AGRICULTURAL NH_3 AND NO_x EMISSIONS IN CANADA

Presented at **"Nitrogen, the confer-N-s"** (Nitrogen Conference)
March 23-27, 1998
Noordwijkerhout, The Netherlands

T. Kurvits[1, 3], T. Marta[2]
[1] Symbiotics Consulting;
[2]Agriculture and Agri-Food Canada
Ottawa, CANADA

First received 27 March 1998 and in final form 30 June 1998.

ABSTRACT

This is a review of the Canadian science and technology related to sources, impacts and abatement for atmospheric nitrogen emissions from agriculture. The primary focus is on the gases ammonia (NH_3) and nitrogen oxides (NO_x). In Canada, recent inventories show a significant increase in agricultural emissions of NH_3. Most emissions are from farm animals, with the remainder from fertilizer application. Current estimates indicate that farm vehicles contribute approximately 5 % of total NO_x emissions in Canada. Fertilized farmland is also a source of NO_x. Techniques that are available to Canadian producers to reduce on-farm nitrogen air emissions include: feeding strategies, manure management and housing for livestock, air purification, and synthetic nutrient management. Improved efficiency of fuel combustion in farm vehicles reduces NO_x emissions. At the present time, relative to significant Canadian studies on agricultural sources of nitrogen air emissions, there is little research into the associated environmental effects and on abatement techniques. There is a need for further investigation into all aspects of atmospheric nitrogen emissions in Canadian agriculture.
Key words: agriculture, ammonia, emissions, nitrogen, NH_3, NO_x.

INTRODUCTION

Emissions of nitrogen compounds into the air is a multi-effects issue and agriculture plays a major role, both as a cause and solution, for associated environmental and human health problems. Among nitrogen compounds being emitted from agricultural sources, the most significant are ammonia (NH_3), primarily from livestock manure and inorganic fertilizers, nitrogen oxides (NO_x), from fuel combustion in farm equipment and the conversion of fertilizers in agricultural soils and nitrous oxide (N_2O) from soils and animal waste. In Canada, N_2O emissions from agricultural sources is being addressed in relation to greenhouse gases and climate change. Agricultural nitrogen air emissions are linked to various negative effects on ecosystems and

---

[3] T. Kurvitz, 613-594-8503 (Tel.), 613-569-7512 (Fax), symbiot@istar.ca.

.../2

human health, such as acidification, eutrophication, ground-level ozone and particulate matter and loss of biodiversity. Concern for the environmental effects of these emissions of nitrogen compounds has led to considerable science and policy efforts, particularly in Europe, to determine the need and options for systematic and targeted management of these air emissions. Domestic and international initiatives, such as the Multi-Pollutants, Multi-Effects (Second Nitrogen) Protocol under the Convention on Long Range Transboundary of Air Pollution (LRTAP) of the United Nations Economic Commission for Europe (UN-ECE), are promoting environmental management actions that could come into force in the near future. These actions could affect agriculture and other activities in Europe and North America.

An important goal of a multi-stakeholder consultation process is to improve science-policy integration to support, in this case, environmental management decisions relative to agricultural NH_3 and NO_x emissions. The basic process begins with a review of scientific and technical information and public policy analysis. The next steps are to identify science-policy scenarios, to assess implications for the agricultural sector and to rank options relative to domestic and international environmental management initiatives.

Scope This paper is a review of Canadian science and technology related to: 1) agricultural sources of emissions of NH_3 and NO_x; 2) impacts of emissions of NH_3 and NO_x on the environment; and 3) abatement techniques to reduce emissions of NH_3 and NO_x from agricultural sources. Agricultural N_2O, a greenhouse gases associated with potential climate change, is not addressed in this paper.

Canadian Context Recent inventories show a significant increase in NH_3 emissions from agricultural sources. Likewise, agricultural vehicles are an important, and increasing, source of NO_x in the transportation sector. The increase coincides with a growth in intensive farming and fertilizer usage. Most of this increase is associated with an increase in livestock numbers, especially cattle and hogs. Total numbers of cattle increased by 15% across Canada between 1991and1996. Growth was strongest in the western provinces, such as Alberta at 25%, Manitoba at 22%, and Saskatchewan at 19% (Statistics Canada, 1997). Beef cow numbers are up in all provinces; however, the increase in eastern Canada is cancelled by a decrease in dairy cows.

.../3

Exports are responsible for most of the growth in the beef sector. The number of hogs in Canada increased 8%, with strongest growth in Quebec at 18% and Manitoba at 38% (ibid). While

Canada's total farmland area is constant, land in crops increased 4%, with growth in all provinces but Manitoba. Increased cropland combined with higher crop prices resulted in a rise in fertilized farmland by 15% between 1990-1995 (ibid).

Environmental issues of nitrogen air emissions relate mainly to human activities which enhance the total nitrogen available to non-targeted ecosystems. Research has indicated a potential for widespread acidification of Canadian ecosystems caused by the cumulative deposition of nitrogen pollutants, emitted primarily as NO_x, but also as NH_3 (Jeffries, 1995). With regard to ozone component of smog in Canada, projections show NO_x from agricultural vehicles are increasing as a source in the transportation sector. Agricultural activities are possible targets for proposed environmental management actions given the associated environmental effects, because they are the primary source of rising NH_3 and NO_x emissions. Efforts are underway in Canada to determine whether proposed national objectives for fine particulate matter ($PM_{2.5}$) in the air should address the link between NH_3 emissions from livestock and fertilizers and the $PM_{2.5}$ formation. Therefore, it is important for the agricultural sector to understand this issue, the related scientific research and technological development, and the opportunities to improve agricultural emissions management as a whole.

EMISSIONS SOURCES OF AGRICULTURAL NH_3 AND NO_x EMISSIONS

The 1990 inventory, Ammonia Emissions In Canada, found that NH_3 emissions were 651 ktonnes, of which 569 ktonnes (87%) were attributed to agriculture (Environment Canada, 1997). Of the total agricultural emissions, 82% was from farm animals and 18 % was from fertilizer application (*ibid.*). The highest emissions from animal manure are in Ontario, Alberta, and Quebec (*ibid.*). Highest fertilizer emissions are from Alberta, Saskatchewan, Manitoba, and Ontario. It should be noted, however, that there is considerable uncertainty associated with these inventories. For example, uncertainty in regional inventories conducted for Europe is at least 30-40% on a country basis (Asman, 1994). The emission estimates in the Canadian NH_3 inventory, for example, do not account for the effect of possible changes in farm management techniques.

.../4

Livestock The amount of NH_3 released from livestock manure depends on the animal type, its diet, and the method of manure management used. According to the 1990 NH_3 emissions inventory, animal husbandry was responsible for 464 ktonnes of NH_3 in Canada (Environment Canada, 1997). Early results for the 1995 inventory indicate an increase in emissions, notably from raising cattle and hogs (Table 1). The inventory makes no distinction between NH_3 emissions from manure of grazing livestock and animals within enclosures.

Manure Storage The manner and duration of manure storage influences NH_3 emissions. NH_3 emissions from manure increase with increasing temperature, increasing pH and increasing exposure to air. Emissions of NH3 are reduced by practices that minimize exposure time of fresh manure in barns (Burton and Beauchamp, 1986). Research in Canada demonstrated that in the stable NH_3 from manure increased with residence time, from 5% after one hour to 27% after one week (ibid).

Manure Application Losses of NH_3 from application of slurry are highest immediately after application, then decline rapidly within 12-24 hours, followed by low rates of loss for another 5-14 days (Thompson and Pain 1990). In their study, 50% of the total NH_3 loss occurred within 24 hours of application. According to Klarenbeek and Bruins (1991), NH_3 emissions from application of animal slurries depends on: type of slurry, rate of application, machinery used, and climatic conditions.

Crops A general observation is that a significant amount of NH_3 can be emitted from crops (Schjørring, 1991). Canadian research has shown an NH_3 loss of 14% of the applied nitrogen by decomposition for a legume green manure (Janzen and McGinn 1991). The total NH_3 lost from crops in Canada is about 10% that of losses from manure applications (Whitehead and Lockyer 1989). There is relatively little NH_3 loss from herbage drying or aging (ibid.).

Synthetic Fertilizer The type of synthetic fertilizer used affects the rate of NH_3 lost. Urea fertilizer has been shown to produce the highest emissions of the total available NH_3 at 6-25% (ECETOC 1994), while emission rate for calcium ammonium nitrate is 5-14% (Bussink, 1994), depending on the rate of application. NH_3 emissions are about 20% of the application in

.../5

dry soil because of diffusion through soil pores, 50% in wet soils because of incomplete closure of injection slits, and insignificant in moist soils (Sommer and Christensen, 1992). The 1990 Canadian inventory in Canada shows that fertilizer application accounts for about 104 ktonnes of of NH_3 emissions (Table 2). Early analysis of the 1995 data indicates an increase in overall emissions of approximately 26% (Environment Canada, 1997). Approximately 11 % of nitrogen in fertilizer is converted to NO_x (Shepherd et al., 1991). Fluxes of NO_x from fertilized fields into the atmosphere are strongly related to nutrient levels, soil moisture, and soil temperature (ibid). There are no reliable estimates for NO_x emissions from soils across Canada.

Farm Equipment Heavy duty diesel vehicles (HDDV) represent the highest single source of NO_x in Canada from the transportation sector. However, with the exception of those vehicles used for on-road transportation, most farm vehicles are not included in this category (most farm equipment is either off-road diesel or gasoline). Agricultural heavy duty diesel vehicles contribute an estimated 25% to the national total in this category (Environment Canada, 1997). In total, agricultural equipment contributed about 5% to NO_x emissions in Canada in 1995 (C. Vézina, pers. comm.). In Canada, the use of diesel fuel in agriculture was responsible for almost 58 ktonnes of NO_x emissions in 1995, or 3% of the total emissions from all sources (Environment Canada,1997).

ENVIRONMENTAL EFFECTS OF AGRICULTURAL NH_3 AND NO_x EMISSIONS

This review indicates that there is little research into the environmental effects of atmospheric nitrogen deposition in Canada, particularly as it pertains to emissions from agriculture. A recent scientific review (Vitousek et al., 1997) found that the effects of increased deposition of nitrogen compounds include: increased regional concentrations of oxides of nitrogen; substantial acidification of soils and waters in many regions; greatly increased transport of nitrogen by rivers into estuaries and coastal waters; and accelerated losses of biological diversity.

Nitrogen Saturation and Acidification Nitrogen contributes to the acidification of terrestrial and aquatic ecosystems through the deposition of nitric acid (HNO_3), NH_3, and ammonium. There is evidence that some North American forests are nearing nitrogen saturation including forests in Ontario (D. Jeffries, pers. comm.). In some areas, such as the eastern North American hardwood forests, increased nitrate leaching and shifts in nutrient ratios in trees are seen in forest sites at high-elevations and with shallow soils having a low ability to buffer acid (Vitousek et al., 1997). Nitrogen saturation and breakthrough leading to acidification is just beginning to be observed in Canada (K. Hedley, pers. comm.).

.../6

Impacts of acidification on Canadian forests ranges from minimal to severe, depending on the region and on the intensity and type of pollutant (AETG, 1997). Damage to forests by acidic deposition, which tends to be more widespread in eastern Canada and more localized in the west, leads to a decrease in tree vitality, regenerative capacity and productivity loss, reported as 10 % in eastern Canada (*ibid*). There is evidence that acidic deposition can cause discernible effects in forests suffering from other forms of stress, such as drought or high-elevation temperature extremes (Canada/U.S., 1996).

Further acidification damage may occur where nitric acid is a significant pollutant accumulating in winter snowpack. When the snow melts in the spring, the acid is flushed out in the meltwater often resulting in a sudden, concentrated "acid pulse" into lakes (Vitousek et al. 1997). A recent review of acidifying emissions reported that nitrogen-based acidification is evident for many lakes scattered throughout southeastern Canada, particularly in south-central Ontario and southwestern Quebec (AETG 1997). The most sensitive lakes are located mainly in central Ontario and Quebec, and Atlantic Canada. Acidified waters demonstrate a number of characteristics, including: fewer species of wildlife living in or around them; greater susceptibility to degradation through mechanisms such as UV radiation (*ibid.*); and changes to the nitrogen cycle within lakes, the long-term effects of which are not known (Rudd et al., 1988).

Eutrophication Plant growth in most Canadian freshwater lakes is limited by the availability of phosphorous. Nitrogen, therefore, is not generally considered a problem in eutrophication of these waters. Signs of eutrophication, however, are appearing in coastal waters, which are limited by nitrogen rather than phosphorous, and increasing attention is drawn to the significant portion of nitrogen deposition from agricultural emissions (Paerl, 1993).

Effects on biota include shifts towards undesirable, often toxic, groups of phytoplankton

.../7

(*ibid.*), nuisance blooms, bottom water anoxia, fish kills, loss of diversity in the sea floor community, including seaweeds, seagrasses, corals, and major changes in the invertebrate grazer and fish communities (Vitousek et al., 1997; Paerl, 1993). In Canada, there are more frequent and intense toxic "red tides" along the Canadian-United States northwest and Atlantic coasts (Paerl, 1993). Likewise, toxic diatom blooms, such as *Nitzchia pungens*, the organism responsible for amnesic shellfish poisoning, are increasing along the Canadian-United States Pacific coasts and in the Atlantic Maritimes (*ibid.*). Blooms of prymnesiophyte, *Phaeocystic* spp., have been noted along continental margins of the North Atlantic (*ibid.*).

Biodiversity Continuous deposition of nitrogen compounds is associated with reduced plant species composition and diversity. While plants absorb and use available atmospheric NH_3 directly, they are adversely affected directly by enhanced NH_3 concentrations that are toxic and indirectly by the effects of nitrogen deposition on soil, as such as acidification.

Shifts in native ecosystems are caused by nitrogen enrichment when species with low nitrogen requirements cannot compete against faster growing species (Wedin and Tilman, 1996; Sutton et al., 1993; Heil and Bruggink, 1987; van Dam et al., 1986). The shift in species composition to plants able to exploit higher nitrogen levels is estimated to reduce carbon storage by more than half, thus having potential implications for global climate change (Raloff, 1996). With increasing nitrogen deposition, shifts in species composition from species-rich heathlands to species-poor grasslands and forest may occur in plant communities in Canada with poorly buffered, slightly acidic, and nutrient-poor soils, such as on the Canadian Shield.

Biodiversity among animals may also be affected by increased nitrogen deposition. Many freshwater fish and invertebrates are sensitive to NH_3 and acidification of waters. Birds and mammals may be indirectly affected by changes to plant communities.

There are some instances where the addition of nitrogen may be beneficial. In Lake Ontario, for example, a combination of increased nitrogen and decreased phosphorous concentration has reduced the total quantity of algae and caused a shift in species composition away from nuisance blue-green algae towards more desirable diatoms which were historically prevalent (Nielsen et al., 1995).

.../8

Tropospheric (Ground-level) Ozone and Particulate Matter Smog is the common name for photochemical fog. It is composed of numerous contaminants, including tropospheric or ground-level ozone and particulate matter. Ground-level ozone is created when NO_x and volatile organic compounds (VOCs), both emitted in vehicle exhaust, react with sunlight. In Canada, the greatest incidences of tropospheric ozone are in the Quebec-Windsor corridor, the southern portion of Atlantic Canada, and British Columbia's Lower Fraser Valley.

Ground-level ozone can have detrimental effects on human health as well as the health and productivity of crops and forests. The major effect of ozone on forests is reduction of net photosynthesis (Aber et al., 1989). Ozone exposure could hasten the occurrence of nitrogen saturation and magnify its effects and together with nitrogen deposition could act synergistically to induce nitrogen saturation and forest decline (*ibid.*).

Particulate matter (PM) is the term given to very small (0.005-100 µm in diameter) ambient solid material and liquid droplets (Environment Canada et al., 1997). It is emerging as an important part of the smog issue. There are two distinct categories of particulate matter, $PM_{2.5}$ (diameter less than 2.5 µm) and PM_{10} (2.5-10 µm in size). Fine particulates, $PM_{2.5}$, are formed from emissions from fuel combustion and in reactions with other chemicals, including NO_x and NH_3 (*ibid.*). $PM_{2.5}$ is composed of soil, nitrate, and sulphate, the latter being higher in western Canada (Hedley, 1997). Coarse particulates, PM_{10}, are made up of soil dust, inorganic and organic carbon compounds, and metals (Environment Canada et al., 1997).

The primary concern with particulate matter relates to human health. $PM_{2.5}$, in particular, has the ability to pass into the lungs. NH_3 gas is implicated in PM formation when it is converted into ammonium nitrate (NH_4NO_3) and ammonium sulphate ($(NH_4)_2SO_4$) which are both solids. It has been suggested that both of these compounds pose significant human health risks with increasing atmospheric particulate concentrations (Gaider, 1997). Some of the health effects include aggravation of existing disease, damage to lung tissue, impaired breathing, cardiac and immune system stress, and premature death (Environment Canada et al, 1997). Although particulate matter seems to pose a significant risk to human health with increased atmospheric particulate concentration, there is currently little understanding about the

.../9

environmental impacts of small particulates containing NH_3/ammonium (*ibid.*). It is thought to decrease productivity in vegetation indirectly via the deposition of acidifying aerosols on soils (*ibid.*). Because PM also refracts, reflects or absorbs light, it contributes to the creation of haze which reduces visibility (*ibid.*).

Odour Odour is primarily a nuisance problem rather than one of environmental damage. Where there is odour in agriculture from waste management, there are usually NH_3 emissions as well. The NH_3 from fertilizers, such as anhydrous NH_3, does not contribute to the odour issue. Odour associated with agricultural operations is particularly a concern in areas of intensive livestock operations. The increasing numbers of cattle in feedlots in southern Alberta and the growing hog production in Quebec are leading to more odour concerns, particularly in agricultural areas with significant non-farm populations (Patni, 1997).

A North American study, however, reported a 12% weight-gain reduction in swine at 50 ppm (Drummond et al., 1980). Safe levels for human health are given as 21 ppm for Europe and 25 ppm for Germany (ETETOC, 1994).

ABATEMENT OF AGRICULTURAL NITROGEN AIR EMISSIONS

Numerous methods are available to reduce on-farm atmospheric nitrogen emissions. A selection of these are provided below. It is in the interest of agriculturalists to reduce nitrogen emissions from their operations, not only because of the environmental effects associated with them, but also because of the financial gains of more efficient use of fertilizers.

Improved Feeding Strategies Feeding strategies influence a number of factors relating to NH_3 emissions from animal raising, including urinary nitrogen concentration; rate of NH_3 formation and emissions for manure; and, frequency and intensity of urination (UNECE, 1996). Examples of such strategies are: balanced amino acid diets for poultry and lower protein diets for dairy cattle (Paul et al., 1997).

Housing Systems for Livestock NH_3 emissions can be reduced from livestock housing by using techniques that slow decomposition, fermentation, and the volatilization process in manure. Moving wet manure more frequently to covered storage and using conveyor belts in combination with forced drying help reduce air emissions (UNECE, 1996). Floor design such as

.../10

an inclined or convex, smoothly solid finished floor for improved drainage of urine or, slatted floors that reduce emitting surface (*ibid*). For practices associated with NH_3 emissions, a survey of management techniques on Canadian farms in 1995 revealed that among the 60% of surveyed farms storing manure, 95% and 11% used, respectively, solid and liquid form (Agriculture and Agri-Food Canada and Statistics Canada, 1996). Among those operators storing liquid manure, 16 % used a tank below a slatted floor and 16 % used a covered tank, compared to 33 % who used an unlined lagoon and 31 % using an open tank (*ibid.*). Bioscrubbers and biofilters can purify the air in livestock housing (Nielsen and Pain, 1991) but their use is generally limited by the high cost of equipment.

Manure Management Techniques to reduce NH_3 emissions from manure, whether in storage or during application, primarily focus on either changing the composition of the manure or reducing the exposure to air. In barns, NH_3 emissions are reduced by flushing the manure from the floor with water (Voorburg and Kroodsma, 1992). NH_3 emissions from stored manure can be reduced by acidification of the manure (*ibid.*). The 1995 Canadian farm impacts management survey found that among operators storing solid manure, 65% used an open pile on the ground without a roof, compared to 3% using an open pile with a roof and 1% using a storage pad (Agriculture and Agri-Food Canada and Statistics Canada, 1996). Field application techniques for manure, such as bandspreading, trailing hose application, and injection of slurry, will lower air emissions to the air (McGinn and Janzen, 1998).

Nutrient Management The best strategy to reduce NH_3 losses from fertilizers is to minimize the amount of excess inorganic nitrogen in the soil at any given time (Jenkinson, 1990), mainly as a function of application method and fertilizer type. This can be achieved by soil testing for nitrogen content, timing of applications (*ibid.*), equipment calibration (Hedger, 1996), and controlled release fertilizers (Cole, 1996). Relative to NH_3 emissions, the 1995 survey of Canadian farm management practices revealed that among those operators applying commercial fertilizer, 63% used soil testing to decide on the amount and type (Agriculture and Agri-Food Canada and Statistics Canada, 1996). Among those operators conducting soil testing, 35% tested yearly and 40% every 2-3 years (*ibid*).

.../11

Improved Efficiency of Farm Vehicles Regulations covering diesel exhaust emissions at various horse power levels that have come into effect recently in the United States, particularly in California, have encouraged manufacturers serving the Canadian market to invest heavily in exhaust emission reductions for off-road diesel engines, such as those used for farm vehicles. Tighter quality controls in manufacturing ensure that component parts of fuel and engine systems are finely tuned to each other. Research and testing is underway to optimize air flow into engines and to refine the combustion chamber. Emissions from ten-litre and larger engines are being reduced by direct injection combustion coupled with electronic controls for multiple functions of engine management. Fuel injection systems are improving the matching of fuel particle size, shape and variable volume. Reductions in NO_x have also been achieved by a reduction in peak cylinder temperature. Many of the off-road engine manufacturers serving the Canadian market have signed the non-road diesel exhaust emission "Statement of Principles"developed by the United States Environmental Protection Agency. This voluntary action commits the manufacturers to reduce emissions from uncontrolled levels, to achieve approximately 75% reductions in NO_x and 40% in particulate matter.

KNOWLEDGE GAPS/EMERGING ISSUES

Scientific studies indicate that the changes to the global nitrogen cycle are extensive and are causing significant effects on many different ecosystems. Preliminary observations suggest that the current Canadian research on NH_3 and NO_x emissions focuses on vehicular emissions of NO_x and on the effects of NH_3 emissions on animal and farm worker health, but is relatively limited respecting other impacts of NH_3. Researchers in Canada, and elsewhere, have identified areas for further study of emission sources, environmental effects, and abatement measures.

Emission Sources The greatest need with respect to emission sources is to increase the accuracy of emission estimates from all sources. The lack of information on NH_3 has lead to an uncertainty in local and global balances of nitrogen and the impact of NH_3 on the environment (McGinn and Janzen, 1998). Much of the uncertainty for estimates of total NH_3, for example, as reported by Asman (1992), originates from emissions modelling and most is related to estimates of animal waste, agricultural practices, soil types, and meteorological conditions. Also,

.../12

there are difficulties in quantifying NH_3 from manure because of its low concentration and variability of emissions in time and space (McGinn and Janzen, 1998).

Environmental Effects Research is needed into the impacts of atmospheric nitrogen deposition on both land and aquatic ecosystems, and specifically on Canadian ecosystems. An improved understanding of the nitrogen cycle is needed. More research on the effects of off-road emissions of NO_x is required. There is a need for more monitoring data in all areas of concern, as well as environmental impact studies in exposed ecosystems (Doyle, 1997), particularly relative to acidification/saturation, eutrophication, changing biodiversity.

Abatement Measures A small number of Canadian researchers are conducting ongoing studies on techniques to reduce agricultural nitrogen air emissions. Key research needs relate to: techniques and data for reducing emissions from solid manure application and livestock housing systems (Nielsen and Pain, 1991); techniques for evaluating the performance of manure and slurry spreading machinery and other management practices for the reduction of NH_3 and odour (*ibid*.); affordable, reliable bioscrubbers and biofilter systems; improving animal diets to balance nitrogen requirements and reduce nitrogen output (John Paul, pers. comm.); cost-benefit analysis and recommendations for different emission reduction techniques (Nielsen and Pain, 1991); and a "whole farm" approach, for example, to match land-use techniques, such as conservation tillage, zero tillage, pasture, irrigated land, with NH_3 emission abatement techniques (S. McGinn, pers. comm.)

CONCLUSIONS

This review of agricultural nitrogen emissions reveals that it is an important emerging issue in Canada. Current inventories show that agriculture is contributing an increasingly significant amount of NH_3 and NO_x to the atmosphere. Even though the amount of research into the associated environmental effects in Canada is limited, existing Canadian and international studies indicate the significance of this issue. The problem of acid rain, for example, was thought by many to be resolved by restrictions placed on sulphur dioxide emissions. We are now learning that not only does this issue still exist, but that the progress made by controlling sulphur dioxide may be undermined by the increasing atmospheric emissions of nitrogen. The same is true for most of the other environmental effects reviewed in this paper. There is a need to better understand the complex relationships between excess nitrogen and other environmental stressors, such as climate change and other atmospheric pollutants.

.../13

There is a range of options available to agricultural producers to address the issue of atmospheric nitrogen emissions. Many of the abatement techniques outlined here focus on improving production efficiency. For producers, this also means a potential financial benefit because nitrogen excreted by an animal or lost from the field is an economic loss. More work is needed to translate the environmental priority of reducing NH_3 and NO_x emissions into a management priority for agricultural producers.

The significant knowledge gaps respecting agricultural nitrogen emissions illustrate the need for further investigation into all aspects of this issue, from refining estimates of emission sources to improving our understanding of the environmental effects to making abatement techniques available and economical to producers. By working together, producers, researchers, and governments have the opportunity to develop ecologically and economically sound strategies to reduce agricultural nitrogen emissions both in Canada and abroad.

TABLES

Table 1. NH_3 Emissions from Animal Husbandry in Canada (Environment Canada, 1997).

	1990 (tonnes NH_3)	1995* (tonnes NH_3)	1990-1995* (% change)
Calves and Cattle	257383	331016	+28
Poultry	107388	118588	+10
Hogs and pigs	92429	106822	+15
Horses	4345	4379	+1
Sheep and lambs	2468	2492	+1
Fur farms animals	279	279	0
ANIMAL HUSBANDRY TOTAL	464292	563576	+21

* Preliminary: Emission factors used for the Canadian Inventory were taken from US-EPA (1994), which in turn are based largely on Asman (1992).

Table 2. NH_3 Emissions from Fertilizer Application in Canada

(Environment Canada, 1997).

	1990 (tonnes NH_3)	1995* (tonnes NH_3)	1990-1995* (% change)
Urea	86081	109232	+6
Ammonium sulphate	3070	4183	+36
Ammonium nitrate	2292	2199	-4
Anhydrous NH_3	4270	5311	+24
Nitrogen solutions	1975	1981	0
Monoammonium phosphate	4565	4948	+8
Diammonium phosphate	2213	1562	-29
Other phosphate fertilizer	9	0.00	--
Other fertilizer materials	2	1925	--
FERTILIZER TOTAL	104477	131341	+26

* Preliminary: Emission factors used for the Canadian Inventory were taken from US-EPA (1994), which in turn are based largely on Asman (1992).

REFERENCES

Aber, J., K. Nadelhoffer, P. Steudler, and J.M. Melillo. 1989. Nitrogen saturation in northern forest ecosystems: Hypothesis and implications. BioScience. 39:378-386.

AETG (The Acidifying Emissions Task Group). 1997. Towards a National Acid Rain Strategy. Report submitted to the National Air Issues Coordinating Committee. Environment Canada. Ottawa.

Agriculture and Agri-Food Canada and Statistics Canada. 1996. Farm Inputs Management Survey, 1995. (A survey of manure, commercial fertilizer and commercial pesticide management practices on Canadian farms). Ottawa.

Asman, W.A.H. 1994. Emission and deposition of ammonia and ammonium. Nova Act Leopoldina NF 70. 288:263-297.

Asman, W.A.H. 1992. Ammonia emission in Europe: updated emission and emission variations Report 228471008. National Institute of Public Health and Environmental Protection. Bilthoven, The Netherlands.

Burton, D.L. and Beauchamp, E.G. 1986. Nitrogen losses from swine housings. Agric. Wastes 15:59-74.

Bussink, D.W. 1994. Relationships between ammonia volatilization and nitrogen fertilizer application, rate, intake and excretion of herbage nitrogen by cattle on grazed swards. Fertilizer Res. 38:111-121.

Cole, V. (ed.) 1996. Agricultural options for mitigation of greenhouse gas emissions. Ch. 23. pp.747-771. In: R.T. Watson, M.C. Zinyowera, and R.H. Moss (eds.). *Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis*. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Doyle, P. 1997. Problem formulation for ammonia in the aquatic environment. PSL2 Ecological Risk Assessment. In: Agricultural Nitrogen Air Emissions in Canada: An Overview. Meeting 1 of Agricultural Sector Contacts. Record of Meeting, May 30, 1997. Environment Bureau. Agriculture and Agri-Food Canada. Ottawa.

Drummond, J.G. Curtis, S.E., Sinon, J. And Norton, H.W. 1980. Effects of aerial ammonia on growth and health of young pigs. J. Anim. Sci. 50(6):1085-1091.

ECETOC (European Centre for Ecotoxicology and Toxicology of Chemicals). 1994. Technical Report No. 62. Ammonia emissions to air in western Europe. Brussels. 196pp.

Environment Canada. 1997. Canadian Emissions Inventory of Criteria Air Contaminants (1995). Off-road use of fuel (gasoline and diesel). Draft report. Criteria Air Contaminant Section, Pollution Data Branch. Hull.

Environment Canada, Natural Resources Canada, and Transport Canada. 1997. Phase 2, Federal Smog Management Plan. November 1997, Hull, Quebec.

.../17

Gaider, K.M. 1997. Analysis of atmospheric ammonia as a potential atmospheric toxin. Unpublished report. Atmospheric Environment Branch. Environment Canada. Toronto.

Hedger, M.M. 1996. Agriculture and forestry: Identification of options for net greenhouse gas reduction. Policies and measures for common action. Working paper 7. Annex I Expert Group on the UN FCCC. OECD. 71pp.

Hedley, K. 1997. The role of nitrogen in particulate matter. In: Agricultural Nitrogen Air Emissions in Canada: An Overview. Meeting 1 of Agricultural Sector Contacts. Record of Meeting, May 30, 1997. Environment Bureau. Agriculture and Agri-Food Canada. Ottawa.

Heil, G.W. and M. Bruggink. 1987. Competition for nutrients between Calluna vulgaris (L.) Hull and Molinia caerulea (L.) Moench, Oecologia. 73:105-107.

Janzen H.H. and McGinn S.M. 1991. Volatile loss of nitrogen during decomposition of legume green manure. Soil Biol. Biochem. 23(3):291-297.

Jeffries, D.S. 1995. Fresh Water Acidification in Canada Caused by Atmospheric Deposition of Nitrogen Pollutants: A Preliminary Assessment of Existing Information. National Water Research Insititute, Burlington, Canada. NWRI Contribution No.95-116.

Jenkinson, D.S. 1990. Leaks in the nitrogen cycle. pp. 35-49. In: R. Merckx, H. Vereecken and K. Vlassak (eds.). Fertilization and the Environment. Leuven University Press. Leuven, Belgium.

Klarenbeek, J.V. and M.A. Bruins. 1991. Ammonia emissions after land spreading of animal slurries. In: V.C. Nielson, J.H. Voorburg. and P. L'Hermite (eds.). Odour and Ammonia Emission From Livestock Farming. Elsevier Applied Science. London.

McGinn, S.M. and H.H. Janzen. 1998. Ammonia emissions in agriculture and their mesurement. Can. J. Soil. Sci. 78:139-148.

Nielsen, M., S. L'Italien, V. Glumac, D. Williams, and P. Bertram. 1995. Nurients: trends and system response. State of the Lakes Ecosystem Conference. Background paper. August 1995. Dearborn, Michigan.

Nielsen, V.C. and B.F. Pain. 1991. Conclusions and recommendations. pp. 214-217. In: V.C. Nielson, J.H. Voorburg. and P. L'Hermite (eds.). Odour and Ammonia Emission From Livestock Farming. Elsevier Applied Science. London.

Paerl, H.W. 1993. Emerging role of atmospheric nitrogen deposition in coastal eutrophication: biogeochemical and trophic perspectives. Can. J. Fish. Aquat. Sci. 50:2254-2269.

Patni, N. 1997. Agricultural nitrogen emissions and odour. In: Agricultural Nitrogen Emissions in Canada: An Overview. Meeting 1 of Agricultural Sector Contacts. Record of Meeting, May 30, 1997. Environment Bureau. Agriculture and Agri-Food Canada. Ottawa.

.../18

Paul, J.W., T.A. Scott and P.K. Barton. 1997. Ammonia emissions and nitrogen balances during poultry broiler production. Pacific Agriculture Research Centre Technical Rep. 133. Agriculture and Agri-Food Canada. Agassiz, British Columbia.

Raloff, J. 1996. Pollution helps weeds take over prairies. Sci. News Online. Dec. 12. (http://www.sciencenews.org/sn_arch/12_7_96/fob2.htm)

Rudd, J.W.M., C.A. Kelly, D.W. Schindler, and M.A. Turner. 1988. Disruption of the nitrogen cycle in acidified lakes. Science. June. 1515-1517.

Schjørring, J.K. 1991. Ammonia Emissions from the foliage of growing plants. In: Trace Gas Emissions by Plants (T.D.Sharkey, E.A. Holland and H.A. Mooney, eds.). Academic Press, Inc. San Diego, USA.

Shepherd, M.F., S. Barzetti, and D.R. Hastie. 1991. The production of atmospheric NO_x and N_20 from fertilized agricultural soil. Atmospheric Environment. 25A(9):1961-1969.

Sommer, S.G. and B.T. Christensen. 1992. Ammonia volatilization after injection of anhydrous ammonia into arable soils of different moisture levels. Plant and Soil 142:143-146.

Statistics Canada. 1997. 1996 Census of Agriculture. Ottawa.

Sutton, M.A. Pitcairn, C.E.R., Fowler, D., 1993. The exchange of ammonia between the atmosphere and plant communities. Adv. Ecol. Res. 24:301-391.

Thompson, R.B. and B.F. Pain. 1990. The significance of gaseous losses of nitrogen from livestock slurries applied to agricultural land. pp. 289-296. In: R. Merckx, H. Vereecken and K. Vlassak. Fertilization and the Environment. Leuven University Press. Leuven, Belgium.

UNECE (United Nations Economic Commission for Europe). 1996. Report on abatement techniques to reduce ammonia emissions from agricultural livestock. Convention on Long-Range Transboundary Air Pollution. Working Group on Technology. Draft report.

United States Environmental Protection Agency (US-EPA), 1994. Development and selection of ammonia emission factors. US-EPA/600/R-94/190 (Section 3). August 1994. Washington, D.C.

van Dam, D., H.F. van Dobben, C.F.J. ter Braak, and T. de Wit. 1986. Air pollution as a possible cause for the decline of some phanerogamic species in the Netherlands. Vegetatio. 65:47-52.

Vitousek, P.M., A. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger, and G.D. Tilman. 1997. Human alteration of the global nitrogen cycle: sources and consequences. Issues in Ecology. Ecol. Appl. 7(3):737-750.

Voorburg, J.H. and W. Kroodsma. 1992. Volatile emissions of housing systems for cattle. Livestock Production Sci. 31:57-70.

Wedin, D. and D. Tilman. 1996. Influence of nitrogen loading and species composition on the carbon balance of grasslands. Science. 274:1720-1723.

Whitehead, D.C. and D.R. Lockyer. 1989. Decomposing grass herbage as a source of ammonia in the atmosphere. Atmos. Environ. 23:1867-1869.