chronic bronchitis, occupational asthma or even worse, farmer’s lung disease. Because swine operations are getting larger, more workers are being exposed to these harsh conditions.

Toward a solution

1. The first essential step to achieve odor abatement is to develop and recommend best management practices and guidelines that apply to livestock buildings and manure slurry management. For example, measures that reinforce the cleanliness of farm buildings and that recommend appropriate weather conditions and timing for land application of manure slurry would have a positive effect on odor attenuation.

   Until some of the newer technologies are available to them, farmers should utilize the “Best Management Practices” already available in several provinces, for the management of the animal manure. For example:
   - keeping animals and facilities clean
   - adding manure from below to the storage pit
   - injecting or incorporating manure below the soil surface
   - applying manure when the wind is blowing away from neighbors and dwellings
   - applying manure in the morning or on cloudy days
   - using trees as windbreaks to promote upwards dispersion of odors.

2. The second step is to identify and recommend cost-effective technologies used in other countries that can be relevant to odor control and air quality, and that are applicable under Canadian climatic conditions and hog facilities management practices.

Some opportunities from research findings for manure storage facilities:

- Covering the storage tank can reduce odors by 90%.
- Adding alkaline material may reduce odors (e.g., by-products from power plants or cement plants can substantially reduce odors by increasing the pH above 9.5, thus reducing hydrogen sulfide emission; such a measure, however, has to be mitigated with the increased ammonia emission, discussed later).
- Adding sphagnum peat moss or other acidifying amendments to manure lagoons reduces odors.
- Manure from anaerobic digestion systems is less offensive than undigested waste.
- Bubbleless oxygenation reduces hydrogen sulfide production to non-detectable levels by GasTec Sensidyne dosimeter tube.
- A floating permeable blanket can allow a 90% reduction in ammonia and hydrogen sulfide.

Some opportunities from research findings for land application of manure:

- Manure would be either injected or incorporated within 24 hours of spreading. Various injection systems are being researched for injection/incorporation of liquid manure into row and field crop systems.

3. The third step is to establish a comprehensive short- and long-term research program.

Recommendations for the short-term

- Assess the potential impact of diet amendment and feeding practices on odor emissions.

  Because nitrogen is a key ingredient of ammonia and other odorous compounds, the higher the nitrogen content in the manure, the greater is the potential for odor emission. Research on feed conversion and odor control proceeds in many different directions:

  - N levels in the swine diet may affect the volatile fatty acid composition and NH_3 concentration.
  - Synthetic amino acids substituted for traditional protein sources contribute to reducing excretion of N by pigs.
  - Proteolytic enzymes in processing or dietary supplements increase protein digestibility.
  - Dietary supplements such as zeolite, bentonite, charcoal etc. can adsorb odor. Effects of the these materials on swine growth and feed conversion efficiency need further research.
  - Plant extracts, enzymes and direct fed microbials may also help to decrease odor. Yucca extracts, as feed additives, may bind ammonia and other gases and thus decrease odor emissions from slurry during storage. Beneficial effects of these additives have been shown for both hogs and poultry.

- Utilize knowledge on odor emissions, diffusion, and abatement gained from Europe and the United States.

  Knowledge of odor concentrations enables experts to establish goals and basis of comparison to improve facilities and management practices. Several techniques, e.g., gas chromatography, distillation, liquid chromatography, and specific ion traps, have been used to characterize odors and to identify its constituents. The human nose is one of the best available odor detectors in the absence of standard methods for measuring hog odors. Dynamic olfactometers dilute pungent air to different concentrations with odor-free air, and the human nose is used as the measuring device.

- Measure the efficiency, adaptability, and economics of existing technologies under local conditions.

- Evaluate the usefulness and reliability of manure slurry additives by standard methods. Such tests will indicate if an additive has disadvantageous side effects on air, soil, and water quality. For example:

  - A 68% reduction in ammonia concentrations was observed in piggeries using De-Odorase ©, but in the absence of ventilation rates, absolute ammonia emissions rates could not be calculated.
  - Added to the diet of grower pigs,De-Odorase © reduced significantly the concentration and emissions of NH_3 by 26%, but did not significantly affect the odor concentration or emissions and did not influence the rate of weight gain.

Recommendations for the long-term

The long-term activities should be oriented toward the development of solutions that have excellent potential to substantially reduce odor emissions and atmospheric pollution, as well as improving the working conditions inside the farm buildings. For example:

- gaining a better knowledge of odor emissions and dispersion mechanisms, to quantify the influence of a wide range of animal management and environmental factors and to recommend distance regulation based on operational features and geographical locations
- studying animal genetics, to develop animals more efficient in using nitrogen, phosphorus, and odor-producing compounds
- developing effective and economic technologies to deodorize swine manure slurry and reduce its negative impact on air, water, and soil quality
- finding a reproducible methodology for assessing manure odors in the laboratory.

DEALING WITH AMMONIA EMISSION

The problem

Ammonia emissions from hog manure contribute a significant loss of N. A computer model of the fate of excreted N, developed in south coastal British Columbia for their specific types of waste management and climatic conditions, demonstrated that over 40% of N excreted from hog production is lost to the air from the barn, during storage, and following field application. In that area, hog manure is generally stored under the barn or in concrete pits. The model showed that improving animal diets was the most effective method to reduce NH_3 emissions. In North Carolina, the Division of Air Quality estimates an 85–95% loss of N from hog manure facilities. In Denmark, agriculture contributes about 93% of the NH_3 emission, with 35, 20, and 40% of the NH_3 volatilization coming from animal houses, manure storage facilities, and following land spreading of the manure, respectively. Danish manure storage systems are typically under the barn or in concrete tanks.

Ammonia itself has a short residence time in the air. It may be redeposited in dry deposition as NH_3 close to the source (6–14%). Alternatively, it may be converted to NO (<1%) and form particulates of ammonium nitrate or ammonium sulfate (86–94%), which can travel distances of up to 2500 km. Most of the NH_3 is redeposited close to the source of production. In Denmark, more than 85% of the NH_3 is redeposited within 100 km of the source, with 75% and almost 100% of the redeposition occurring within 4 km from the source during the day and night, respectively. In the Netherlands, N deposition corresponded to 68 and 42 kg N ha^{-1} at distances of 75 and 700 m from a poultry barn. NH_3 volatilization has therefore a significant effect on N supply in neighboring nutrient-poor ecosystems.

Ammonia emissions cause direct ecological and human health concerns, in addition to poor nutrient accountability and nutrient recycling. Ammonia and ammonium particulate deposition is causing eutrophication problems in surface waters and on soil ecosystems. Ammonia is a localized pollutant not likely acting as an atmospheric toxin; however, it is a precursor for ammonium particulates or aerosols, which are delocalized pollutants. Aerosols of ammonium nitrate and ammonium sulfate are particles less than 2.5 Fm in diameter. These particles have been suggested to pose a significant health risk to human health with increasing atmospheric particulate concentrations. Particles of this size bypass the normal defenses of the respiratory system. The amount of NH_3 that combines with airborne acidic nitrates and sulfates to form aerosols depends on the concentration of these compounds in the air. Acidic nitrates and sulfates are produced by industry and automobiles. For example, the areas near Los Angeles and Vancouver have been noted to have significant quantities of ammonium nitrate and ammonium sulfate aerosols because of the close proximity of intensive animal production units to urban centres. In the eastern Fraser Valley of British Columbia, aerosols of ammonium nitrate and ammonium sulfate were measured to be up to 70% of the fine particulates during the summer, and have resulted in visibility impairment.

Toward a solution

Ammonia emission and its control

As discussed above, it is sometimes difficult to distinguish ammonia emission from the barn from emission during storage because, on some farms, storage pits are directly below the barn. In a recent European study, NH_3 emission from pig barns was estimated at 37–40% of the excreted N. Using an N budget approach on a hog facility in Ontario, it was estimated that 43% of the excreted N was lost from the facility, primarily as NH_3. Direct measurements of NH_3 emission from hog barns in Ontario have shown a 9–19% loss of excreted N. In terms of animal mass, the NH_3 flux ranged from 4.6 to 7.0 mg N h^{-1} kg^{-1}, a figure comparable to estimates of 2.5–6.5 mg N h^{-1} kg^{-1} from pig facilities in Scotland.

Much of the excess dietary protein is excreted in the form of urea. Urea hydrolysis starts immediately on the barn floor, causing a pH increase that results in NH_3 emission. With dairy cattle manure, NH_3 emission was highest during the first 24 hours following excretion. Ammonia emission from manure depends on the animal diet and on the exposure of manure to the air. The rate of NH_3 emission from the manure is related to temperature, air exchange, pH, depth of manure, and the length of exposure.

Improving the diets, particularly the protein content

- Phase feeding to balance amino acids in the diet is the primary strategy to reduce NH_3 emissions during hog production; this can be achieved on most existing production facilities and is one of the most effective strategies for reducing NH_3 emission.
- Improving diets has demonstrated a 26% reduction in N excreted, which also resulted in a 25% reduction in NH_3 emitted.
- Inclusion of bacterially fermentable substrates in the ration reduced NH_3 emissions by 18% during pig finishing.

Decreasing the exposure time of the animal excretions with the air

- Frequent barn cleaning using manure scrapers with separate urine channels is effective; this least cost conventional manure management system resulted in low NH_3 emissions.
- Using slurry collection pans contributed to a 30% decrease in NH_3 emission. A combination of improved diets, phase feeding, and optimal housing reduced NH_3 emission from the barn by 45%, compared with conventional feeding and housing systems.
- Deep bedding facilities for growing and finishing hogs may help reduce NH_3 emissions by 70%, compared with conventional housing, but with a net increase in N_2O, a major contributor to global-warming gas emission.

Ammonia emission during manure storage

Exposure of manure to the air is the primary factor in NH_3 emission. Unlike liquid dairy cattle manure, hog manure rarely forms a crust during storage, which results in high NH_3 emission rates. N losses in the United States during storage and handling were estimated at 60–80% from anaerobic lagoons and 30–65% from underground pits with liquid spreading. N losses of up to 95% were observed in the eastern United States in lagoon storage of liquid hog manure.

Several recommendations may be effective:

- Reducing NH_3 losses during manure storage may require a large investment for changing storage systems. In a laboratory experiment, NH_3 volatilization losses of 24% of manure total N were recorded with the use of artificial covers on liquid hog manure, compared with a 76% loss with uncovered storage. In Canada, most new hog operations in the Prairies are accompanied with large lagoons for storage. In contrast, in the Netherlands, the trend is to store liquid hog manure in enclosed pits or containers in order to minimize NH_3 loss.
- Sphagnum peat moss, sulfuric acid, and phosphoric acid contribute to reducing NH_3 emission from stored pig slurry by at least 75%.
- A covering of straw or plastic reduces NH_3 emissions by 65–70% and 77–84%, respectively, and a covering of mineral oil on the slurry reduces NH_3 emission by 34% to 90–95%.
- Reductions in NH_3 emission during fattening pig manure storage have been achieved by addition of organic acids, by manure additives, by cooling the manure, or by separation, aeration, and recirculation.
- Composting of separated hog slurry solids, solid hog manure from shallow or deep bedded hog facilities, or slurry bulked with peat or straw has been promoted as a more environmentally sustainable manure management system. However, significant emissions of NH_3 and N_2O are produced during composting of hog wastes.

Ammonia emission following field application

Ammonium-N constitutes up to 90% of the N in anaerobically stored hog manure. Following field application, pH increases when short-chain fatty acids are oxidized. This pH increase, in combination with exposure to the air, results in a loss of N as NH_3. Ammonia emission increased when manure is applied on impervious soils, on high pH soils, and under climatic conditions with higher temperatures and greater wind speed. A wide range of values were reported: up to 90% of the ammoniacal N fraction of the manure may be lost following application to the field. In France, NH_3 emission losses from pig slurry applied to grassland or arable land ranged from 37 to 63% of the ammoniacal N in the slurry, with 83% of the emission occurring during the first 6 hours when the manure was applied at midday. Between 25 and 50% of the ammoniacal N applied in pig slurry was volatilized during the first 1.5–4 hours following application. In the Netherlands, loss of the ammoniacal N fraction of pig manure as NH_3 amounted to 36–78% following application to pasture. In the United Kingdom, 24–39% of the NH_3 lost was emitted during the first hour and 85% of the loss occurred during the 12 hours following application of slurry. All these values indicate a significant loss of N.

A solution may be found in the following:

- An effective and easily achievable strategy to reduce NH_3 emission is improved manure application, either by injection or immediate incorporation on arable soils, or using a sleigh foot on grasslands. Immediate incorporation of the hog manure is the most effective method of reducing NH_3 loss following field application of the manure. Tilling the soil before manure application also reduced NH_3 emission. Ammonia emission was 1.5 times higher following slurry application to grassland than application to arable land. Use of a sleigh foot type manure applicator on grassland has demonstrated significant reductions in NH_3 emission, and higher recovery of manure N in the grass.

DEALING WITH SOIL/LAND SUITABILITY FOR MANURE UTILIZATION

The problem

Hog manure should be regarded as a resource, and its management and utilization would be approached accordingly. Application to cropland is one of the most obvious methods of recycling plant nutrients. Plant nutrients removed from the soil in the harvested product fed to the animals are then returned in part to the soil as manure. The availability of plant nutrients from manure depends on its composition and on other factors such as management practices and soil characteristics.

A number of hog production facilities are being established on lands with lower productivity for economic reasons, in particular land price and location as close as possible to the market. Lands within classes 4 and 5 for agriculture have commonly sandy to loamy textures with frequent limitations related to wetness. These lands overlay various types of shallow aquifers and are sensitive areas from the point of view of maintaining soil and water quality. Because of these considerations, it is most important that environmentally acceptable protocols or guidelines for soil applications of hog manure be available to hog producers. The availability of a digital soil database could form the geographical basis for these guidelines, and provisional application maps could be produced using GIS technologies.

Land suitability for receiving liquid manure must take into account several parameters:

- 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 that are highly permeable and promote rapid decomposition of manure.

- High application rates of manure to coarse-textured soil may contaminate groundwater through the leaching of nutrients, whereas high application rates of manure on heavy-textured soil may be beneficial because of the high nutrient-holding capacity of these soils.
- Manure should not be applied on snow or frozen ground, particularly when the land is subject to rapid spring run-off.
- Heavily manured fields should not be summer fallowed, to avoid leaching of N and the possibility of groundwater contamination.

Information on the effects of hog manure on soil physical properties is limited. However, the effects of hog manure may be expected to be similar to those reported for cattle manure. Cattle manure improves soil aggregation, lowers bulk density, and improves structure and water holding capacity of soils due to an increased organic matter content. Changes in the chemical composition of the soil caused by application of manure are much influenced by factors such as soil texture, rate, time and method of application of manure, the amount of local precipitation, and the crops grown.

Heavy application of manure has been shown to increase NO_3-N, available P, and exchangeable K and Na more rapidly than inorganic fertilizers. Manure application also results in accumulation of NO_3-N and extractable P and Na in the subsoil. The level of accumulation increased with the rate of application. Hog manures have a lower N-to-P ratio than crop plants. Thus when N is supplied through manure to a crop, more P is applied than is required by the plants, and this may result in leaching and runoff of P. This point will be discussed in more detail later.

At high rates of application, Ca and Mg may be displaced from the 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 the deeper layers. The H^+ produced during conversion of NH_4+ to NO_3- may successfully compete for Ca- and Mg-sites on the soil colloids, and consequently lower the soil pH in the surface horizon. Salts or additives to the feed can change the manure composition, and different ions may accumulate in the soil. Manure from pigs fed high dietary Cu increased soil Cu, Zn, P, Ca and Mg levels slightly, compared with a control. Similarly, increasing dietary salt levels increased Na levels in manure and the soil.

The intensity of NO_3-N leaching following heavy application of manure depends on factors such as the rate and the period of application, the soil type, type and duration of crops grown, and rate and amount of precipitation. In temperate regions, NO_3-N concentrations in the soil solution are generally highest in May and decline during the growing season because of N uptake by the crop and leaching. The fate of manure N is influenced also to some extent by the carbon content of the manure. Thus increasing C in manure may increase the level of denitrification in the soil and can reduce the potential for nitrate contamination of groundwater. In Quebec, maximum concentration of NO_3-N occurs in late June and July. Denitrification is not particularlyC-dependent in cool and humid regions, and it proceeds as soon as anoxic conditions are prevailing. N_2O emission is important soon after fertilizer addition, or in the 20 days following manure application. Volatilization here is much more important than denitrification, which would represent only 2–5% of the losses. Leaching of soluble nutrients, especially NO_3-N, to lower parts of the soil profile may be of greater concern when manure is applied by injection than when broadcast on the soil surface, depending on the accessibility to soil macropores.

Toward a solution

Soil suitability for hog manure application is a national and international issue. The common method of determining application rates is currently based on the capacity of the crops to take up the nutrients, most often on the N requirement for the selected crop.

- Additional considerations would improve the management of both soils and manures, and provide for environmental protection. For example, developing recommendations on soil-based application rates would be valuable for producers and commercial contractors, and would ultimately benefit the general public. Appropriate resource information using GIS techniques could be combined with data on volume and quality of manure to achieve this objective.

- Information on the capacity of soil to assimilate hog manure is limited. Research focus was more on technologies related to processing, handling, reducing, and applying manure. Existing soil and crop information can be used to develop soil-manure loading rates in the form of "risk" maps, in terms of soil, landscape, hydrology, temperature, precipitation, crop type and cropping practices, quality of manure, and time of application. Guidelines for the utilization of hog manure to sustain and enhance the productivity of agricultural and non-agricultural soils, and to provide an option for hog producers to dispose of a resource by-product, will have major impact on land management and cropping practices. Risks for loading rates can be developed.

- An objective will be to establish guidelines for rates of application based on the fate of the material applied, in order to optimize the utilization of nutrients and to minimize losses through leaching, to minimize salt and metal build-up in the soil and to protect groundwater.

- Multi-disciplinary projects bringing together the required critical expertise in areas of environmental geochemistry, landscape pedology, soil physical chemistry and microbiology will contribute significantly to the solution of the problem.

- Detailed knowledge of soil types, their chemical, physical, biological, and mineralogical characteristics as well as their spatial variability, and local climatic conditions can be used to identify probable soil-plant relationships and potential productivity.

- Research protocols should focus on the efficient use of manure as a soil nutrient enhancement, and methodologies would incorporate soil and landscape information such as soil permeability (texture and thickness), pH, organic matter content, soil temperature and moisture, and risk of surface runoff, as well as rate of biodegradation and quality of the manure (for example, nutrient and salt status and micro-element and heavy metal contents).

- Soil resource information from several provinces has been compiled into standard digital data bases suitable for analysis and display using geographic information system (GIS) technology. Soil information for Agro-Manitoba is now digitized, and is managed in standard formats for use and application in a GIS environment. Such a database can be used to facilitate extrapolation of management recommendations to farm fields and landscapes.

DEALING WITH PHOSPHORUS ISSUES

Managing animal wastes as liquid manure contributed to the rapid expansion of the hog industry in Canada, and this is likely to continue in the Prairie Provinces. In 1996, about 55% of the total hog inventory was located in Quebec and Ontario and 42% in the Prairies, mainly in Alberta and Manitoba. Liquid manure used to be spread at large application rates, and uniformity of application was a problem. Quebec may be the only province with a legislation controlling manure management. Since 1978, the law has specified the distance from buildings for the storage and the rate of spreading according to crop-N requirement. British Columbia has legislation controlling some aspects of manure management, including distance from streams and buildings, as well as field storage requirements. British Columbia also has guidelines for field application that are based on nitrogen and depend on the receiving crop.

Traditional application rates are based on N needs for the crops. This has led often to an increase in soil P level in excess of crop requirements because of the greater N-to-P ratio (average ratio of 4:1) in manure than taken up by the crops (major grain and hay crops ratio of 7:3). The problem of P accumulation in the soil is different in each part of the country. The amount of hog manure is not exceedingly abundant in the Atlantic Provinces. Phosphorous levels are a problem in Ontario, Quebec, and British Columbia. Most of the hog producers in Quebec and British Columbia do not have an adequate land base to use all the manure in an environmentally acceptable manner. Some 3000 Quebec farms are in this situation. There is a sufficient land base on the Prairies to handle the manure. Soils are considered deficient in N and P, and require annual inputs of both nutrients for optimal crop growth. The calcareous nature of these soils restricts inorganic P mobility. However, inadequate manure management creates a risk of surface water contamination by P through surface runoff on sloping land. Furthermore, excessive application of manure may increase the risk of downward movement of organic P to shallow aquifers.

The problem

Liquid manure, with a large content of soluble C and P, may lead to high water soluble P (P_w) in the plow layer and the subsoil, increasing the risk of P transport by surface and subsurface runoff. Plot studies have shown high P losses in runoff, even at recommended application rates. P migration is crop-dependent. Migration is much larger for forage crops than for corn, because the biopores are more accessible in the absence of tillage. In poorly drained, level sandy and clayey soils, tile drains can contribute to move P to the water bodies when conditions are favorable. In clay soils with cracking or shrink-swell properties, preferential by-pass flow may transport manure directly from the soil surface to the tile drains.

Studies conducted in watersheds with a high concentration of hog production units in Quebec have shown a large increase in bioavailable P content in the soil and a decrease of the P sorption capacity of soils on the hog farms. Concentrations of P much in excess of the 0.03 mg L^{-1} threshold value were found in drainage outlets and stream and river waters. At least six watersheds in the province of Quebec have a surplus of over 1 000 000 kg of N and P in comparison to crop needs. Application rates in excess of crop need lead to soil enrichment and filling of a significant part of the soil retention capacity. Increases of over 1000 kg ha^{-1} in the plow layer, 275 kg ha^{-1} in the B horizon, and 500 kg ha^{-1} in the C horizon were measured in hog farm soils, compared with the forest soils in the Beaurivage watershed in Quebec. Sediments of the Boyer River watershed, very important for smelt spawning, are saturated with P. A significant relationship between the amount of suspended solids and the total river P concentration at the outlets was found in 16 major rivers in the St.-Lawrence Lowlands. This suggested that erosion from P-enriched soils was an important process along the slopes, although preferential infiltration in level tile-drained soils was also important.

A proposed legislation in Quebec would prevent application of manure on P-rich soils, or at the minimum limit the inputs to the amount removed with the harvested plant material. This legislation, yet to be passed, could worsen the problem of excess manure in some watersheds. It could increase substantially, even double the land area required to dispose of the manure slurry.

On the Prairies, there is a need for nitrogen and phosphorus to sustain crop production. In calcareous prairie soils, soluble inorganic phosphates react quickly with calcium and magnesium to become immobile. However, only 40–50% of the P in manure is mineralized during the first year following application. Poorly managed manure application poses a risk of pollution to surface waters from phosphate runoff on sloping land or from leaching of organic phosphate into shallow aquifers.

Toward a solution

Feeding systems to reduce manure P

- Addition of phytase to hog diet may increase the utilization of feed P by 50 to 70%, and reduce the requirement of mineral P supplements (mono- and dicalcium phosphate) in hog rations.
- Cellulase addition and improved processing techniques may decrease manure P content by 5–30%.
- Adjusting feed composition to meet the nutrient requirements at defined stages of growth will decrease P excretion. However, this may have some impact on maximum animal growth.
- Increasing feed digestibility by processing techniques will reduce the excess nutrients fed to achieve maximal growth and thereby decrease excreted P by up to 5%.

Agronomic systems to monitor the impact of P

- New guidelines are needed to apply liquid manure on a P rather than on a N basis. This will result in more land being necessary to dispose of the same amount of manure.
- Site-specific soil tests, based on soil type characteristics important for P movement (e.g., slope, Al content, tile drainage, and susceptibility to soil cracking) are needed. Soil information system and GIS technology may assist in developing an integrated computerized decision-making support system that can be used easily by agronomists and farmers.
- Manure management on a watershed basis, run by farmers' associations, will be needed to coordinate and priorize the use of manure over all other sources of nutrients. Soil-specific rates have to be identified, and long-term impacts of repeated additions monitored.
- Removing the solids (5% in volume) from hog manure would reduce the phosphorus content by 50%. The liquid phase could be further treated to obtain a concentrated solution.
- Reaction with aluminum sulfate to precipitate the phosphate, as it is done with urban sewage sludges, could transform manure P in very sparingly soluble forms to be added to the soils without enriching them to a large extent in other labile nutrients. The long-term bioavailability of such compounds has to be investigated.
- An alternative is to raise pigs on litter with a highC-to-P ratio or to add liquid manure to carbon-rich materials (e.g., wood chips and pulp and paper sludges) in order to produce composts to be used off-site to restore soils with low organic matter content.

Manure management to control P accumulation

- Spreading of liquid manure in the fall without incorporation should be banned, as any significant rainfall would result in large contamination of water and sediments.
- Calibration of manure spreading equipment is necessary to ensure the addition of adequate amounts of nutrients.
- Strip-cropping systems using perennial grasses or planting of multi-storied hedgerows to act as buffers along waterways have great potential to reduce P contamination by runoff on sloping land. Such systems may also remove P from lateral subsurface water flow on shallow soils and retain windblown particles.
- Minimum tillage may reduce P losses by runoff on sloping land and increase P uptake in the Prairies where drainage water P losses are limited.
- Strategic N application in ammonia form is known to increase P uptake either directly or by increased soil P solubility.
- Recommendations would be based on the use of residual soil phosphorus coupled with small amounts of starter soluble P.
- Use of companion crops in spring cereal production may allow safe manure fall application in areas of low rainfall.
- Use of crops with high P uptake (for example, silage corn in areas with >2500 CHU, or canola in cool climate areas with < 2500 CHU).
- Use of alternate crops such as forage or forests (e.g., Sugar maple) should also be investigated.

Water management

- Conservation tillage can reduce soil and P transfer in surface runoff, although the proportion of P that is bioavailable both in soluble and particulate forms may increase. Consequently, eutrophication-agricultural management decisions should evaluate and consider total and bioavailable P loss from the manure.

- Use appropriate methodology to estimate P bioavailability as both soluble phosphorous (SP) and bioavailable particulate P (BPP) essential to more accurately estimate the impact of hog manure spreading or agricultural management practices on the biological productivity of surface waters.
- Evaluate potential response to soil residual P from manure-amended soils in combination, with or without rotations after short- or long-term manure applications.

RESEARCH CONTRIBUTION

New technologies to address short-term concerns

- Establish standardized methodology for evaluating additives, air, soil, and water quality and offensive odors.
- Improve practices for land application of manure to reduce NH_3 emissions.
- Reduce NH_3 losses during storage.
- Develop manure management guidelines that incorporate information on the interaction between, for example, the soil and manure nutrients, impact of soil characteristics, seasonal factors, mineral interactions, surface and subsurface water movement.
- Investigate the effect of addition of carbon-rich materials to manure slurries to improve the handling characteristics of the manure nutrients.
- Evaluate adaptability and economics of implementing existing technologies.
- Evaluate phase feeding, diet composition, and diet amino-acid balance to reduce manure ammonia emissions, modify manure composition, and reduce odors emanating from the manure.
- Separate manure liquid and solids, and compost the solids to reduce gas emissions.
- Modify the hog facility design to improve manure management and control gas emissions.
- Obtain information on cycles for the nutrients present in manure and the effectiveness of their use by annual crops (also a longer-term research objective).
- Identify crops that, under Canadian climatic conditions, use nutrients in the fall, because they would allow fall application of manure and therefore decrease the total storage period.

- Continue evaluating soil types and their suitability for various methods of application.

- Increase the efficiency of utilization of dietary phosphate (phytase, cellulase, and dietary formulation) to decrease the over supplementation to meet basic requirements.

Research needs over the longer-term

Hog production, an industry with a value in excess of $2 billion, is found in all parts of Canada. It is increasing, but not at the same rate in all provinces. Overall, hog production in 1995 was 7% greater than in 1994, and much of the production is going to the export market. About 30% of the Canadian production has been exported to 55 countries, and the potential for increased hog production is real. Any increase in production will also increase the requirements for feed production, feed quality, housing, manure storage, land to spread this manure, and the ability to deal with more people affected by the hog-raising environment.

Four problems have been discussed in the previous chapters:
- odor production from hog production facilities and manure storage
- air pollution
- land suitability for manure application
- phosphorus accumulation on land where manure is spread.

These problems can be considered as short-term problems that have a possibility of significant progress being made over the next four years. Impact of hog production on water quality has also been referred to as an issue.

The long-term aspects of hog production and the associated aspects of manure handling and disposal are multifaceted. To fully address the problems, an integrated plan that deals with the whole system of hog production must be developed. The component parts will include
- feeds and feeding
- hog buildings
- hog health
- manure production and storage
- manure odors and gas production
- manure handling and spreading for the conservation of valuable nutrients
- cost effective ways of processing and /or packaging manure for subsequent usage
- impact of manure on the environment.

These issues will require ongoing work and must ultimately be addressed before the problem of hog production increase will be adequately resolved.

In order to be successful, this approach will require the participation of the private sector, producers, and agricultural engineering, along with the research groups.

Feeds and feeding

- Develop feed systems to maximize growth, minimize feed costs, and maximize profits to the producers. Producers are looking for ways of optimizing production efficiency. Other problems can be addressed through diet formulation.

- Modify the amino-acid balance in rations to reduce nitrogen levels in feces of dietary origin. Increasing the efficiency of animal feed can decrease feed costs and the amount of manure that must be handled. Modified composition of the manure will have implications for the types of fermentation that develop in the manure pit, the odors (the compounds responsible are by-products of manure ingredients), and the gas production (gases are fermentation by-products of, for example, manure nutrients and mineral recycling).

- Consider mineral complexes. Minerals in feeds are normally in the form of organo-mineral complexes. Mixing feeds may cause new organo-mineral complexes to form, which may make certain minerals less available to the animal and also make those same minerals in manure less available to the plant in the field.

Animal environment and buildings

- The key factor is adequacy of ventilation. Hogs have very specific requirements for adequate fresh air. This is essential for maintaining animal health, regulating body temperature, minimizing dust in their atmosphere, maintaining growth rates through well regulated metabolism, etc. Most of the technology concerning this part of the environment is understood, but they have to be applied to have the desired effects.

Manure storage

- Consider storage facilities. Much work has gone into establishing the proper conditions for storage of manure. Many different types of storage systems are available depending, for example, on the type of barn, the number of animals, the natural topography, and the annual rainfall. The main issue is the correct type and size of storage facility for each operation. Cost is a major factor.

- Storage and separation of manure is a factor. Storage of liquid manure requires storage and handling of large quantities of water for much of the year. If the manure is separated into liquid and solid fractions, each will be handled differently. The liquid can be concentrated, fermented, dried, used as a hydroponic medium, added to irrigation water, etc. The solids can be dried and stored at much less cost, composted, bagged, and spread with conventional equipment.

- Combine other wastes with manure in the storage pit. Many wastes from forestry, fisheries, and agriculture may be effectively combined with manure to increase the stability of the manure or to add more nutrients to the final product.

Manure spreading

- Apply manure in the fall effectively. When the crops stop growing in the fall, application of manure is likely to have the nutrients lost with rain and surface runoff, and with spring snowmelt. Hog producers need to empty their manure storage tanks in the fall to accommodate the winter and spring production. Annual storage requirements can be as much as 9 months in some parts of Canada. This problem requires crop species that will tolerate some frost and grow late into the fall, in addition to determining the optimum time and method of spreading fall manure.

- Consider the handling methodology for wet and dry manure ingredients. This will evolve with the decision about the best methods for handling whole liquid manure or separation of the manure into solids and liquid with soluble ingredients.

- Assess the impact of soil and weather conditions on loss of manure volatile components. The impact of factors like temperature, time of day, impending precipitation, wind, relative humidity, soil type, soil surface, topography, type of manure, cropping, type of spreading equipment, and size of tractor can play a significant role in determining the efficacy of manure application.

- Adapt manure application systems under conservation tillage. Conservation tillage does not open up the soil so that surface-applied manure can be buried and protected from those factors that will take away volatile components. Similar adaptations to spreading technology are needed for spreading on perennial crops, such as forages.

- Assess the accumulation of manure borne bacteria. The impact of bacteria of animal or environmental origin that are spread with the manure is not well understood. Do they have long-term accumulated impacts on the soil and/or crops? Are the pathogens anaerobic and hence killed when spread into an aerobic environment? Is composting necessary to save reinfecting animals fed the crops that are fertilized with their own manure?

- The problem of bacteria is also an issue from the point of view of food safety.

Water

- Consider the handling of the water portion of liquid manure. This portion of the manure contains high quantities of soluble nutrients which are readily available to plants and easily moved in the environment with surface water. As processes are developed for separating the liquid and solid portions of the manure, techniques for transporting and applying this water must also be addressed.

- Evaluate the potential for soluble nutrients and other elements (e.g. Zn and Cu) to enter the groundwater. Much of the basic data on movement of water and dissolved chemicals through different soil types is known. This needs to be summarized in an easily understandable form and presented to producers so that they will not unwittingly contaminate their groundwaters. This will also have implications for human water supplies and recycling of nutrients to livestock.

- Assess the handling of nutrients that may be part of surface water and runoff into adjacent fields, farm dugouts, or environmentally sensitive streams and rivers. This will involve studying factors like time of application, carrying capacity of soils, height of the water table, rate of incorporation of water into the soil matrix, metabolic activity of the soil, mineral interactions, and soil Ph.

CONCLUSION

A systems approach is required for economically viable and environmentally sustainable hog production in Canada.

- Minimizing NH_3 emission during hog production must occur using a system approach, that takes into account both the economic viability and the environmental sustainability. Environmental sustainability is concerned with NH_3 and greenhouse gas emission, odor, and surface and ground water contamination by nitrates and BOD. Most hog production facilities have been designed with little consideration of a cost-effective manure management based on maximizing the nutrient value of the manure and minimizing the negative environmental impacts. Considering that the size of hog production facilities is increasing in Canada, taking into account the cost of environmentally sustainable manure management is a priority.

- Reducing NH_3 emissions from manure storage facilities and following field application may increase the cost of production through increased capital cost for storage and equipment, and by the need for additional land in order to apply the manure without increasing the potential for groundwater contamination by nitrate and phosphorus.

- Improved feeding strategies may result in slightly higher feed costs but will reduce at the same time the amount of land required to apply the manure in an environmentally sustainable manner.

- Environmentally sustainable manure management has to be part of the economic equation for hog production. This may lead to the development of alternative hog production strategies, such as group housing on bedding that can be composted and exported further from the intensive production facilities. Creativity has to be combined with the full understanding of the environmental implications of the production systems.

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