

## 4. Other links between agriculture and the atmosphere

Although CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, and O<sub>3</sub> have attracted much attention recently, agriculture also releases other materials into the air, including ammonia, other odors, aerosols, nitrogen oxides, and pesticides. As well, agriculture may be affected by changes to stratospheric O<sub>3</sub>. Many of these issues have not yet been thoroughly studied in Canada. Our main aim is to identify the potential issues and point to some possible effects.

### Ammonia

Current farming practices rely heavily on inputs of extra N, most of which ultimately derives from atmospheric N<sub>2</sub>. These high inputs help sustain food production, but they also stress the natural N cycle, resulting in “leaks” of N into the environment. The release of N<sub>2</sub>O is one such leak; another is the emission of ammonia (NH<sub>3</sub>).

### Background

Globally, agriculture is the main source of atmospheric NH<sub>3</sub> from human activity. Much of this NH<sub>3</sub> comes from livestock production. In parts of Europe, notably the Netherlands, NH<sub>3</sub> emissions from animal production are so high that they warrant strict regulations. In Canada, the problem is not yet as acute, except perhaps in local areas with high livestock numbers.

Ammonia is a colorless gas, lighter than air, with a sharp odor. In remote areas, away from sources, it occurs in the atmosphere at very low concentrations (less than 0.01 ppmv). In areas near intensive livestock production, however,

concentrations may be much higher, sometimes well above the threshold at which it can be detected by smell (~0.6 ppmv).

Unlike N<sub>2</sub>O, NH<sub>3</sub> is highly reactive and remains in the atmosphere only a short time. It reacts quickly with water, forming ammonium (NH<sub>4</sub><sup>+</sup>). Thus any moist surface—soil, plants, or open water—readily removes NH<sub>3</sub> from the air, as long as the surface is neutral or acidic in pH. In the air, NH<sub>3</sub> can dissolve in precipitation and fall to the earth as NH<sub>4</sub><sup>+</sup>, or it can be oxidized or dissociated by sunlight. As well, NH<sub>3</sub> can react with pollutants such as acidic sulfates and nitrates, forming tiny particles of ammonium nitrate or ammonium sulfate. Because NH<sub>3</sub> is so reactive, its concentrations are localized: high near sources and almost negligible elsewhere. In an area near Lethbridge, Alta., for example, high concentrations were found close to feedlots, but relatively low values just 1 km away.

Ammonia has many undesirable effects at high concentrations. Near sources, where concentrations are high, it produces an unpleasant odor and may affect human and animal health. Local deposition of emitted NH<sub>3</sub> may “fertilize” the land, but excessive amounts can result in leaching of N and contamination of ground- or surface-water. Excessive NH<sub>3</sub> may even be converted to N<sub>2</sub>O, thus indirectly contributing to the greenhouse effect.

Though many of the effects of NH<sub>3</sub> occur locally, it also has long-range effects. Ammonium particles, formed

upon reaction with other N or sulfur compounds, can be carried long distances by wind before being deposited. Because N is often a growth-limiting nutrient, the deposition of this  $\text{NH}_4^+$  can cause undesirable growth in lakes, alter forest growth, or disrupt sensitive ecosystems. When deposited on native grasslands, for example, atmospheric  $\text{NH}_3$  or  $(\text{NH}_4^+)$  may favor the growth of some species at the expense of others, causing a shift in the mixture. Atmospheric  $\text{NH}_3$  can also result in acidification because it accelerates the rate at which sulfur dioxide ( $\text{SO}_2$ ) converts to sulfuric acid, leading to acid rain. The  $\text{NH}_3$  itself produces acid when it undergoes nitrification, once deposited on soil as  $\text{NH}_4^+$ .

Because of its numerous potential effects, both near sources and in remote areas,  $\text{NH}_3$  can be a serious pollutant and efforts to reduce its emission are warranted. Before examining possible ways of reducing emissions, however, it may be helpful to briefly review the sources of  $\text{NH}_3$  in agriculture.

### *Agricultural sources of ammonia*

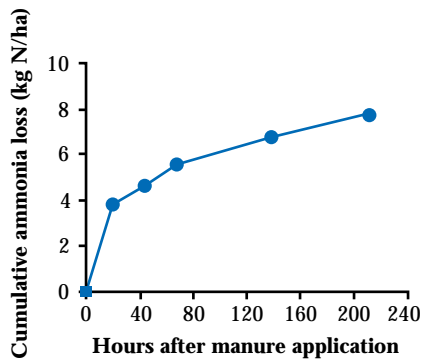
The three main sources of  $\text{NH}_3$  on farms are animal wastes, fertilizers, and crop residues. The first of these accounts for about 80% of agricultural emissions.

Of the N consumed by farm animals in feed, only a small proportion (roughly one-fifth) is retained by the animal; the rest is excreted in feces and urine. Some of this N (especially in urine) occurs as urea, a form easily converted to  $\text{NH}_3$  and  $\text{CO}_2$ . As a result, a large proportion of the N in manure can be lost as  $\text{NH}_3$  soon

after excretion. On pig farms, for example, 40–95% of the nitrogen excreted may be lost before the manure is applied to the field. Much of that, perhaps 10–40% of the N lost, may occur from the barn even before storage. Ammonia losses from cattle manure are often less than from pig manure, probably amounting to less than 50% of the total N content.

Losses of N during storage of manure can also be high, depending on method of storage. In a US study, about 60–80% of N was lost from pig manure in lagoons exposed to air, compared to losses of only 30–65% from that stored in underground pits and later spread as liquid. Another estimate suggests that the proportion of pig manure N lost as  $\text{NH}_3$  is less than 10% for anaerobic storage, 10–25% for semi-aerobic systems, and 25–85% during composting. The differences reflect the degree of exposure to air and the amount of water and acid present.

Some  $\text{NH}_3$  is also released when manure is applied to land, particularly if a slurry is sprayed into the air. Most loss occurs shortly after application. For example, a study of  $\text{NH}_3$  loss from cattle manure showed that about half of the total emission occurred within 1 day (Fig. 33).



**Figure 33**

**Pattern of NH<sub>3</sub> loss from manure applied to the surface of soil. (S. McGinn, AAFC)**

Another potential source of NH<sub>3</sub> is fertilizer. Two forms, both widely used in Canada, are especially important: anhydrous ammonia (pure NH<sub>3</sub>) and urea. When anhydrous ammonia is injected into soil, it normally converts immediately to NH<sub>4</sub><sup>+</sup> in soil water and then is held tightly by the soil. If the soil is extremely dry, however, as much as 20% of the NH<sub>3</sub> can escape. On the other hand, if it is so wet that the soil does not close up after injection, as much as 50% can be lost. Urea fertilizer, like the urea in livestock manure, quickly converts to NH<sub>3</sub> and CO<sub>2</sub> after it is applied. If the fertilizer is not mixed into the soil, large amounts of NH<sub>3</sub> can be released to the atmosphere.

A third possible source of NH<sub>3</sub> from farms is crop residues. Appreciable amounts of NH<sub>4</sub><sup>+</sup> can be produced during the decay of N-rich residues like legume green manures. If the residues are allowed to decay on the soil surface, some of this NH<sub>4</sub><sup>+</sup> may convert to NH<sub>3</sub> and be lost to the atmosphere.

Based on data from 1990, NH<sub>3</sub> emissions from all sources in Canada amount to about 520 Gg (thousand

tonnes) of N per year. Of this, about 90% comes from agriculture, largely from livestock production (Table 17). These estimates, however, are still preliminary.

**Table 17 Estimated ammonia emissions from Canadian agriculture in 1990**

Source	NH <sub>3</sub> emission (Gg N)
<i>Animals</i>	
Dairy cattle	incl. with beef
Beef cattle	211
Pigs	76
Poultry	88
Sheep/lambs	2
Horses	4
Total animals	381
<i>Fertilizers</i>	
Urea	71
Ammonium sulfate	2
Ammonium nitrate	2
Anhydrous ammonia	4
Nitrogen solutions	2
Ammonium phosphates	6
Total fertilizers	87
Total agriculture	468

## Reducing ammonia emissions

Producers can reduce the emission of  $\text{NH}_3$  from farms in a number of ways. In general, these methods rely on absorbing  $\text{NH}_3$  in water or acid, preventing excessive N excretion by livestock, and minimizing exposure of  $\text{NH}_3$  sources to the air. Specific examples of control methods include the following:

*Use improved methods of fertilizer application* : Farmers can reduce ammonia loss from fertilizer by ensuring good contact between the applied fertilizer and moist soil. They should place urea either below the soil surface or till it into the soil immediately after applying it to the surface. Injecting anhydrous ammonia into moist soil at sufficient depth prevents it from diffusing to the surface.

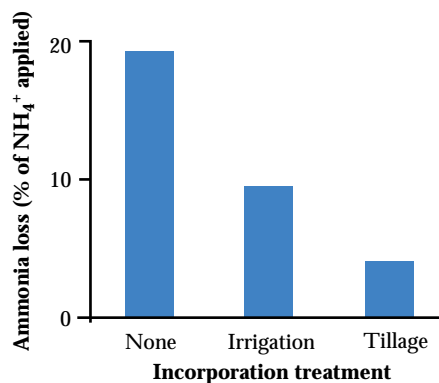
*Minimize nitrogen excretion from livestock* : The most basic way of reducing  $\text{NH}_3$  emission from animal wastes is to produce less manure N in the first place. Although animals cannot avoid excreting N, farmers can reduce the N content of the manure by using rations with a better N balance, by avoiding excessive N in the diet, or, possibly, by adding bacteria that help convert uric acid (a forerunner of urea) to nitrate. Use of these practices could reduce N excretion by up to 25% in cattle, pig, and broiler poultry operations. Indeed, simulation models suggest that, for Quebec conditions, better diets could reduce the N content of pig manure by up to 60%. Nitrogen excretion can also be reduced, indirectly, by using breeds of livestock, feed formulations, or other practices that improve animal performance and, hence, the product yield per unit of manure N.

*Improve manure handling in the barn* : Large amounts of  $\text{NH}_3$  can be emitted in the barn when the manure is exposed to air. Farmers can minimize this exposure by removing manure frequently; washing barns with water, which absorbs  $\text{NH}_3$ ; collecting liquid wastes in deep, narrow channels, to reduce surface exposure; and, in poultry barns, maintaining a deep layer of litter. As well, maintaining cool temperatures can reduce emission of gaseous  $\text{NH}_3$ . In Europe, changes in handling procedures (including diet) have reduced  $\text{NH}_3$  release from pig barns by 45%.

*Improve manure storage* : Farmers can reduce ammonia loss during manure storage by minimizing exposure to air and lowering temperature. For example, applying a cover of mineral oil, straw, or peat over lagoons or tanks holding pig manure can reduce losses. Covers placed on tanks can cut  $\text{NH}_3$  losses by two-thirds, and a thin layer of mineral oil on a slurry can reduce emissions by more than 30%. As well, adding acids to manure or covering composting manures with mildly acidic peat can minimize  $\text{NH}_3$  loss. Ammonia is readily absorbed and held by acid, preventing escape to the atmosphere. Farmers can achieve reductions of at least 75% by using peat moss, sulfuric acid, or phosphoric acid during storage.

*Use more effective application procedures* : Ensuring quick and effective mixing with soil can minimize losses of  $\text{NH}_3$  during application. For example, tillage or irrigation immediately after application drastically cuts emissions (Fig. 34). Farmers can also reduce losses by applying manure before rain, injecting slurry directly into soil, or using diluted slurry for irrigation. Where they must apply slurry to grassland, banding it on the surface,

rather than spraying it, can reduce losses. Finally, since rate of gaseous loss is related to temperature, applying  $\text{NH}_3$  in cool weather (though not on frozen soil) can curtail emission.



**Figure 34**  
**Proportion of manure  $\text{NH}_4^+$  volatilized within 8 days of application as affected by irrigation or tillage. (S. McGinn, AAFC)**

This list shows several ways of cutting  $\text{NH}_3$  emissions from agriculture. Not all these are practical or even advisable in all cases. For example, incorporating manure by ploughing is not compatible with the no-till systems advocated elsewhere. Nevertheless, given the number of options available, large cuts in emissions are probably easier for  $\text{NH}_3$  than for some of the other gases, notably  $\text{N}_2\text{O}$ . With increasing attention to health, environmental, and odor issues related to  $\text{NH}_3$ , efforts to achieve such reductions will likely increase in the future.

The Netherlands has decided that, by 2000,  $\text{NH}_3$  emissions must be no more than half of those in 1980. There, the annual N deposition has reached 85 kg/ha in parts of the country. Though deposition rates in Canada are usually much lower, high rates of deposition may already occur in local areas of intensive livestock production.

## Composting

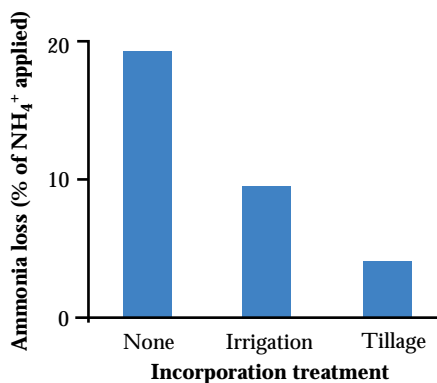
Gases emitted during composting of organic waste may include  $\text{CO}_2$ ,  $\text{NH}_3$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ , and NO. Smaller quantities of reduced sulfur and nitrogen compounds may also be produced in anaerobic microsites. The form and quantity of gaseous compounds emitted during composting depends on the material being composted and the method used. Odor-producing compounds can be virtually eliminated with a properly designed aeration system. A biofilter system in enclosed composting facilities also ensures odor-free exhaust air.

Methane emission can also be eliminated with adequate aeration. Ammonia emission is controlled by the available C:N ratio of the composting material and by the aeration system used. When  $\text{NH}_3$  emission occurs, it is usually early during the composting process. Ammonia may be captured using a scrubber. The factors influencing  $\text{N}_2\text{O}$  and NO emissions during composting are not well understood. Researchers are working toward a better understanding of  $\text{N}_2\text{O}$  emissions during composting and strategies to minimize emissions. A well-designed compost facility should not negatively affect the health of our air.



(J. Paul, AAFC)

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## Other odors

Ammonia is only one of the gases released from farms that has an unpleasant odor. Many other gases also irritate the human nose. Some of these are not only unpleasant but also dangerous. Perhaps the most noteworthy is hydrogen sulfide ( $H_2S$ ), a poisonous gas with the smell of rotten egg. High concentrations of this gas can be released when liquid pig manure in tanks is stirred. It can be fatal to humans, though only at high concentrations produced where ventilation is poor. Many other compounds, although not known to be poisonous, have an objectionable odor; more than 150 such compounds have been identified in pig manure alone.

To date, people have perceived farm odors only as nuisances, but awareness of this problem is now growing. Indeed, some countries have already established regulations regarding allowable odor intensities.

Odor-causing gases can come from many sources. Some of the most offensive arise from organic substances decaying in the absence of oxygen. The decomposing matter may be manure, effluent from manure piles, silage, plant debris, or a wide range of other organic materials. When decomposed without an adequate oxygen supply, they are not completely broken down into  $CO_2$  and simple salts but rather are released as various intermediates such as organic acids, alcohols, aldehydes, sulfides, and  $CH_4$ . Of these, the compounds with the most offensive odors are the volatile organic acids.

Many odor-causing compounds come from the same source and therefore occur together. For example, volatile organic acids are often found with  $NH_3$

and  $H_2S$ . Given the many compounds involved, odors are not easily measured and quantified. Indeed, the most sensitive and reliable sensor is still the human nose. One way to measure odor intensity is to count the number of times an air sample has to be diluted with fresh air before its odor becomes nearly imperceptible. A panel of human evaluators is used to determine the number of “dilutions to the threshold” (DT), which may range from 0 to 200 or more. On this scale, a reading of 170 DT or higher would be considered “unacceptable.” The lowest value achievable within a feedlot operation is about 7 DT.

A variation on this approach is to compare the air sample with known concentrations of a reference compound, like butanol. With this method, the intensity of odor is reported in terms of equivalent concentrations of butanol. The scale normally ranges from 0 to 80 ppmv butanol (the highest intensity to which the nose is responsive). Most ambient odors have a rating of less than 60 ppmv butanol.

Researchers have used these techniques to evaluate the odor from various types of farms. Odors from pig farms usually rate “high” to “very high,” whereas poultry and cattle operations normally rate “high,” comparable to that of paper mills, petrochemical plants, and oil refineries. Of course, odor intensity varies considerably depending on wind speed, air stability, humidity, and distance from source.

Producers can reduce the intensity of odors from farms in several ways. The most obvious, perhaps, is to plan the farm layout carefully, placing sources of odor, like barns and lagoons, downwind

and far from dwellings. Other methods include cleaning and washing barns frequently, aerating stored manure (although this action may favor  $\text{NH}_3$  release), injecting slurries, and immediately incorporating solid manures after they are applied. Finally, various chemicals and bacterial cultures have been proposed for odor control, but their cost is often high and their efficacy limited. One possible approach is to add calcium bentonite, a clay with high absorption capacity, to animal diets. This additive has even been found to enhance weight gain under some conditions.

## Nitrogen oxides

Nitrogen oxides, upon reaction with volatile organic carbon (VOC) in the presence of sunlight, produces  $\text{O}_3$ , the main constituent of smog. Nitrogen oxides come mostly from combustion of fossil fuel, and are usually linked to automobiles and industrial sources. But farm machinery also uses a lot of fuel; for example, agriculture accounts for about 25% of the heavy-duty diesel vehicles in Canada. Although the importance of farm machinery as a source of nitrogen oxides is not known, its contribution to smog is likely negligible. Even so, energy-conserving steps like reduced tillage can reduce somewhat the emissions of nitrogen oxides.

Nitric oxide (NO), like  $\text{N}_2\text{O}$ , is sometimes produced in soil as a by-product of nitrification and denitrification. In rural areas, the release of NO from this source can rival that of nitrogen oxides from industrial sources. Using methods similar to those described for  $\text{N}_2\text{O}$  can probably reduce the emission of NO from agricultural soils.

## Aerosols

Aerosols are solid particles in atmosphere, either formed in the air by reactions among gases or injected into the air by processes on the ground. They consist of a variety of materials and vary in size from less than 1 micrometre ( $\mu\text{m}$ , one-thousandth of a millimetre) to the size of a sand grain. The main sources of aerosols are natural events like volcanoes, sea spray, forest fires, and soil erosion. But some aerosols are also produced by human activity, like combustion of fossil fuel.

Particles smaller than  $2.5 \mu\text{m}$  are a serious concern for both visibility and human health. Aerosols absorb and reflect light, producing the haze in cities. They can also be breathed in and stay in the respiratory system causing respiratory illness and even cancer.

Aerosols also have an important effect on global climate. They provide the nuclei or “seeds” that encourage cloud to form. They also reflect solar radiation, thereby cooling the earth. In some regions, the cooling effect of aerosols is now about the same as the warming effect of  $\text{CO}_2$ , though it is not expected to increase enough to offset further increases in  $\text{CO}_2$ .

The amount of aerosols produced by Canadian agriculture has not been measured routinely but is probably small. Nevertheless, farms do emit some aerosols of two types: primary particles, which are released intact into the air (e.g., field dust, soot, and pesticide crystals); and secondary particles, which are formed in the air from gases emitted by agriculture (e.g.,  $\text{NH}_4^+$  particles from  $\text{NH}_3$ ). Some secondary particles were described earlier; here we focus only on primary particles.



The most common aerosol from Canadian farms is probably dust from soil erosion. When soil is dry, loose, and without plant cover, the wind can pick up surface particles and carry them great distances. The problem was most severe in the southern prairies during the dirty thirties, when as much as several centimetres were lost from some fields, obscuring the sky and depositing dust everywhere. Although conservation measures now prevent such large-scale dust storms, occasional erosion episodes still occur locally.

Erosion occurs in two steps. The wind first detaches tiny soil grains (0.1–0.5 mm), which then act as abrasives on

larger soil particles. The detached particles travel in three ways: saltation, creep, and suspension. In saltation, particles bounce across the surface; in soil creep, larger particles (0.5–1.0 mm) roll and slide after they are hit and accelerated by “bouncing” particles. These two processes account for most erosion. But in fine-textured soils, with many particles smaller than 0.1 mm, soil may be lifted high above the surface (suspended), creating dust clouds that can travel for hundreds of kilometres. Eventually, the suspended particles settle out in calm winds or are washed out in rain.

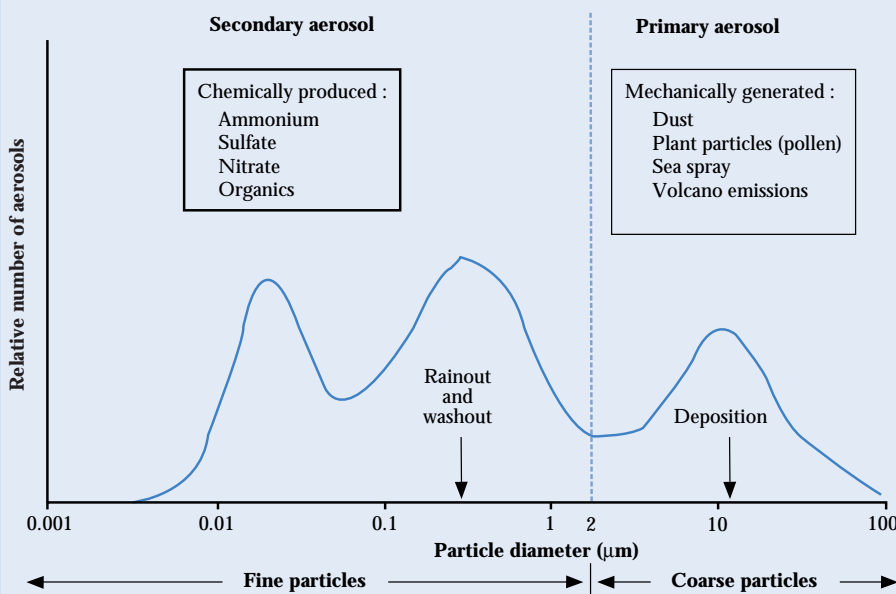
After the bad experience of the 1930s, researchers developed many erosion control measures. Some of these are now commonly used: reduced tillage, keeping residues on soil surface, shelterbelts, and less-frequent use of summer fallow. Consequently, although about half of Canada’s agricultural soil is moderately or highly susceptible to wind erosion when it is bare, less than 5% of cultivated land is now at high risk.

Although severe and widespread erosion has been largely halted, some dust from farmland still enters the air through localized erosion events or during tillage and other farm operations. The dust emitted from soils is not just inert mineral particles. It may also contain seeds, pollen, and plant tissue, as well as agrochemicals, including pesticides. These materials can cause health problems and, in the cases of pesticides, contaminate other environments.

Another agricultural aerosol is smoke from burning of weeds or straw. Smoke contains soot (particles of carbon) that can cause respiratory problems. Until recently, burning excess straw was commonly practiced in areas with high

### Aerosol size distribution and global warming

The size distribution of an aerosol is closely related to its source. Coarse particles are generated mainly from mechanical processes, such as wind, whereas fine particles are produced by chemical reactions. Size distribution and chemical contents of aerosols are important factors determining global climate change and visibility. Aerosols have a cooling effect, which offsets, in part, the warming effect of greenhouse gases.



(T. Zhu, Ottawa, Ont.)

yields, like southern Manitoba. Now provincial and municipal regulations have almost eliminated this practice. Some excess straw now goes to industrial uses, like “strawboard,” which eliminates the health hazard and also provides additional income.

## Ultraviolet radiation

### Background

The sun produces radiation with a wide range of wavelengths. Some wavelengths stimulate receptors in human eyes, so that we can “see” them. Thus, radiation with a wavelength of about 390 nm ( $10^{-9}$  m) to 760 nm is called “visible light.” Within this range, different wavelengths correspond to various colors: the shortest wavelengths correspond to violet, the longest to red. But the sun also produces radiation outside the visible range. Radiation of wavelength longer than red is called infrared radiation; radiation of wavelength shorter than violet is called ultraviolet radiation.

The energy of radiation increases as the wavelength gets shorter. Ultraviolet radiation, therefore, has much higher energy than visible light, enough to cause severe injury to living things. But little of the sun’s UV radiation reaches the earth’s surface; most is filtered out by  $O_3$  in the upper atmosphere (the stratosphere). This effective screening of UV radiation occurs despite the very low concentration of  $O_3$ . If all the  $O_3$  were placed in a layer at the earth’s surface, it would be only 3 mm thick. Because it protects the earth’s surface from damaging UV radiation,  $O_3$  in the upper atmosphere (unlike that at ground level) is essential to life.

Soil erosion in southern Alberta, 1935



Because of its vital function, scientists were alarmed to learn, in recent decades, that the amount of  $O_3$  in the upper atmosphere is declining; that is, the  $O_3$  layer is “thinning.” Worldwide,  $O_3$  concentrations have already declined by an average of 3%. But much of the depletion has occurred near the poles. Average values in Canada have declined by about 6% since 1980. Decreases near Antarctica have been as high as 60%, forming the so-called “Antarctic ozone hole.”

The thinning of the  $O_3$  layer, scientists now believe, is caused by the release of various gases from industrial activity. Most noteworthy of these are the chlorofluorocarbons (CFCs) that are used in refrigeration and as a propellant in aerosol cans. These molecules, which have a very long life, migrate into the upper atmosphere where they cause  $O_3$

to break down into  $O_2$ . Another gas known to break down  $O_3$  is methyl bromide, used throughout the world as a fumigant to kill insects and nematodes in farm fields, greenhouses, and food storage and processing plants. Methyl bromide accounts for up to 10% of global  $O_3$  losses. Finally, nitric oxide (NO) can accelerate  $O_3$  breakdown. This gas is produced naturally in the atmosphere from  $N_2O$ . Increases in  $N_2O$  emissions, therefore, can also indirectly cause  $O_3$  breakdown.

Once they had recognized the cause of  $O_3$  depletion, the international community set up an agreement (Montreal Protocol on Substances that Deplete the Ozone Layer) to curb emissions of gases like CFCs and methyl bromide. All developed countries have agreed to eliminate the use of CFCs by 2000 and the use of methyl bromide by

2015. Canada has committed to eliminate use of methyl bromide by 2001 (with some exceptions where no practical alternatives are available). Already in 1995, the use of methyl bromide had declined by about 40% relative to that in 1990. Promising alternatives to methyl bromide include using other chemicals, diatomaceous earth (which physically damages insects), and integrated pest management strategies.

By adopting strict controls on CFCs and other  $O_3$ -depleting substances, we can probably halt the continued depletion of  $O_3$  by about 2000. But, because of the long life of CFCs already in the atmosphere, it may take until 2060 before  $O_3$  concentration returns to its pre-1980 levels. Consequently, we can expect high UV intensity for several more decades and need to consider some of its effects on agricultural production.



Soybean leaves damage by UV-B radiation

(M. Morrison, AAFC)

## Effect of ultraviolet radiation on crops

Because some UV radiation reaches the earth's surface, terrestrial plants have evolved protective mechanisms. Some produce pigments, similar to sun screen, that absorb UV radiation. Others, like soybean, have UV-absorbing pigments in fine hairs on the upper surface of leaves (hence, symptoms of UV radiation are often more severe on the under surface of leaves). As well, most plants have some ability to repair cells and DNA damaged by excessive UV.

Despite these defense mechanisms, high exposure to UV can injure cell membranes and DNA within cells. Perhaps its most damaging effect is to disrupt the chloroplasts (the chlorophyll-containing organs where photosynthesis occurs). Damage to the chloroplasts reduces photosynthesis, which, in turn, can reduce plant growth.

Many recent studies have evaluated the effects of increased UV on plant growth using a combination of UV filters and UV lamps to produce a range of UV intensities. Much of the research has focused on UV-B, a band of wavelengths from 290 to 315 nm. Ultraviolet radiation with longer wavelengths (UV-A) has less energy and is therefore less damaging. Ultraviolet radiation with shorter wavelength (UV-C) is absorbed so effectively by the atmosphere that it never reaches the earth's surface.

Scientists have observed plant growth or yield effects from UV-B in numerous crops, including timothy, soybean, tomato, and canola. The effects of UV-B on yield are not always consistent, because some varieties yield more with increased UV-B than without. Studies with some species (e.g., corn) showed no

damage even at high UV-B levels. Furthermore, as observed with canola and soybean, the response to UV-B seems to vary among varieties of the same crop. For example, in a study of eight soybean varieties, six had lower yield under high UV-B, but two had higher yields. Consequently, though there is good evidence of potential yield loss from increased UV-B intensity, there are many factors which complicate the results of UV-B studies.

To evaluate the potential effects of increased UV intensity on agriculture, researchers measured the growth response of 100 varieties from 12 crops to an increase in UV corresponding to a 20% reduction in O<sub>3</sub>. Of these 100 varieties, 40 showed no effect. A simple model, based on these and other data, describes the sensitivity of crops to UV-B (Table 18). "Tolerant" crops would show little yield loss from an increase in UV-B radiation as high as 20% increase over 1980 levels. Crops with "intermediate" sensitivity may have yields reduced by 1, 2.5, and 5%

Table 18 Sensitivity of Canadian crops to UV-B radiation

Tolerant	Intermediate	Susceptible
Wheat	Barley	Oat
Sunflower	Rye	Pepper
Corn	Soybean	Cucumber
Tobacco	Pea	Mustard
Red clover	Tomato	Canola
Alfalfa	Potato	
Bluegrass	Soft fruit	
Orchardgrass		
Cabbage		

(M. Morrison, AAFC)

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with increases in UV-B of 5, 10, and 20%, respectively; whereas “susceptible crops” may have yields reduced by 2, 5, and 10% with the same UV-B increments. Using these estimates, we can predict potential economic losses from increases in UV-B. For example, a 5% increase in UV would result in crop yield losses of about \$90 million per year; a 20% increase in losses of about \$400 million.

Ultraviolet radiation may also affect crop quality. Exposure may produce surface blemishes on vegetables and fruits or may affect flavor by causing increased pigment production. In one study, for example, amounts of UV-B-absorbing pigments in broccoli were higher with UV-B than without UV-B exposure. All these effects can reduce the value of the crop.

There may also be ecological effects of UV on plant communities. Under high UV-B, species with higher tolerance may

out-compete susceptible species. This effect could be important in mixed grasslands or it could alter weed-crop competition. Furthermore, elevated UV-B can affect seed production, because exposed reproductive parts may be especially vulnerable.

Aside from effects on yield, quality, and ecology of crops, elevated UV-B could also have other implications. For example, it could affect animal health, plant diseases, pests, and pesticide efficacy. These effects have yet to be studied.

Research into ways of reducing the UV-B effect on crops has made little progress as yet. Given the differences in response among plant species and varieties, however, it may be possible to limit economic losses by selecting UV-B tolerant varieties.

## Pesticides

Most farms in Canada use some pesticides to control weeds, insects, and diseases. Many of these pesticides have at least some toxicity for humans or potential adverse effects in the environment. Pesticides applied to the soil and crops can either drift while being applied or volatilize afterwards. Once in the air, wind can transport the pesticides long distances before depositing them on soil or water. Pesticides deposited in the Great Lakes, for example, have caused concern over water quality.

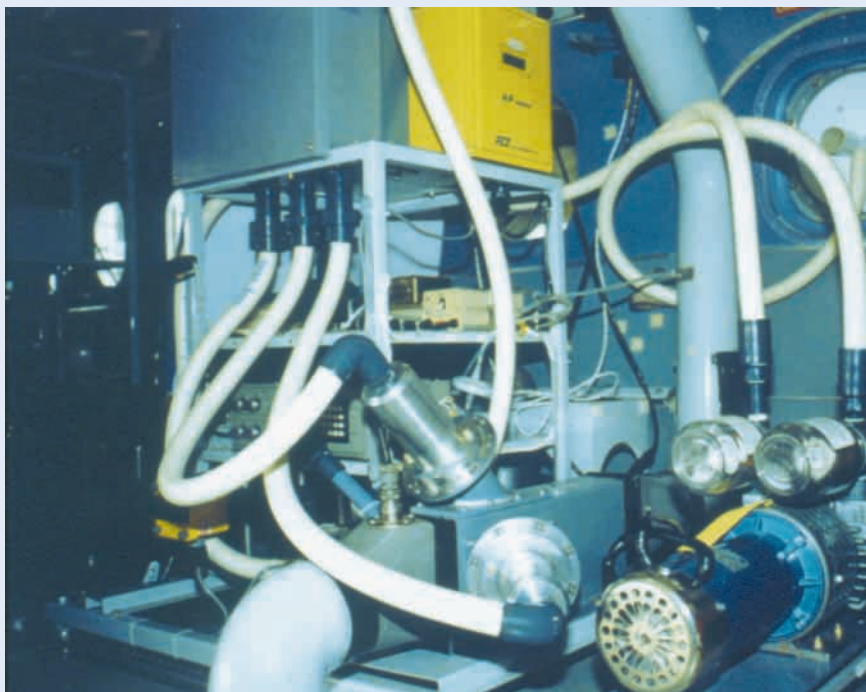
Some of the earlier concerns about pesticides are no longer as valid today because older, persistent pesticides (like DDT) are no longer used in Canada. Farmers now usually use newer formulations designed to control specific pests and to be easily degraded by soil microbes. Further, pesticides are now often applied at much lower rates, typically at grams per hectare rather than kilograms per hectare as in the past.

Despite the improvements in current pesticides, however, further precautions may be helpful to reduce losses to the atmosphere. For example, spraying only during calm conditions and ensuring that droplets are large enough to prevent their suspension in the air reduces pesticide drift. In some cases, it may be possible to reduce rates or frequency of pesticide application by relying on other methods of pest control. For example, biological methods can now control some weeds and insects. The use of “Integrated Pest Management” (IPM) techniques, which rely on optimum combinations of chemical, biological, and cultural methods, may provide the best approach to reducing pesticide usage.

Pesticides help to produce high yields on Canadian farms. Given their potential effects on human health and the environment, however, farmers need to be vigilant to prevent pesticides from leaving the target site.

## Agrochemicals

Agrochemicals, such as insecticides and herbicides, can be released into the environment by drift, volatilization, and runoff. For example, some have found their way into the Great Lakes. Scientists use a high-volume sampler, installed in an aircraft, to measure agrochemicals fluxes on a regional scale.



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