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Executive Summary

Ammonia is a, colourless gas composed of nitrogen (N) and hydrogen (H) with the chemical symbol NH₃. The gas is released mainly during naturally occurring processes, i.e. the breakdown of the urea excreted by farm livestock and other mammals or of the uric acid excreted by birds. Ammonia is very soluble in water and readily reacts with other substances in the atmosphere to form ammonium (NH₄⁺) compounds such as ammonium sulphate and ammonium nitrate. Following the emission of ammonia gas to the atmosphere, it may be deposited to land either as gas or as ammonium-N compounds in rainfall. This can have profound effects on natural ecosystems (e.g. heathland, moorland).

This booklet:

- explains why ammonia emissions from farming are causing concern; and
- summarizes the findings of many years' research, funded mainly by DEFRA, into the sources and effects of ammonia emissions on the environment.
- describes studies to identify and develop practical and cost-effective ways of reducing ammonia emissions from farming.

The main points are summarized below:

- Concentrations of ammonia in the air are greatest in those parts of the country with the most livestock farming, particularly where ammonia emissions are mainly from pig, poultry and cattle farming. High concentrations of ammonia are also found in some urban areas. (See Chapter 2)
- Ammonia can also react with other chemicals in the atmosphere to produce fine particles. There are legally binding targets for the levels of particles in air. Reducing ammonia emissions could help meet these targets.
- Ammonia reacts in the atmosphere to form particles containing ammonium. Most of these particles are removed from the atmosphere by rain, while the gaseous ammonia is absorbed by land surfaces (such as soil, water and vegetation).
- Although the greatest concentrations of ammonium-N in rain are found in the south and east of the UK, the deposition of ammonium-N in rain is largest in the north and west, because of greater rainfall. Ammonia compounds can be transported in the atmosphere over long distances. Some of the ammonia deposited in the UK comes from emissions sources outside the UK, while a significant amount of the UK's ammonia emission is deposited in other countries.

- Direct deposition of ammonia gas is largest in high-emission areas, where ammonia concentrations are greatest. Deposition rates vary depending on the vegetation and the nearest ammonia source.
- There is little deposition of ammonia gas to intensively farmed land with high N fertilizer inputs, because that land is largely a net source of ammonia. As a result, deposition of ammonia from the atmosphere is mainly to unfertilized land with a small N content. This makes semi-natural ecosystems and conservation areas more vulnerable to ammonia deposition.
- The concentration of N in foliage increases with increasing levels of N deposited from the atmosphere onto soils and vegetation (see Chapter 3). This may increase plant sensitivity to stress (for example from frost, drought and insect damage).
- Nitrogen deposition has contributed to changes in the mix of plant species growing in a range of semi-natural habitats (e.g. heathland, moorland and bogs) in many parts of the UK.
- In a number of semi-natural habitats over large areas of the UK, the current deposition of ammonium-N from the atmosphere is above the critical load of N. The critical load is the amount of pollutant deposited below which significant harmful effect on specified elements of the environment do not occur, according to current knowledge. Nitrogen deposition can also make soil and surface waters acidic.
- Agriculture is the largest source of ammonia and the increased use of N in livestock farming has increased ammonia emissions over the last 50 years.
- Emissions of other air pollutants, such as sulphur dioxide, that can damage the environment have been greatly reduced over recent years due to reductions by industry and the transport sectors. This means that the relative importance of ammonia as a pollutant has increased.
- In order to protect sensitive habitats the UK has signed a number of international agreements to reduce ammonia emissions: the UNECE Gothenburg Protocol, the EU National Emission Ceilings Directive and the EU Intergrated Pollution, Prevention and Control Directive.
- An inventory, or detailed list, has been drawn up to estimate how much ammonia is emitted by each of the main livestock groups (cattle, pigs, poultry, sheep and other livestock), and nitrogen fertilizer we use in the UK. Non-agricultural sources (e.g. industrial processes, sewage, wild animals and birds) of ammonia are also included in the inventory.

- Total UK emissions of ammonia are currently estimated to be 320 kilotonnes (kt), give or take 15%, which gives an estimated range of emissions of 270-370 kt. Around 80% of these emissions are from agriculture.
- Cattle farming produces 44% of the UK's total ammonia emissions. Most of the ammonia losses are from manure spreading on land (48% of cattle emissions) and from livestock housing (34% of cattle emissions).
- Pig farming produces 9% of the UK's total ammonia emissions. Most of the ammonia losses are from housing (64% of pig emissions) and following manure spreading on land (26% of pig emissions).
- Poultry farming produces 14% of the UK's total ammonia emissions. Just under half of the emissions from poultry production come from housing, with the same amount coming from manure spreading.
- Significant emissions of ammonia come from categories of livestock other than cattle, pigs and poultry, but these emissions are smaller and mostly associated with the UK sheep population.
- Using N-containing fertilizers on land produces around 9% of the UK's total ammonia emissions.
- Non-agricultural sources emit around 50–60 kt of ammonia emission. A wide range of non-agricultural sources contribute to ammonia emissions in the UK, including:
 - pets;
 - wild animals;
 - sewage sludge;
 - industrial and combustion (burning) processes; and
 - petrol vehicles fitted with catalytic converters.
- There are several potential options to reduce ammonia emissions from non-agricultural sources. Given the large number of small sources a broad approach would be required to make significant reductions. Vehicles fitted with catalytic converters, sewage sludge processing and industrial processes are the sectors with the most potential to reduce non-agricultural emissions.
- A wide range of possible ways to reduce ammonia emissions from agriculture has been examined experimentally within the research programme funded by DEFRA. These are discussed at the end of each livestock chapter and summarized in Chapter 11.
- A simple model has been developed by researchers to see which are likely to be the most cost-effective ways of reducing ammonia emissions from agriculture. These are usually techniques to reduce emissions following manure spreading and during slurry storage.
- Work is continuing to assess viable emission reduction techniques which:
 - do not increase emissions at a later stage in the management of manure;
 - are cost-effective;
 - are practical; and
 - can be used by most farmers.
- It is important to consider ammonia emission and abatement within the wider context of nitrogen flow and use on farms.
- The most promising methods are being assessed on commercial farms in the UK to see how practical and expensive these methods are (Chapter 11).

Chapter 1

Background to the problem of ammonia in the UK

J Webb (ADAS), Brian Pain and Mark Sutton (CEH)

Main Points

- Ammonia may damage sensitive habitats by nitrogen enrichment and acidification.
- Agriculture is the largest source of ammonia, and increased N inputs to livestock farming have increased ammonia emissions over the last 50 years.
- Since emissions of other air pollutants such as sulphur dioxide that can also damage wildlife habitats – have been greatly reduced over recent years, the relative importance of ammonia has increased.
- The UK has signed international agreements to curb ammonia emissions, in order to reduce their effects on the environment.

“He who is within the sphere of the scent of a dunghill, smells that which his crop would have eaten, if he had permitted it. Instead of manuring his land, he manures the atmosphere; and before his dunghill has finished turning, he has manured another parish, perhaps another county.”

Statement made by Arthur Young, the 18th century agricultural pioneer, as reported by Thomas Potts in 1807. Perhaps without realising, Young identified the problem of ammonia emission.

Why ammonia?

Ammonia is a soluble and reactive gas. This means that it dissolves, for example in water, and that it will react with other chemicals to form ammonia containing compounds. It contains nitrogen (N) and is readily deposited from the atmosphere onto soils and plants. This ‘deposition’ of ammonia from the atmosphere may damage plant communities that have evolved on nutrient-poor habitats (such as heathlands, upland bogs and some forests) by increasing the amount of N in the soil. While this extra N may increase the growth of plants adapted to a limited N supply (such as heathers), other plants (such as rough grasses) can use the N more effectively. This enrichment by N, also known as ‘eutrophication’, can overwhelm those existing species that are not as well able to cope with the extra N and mean that they are replaced by a few rank (fast-growing) grass species and other undesirable species. A major concern is that the plants growing on many valuable conservation areas in the UK are adapted to a limited supply of N and are therefore particularly vulnerable to increased ammonia deposition.

Ammonia may also cause soils to become acidic. Once deposited on soil, ammonia may be oxidised to nitrate by a chemical process that increases soil acidity (acidification). Soils can neutralize limited amounts of acid, but they may reach a point where they are not able to cope with the increasing amount of acid deposited. Once this level is reached and soil acidity increases, toxic elements such as aluminium will become more available to plants while other elements vital for plant growth will become less available. Toxic elements may then be leached into surface waters where they also poison fish and other aquatic life. The most obvious examples of acidification in the UK are the acidified lakes and streams in many upland areas. While acidification has been largely caused by sulphur dioxide emitted from industry, N can also play a role. Nitrogen deposition is thought to delay the recovery of habitats now that sulphur dioxide emissions have been reduced.

Ammonia is a very reactive gas, which means that most of it is deposited close to where it was emitted. However, some ammonia may reach higher levels in the atmosphere and be blown long distances before being deposited in rainfall. When ammonia reacts with sulphur and nitrogen oxides in the atmosphere, it forms particles containing ammonium-N. These particles can travel for hundreds of miles, so ammonia emissions from one country may cause damage in another.

Another effect of ammonia is that, close to large emission sources (such as buildings that house livestock), very high concentrations of the gas can damage vegetation.

Ammonia can also react in the atmosphere to produce fine particles. These are legally binding targets for the levels of particles in the air. Reducing ammonia emissions could help to meet these targets.

In December 2001, the National Expert Group on Transboundary Air Pollution published a report for DEFRA and the devolved administrations on the impact of air pollution on ecosystems in the UK and prospects for the future. The report highlighted the adverse environmental effects of ammonia.

Why agriculture?

Agriculture is by far the largest source of ammonia in Europe. Ammonia gas is emitted when ammonia dissolved in water is exposed to the atmosphere. Ammonia emissions come from livestock urine and manures, and from some N fertilizers and crops. The main source of ammonia in the urine of cattle, pigs, sheep and other mammals is urea. Urea is rapidly broken down by an enzyme called urease, to produce ammonium-N. Urease is a common enzyme and is found in many sources, including animal manure and soil.



Ammonia moves from an area of high concentration (such as urine or manure) to an area of lower concentration (such as the atmosphere) through a process called 'volatilization'. Basically, this means that the ammonia is emitted from the liquid as gas.

Poultry excrete uric acid, not urea. Under moist conditions, uric acid is quickly broken down to urea, and the ammonia within the urea may then volatilize as described above. Livestock manures – whether they are stored on the floor

of buildings, collected in stores or spread on land – are the major sources of ammonia emission. Emissions also come from urine deposited outdoors, for example on pasture by grazing animals. The larger the surface area covered with urine or manure, the greater the emissions of ammonia. This is why emissions are especially large from the floors of livestock houses and from fields after manure has been spread.

Ammonia emission from mammal manure and urine, and from bird droppings, is a natural process that has taken place on farms since animals were first domesticated. However, to increase livestock production, the use of N in fertilizers for grassland and in animal feeds has also greatly increased over the last 50 years. Since livestock are not very efficient at converting the N in their diets to milk and meat, the amount of N in dung and urine has also increased, leading to greater emissions of ammonia. Ammonia emissions from agriculture in the UK now appear to be levelling out, as N inputs are no longer increasing.

There is some ammonia emission from most types of N fertilizer, but urea-based fertilizers produce the greatest emissions. Agriculture, particularly manure management, accounts for about 80% of ammonia emission in the UK. The remaining 20% comes from small natural, domestic, industrial and transport sources, such as:

- wild animals and domestic pets;
- sewage treatment and spreading on land; and
- catalytic converters fitted to petrol vehicles.

Ammonia emissions from agriculture not only affect the wider environment but also represent an inefficient use of manure-N as a fertilizer. More efficient use of manure-N would save the industry money.

The effects of how livestock and manures are managed

How livestock and their manures are managed will greatly affect the rate and amount of ammonia emission from farms. DEFRA has funded research to measure emissions from different classes of livestock and different types of manure-management systems. This has been essential for putting together emission inventories and for developing potential systems to reduce emissions. Livestock-feeding systems are important because only about 20-40% of the protein-N in the livestock diet is found in the animal or animal products (such as meat and

milk). The rest is excreted (in dung and urine), of which at least 50% is urea (or uric acid for poultry). One of the first steps to reducing ammonia emissions is to make sure that animals are not fed more protein than they need.

Ammonia losses are usually less from urine deposited directly onto soil (such as by grazing animals) than from that deposited in or around livestock buildings. This is because urine may be absorbed quickly by the soil, so that ammonia emissions stop. Urine deposited in and around buildings (on concrete or other solid surfaces) cannot be absorbed. Instead, it mixes with dung that contains urease, so the urea is rapidly broken down to release ammonia. Depending on the type of management, manures are commonly collected and spread onto land as liquid slurries, or more solid materials such as farmyard manure (FYM) or poultry litter. Slurries (urine mixed with dung) are much thicker than urine and so are more slowly absorbed by the soil. Nitrogen dissolved in FYM and poultry litter takes even longer to be absorbed.

Taking into consideration the whole manure management process from housing to land spreading there are no consistent differences in emissions between straw- and slurry-based systems. However, since slurry can be pumped into covered manure stores, and spread either directly into soil or under crop canopies, there is greater scope to reduce emissions from slurry-based systems.

While livestock are being housed, ammonia emissions are affected by physical factors such as:

- temperature;
- ventilation (air-flow) rate; and
- for slurry systems, the design of the floor (such as fully slatted or partly slatted) and how often and with what it is cleaned.

For stored manures, emissions increase with increased:

- mixing, or 'turning';
- temperature;
- windspeed; and
- slurry pH.

When slurries are being spread on land, ammonia emissions are affected by:

- slurry dry-matter content;
- windspeed;

- rainfall;
- temperature;
- soil condition (such as moisture content); and
- the slurry-spreading method used.

The close relationship between the amount of ammonia emitted and the dry-matter content of cattle slurry suggests that for every 1% increase in dry matter, there is a 5% increase in the loss of ammonium-N. This is because dilute slurries are absorbed more quickly into the soil and so the ammonium-N is less likely to be released as ammonia. Conditions at the soil surface are also important and anything that prevents the slurry being absorbed may increase emission; such as:

- surface capping;
- compaction;
- wet soil; or
- a layer of crop residues.

Why now?

It takes a long time for the damage caused by ammonia to be noticeable. Soils can neutralise limited amounts of acid, and it may take decades before they exhaust this ability. Also, enrichment by N may take place for many years before more competitive undesirable plants replace sensitive plants of high conservation value.

Over recent years, there have been large reductions in the emissions of some other important atmospheric pollutants. Sulphur dioxide emissions were the first to be identified as a cause of acidification, and they have been reduced by 80% from their peak. Emissions of various nitrogen oxides have been reduced by 40%. However, in some sensitive areas, deposition of ammonia alone is enough to damage sensitive habitats.

Policy on Ammonia

- The Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol) of the UNECE Convention on Long-Range Transboundary Air Pollution was signed by environment ministers in 1999, and is expected to come into force in 2003. Annex II of the Protocol sets annual emission limits (ceilings) for four pollutants, including ammonia, which are to be met by 2010. The ammonia target for the UK is 297 kt a year. Annex IX of the Protocol contains a number of requirements. Signatories (those signing up to this Protocol) must:
 - distribute an advisory code of good agricultural practice to control ammonia emissions;
 - take reasonable steps to limit ammonia emissions from using solid fertilizers based on urea;
 - ban the use of ammonium carbonate fertilizers;
 - put in place specific measures on manure spreading and storage, and animal housing, for pigs and poultry. In the UK, these specific measures are the same as those required in the IPPC Directive.
- The EU National Emission Ceilings Directive came into force in November 2001 and will become UK law in November 2002. This targets the same air pollutants as the Gothenburg Protocol and sets the same limit on ammonia emission, which is also to be met by 2010.
- The EU Directive on Integrated Pollution Prevention and Control (IPPC) includes a requirement for large pig and poultry units to take measures to reduce emissions of a range of pollutants, including ammonia (applies now to new units and from 2007 to existing units).

Some countries have already taken action to reduce ammonia emissions from farms. Strict regulations are in force in the Netherlands, for example, where the combination of intensive livestock production and valuable natural habitats on acid-sensitive soils has led to a serious ammonia problem.

In the UK, estimates suggest that ammonia emissions could decline by 10% between 1990 and 2010. This is a result of decreases in national livestock numbers and a reduction in fertilizer-N use, which is bringing the national emissions close to the target of 297 kt a year agreed under the Gothenburg Protocol and the National Emission Ceiling Directive (see above). However, future emission estimates are basically uncertain so specific abatement (reduction) methods may

be needed. And, it may be necessary to look at how ammonia affects sensitive habitats on a more local or regional level.

Whether or not specific abatement measures will be needed, there is a strong argument for reducing ammonia emissions – not only to avoid environmental damage but also to use N for grass and crop production as efficiently, and cost-effectively, as possible.

Ammonia can also react with other chemicals in the atmosphere to produce fine particles. These are legally binding targets for the levels of particles in air. Reducing ammonia emissions could help meet these targets.

The following chapters give more information on the environmental effects and size of ammonia emissions, including:

- results of work on each of the main livestock-production groups;
- data from crops and fertilizers; and
- information on what can be done by each group to reduce those emissions.
- information on non-agricultural sources of ammonia

The final section is an overview of potential methods to reduce emissions from the farming industry as a whole.

The inventory of annual ammonia emissions in the UK for 2000 is presented at the end of this booklet.

Chapter 2

Atmospheric concentrations and deposition

Mark Sutton and David Fowler (CEH)

Main Points

- The concentrations of ammonia in the air are greatest in parts of the country with a large proportion of livestock farming, particularly where pig, poultry and cattle farming produce the ammonia emissions. Concentrations are also high in some urban areas.
- A proportion of ammonia emitted reacts with other chemicals in the atmosphere to form particles containing ammonium. Most of these particles are removed from the atmosphere by rain, while the ammonia itself is absorbed directly by land surfaces (such as vegetation, soil and water).
- Although the greatest concentrations of ammonium in rain are found in the south and east of the UK, the total deposition of ammonium in rain is largest in the north and west, because of greater rainfall. Some of this deposition comes from emissions outside the UK, while a significant amount of the UK's ammonia emission is deposited in other countries.
- Direct deposition of ammonia gas is largest where ammonia concentrations are greatest in parts of the country with most livestock per unit area. Deposition rates vary greatly depending on the distance from large sources of ammonia, such as farms.
- There is little deposition of ammonia gas to intensively managed farmland, which is largely a net source of ammonia. As a result, atmospheric inputs are concentrated on unfertilized land. This makes semi-natural areas, which are a priority for conservation more vulnerable to ammonia deposition.

Introduction

Ammonia emissions increase both the concentrations of ammonia in the air and the atmospheric deposition of compounds containing N. The areas where the ammonia concentration is high enough to damage plants are limited to areas near to large sources of ammonia, such as intensive livestock farms. In the UK and Europe, the problem of ammonia is largely due to the indirect effects of increased nitrogen deposition rather than the direct effects of ammonia concentration (see Chapter 3).

Ammonia can react in the atmosphere to form fine particles containing ammonium (NH₄⁺), which can be carried over long distances before they are removed by rain. Together ammonia and ammonium are often called 'reduced nitrogen' (NH_x). Gases and particles can be removed from the atmosphere by being absorbed by land and water surfaces (dry deposition). Most of the ammonia is removed from the atmosphere in this way. Ammonium and ammonia can also be removed from the atmosphere by rain or snow (known as wet deposition).

To assess the risk of environmental damage due to ammonia emission, requires information on the concentrations of ammonia in the atmosphere and the rates of deposition. Given the short lifetime of ammonia in the atmosphere, and the uneven distribution of emissions and rainfall across the country, there is a large variation in ammonia concentration and deposition. To deal with this variation, both measurements and mathematical models are required. Models are useful to analyze possible future changes in emissions. They can also give detailed estimates for different parts of the UK, which would be very expensive to obtain by taking measurements.

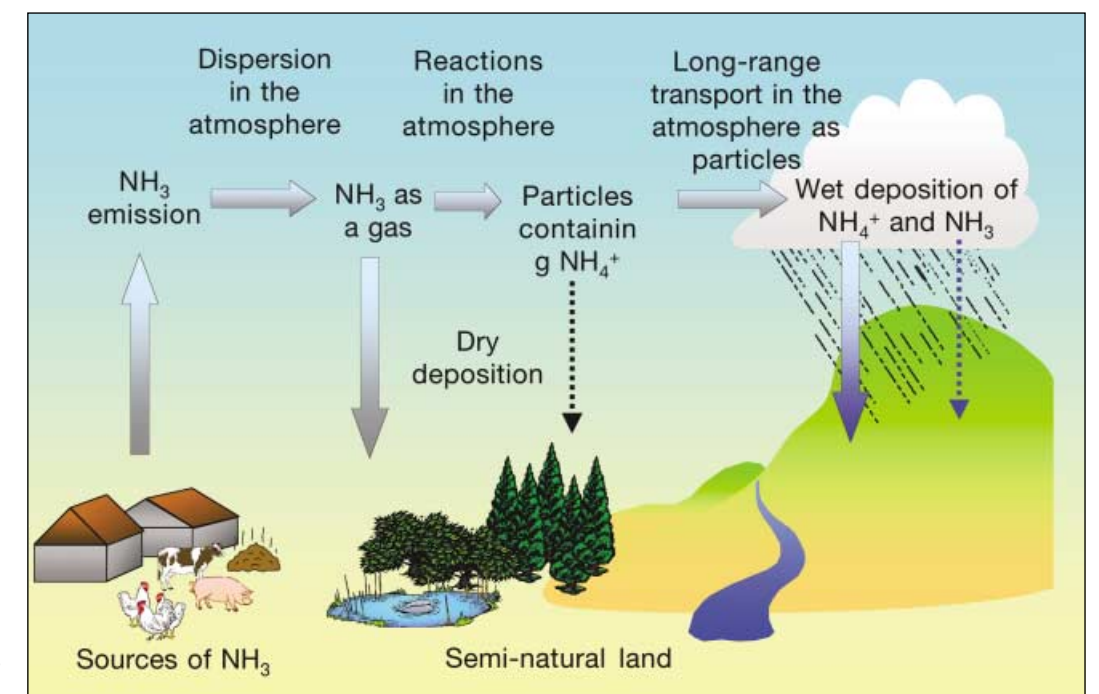


Figure 2.1
Ammonia flows in
the atmosphere

Modelling the distribution of ammonia emissions and concentrations

The distribution of ammonia emissions has been modelled by dividing the UK map into a grid of 1km by 1km squares, and calculating emissions from each square, using information from:

- the annual June agricultural census;
- land-cover maps; and
- information on emissions for each source type.

The results are summarized at a 5 km resolution for input into national models of atmospheric transport and deposition (see Figure 2.2). The emission estimates can also show where different sources of ammonia are greatest (see Figure 2.3).

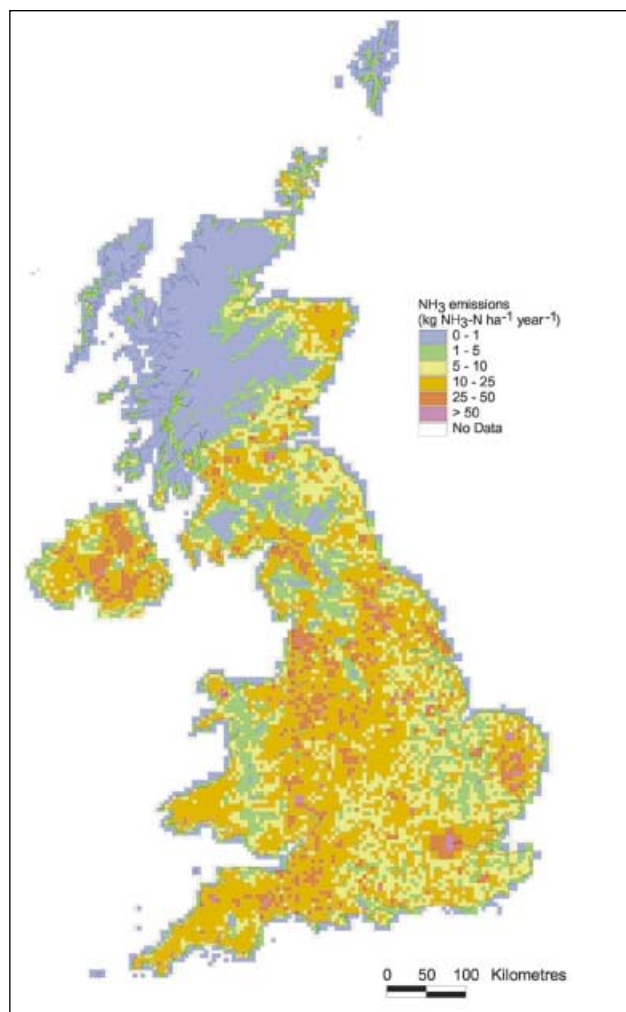


Figure 2.2
Modelled distribution of ammonia emissions across the UK for 1996.

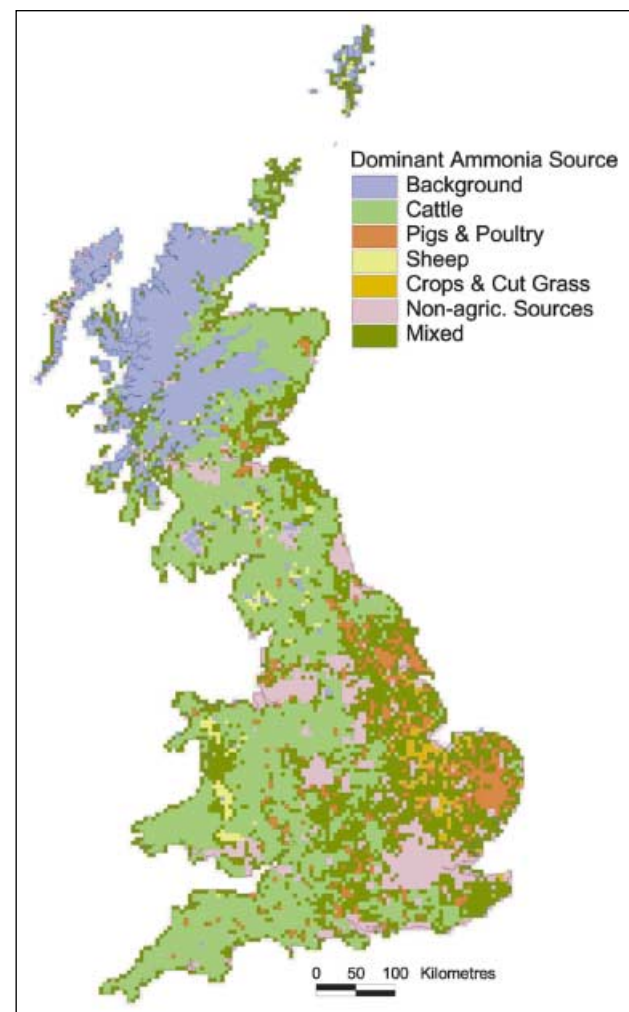


Figure 2.3
Distribution of dominant ammonia emissions by source-sector (>45% of total emission in each square). Background refers to areas with annual ammonia emission of <1 kgN/ha.

The emitted ammonia gas can be rapidly converted into ammonium in particles. It is therefore necessary to model both the gas and particle forms to characterise of the concentrations and deposition of reduced N. The estimated concentrations of ammonia gas and ammonium particles are given by the FRAME model (see later) (figure 2.4). The concentration of ammonia varies greatly at a local and regional level, in line with variation in emissions. On the other hand, the estimated distribution of ammonium particles does not vary as much, because processes that produce and remove ammonium generally take place over hours and days.

National Ammonia Monitoring Network

The National Ammonia Monitoring Network was set up in 1996 to provide a reference for ammonia concentrations in the UK. Since 1999, the network has also included measurements of ammonium particles. As ammonia concentrations vary greatly from area to area, the network has over 80 sites and this allows areas of the country with different ammonia source types (figure 2.3) to be considered. These sampling sites were deliberately chosen to compare a wide range of locations across the country, and to cover areas where concentrations were expected to be both high and low. The FRAME model was also used to identify some areas for intensive sampling, such as a transect across East Anglia.

When monitoring ammonia, long-term trends, seasonal patterns and a large number of sites are more important than frequent sampling at each site. Because of this, new methods were developed to allow the network to measure ammonia and ammonium continuously with a monthly change-over. The peaks in ammonia concentration are found in the major livestock-farming regions (see figure 2.4), while the much smoother pattern of ammonium particles shows a combination of:

- the main emission regions;
- the average westerly air flow; and
- the time it takes to form ammonium particles.

There is a substantial seasonal variation in measured ammonia concentrations, which differs according to the main sources of ammonia emissions. In remote areas, and those where sheep are the main ammonia source, ammonia concentrations are largest in the summer. However, in areas with housed livestock, peak ammonia concentrations coincide with manure spreading on grassland (late winter, early spring) and on arable land (early autumn).

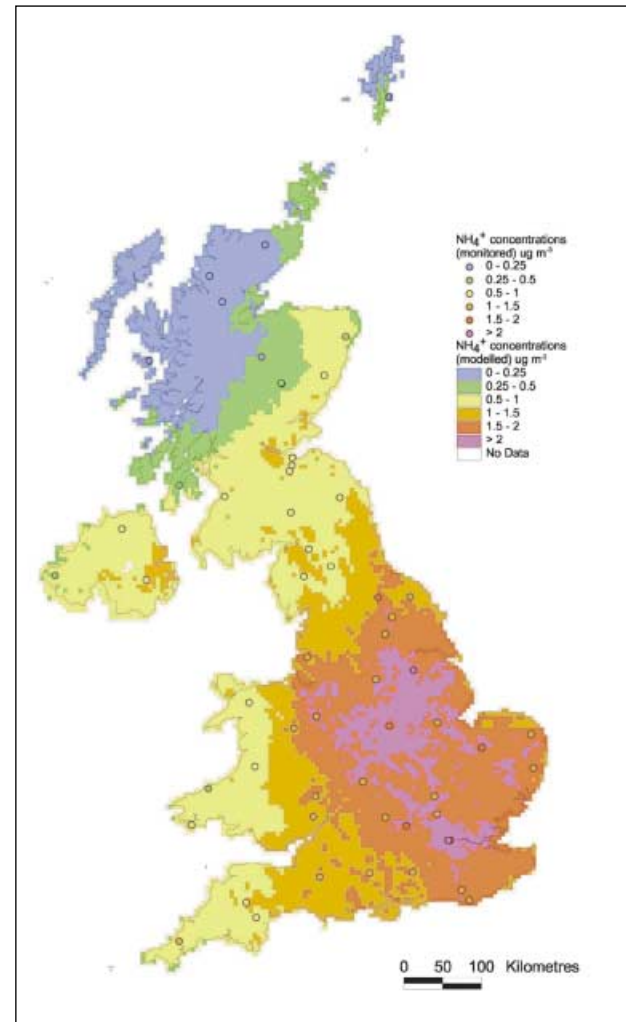
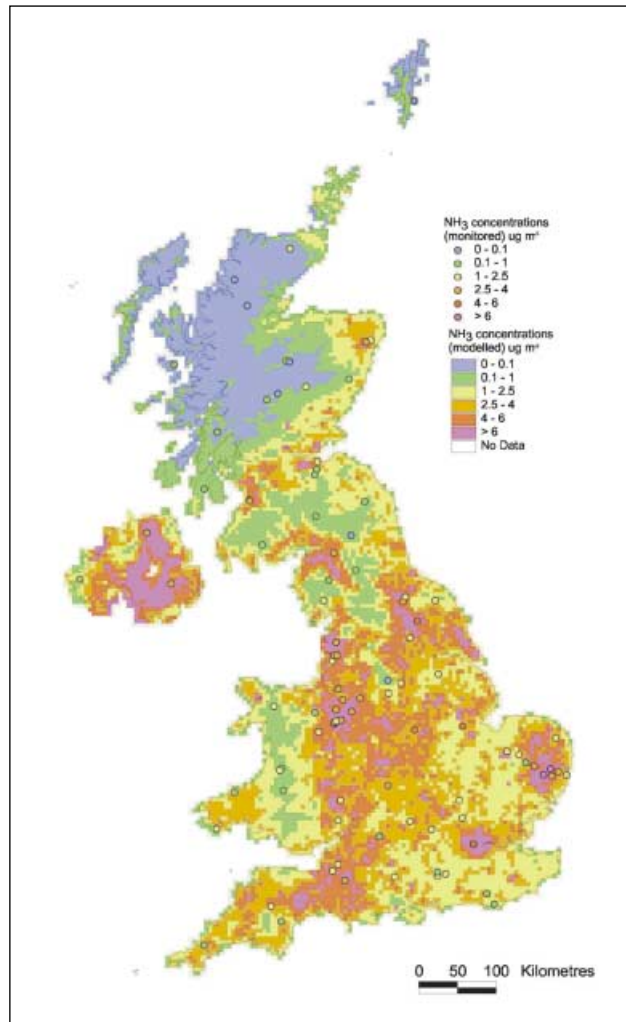


Figure 2.4a
Concentrations of atmospheric ammonia gas (NH₃) and ammonium particles (NH₄⁺) across the UK. The values mapped on a 5-km grid are those estimated by the FRAME model, while the overlying circles are the measured values from the National Ammonia Monitoring Network.

Figure 2.4b

Deposition of ammonia and ammonium

Because ammonia is a gas which reacts chemically with many other substances, it can be deposited to land surfaces as well as emitted from them. Agricultural land receiving large inputs of N in fertilizers or manures, normally acts as a source of ammonia but, for some periods, it may act as a 'sink' and absorb ammonia from the atmosphere. On the other hand, unfertilized land normally acts as a sink for ammonia. This is important because the habitats most affected by N deposition are unfertilized, semi-natural ecosystems such as moors, heaths and forests. The result is that agricultural land generally receives less than average deposition, while unfertilized ecosystems receive much more than the average.

Given the uncertainties in the model the most reliable national assessment is obtained by combining the output of the FRAME model with the results of the National Ammonia Monitoring Network, together with a detailed description of interactions between ammonia and the land surface. Figure 2.5a shows that the largest dry deposition is found in lowland areas where ammonia emissions are largest. Dry deposition is much larger than wet deposition in these areas. By contrast, wet deposition is largest in the hill areas of the north and west, where dry deposition is rather small (figure 2.5b). Because of these regional differences, the problem of reduced N deposition can be roughly divided into dry deposition of ammonia gas in areas where there are large emissions, and wet deposition of ammonium in remote areas. This difference is caused by the varying distances that ammonia and ammonium travel in the atmosphere, with most ammonia dry deposition coming from local emissions. Conversely, a large proportion of ammonium wet deposition comes from other countries, while the UK itself contributes to wet deposition of ammonium in other parts of Europe.

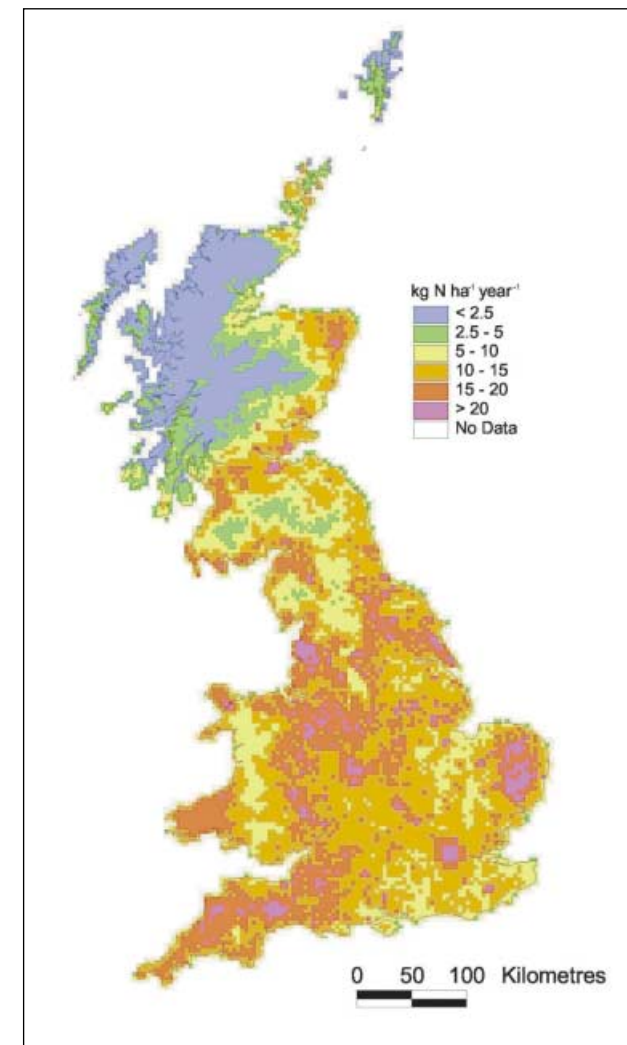


Figure 2.5a
Estimated distribution of dry deposition of ammonia to low, semi-natural vegetation.

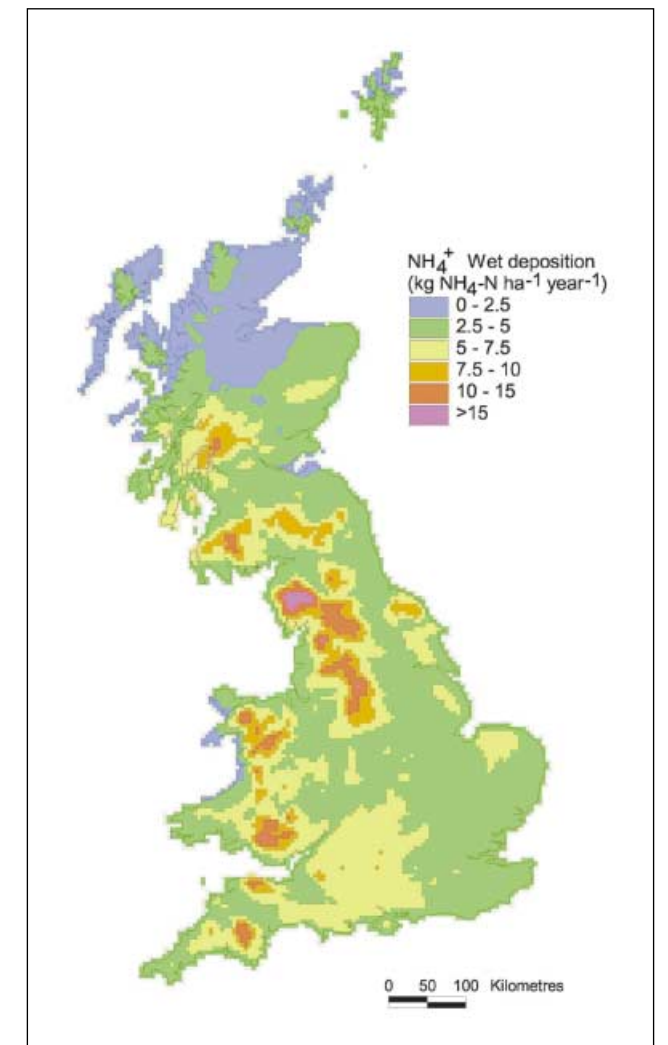


Figure 2.5b
Estimated distribution of wet deposition of ammonium in rain and snow.

Local variability

The 5 km-resolution maps show the distribution of ammonia concentrations and deposition in the UK. However, to assess the effects on the environment, even a resolution of 5 km is limited – given the local variability in reduced N deposition. There is substantial local variation in wet deposition of ammonium in mountain areas. However, the problem is even more obvious for ammonia dry deposition in agricultural areas. Figure 2.6 illustrates the problem of local variability in ammonia deposition for a lowland area of the UK. The map shows the high values of modelled dry deposition near a large poultry farm and two small, mixed farms. Values are highest near the poultry farm, and the zone of increased dry deposition due to this farm extends to a 2-km radius. Deposition is also high for areas of semi-natural land and forest, with larger values at those edges next to managed farmland.

The large variation in ammonia concentrations and deposition between areas has important consequences for assessing the effects on the environment. While the national maps show the average deposition to different land types in each grid-square, there is a huge range within each square. So, while the centre of a large nature reserve may be less at risk than the overall national assessment suggests, smaller reserves and the edges of large reserves are much more at risk. The greater risk near emission sources is of particular concern because the amount of deposition multiplies substantially the closer you get to the source.

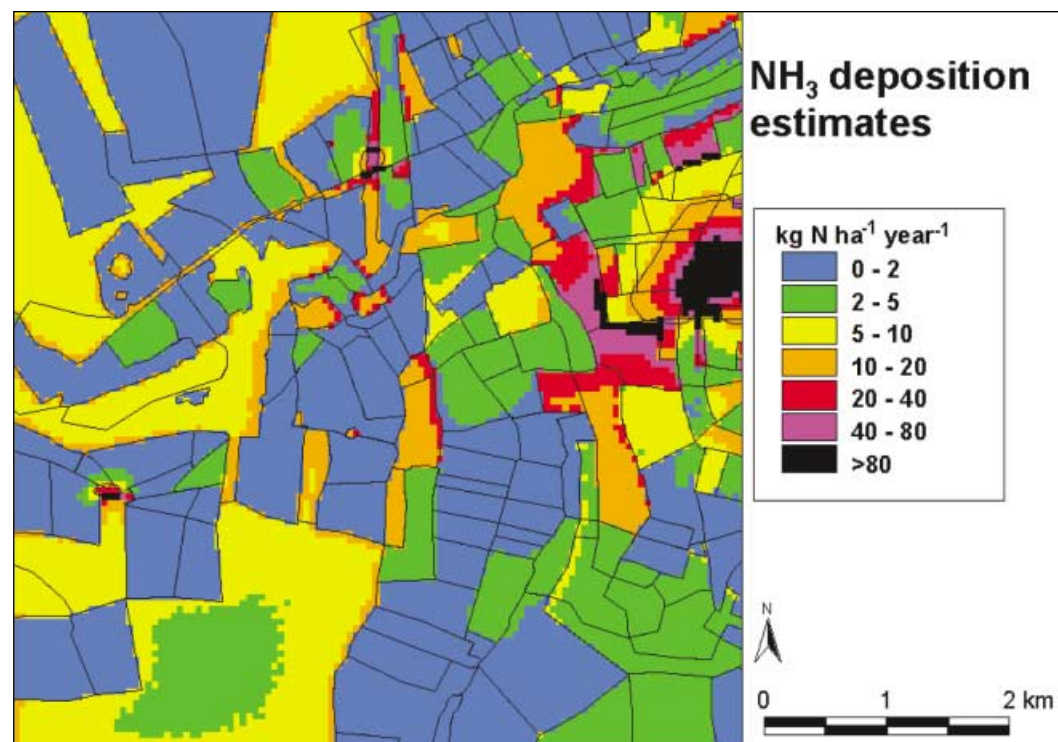


Figure 2.6
Distribution of estimated nitrogen deposition from a case study lowland landscape in the UK. Ammonia emissions in the area include an intensive poultry farm, two small mixed farms and field sources (manure spreading, grazing and fertilized crops).

Methods of ammonia abatement

To a large extent, abatement of the environmental impacts of ammonia focuses on reductions in ammonia emissions. In this context the national targets of the UNECE Gothenburg Protocol and the EU National Emissions Ceilings Directive play an essential role. However, given the potential costs of reducing ammonia emissions, such ceilings should not be considered as the only tool for reducing environmental impacts.

The high degree of spatial variability is a key feature of ammonia concentrations and deposition. While this leads to the potential for major localized impacts on the environment, it also provides the opportunity to reduce deposition to particularly sensitive habitats by spatial planning. At its simplest, this might mean not siting a new development of an ammonia source, such as an intensive livestock farm, adjacent to a vulnerable nature reserve. Such approaches could also include the establishment of buffer zones to limit ammonia emissions from fields around nature reserves. A further possibility is the increased planting of tree belts (strips of woodland) adjacent to sources, which may be used to recapture a fraction of the ammonia as well as to increase dispersion, with the result that deposition to other particularly vulnerable habitats is reduced. By contrast to dry deposition, wet deposition of ammonium could only be reduced through national and international emission reduction measures.

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You will find information on the National Ammonia Monitoring Network at: www.nbu.ac.uk/cara

Chapter 3

Environmental impacts of ammonia on semi-natural habitats

Mike Hornung (CEH), Mike Ashmore (Bradford University) and Mark Sutton (CEH)

Main Points

- Nitrogen deposition has contributed to changes in the mix of plant species growing in a range of semi-natural habitats in many parts of the UK.
- The concentration of N in foliage increases with increasing N deposition, which may increase plant sensitivity to stress (such as from frost, drought and insect damage). Increasing N deposition can also change the balance of nutrients in the ecosystem.
- The current deposition of ammonia and ammonium from the atmosphere is above the critical load of N for a number of semi-natural habitats over large areas of the UK.
- Nitrogen deposition can also make soils and surface waters acidic, and is likely to become more important as sulphur deposition decreases.
- Only when they occur close to the sources of ammonia (such as livestock housing) can the changes seen in the vegetation and soil be definitely linked to ammonium-N. Larger-scale changes may be related to the total nitrogen deposition, which comes from ammonia and nitrogen oxides (mainly from burning fuel), but will also be influenced by other factors such as grazing.

Introduction

In the UK over the last 20 years, evidence has been collected to show the damage that N deposition has caused to land and water habitats. Increased concentrations of N in the atmosphere can also damage vegetation, while increased deposition can lead to both N enrichment and acidification of habitats (see figure 3.1). The form of the N and the characteristics of the habitats have a major influence on the effect of the deposited N. Nitrogen may be deposited as reduced-N compounds (NH_x) that result from ammonia

emissions and as oxidised nitrogen compounds (NH_y) that result from emissions of nitrogen oxides (NO_x). Although the effects of increased N deposition on land-based ecosystems are now clear, it is often difficult to separate the effects of nitrogen oxides and ammonia in field observations.

In December 2001, the National Expert Group on Transboundary Air Pollution (NEG-TAP) published a report for DEFRA and the devolved administrations on the impact of air pollution on ecosystems in the UK and prospects for the future. The report highlighted the adverse impacts of reduced N on vegetation.



Figure 3.1
Invasion of heathland in southern England by wavy-hair grass and birch trees.

Impacts

Different types of vegetation vary greatly in their sensitivity to atmospheric N deposition. Arable crops and improved grasslands are unlikely to be affected. The most sensitive ecosystems are those that are naturally adapted to small supplies of N available as a nutrient, such as:

- montane systems;
- heathland and moorland;
- blanket bogs; and
- some grasslands.

Some of these habitats have decreased in size over the years and there are policy commitments to protect them such as the EU Habitats Directive. Nitrogen deposition can affect vegetation, and land and freshwater habitats, in four main ways:

- changes in the competitive balance between species;
- changes in plant sensitivity to stresses such as frost, drought and insect attack;
- acidification of soils and waters; and

High concentrations of ammonia can also be directly toxic to sensitive vegetation in the vicinity of large emission sources, such as intensive livestock buildings. The evidence for the effects of N deposition comes from three major sources:

- changes in the N content of foliage;
- changes in the species of composition across the countryside; and
- increased acidity and nitrate concentrations in soils and drainage waters.

These changes in soils and vegetation can be directly related to ammonia emissions close to the sources, but the contribution of these emissions to more widespread changes in plant species occurrence is much more difficult to measure.

Changes in N content of foliage

Increased N from atmospheric deposition can increase N concentrations in foliage. Particularly high concentrations are found downwind of large sources of ammonia, such as pig and poultry units, but there is also evidence of long-term increases across many parts of the country. Analysis of historical plant specimens and current material from the same sites has shown an increase in N content in foliage throughout the last century, which can be related to the known increase in N deposition.

The increased N content may increase the plants' sensitivity to environmental stresses, such as drought, frost and insect damage. For example, both winter-moth and heather-beetle populations increase as plant N increases. There is also a connection between the number of insect-damaged Scots pine trees and total N deposition in the UK. The increased N content can also lead to changes in decomposition and other processes that recycle nutrients into forms that can be taken up by plants.

Changes in the occurrence of plant species

The characteristic plant species of semi-natural habitats are generally adapted to grow in conditions of limited N availability. Increases in N deposition to these systems can result in increases in available N in the soil, which benefits those species that need fairly large supplies of N. These species then begin to outnumber those species adapted to a limited supply of N. This can mean the loss of species of conservation importance.

It is clear that areas of semi-natural vegetation, including official conservation sites close to agricultural sources of emission are at particular risk from ammonia deposition. For example, in a detailed study around a poultry farm in southern Scotland, the number of plants adapted to low N (such as wood sorrel and many moss species) decreased close to the farm, while the number of species adapted to high N (such as rose bay willowherb and certain grasses) increased.

The best evidence of species change across the country comes from the 1978, 1990 and 1998 UK Countryside Surveys, in which the same vegetation plots were surveyed at different intervals. The surveys have shown that in habitats adapted to limited supplies of N (such as infertile grassland, upland woodland, moorland grass, and heath and bog), there have been small increases in the number of species that have greater N requirements throughout much of the UK. In contrast, the species composition of agricultural grassland has not changed in the same way.

Outside these monitored plots, there have been changes in vegetation composition over the past few decades that are in line with changes due to excess N deposition. The most widely reported changes are:

- a shift from mostly heather to grass (for example, in Breckland heaths and on Scottish moors); and
- a decrease in moss cover (for example, on moss-dominated heath in northern England and parts of Scotland; in upland grassland in the northern Pennines; and on blanket bogs in the southern Pennines).

However, in many of these cases, changes in land management have been important, and may have acted with increased N deposition to cause the changes in vegetation that we have seen.

Results from experiments also show the loss of species with a small N requirement and an increase in those with a large N requirement. Results from adding N in long term experiments demonstrate a reduced cover of species with a low N requirement

and increased cover of species with a larger N requirement. In general terms, mosses, lichens and forbs tend to decrease relative to grasses, although individual species within these groups may show different trends. Some experiments in which N additions have been reduced have shown that these changes in species composition may last for decades, and that active management may be needed to restore the original species.

Acidification and nitrate leaching

Deposition of ammonia, nitrogen oxides (mainly from industry and transport) and sulphur dioxide (mainly from electricity generation) can acidify the soils and, in some cases, drainage waters. This acidification affects biodiversity (plants and animal species) in both land-based and freshwater habitats, with the loss of acid-sensitive species.

What happens to the deposited ammonium-N in the soil-plant system will decide whether or not acidification takes place. Acidification will result if the ammonium-N is converted to nitrate by bacteria and that nitrate is leached from the soil in drainage. However, acidification is prevented if the ammonium-N is used in increased plant growth, absorbed into the microbes in the soil (the microbial biomass), or held on soil particles (colloids).

Ammonium-N deposition to soils that are not naturally very acidic will lead to the ammonium-N being converted to nitrate. It will also lead to the soil becoming acidic and nitrate leaching to ground waters, as seen in woodland downwind of a livestock unit in north Yorkshire. But, in naturally-acidic upland soils, much of the ammonium-N input is incorporated in the microbial biomass and not leached. However, if the nitrogen deposition continues, even acid upland soils will eventually become unable to hold any more and there will be some leakage of nitrate, with the possible acidification of the soils and waters. Deposition of sulphur (from sulphur dioxide emissions) has been the main cause of acidification of surface waters over the last 150 years. Many of the UK's acid-sensitive areas have been affected by historical sulphur deposition. In the last 20 years, sulphur emissions – and therefore sulphur deposition – have decreased sharply, while N deposition increased until the 1990s. This increase was mainly due to increasing emissions of nitrogen oxides from transport and gradual increases in ammonia emissions from agriculture. Monitoring has shown a decrease in sulphate but gradual increases in nitrate concentrations at some freshwaters in the uplands. Increasing nitrate concentrations may mean that in these freshwater catchments the soils have more N than can be taken up by plants, so that any additional N is leached. If so, nitrate will become increasingly important in deciding how well and how quickly the soil recovers from acidification as sulphate declines.

Risk assessment using critical levels and critical loads

Critical levels

Critical levels are set to prevent gaseous pollution directly affecting plants. If the concentration of the pollutant goes above the critical level, sensitive vegetation may be damaged. Experiments have found the critical levels for ammonia to be $23 \mu\text{g m}^{-3}$ if the vegetation is exposed to it for one month, and $8 \mu\text{g m}^{-3}$ for the average exposure over a year. Average annual concentrations of ammonia are above the critical levels in very small areas of the UK. Only one of the 80 monitoring sites in the National Ammonia Monitoring Network, which is in an area with a large number of pig and poultry farms in East Anglia, shows annual average concentrations above the critical level. Much larger concentrations have been reported immediately downwind of animal units; for example, average annual concentrations of $30\text{--}60 \mu\text{g m}^{-3}$ were measured about 15 m from chicken farms in southern Scotland. Therefore, direct toxic effects of ammonia on vegetation in the UK are only likely to be of concern very close to large sources.

Critical Levels and Loads

Critical level: is the concentration of a pollutant in the atmosphere, below which vegetation is unlikely to be damaged according to present knowledge.

Critical load: the critical load is the amount of pollutant deposited below which significant harmful effect on specified elements of the environment do not occur, according to current knowledge.

The idea of a critical load was developed to provide a receptor-based system for measuring emission reduction targets for pollutants, in the areas of acidification and nutrient over-enrichment. Critical loads of N for nitrogen **enrichment** have been based on the results of field monitoring experiments, and links between N deposition and changes in vegetation. Critical loads of acidity, which include the contributions from N and S (sulphur), are generally set to limit changes in the chemistry of soil or soil solution so that the biological system is protected. The critical limits have been set to prevent changes in the species present, or changes in the ecosystem

Critical loads

Critical loads are set to prevent the long term effects of deposition. If the deposition is above the critical load, the ecosystem may be damaged. When the total deposition of acidifying pollutants (from ammonia, nitrogen oxides and sulphur dioxide) is above the critical load for acidity, ecosystems are at risk from acidification. When total deposition of ammonia and nitrogen oxides is above the critical load for N, ecosystems are at risk from nitrogen enrichment. Areas where deposition is above the critical load, and where damage is therefore possible, can be shown on a map by comparing the distribution of different habitats and their critical loads with geographical information on deposition.

Critical loads for nitrogen enrichment

Studies suggest that the critical load to protect heathland and moorland from N enrichment is exceeded over 64% of the UK. Indeed, deposition of reduced N alone is enough to go above the critical load in over 36% of the area, whereas deposition of nitrogen oxides alone would only account for this in about 1% of the area (see figure 3.2).

The critical-loads approach for the UK in figure 3.2 is based on maps of the critical load of the main habitat in each 1 by 1 km grid square, and a 5 km grid for deposition. Much of the local variation in deposition is not shown on these national maps but it will lead to critical loads being exceeded in very localised areas. A detailed model study of an area in central England (see figure 3.3) showed large increases in deposition near to farms and into nearby semi-natural areas. It is likely that critical loads were exceeded at the edges of woodland and natural areas but not in the centre of nature reserves. This is because of increased deposition at the edges of the semi-natural habitats, where these are next to farmland or livestock buildings.

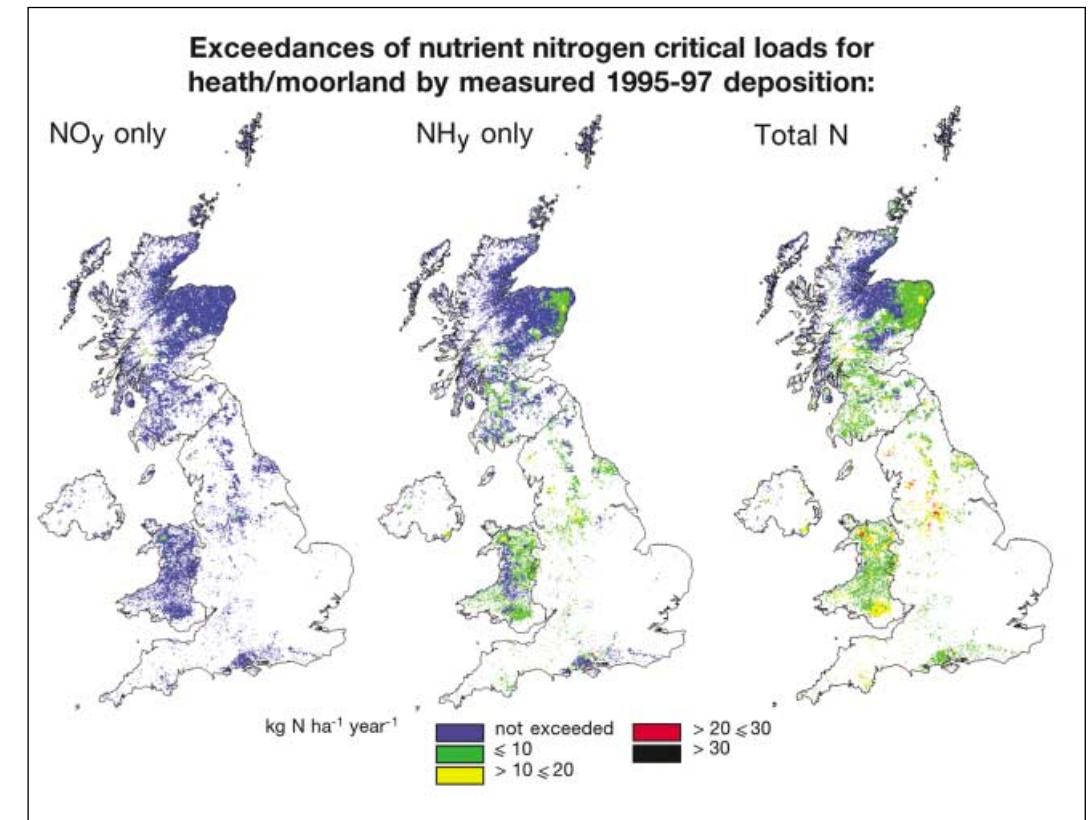


Figure 3.2
Areas of heath and moorland in the UK receiving N deposition above the critical load for nitrogen 1995-97. The amount of deposition above the critical load is the exceedance.

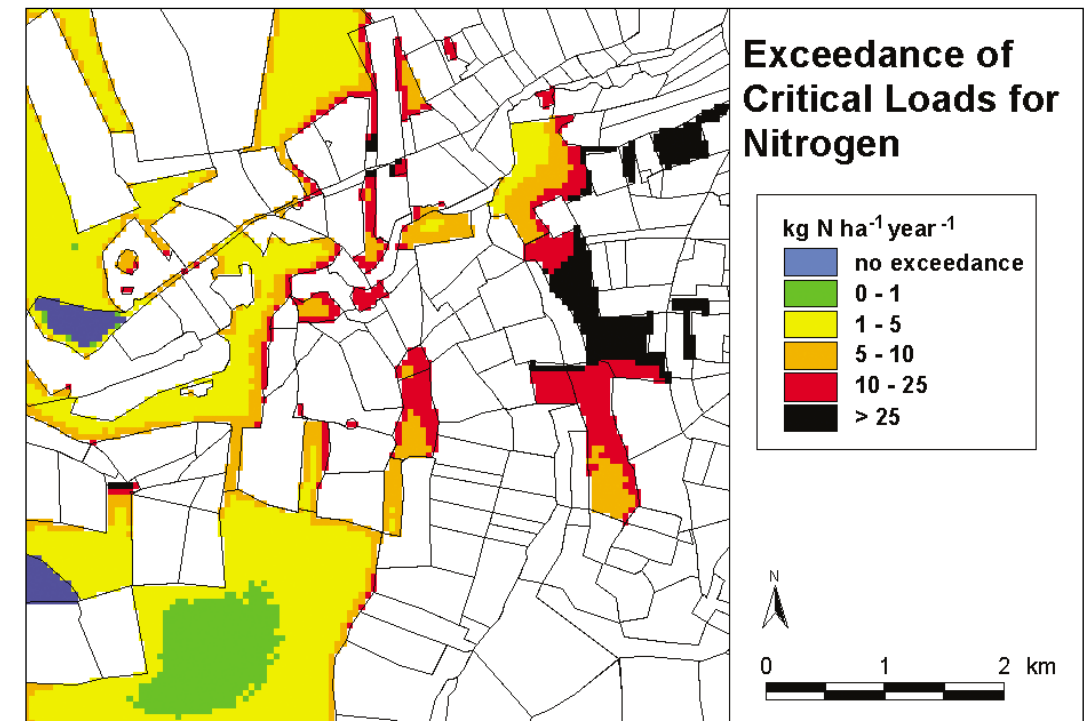


Figure 3.3
An area of lowland landscape in central England receiving total N deposition above the critical load for nitrogen, based on a detailed model. Areas adjacent to agricultural land and near farms receive the highest deposition above the critical load.

Critical loads for acidification

Assessing the contribution of N deposition to soil acidification is complicated because it is difficult to know what will happen to the deposited ammonium-N. However, if we assume that all deposited ammonium adds to soil acidification and does not stay in the soils, we can calculate the maximum potential effects. Studies suggest that current ammonium-N deposition alone is actually large enough to exceed the critical load in over 40% of the UK's woodland soils. This is mainly in areas on the acid-sensitive soils of the uplands. For freshwaters, the data suggest that over 11% of the UK is above the critical load. As with plant-soil systems, the main areas of concern are in the sensitive upland areas.

Long term change and recovery

Historic data clearly show that increased N deposition has affected vegetation in the UK during the last century. The effects of ammonia deposition are clear from sites around N sources. There is evidence of more widespread changes in vegetation in N-sensitive habitats, but the relative sensitivity to reduced nitrogen (NH_x) versus oxidised nitrogen (from nitrogen oxides) deposition is still not certain. It is likely that other issues, such as the way the land is used and plant sensitivity to stress, are also involved. Surface waters have clearly become more acidic over the last 150 years. Nitrogen deposition has contributed to this, but sulphur has been the main cause. Nitrogen deposition is now important in determining the rate of recovery of soils and waters as sulphur deposition declines. The build-up of N in soils from historical deposition may also slow down or prevent the recovery of sensitive plant species, even after atmospheric deposition has decreased. Therefore, recovery may need changes to land use as well as reduction in ammonia emissions.

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Chapter 4

Estimating total ammonia emissions from the UK

J Webb (ADAS), Tom Misselbrook (IGER), Mark Sutton (CEH) and Helen ApSimon (Imperial College)

Main Points

- An inventory has been drawn up to estimate how much ammonia is emitted by each of the livestock groups (cattle, pigs, poultry, sheep and other livestock) and by nitrogen fertilizer in the UK. Non-agricultural sources of ammonia (e.g. transport, wild birds) are also included in this inventory.
- Total emissions of ammonia in the UK are currently estimated to be 320 kt per year (give or take 15%), giving an estimated range of emissions of 270-370 kt. Around 80% of these emissions are from agriculture.
- The largest emissions are from cattle farming, making up 44% of the total.
- Across all livestock groups, the largest emissions are found from manure spread on the land, and from livestock buildings.
- A simple model has also been developed to find the most cost-effective ways of reducing ammonia emissions from agriculture. These are usually ways of reducing emissions after manure spreading and during slurry storage.
- Non-agricultural emissions come from a large number of diverse sources.

Introduction

It is essential to prepare accurate inventories to estimate how much ammonia is in the atmosphere and its likely effects on the environment. An inventory is a list of all the estimated emissions from all known sources. Having this inventory means that we can identify the major sources of emission and look at ways to reduce them.

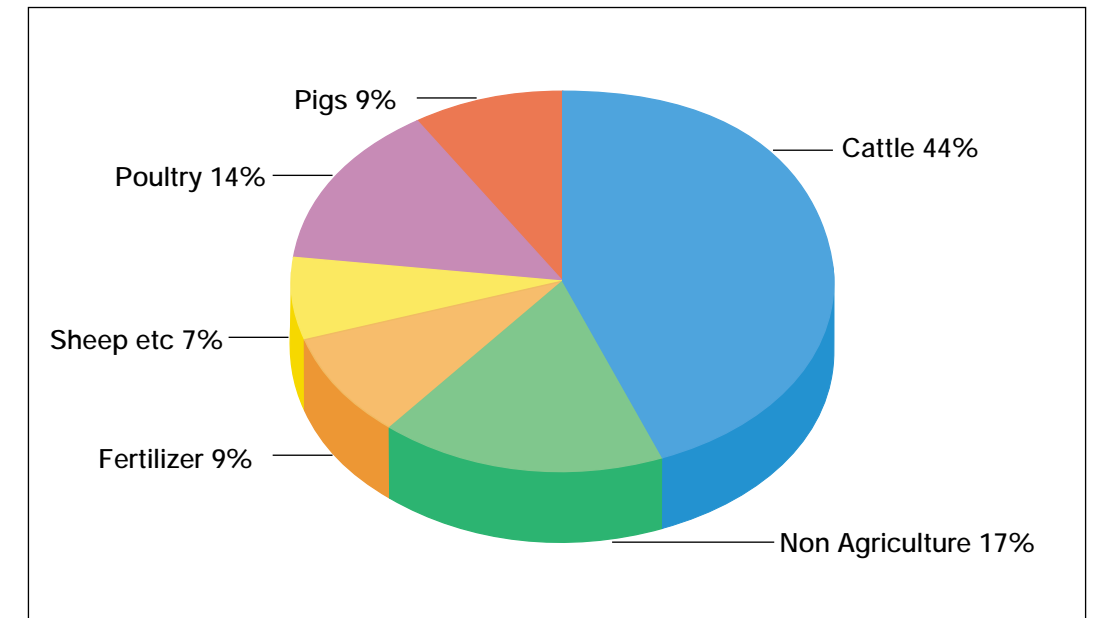


Figure 4.1
UK ammonia emissions by source

Two methods have been developed to calculate emissions. In one method, the Unit Approach, independent estimates are made of emissions from each source at each stage of manure management, and these are added together to give the total. In the other method, the Mass Flow Approach, ammonia losses from livestock farming are seen as part of the flow of N during manure management, so that the effect of changes to emissions at one stage of management can be calculated when examining the effects of later manure management practices.

Inventory of ammonia emissions in the UK

Some of the earlier inventories of ammonia emissions were made for Europe by researchers in the Netherlands, and by the European Centre for Ecotoxicology (ECETOC). These inventories relied heavily on emissions data from the Netherlands, although some adjustments were needed in the ECETOC inventory to allow for the differences in farming systems between countries. Agriculture was identified as the source of 80-90% of European ammonia emissions, with about 80% of agricultural emissions produced by livestock farming. Since there are significant differences between livestock farming in the UK and the Netherlands it was essential to compile a national inventory based on measurements made within the UK. In 1996, an official UK inventory was constructed for the then-MAFF and it has been updated every year. The inventory of agricultural sources has sections on each of the major livestock production groups (such as cattle, pigs, poultry, sheep and other livestock), as well as a section on emissions from crops and fertilizers using the Unit Approach. The inventory uses emission levels for each livestock class for each of the various stages of manure management (from livestock housing and yards; manure stores; after manure spreading; and from grazing and using N fertilizer).

In this way, the amounts of ammonia emitted by each livestock production group, and each stage of manure management, can be clearly assessed. To make sure the calculations are easily understood, the emission units used are those commonly reported by researchers in their publications and are as follows:

- g LU⁻¹ day⁻¹ (where LU means livestock unit, which is 500 kg of weight for a live animal, or ‘liveweight’) for emissions from buildings and during grazing;
- g m² day⁻¹ for emissions from outdoor yards and manure stores; and
- % of ammonium-N after spreading manures and N fertilizers on the land.

Ammonia emissions are calculated from emission sources and ‘activity data’. Activity data includes:

- the number of livestock in each production class or group;
- the surface area of storage facilities; and
- the times of the year when manures are spread on the land.

These data have been collected from a range of sources, including the annual census of livestock numbers, expert opinion and surveys of manure management practice.

Table 4.1 Example of a calculation from the UK ammonia inventory to estimate the emissions from dairy cows during housing in cubicles (producing slurry) in the UK each year.

Activity data			Emission level	Ammonia emission
Number of dairy cows in the UK (A)	Percentage (%) of dairy cows kept in cubicle houses (B)	Number of days spent in housing each year (C)	For one dairy cow in cubicle housing (in gLU ⁻¹ d ⁻¹) (D)	A/1000 x B/100 x C x D x 550/500 (in kg y ⁻¹)
2,336,000	66	199	38.2	12,892,166

Table 4.1 shows the calculation of emissions from dairy cows in cubicles. Other livestock groups are treated in a similar way. Emissions will vary between different farming systems, and the type of manure produced – slurry (liquid) or solid. Agricultural practices, and therefore emissions, may vary with time. A disadvantage of the Unit Approach is that emissions at different stages of manure management

are calculated separately, so the effects of efforts to reduce emissions at earlier stages of the cycle cannot be easily assessed. Work is underway to compile the UK ammonia inventory using the Mass Flow approach, to avoid this disadvantage.

Estimates from the UK inventory

Based on data from the year 2000, the UK’s total ammonia emission is estimated to be 320 kt (give or take 15% (about 50 kt). About 256 kt (80%) of the UK’s total emission comes from agricultural sources.

The inventory shows that most (89%) of the ammonia emitted from **agricultural sources** is from livestock production, with the rest (11%) coming from fertilizers and crops. The emissions from livestock production are greatest from cattle (53%). Across all livestock, the greatest emissions are from livestock housing (39%) and from land after manure spreading (41%) (see figure 4.2).

Emissions from different stages of manure management vary between the livestock groups. For pigs and poultry, usually raised indoors, the greatest emissions are from buildings (64% and 52% respectively of the group totals). For cattle, often outdoors for about six months of the year, emissions after manure spreading are 48% of the group total, with emissions from buildings at 34%. Emissions from grazing cattle are fairly small, as the ammonium-N in the urine deposited on pasture is quickly absorbed by the soil.

	cattle	pigs	poultry	sheep etc	total	% agric	% livestock
housing	48	19	24	2	92	35	39
storage	13	2	0	0	15	6	6
spreading	67	8	20	2	96	36	41
outdoors	12	1	2	18	33	13	14
						90	
housing	34	64	52	8.4			
storage	9	6	1	0.3			
spreading	48	26	44	7.0			
outdoors	9	4	3	84.2	15	26	
					12	10	
total	140	30	45	22	263	100	
% ag total	53	11	17	8	100		
% livestock	59	13	19	9	237		
% of livestock total							
% of agric total							

Figure 4.2
Percentage (%) of ammonia emissions from livestock at each stage of manure management.

Each year in the UK, non-agricultural sources account for about 50-60 kt of ammonia emission. A wide range of non-agricultural sources contributes to ammonia emissions in the UK, including pets, wild animals, sewage sludge, industrial and combustion processes and vehicles fitted with catalytic converters (chapter 10). The emissions from each of these sources are usually small and very uncertain because of their variability and lack of measurements.

Models of ammonia abatement

Work is continuing to develop models of ammonia emissions from livestock production systems. Since manures are by far the greatest source of ammonia, the first step to reduce emissions is to look at the total amount of ammonium-N in the dung and urine produced by livestock, from which ammonia is released. This pool is reduced by ammonia being emitted from manure in livestock houses, in storage and after spreading. Very little of the organic N in dung actually breaks down in the soil to replace the ammonium-N lost as ammonia. So, if ammonia emission is prevented from an early stage of manure management (for example, emissions from livestock buildings or manure stores), a larger pool of ammonium-N will stay in the manure, to be emitted later (for example, from manure spreading) unless further abatement methods are used. Abatement in this case means to reduce or even prevent ammonia emissions.

The idea of a fixed total amount of ammonium-N in the farming system means that it will be easy to assess the effects of introducing abatement techniques at one stage of manure management on the possible size of later emissions (see figure 4.3). The Mass Flow approach was used in the **Model for the Assessment of Regional Cost Curves for Abatement Strategies (MARACCAS)** model. The MARACCAS model was used to review the possible ways of reducing emissions, including how efficient, practical and expensive the current methods are. This review was based on the information and experience available at the time, which was mostly limited to a few countries such as the Netherlands. The results were used to compare the possibilities for ammonia reduction in different European countries, including the UK. More information is now available and this approach is being adapted for use in the **National Ammonia Reduction Strategy Evaluation System (NARSES)** model. The aim of NARSES is to develop a national-scale model to estimate the size, geographical distribution and seasonal variation of ammonia emissions, and the potential for emission reduction methods with their associated costs. When it is finished, NARSES will help policy makers to identify and assess cost-effective ways to reduce ammonia emissions at a national, regional and farm level. NARSES will also allow the effects on ammonia emissions of other changes in the agricultural industry to be assessed. Designing a model to calculate regional differences in the potentials for both ammonia emissions and reductions will

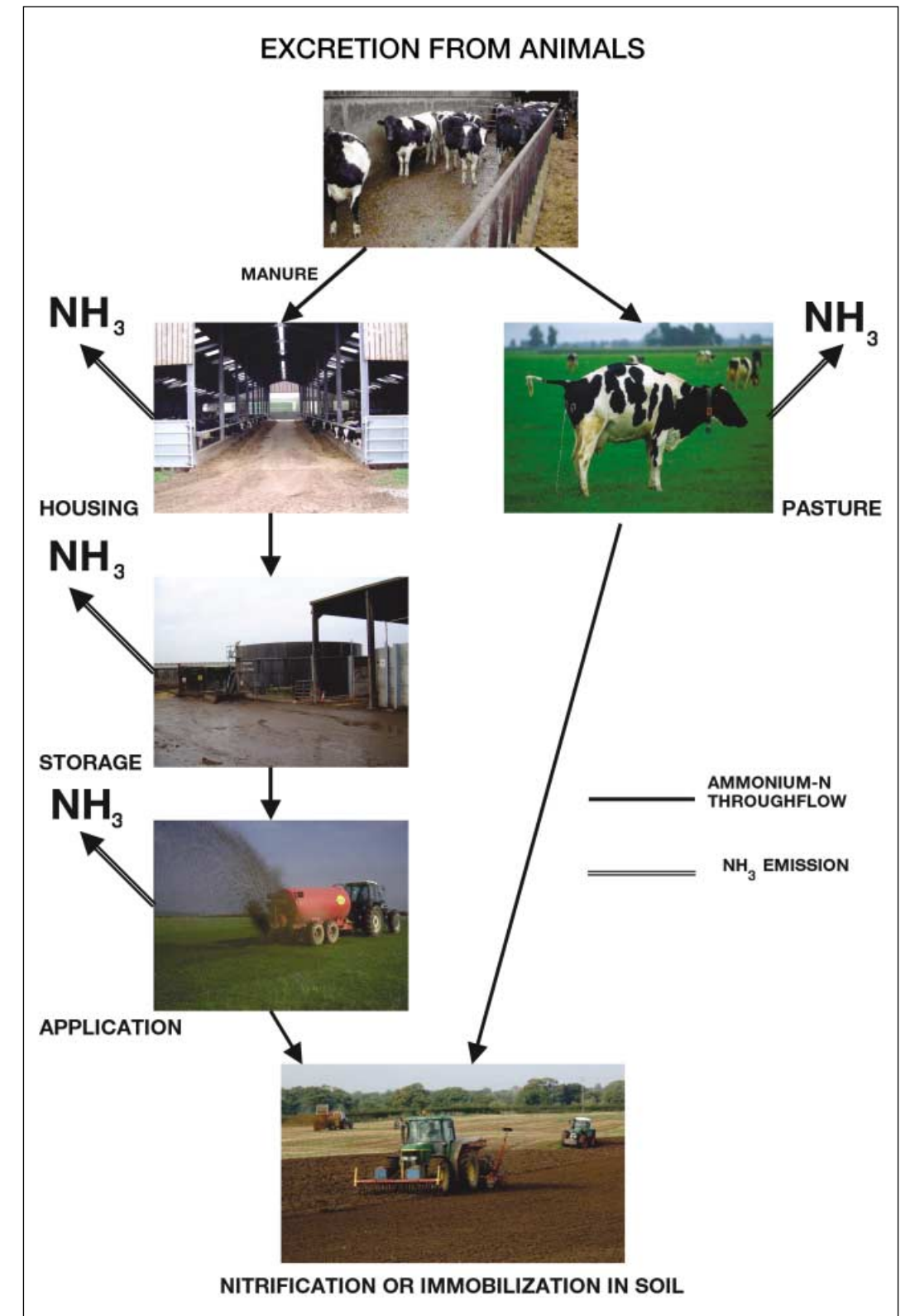


Figure 4.3
Percentage (%) of ammonia emissions from livestock at each stage of manure management.

also allow more accurate estimates of total emissions and emission reduction potential to be made.

Models have shown that some of the most cost-effective emission reduction methods are those that reduce emissions after manure spreading on the land. This is the final stage of manure management, and thus the final stage where ammonia emissions can be reduced. Abatement at earlier stages, e.g. during housing or storage, will mean the manure to be spread has a higher ammonium-N content and thus the potential for greater ammonia emission after spreading. Use of low-emission spreading techniques will ensure that ammonia saved earlier is not lost during this final stage of manure management.

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Chapter 5

Ammonia emissions from cattle farming

Tom Misselbrook (IGER) and Ken Smith (ADAS)

Main Points

- Cattle farming accounts for 44% of the UK's total ammonia emission, and 53% of that which comes from agricultural sources.
- Manure spreading and livestock housing are the major sources of emission.
- Emissions from slurry-based manure systems are greater than from straw-based systems.
- Research suggests that the most cost-effective emission reduction methods focus on spreading manures on land, either by injecting the manure just under the surface or by application using band-spreading machinery and by quickly mixing the manure into arable soils.

Introduction

Cattle production is the major source of ammonia from UK agriculture, emitting approximately 140 kt of ammonia each year. This accounts for 44% of the UK's total ammonia emissions and 53% of the total from agricultural sources. Dairy cattle tend to have more protein in their diet than beef cattle, which means that dairy cattle produce more N and ammonia in their excreta. Cattle may be housed on either a slurry (liquid manure) or straw-based (solid farmyard manure, or FYM) manure system, or a combination of both. This influences both the way that manure is managed and how much ammonia is produced by:

- housing;
- manure storage; and
- manure spreading.

The manure-management system used also affects the possible emission reduction methods that could be used.

Emissions from housing

Housing is second only to spreading of manures on land as a source of ammonia emission from cattle farming. This is because within buildings and following manure spreading, manure is distributed over a large surface area from which emissions may take place. Ammonia is released almost immediately when the cattle urinate in the housing cubicles. The present estimate of UK emission from cattle housing is 48 kt ammonia each year, with dairy and beef houses accounting for approximately 50% each. Recent survey data suggests that approximately 65% of dairy-cattle manure and 20% of beef-cattle manure is produced as slurry (dung and urine), with the rest (35% and 80% respectively) produced as straw-based FYM. Slurry systems usually have houses with individual cubicles for the cattle to lie in (cubicle houses). A small amount of bedding, such as wood shavings or sawdust, is spread over the concrete floors of the cubicles, or there may be rubber mats. The access passageways are cleaned using either automatic or tractor-mounted scrapers. Beef cattle reared on slurry systems may also be housed in buildings with slatted floors, where dung and urine drop through the slats to a store below. Cattle housing in the UK is almost entirely naturally ventilated, in other words, through gaps in the walls and roof.

Ammonia emissions from slurry-based (cubicle) systems are greater than from straw-based systems. Straw acts as a barrier to emissions and can also absorb some of the ammonium-N in urine, so reducing the amount available for emission. Scraping the passages in cubicle houses leaves a thin film of slurry from which emission continues. Recent measurements show that the average emission from slurry-based systems is 30% of the ammonium-N produced from animal dung and urine excreted in the house (which is 18% of the N deposited in the house) compared with 23% for straw-based systems (14% of the N deposited in the house). There is some evidence that emissions from buildings in summer, when cattle are only housed overnight, are as great as emissions in winter, when cattle are housed full time. This could be due to both the higher background temperature in the summer and the continued emissions from dung and urine deposited by the animals during the limited overnight housing.

Emissions from stored slurry and FYM

Recent survey information shows that approximately 20% of the slurry and 50% of the FYM (solid farmyard manure) collected from cattle housing is regularly spread directly onto land. The rest is stored before being spread. Ammonia emission from manure stores depends on the surface area of manure in contact with the air rather than the total amount of manure stored. Most stores have a small surface area in

relation to their volume, so only a fairly small proportion of the N they contain is released as ammonia. Total emission from cattle manure stores in the UK is estimated to be 13 kt of ammonia each year.

The most common types of manure store, for slurry and dirty water, include:

- below-ground tanks;
- above-ground circular tanks; and
- earth-banked lagoons and weeping-wall stores (which are above-ground concrete-panelled stores with slots allowing liquid seepage).

FYM is stored in heaps either in fields or on concrete pads. The major types of manure stores – circular tanks, lagoons, weeping-wall compounds and FYM heaps – account for 7%, 38%, 5% and 50% respectively of the total surface area of manure stored on farms in the UK.

Emissions from slurry stores increase with increasing temperature, windspeed, slurry pH and, especially, with frequency of mixing. Natural crusts often form on slurry stores as the gas produced by bacteria within the slurry carries fibrous particles to the slurry surface. Such a crust will prevent some ammonia emission from the store. Stores may be filled from the top or bottom. Filling from the top may prevent a complete surface crust from forming and may also increase ammonia emission during filling.

Emissions from FYM heaps increase to a maximum in the first few days of storage as the bacteria cause the temperature to rise. Most of the emission from FYM heaps takes place within the first 30 days of storage, unless the heap is turned, or forked, to encourage composting and more ammonia is emitted. Heavy rainfall reduces emissions by slowing the composting process, but it may increase drainage from the heap and the movement of water-borne pollutants down through the soil. There may be a further peak of ammonia emission when the heap is broken up before being spread on the land.

Emissions from spreading manures on land

Spreading manures on land is the major source of ammonia emission from cattle farming, with an estimated total for the UK of 67 kt of ammonia each year. Of this, 30 kt come from slurry spreading and 37 kt from FYM. Emissions are influenced by a large number of environmental and management factors (Chapter 1).

For slurries and FYM, most of the emission takes place during the first few hours after spreading. After that, emission rates decline rapidly, though they continue for a number of days at steadily decreasing rates (see figure 5.1).

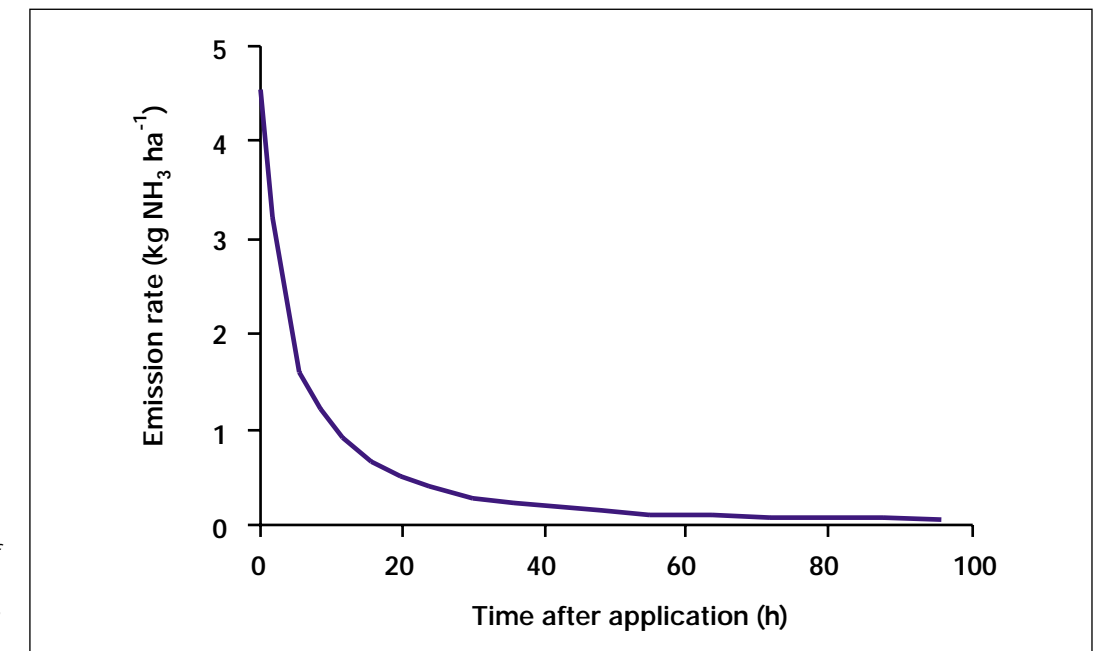


Figure 5.1
Typical pattern of ammonia emission after spreading manure on land.

Cattle slurry is most commonly spread evenly or 'broadcast' over the whole surface of fields. For slurries, important factors influencing emission include slurry dry matter content. There is a strong relationship between the magnitude of ammonia loss and the dry matter content of cattle slurry. For every 1% increase in dry matter there is a corresponding 5% increase in proportional loss of ammonium-N. This reflects the faster infiltration of dilute slurries into the soil where the ammonium-N absorbed on to soil particles becomes less likely to be released as ammonia. Conditions at the soil surface are also important and any impediment to slurry infiltration, e.g. surface capping, compaction, wet soil or a layer of crop residues, may increase emission. Actual emissions after cattle slurry has been spread vary widely, from less than 10% to over 80% of the ammonium-N applied. This variation depends on the slurry itself, and environmental and soil conditions. Dirty water (such as from washing milking parlours, rainfall and run-off from hard standings) may be considered as a very dilute slurry and, since it also contains little ammonium-N, it emits very little ammonia.

FYM is broadcast onto the land using side- or rear-discharge manure spreaders. It is mainly spread in the autumn onto cereal stubble and grassland, but also onto forage maize land in early spring, before sowing. A greater proportion of the applied ammonium-N is lost (typically 65%) because FYM is not washed into the soil as quickly as slurry. About 50% of FYM is not stored but spread directly from buildings. The ammonium-N content of unstored, or fresh, FYM is usually 25% of the total N, but only 10% for stored FYM because of the losses during storage. Ammonia emission from spreading is greater when unstored fresh FYM is spread onto land.

Emissions from grazing

Ammonia emissions from grazing cattle come from urine deposited on pasture. As the urine is usually quickly absorbed into the soil, emissions from pasture are lower than from urine and dung deposited on concrete floors in houses. The amount of ammonia emitted depends very much on the amount of N fertilizer applied to pasture (see figure 5.2). Increasing the amounts of fertilizer-N not only increase grass growth, but also the concentration of N in the grass. This leads to an increase in the amount of N excreted by the grazing cattle. Emissions from grazing cattle in the UK are estimated to be 12 kt of ammonia each year. Total emission largely depends on how long the grazing period lasts. There is some evidence that emissions continue for some days after cattle are removed from a pasture. It is likely, therefore, that overall emissions from grazing will be greater from systems where cattle spend short periods in a series of small paddocks (rotational grazing) than where they are kept in one large field for a relatively long period (set-stocking).

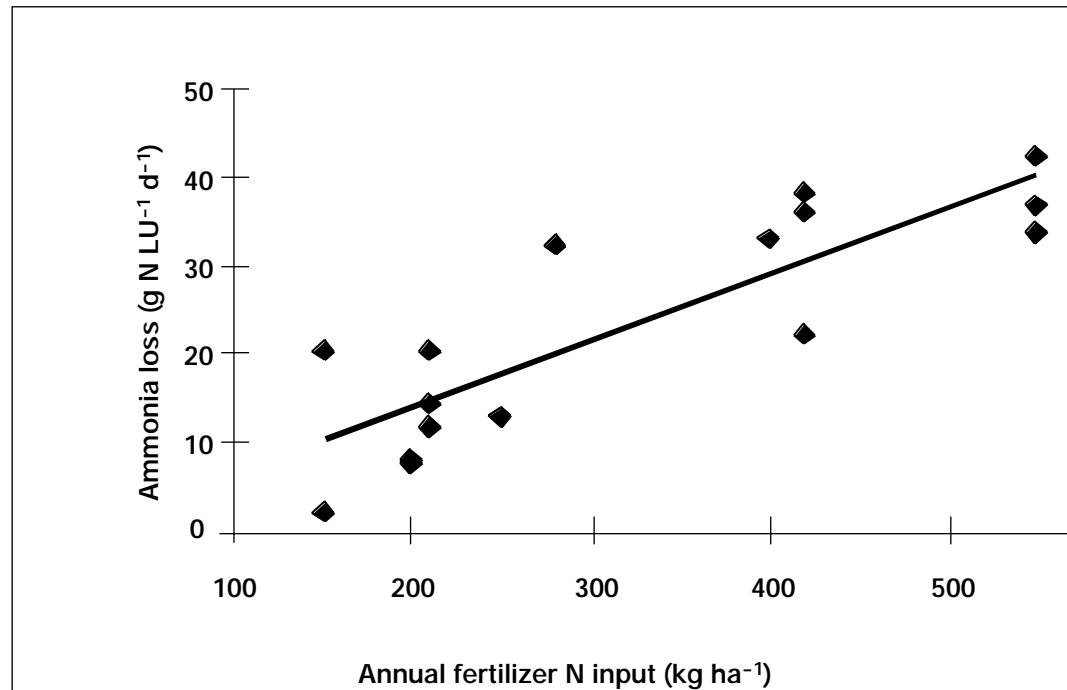


Figure 5.2 Ammonia emission from grazed pastures as affected by fertilizer N input.

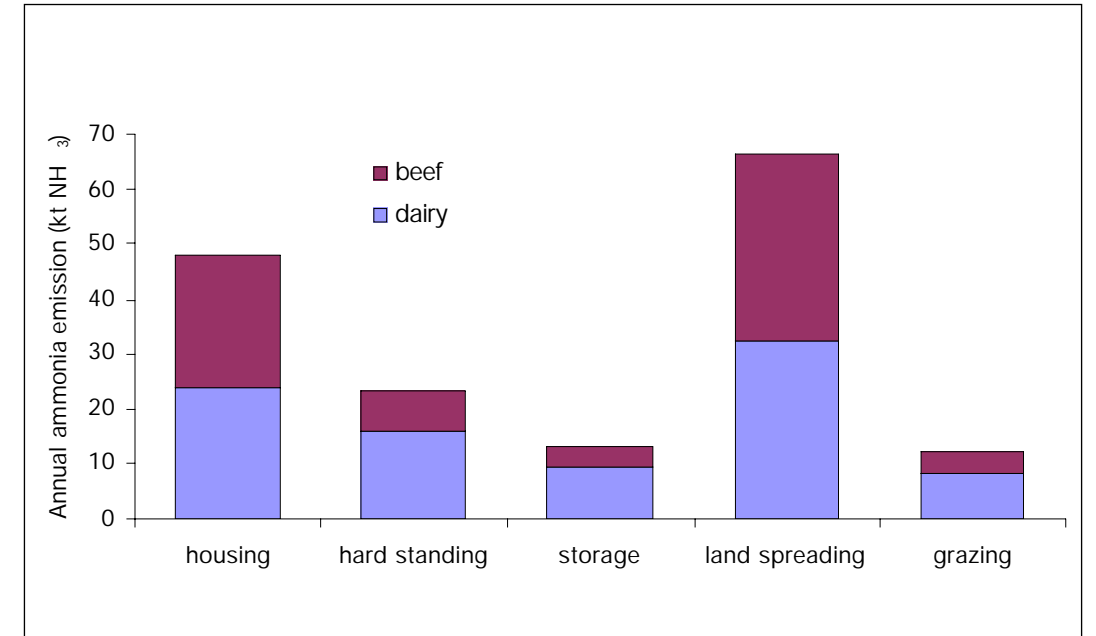


Figure 5.3 Estimates of total ammonia emissions (kt of ammonia each year) from each of the major sources within dairy- and beef-cattle farming in the UK.

Emissions from hard standings

Hard standings are outdoor, unroofed, concrete yard areas and, on cattle farms, they include dairy cow-collecting yards, feeding yards and walkways (Fig 5.4). They are not currently contained in the UK inventory of ammonia emissions, as work continues to refine emission estimates. Hard standings are generally next to livestock housing and are used for moving cattle between buildings or between pasture and buildings, or as purpose-built feeding areas. The use and size of these hard standings vary from farm to farm, with some farms having only limited areas of open concrete to keep the dirty water produced from rainfall to a minimum.

Early estimates of ammonia emissions from cattle hard standings in the UK suggested up to 20 kt of ammonia each year. Emissions are thought to be greatest from feeding yards because animals spend longer on these areas and they tend to be cleaned less often. Tractor-mounted scraping is the commonest cleaning method but this leaves a thin layer of manure from which emissions can continue after scraping. Work will continue to review these emission estimates.



Figure 5.4
Hard standing.

Methods of ammonia abatement

Taking into account what is practical, possible and cost-effective, the two main potential ways to reduce emission from cattle farming are:

- to find other ways to spread slurry on the land; and
- to cover slurry stores.

Methods of ammonia abatement: Research shows that ammonia emission after slurry spreading can be greatly reduced by using injection or band-spreading/trailing shoe machinery instead of the more traditional machines that broadcast slurry all over the field surface. Injection places the slurry into narrow slots within the soil. This increases the contact of the slurry with the soil, where the ammonium-N it contains becomes bound to soil particles, and decreases the surface area from which emission occurs. Band spreading also decreases the surface area by placing slurry in narrow bands on the soil or crop surface.

Trailing shoe machines place the slurry in narrow bands on the soil surface below the leaves and stems of grass swards, so decreasing the surface area and the air flow over the slurry surface. Currently, only about 1% of cattle slurry is injected.

Store covers: Research shows that specially-made covers – fitted to circular,

above-ground tanks and slurry lagoons – reduce ammonia emissions by up to 80% by reducing the air flow over the slurry surface. This method will need some investment, but these covers also have the advantage of keeping rainwater out of the store. This can significantly reduce the amount of slurry to be spread in higher rainfall areas.

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Chapter 6

Ammonia emissions from pig farming

Brian Chambers and John Williams (ADAS) and Roger Phillips (SRI)

Main Points

- Pig farming accounts for about 9% of annual ammonia emissions from the UK and 11% of those from agricultural sources. Housing (64% of pig emissions) and manure spreading (26% of pig emissions) are the largest sources.
- Taking into consideration the whole manure management process from housing to land-spreading, there are no consistent differences in emissions between straw- and slurry-based systems.
- The leading abatement methods are similar to those for cattle farming e.g. rapid incorporation of manures into the soil after spreading or use of band spreader or injection machinery for slurries. Covering of slurry stores (tanks and lagoons) and the storage of solid manures before spreading on land also reduce ammonia emissions.

Introduction

Much of the research on ammonia emissions from pig farms has been conducted in parallel to that on emissions from cattle farms. There are important differences between the way in which cattle and pigs are fed, housed and managed, and in the composition of their manures. These differences impact on ammonia emissions from the two types of livestock and on the potential for abatement.

Annual ammonia emissions from UK pig farms have been estimated at 30 kt, representing 9% of total emissions from the UK and 11% of those from agriculture. Around two-thirds of ammonia emissions from pig farms are from housing (19 kt), a quarter from spreading manures (8 kt) and the remainder from manure storage, hard standings (concrete areas used by pigs around the housing) and from pigs kept outdoors.

Approximately 55% of the pig manure is handled as slurry (i.e. liquid manure), with the remainder managed as solid, straw-based farmyard manure (FYM). Typically, ammonium-N in pig slurry accounts for 60% of the total N, but only 10-25% of that in FYM where most is bound up in organic compounds. The different manure types and amounts of ammonium-N that they contain influence the extent of emissions from housing, storage and spreading on land. The type of manure management system also has implications for potential techniques to reduce emission.

Emissions from housing

Emissions from pig housing are estimated at 19 kt ammonia per year. Ammonia is released almost immediately when urine is voided by animals in the house. Part and fully-slatted floor designs are illustrated in Figure 6.1.

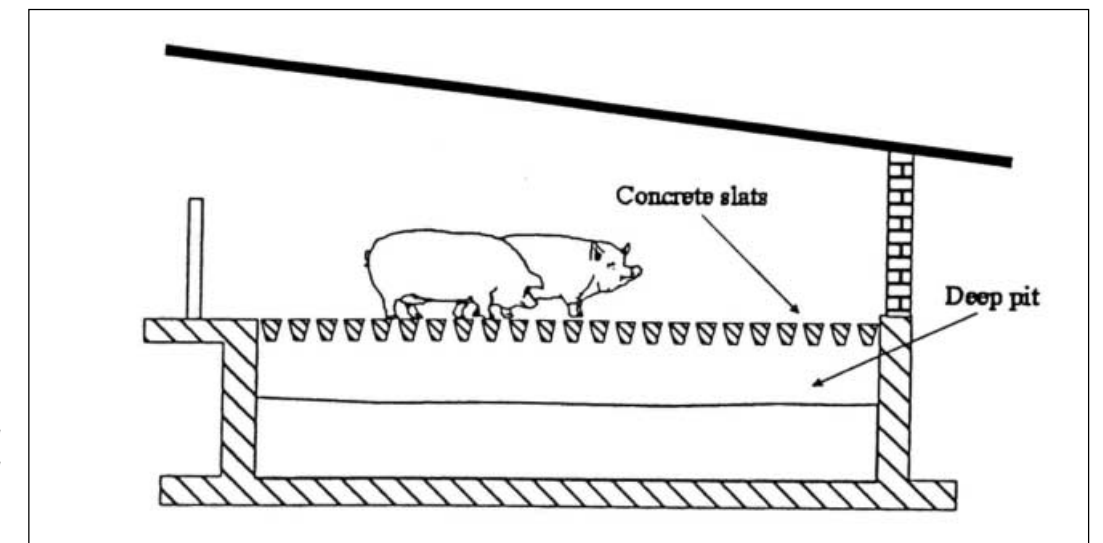
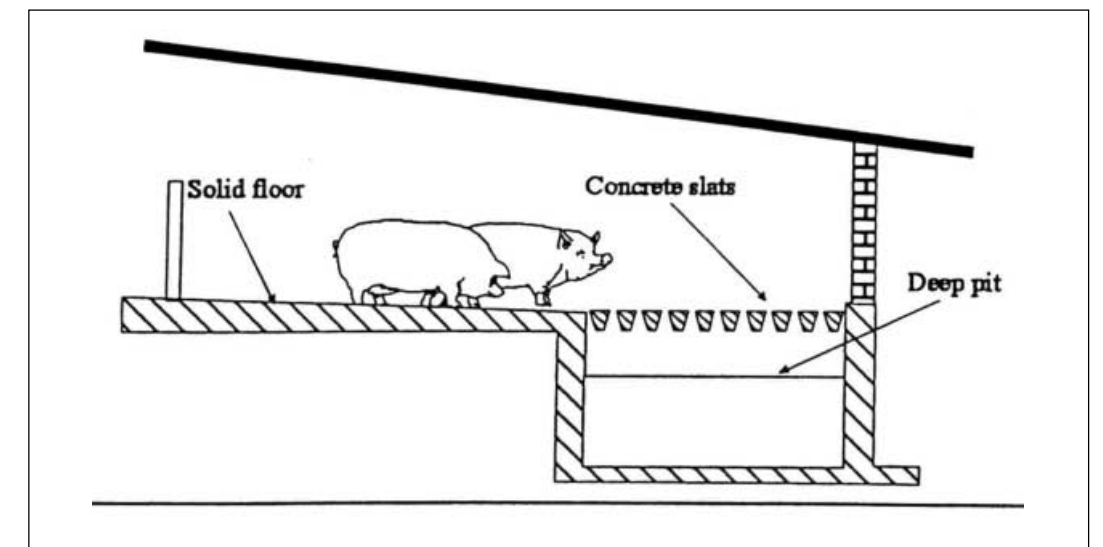


Figure 6.1
Part-slatted
and fully-slatted
housing systems
in the UK.

Measurements from finishing pigs (30-100 kg liveweight) showed that ammonia emissions during housing were around 50% greater from a straw-based than a slurry (fully-slatted) management system. On straw-based systems, dung and urine usually build up on the floor of the house and, therefore, are in close contact with air circulating in the house. On slurry systems, dung and urine fall through the slatted floor to an underground storage tank that acts as a 'barrier' between the ammonia emitting surface of the slurry and the air circulating in the house. These studies indicated that around 40% of N excreted by pigs on the straw-based system and 25% on the slurry system were lost as ammonia during housing. Ammonia losses from part-slatted slurry systems are usually less than from fully-slatted systems because of the non-slatted floor area, that typically covers 50-75% of the pen. Research is underway to evaluate different systems in terms of ammonia emissions, taking into account animal welfare and other aspects of managing pigs.

Emissions from manure storage

Ammonia losses during storage are estimated at 2 kt/year and are mainly influenced by the ammonium-N content of the manure, temperature and surface area of the store.

The most common types of slurry store include above-ground circular tanks, earth-banked lagoons and below-ground tanks, with around 30, 25 and 45%, respectively, of pig slurry in the UK stored in these structures. Ammonia emissions from slurry tanks and lagoons increase with temperature, windspeed, slurry pH and ammonium-N content, as well as the frequency of mixing and the storage period.

Approximately 50% of the FYM collected from pig housing is spread directly to land. The remainder is stored in heaps before spreading, either in the field or on concrete pads. Ammonia losses from pig FYM heaps reach a peak in the first few days after they are made, driven by increased heap temperatures (55-60°C) during 'composting' of the manure, with most of the emissions occurring in the first 30 days of storage. Turning pig FYM heaps to aid the composting process typically increases ammonia emissions by about 50% compared with no turning. Further emission occurs once the heap is broken out for spreading on land, however, since this usually takes only a short time, it should make only a small contribution to overall losses.

Emissions from spreading manures on land

Around 10 million tonnes of pig manure are produced in the UK each year, with a total N content of about 70 kt. Ammonia losses following the spreading of pig FYM and slurry on land have been estimated at 8 kt per year. This is worth almost £2 million in lost fertilizer value.

FYM is spread onto land using rear and side discharge spreaders, principally on arable land in the autumn before sowing cereals and during the autumn-spring period before planting root crops and on grassland. Pig slurry is most commonly spread evenly over fields (i.e. broadcast) with tankers or irrigation machinery, often on arable land in the autumn and on grassland throughout the year. About 4% of pig slurry in the UK is injected 25-30 cm deep into the soil, largely for odour control, using specialised machinery.

For both slurry and FYM spread on the surface, most of the emissions occur in the first few hours and decline progressively thereafter over a period of days. Typically 65% of the ammonium-N content of FYM is lost as ammonia following spreading, though this can range between 30-100%. About 50% of losses occur in the first day after spreading and emissions continue for a further 10 days or so (Figure 6.2). Pig FYM that has not been stored before spreading has a typical ammonium-N content equivalent to 25% of the total N, compared with only 10% for stored FYM. As a result, ammonia losses are greater from 'fresh' FYM.

Ammonia emissions occur more rapidly from pig slurry than from FYM, with typically half of the total emissions occurring in the first 6 hours after spreading and continuing for around 5 days. The dry matter content of slurry has an important influence on ammonia emissions. Emissions increase by about 5% of the ammonium N applied for every 1% increase in slurry dry matter content. Emissions

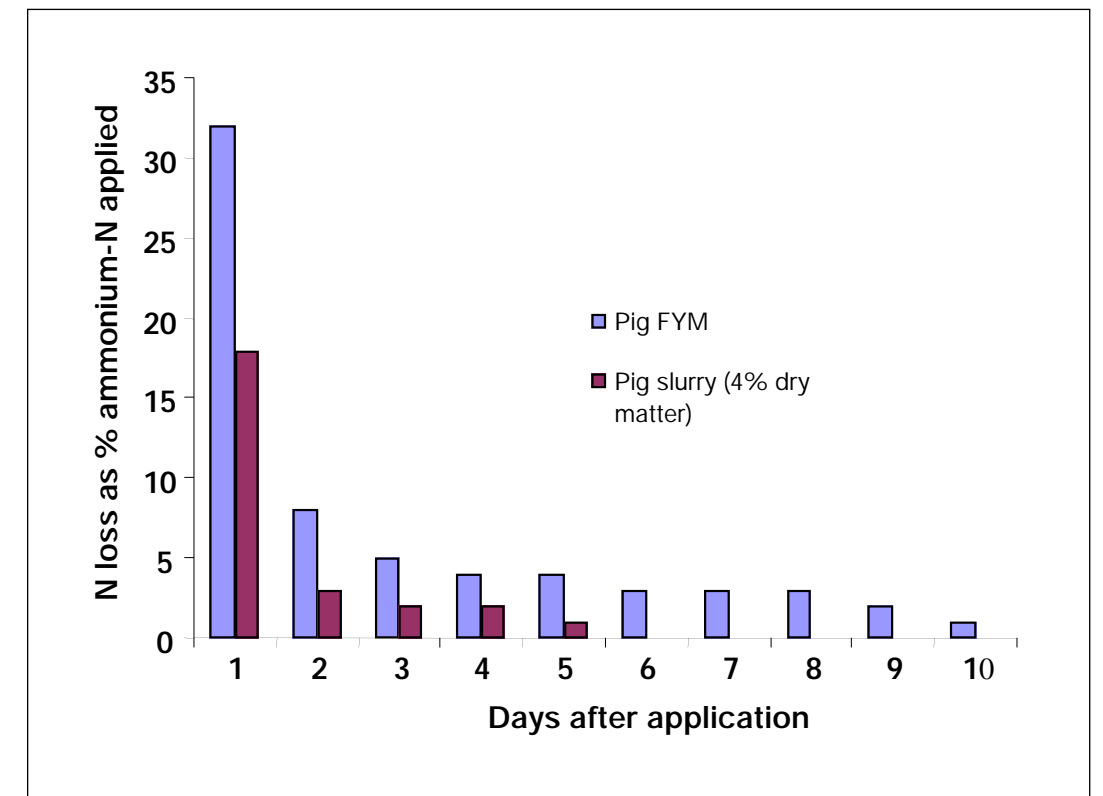


Figure 6.2
Caption needed

are also greater at higher windspeeds and when slurry is spread on to dry soils. Therefore, actual losses can vary between 10-60% of the ammonium-N applied depending on slurry composition, soil and environmental conditions. Typical ammonia losses from pig FYM and slurry are summarised in Table 6.1.

Table 6.1 Typical ammonia emissions after spreading pig manures on land

Manure type (% dry matter)	Nitrogen contents (Kg t ⁻¹) of manure		N loss as ammonia (Kg t ⁻¹)	Ammonia emission factor (i.e. loss as % ammonium-N applied)
	Total	Ammonium-N		
Fresh pig FYM* (25%)	7	1.8	1.2	65%
Old pig FYM* (25%)	7	0.7	0.5	65%
Pig slurry (4%)	4	2.4	0.6	26%

* Fresh FYM has not been stored prior to land application.
Old FYM has been stored for 3 months or more.

Emissions from pigs kept outdoors

Currently, around 25% of the UK breeding herd is kept outdoors, covering approximately 10,000 hectares. Measurements carried out on dry sow paddocks indicate that ammonia losses, largely as result of emissions from urine deposited in the field, are in the region of 1 kt per year, representing around 4% of total emissions from UK pig farms. Ammonia emissions per pig are generally lower for outdoor pigs.



Methods of ammonia abatement

The Integrated Pollution Prevention and Control (IPPC) Directive will apply to pig units with more than 2,000 places for finishing pigs (over 30 kg) or 750 places for sows. The Directive aims to prevent or reduce pollution to achieve a “high level of protection of the environment” and will require the adoption of “best available techniques”. In developing effective ammonia abatement practices, it is important to consider all three stages of manure management together, as reductions in emissions at early stages (i.e. from housing) will impact on emissions at later stages (i.e. from storage and spreading of manures).

As outlined in Chapter 1, decreasing the amount of N excreted by livestock, through improved utilisation of the protein in their diet, is one way of reducing ammonia losses from pig farms. In experiments, feeding a diet containing 70% less N than typical commercial diets, halved ammonia emissions during housing and reduced the ammonium-N content of the slurry by about 30%, without compromising pig performance. Synthetic amino acids were used to formulate the experimental diet. Such diets would be somewhat more expensive than conventional ones.

Presently, research suggests that the most practical and cost-effective methods to reduce emissions focus on the storage and spreading of manures on land, as outlined below:

Storage: Covering slurry stores is an effective method for reducing ammonia emissions and is a requirement for all new storage facilities on installations covered by IPPC. Results from recent research indicate that, in addition to specially engineered covers, potentially cheaper covers such as a floating layer of LECA (light expanded clay aggregate) or UV-stabilized plastic sheets, give a significant reduction in emissions from stored pig slurry. There are also prospects for reducing ammonia emissions by simply storing FYM for a period before spreading on land. Although some emission occurs from the store, this is not as great as that after spreading because some of the ammonium-N becomes incorporated into biomass during storage and so is not lost as ammonia.

Spreading on land: The rapid incorporation of slurry and solid manure into the soil is a simple way of reducing ammonia losses where the manures are spread on bare land. Ploughing pig slurry into the soil within 6 hours of spreading and pig FYM within 24 hours will, typically, halve ammonia emissions compared with leaving the manure on the soil surface. Cultivation using discs and tines is likely to be less effective than ploughing because the manure will not be buried completely. However, these quicker and cheaper cultivation methods may enable more rapid incorporation compared with ploughing.

Recent research has shown that using band spreading machinery (e.g. trailing hose and trailing shoe) (Figure 6.3) to apply slurry to land reduces ammonia emissions by 30-40%, compared with conventional broadcast spreading. Additionally, band spreading machines enable slurry to be applied between the rows of growing arable crops as a topdressing. Research has shown that using shallow injection (to a depth of c.7cm) and deep injection (to a depth of 25-30cm) reduces ammonia emissions by 30-40% and 90%, respectively, compared with conventional broadcast spreading. Trailing shoe and shallow injection techniques reduce the contamination of grass swards intended for silage or grazing. Decreased ammonia emissions from spreading will also increase the fertilizer N value of the manure.



Figure 6.3
Top dressing a crop with pig slurry using a trailing hose boom.

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Chapter 7

Ammonia emissions from poultry farming

Roger Phillips (SRI) and Brian Chambers (ADAS)

Main Points

- Poultry farms account for 14% of the UK's total ammonia emissions and 17% of the total emissions from agricultural sources.
- Livestock housing and manure spreading are the largest sources, each contributing around half the total emissions from poultry farms. The rest of the emissions, from manure stored outdoors, are small because, with poultry, most of the manure is stored within the housing.
- The most effective emission reduction options are:
 - to reduce the nitrogen content of the diet;
 - to keep manure as dry as possible, both in the housing and during outdoor storage; and
 - to mix manure into the soil quickly after spreading on land.

Introduction

Poultry farms account for an estimated 14% of the UK's total ammonia emissions, and 17% of the agricultural total. This represents a loss of 40 kt of plant-available N each year, worth around £12 million.

Emissions from housing

Ammonia emissions from poultry housing depend mainly on how the manure is managed, on how the house is ventilated and, where appropriate, on the amount of litter used on the floors. As explained in Chapter 1, the source of ammonia from poultry excreta is uric acid which, under moist conditions, is quickly broken down to urea and then to ammonium-N from which ammonia is released. Ammonia emissions from poultry buildings, therefore, depend greatly on whether the excreta are kept wet or dry.

A number of different house designs are used in the UK, and they are all either ventilated by fans (mechanically ventilated) or through gaps in the walls and roof (naturally ventilated). Mechanical ventilation is more common. Laying hens are commonly kept in rows of cages, one on top of the other (Figure 7.1). The UK's total population of caged laying hens (28 million) is housed in different systems deep pit (Figure 7.1a), stilt (Figure 7.1b) and belt-scraped (Figure 7.1c). As well as these, there are several million hens in barn systems (which have a central pit for bird droppings and part-slatted, part-litter floor) or that are free-range, with simple housing for them to go in and out of when they choose to.

Figure 7.1a
End view of typical deep pit laying hen house. The A-frame (fully stepped) cage configuration is shown.

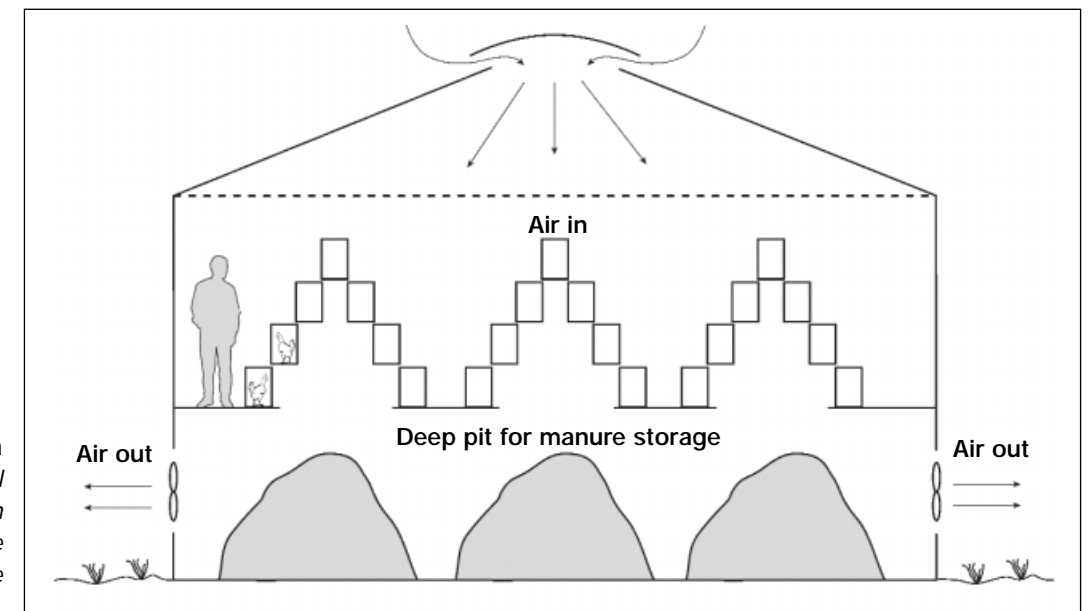
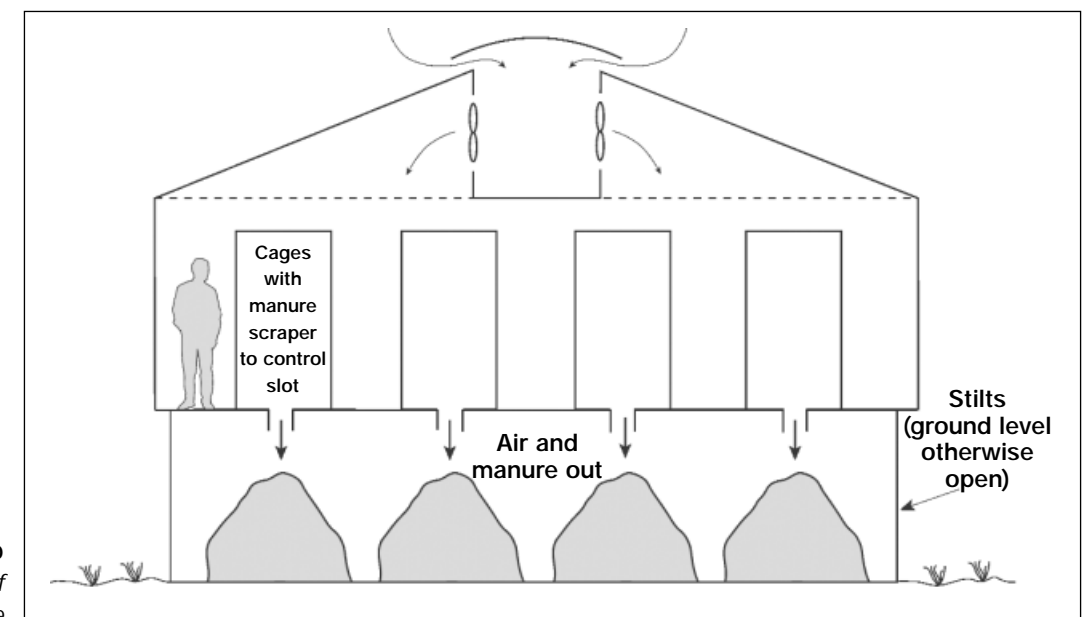


Figure 7.1b
End view of typical stilt house for laying hens.



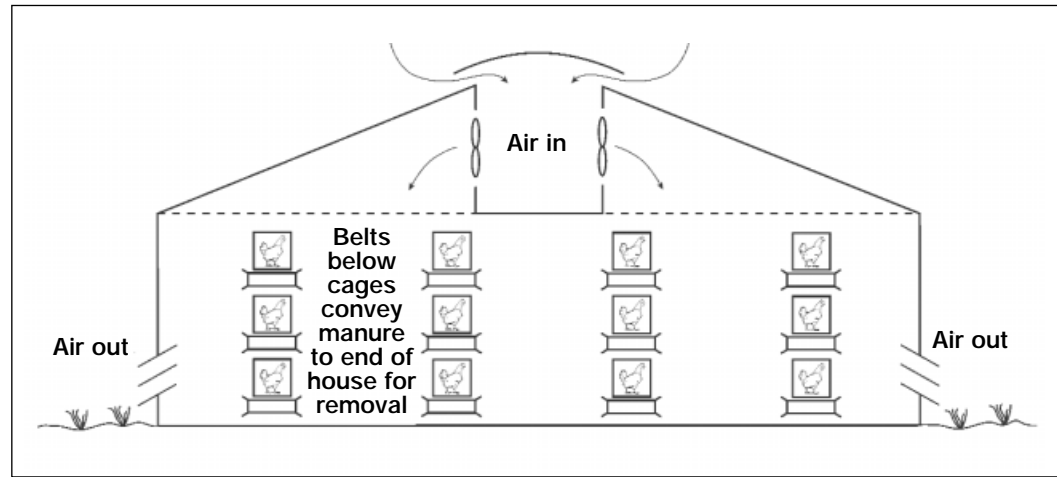


Figure 7.1c
End view of typical caged laying hen house with manure belts.

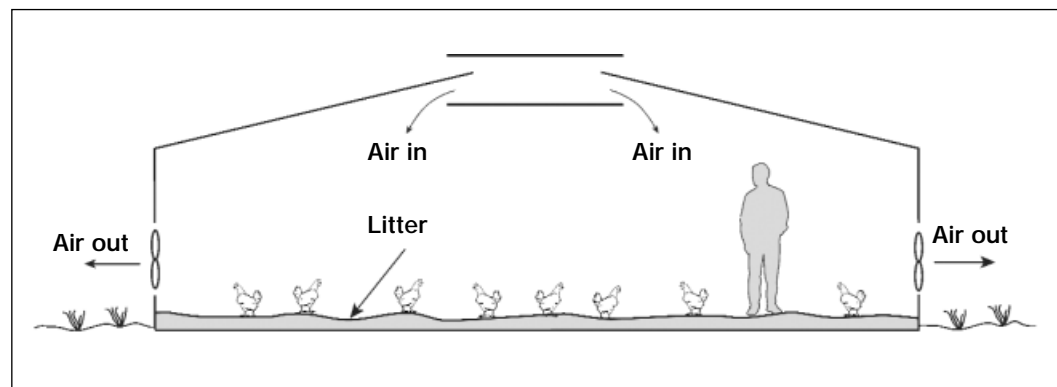


Figure 7.1d
End view of typical broiler chicken house, with ridge inlet ventilation system (this type of house often is also used for turkeys and ducks also).

In deep-pit systems, the birds' droppings are stored in a large pit or tank beneath the cages. Or, the droppings may be collected on a conveyor belt under the cages that removes them from the building. Sometimes, air is blown over the droppings to dry them quickly. In stilt houses, the droppings fall through to a large, open-sided chamber under the house, where the collected manure is dried and stored. Unlike laying hens, most broiler chickens (those reared for their meat rather than eggs) are kept in large, undivided houses with a deep layer of litter (such as sawdust) on the floor (Figure 7.1d). Around two-thirds of UK poultry manure is litter-based and one-third is just droppings.

The type of house and system of manure management both greatly affect ammonia emissions and Table 7.1 gives the average emission rates for the different types. The values are given as an emission factor, which means the weight of ammonia emitted per unit of time and per unit of liveweight housed (liveweight means the weight of the live bird.) Total ammonia emissions from poultry houses are estimated to be 24 kt each year, or half of the total emissions from poultry farms.

Table 7.1 Ammonia emission factors from different housing systems.	
Housing Type	Average emission factor (g NH ₃ 500kg liveweight ⁻¹ h ⁻¹)
Laying hens (in cages with a deep pit*)	6.9
Laying hens (in cages with belt cleaning once a week)	2.9
All birds kept on litter	5.5

* A similar value is likely for free-range laying hens because they produce most of their droppings while they are inside their house.

These emissions make up between 15 and 35% of the total ammonium- and uric acid N in fresh droppings.

Nitrogen content of poultry manure removed from buildings

Each year, around 4,400 kt of poultry manure are produced in the UK, containing about 100 kt of N. When poultry manure is removed from the housing, typical N contents of the two main types of the manure are 16 kg/t (fresh weight) for layer manure and 30 kg/t for litter-based manure. The large ammonium and uric acid-N content of these manures means that there is a high potential for ammonia emission from outdoor storage and after spreading on land.

Emissions from poultry manure stored outdoors

Most ammonia is emitted during the manure's first month in storage, with emissions ranging from 700 g m⁻² of heap surface area for layer manure, and 500 g m⁻² for litter-based manures. It is estimated that a further 50 g m⁻² and 10 g m⁻² respectively will be lost when heaps are broken-out before manures are spread onto land. In the UK, ammonia emissions from poultry manure stored outdoors are estimated to be about 0.3 kt each year. This is only 0.2% of all emissions from poultry farms because, unlike cattle and pig manures, most poultry manure is stored within housing rather than outdoors.

Emissions from spreading poultry manure on land

These emissions are estimated to be 20 kt each year, which is equivalent to 44% of the total from poultry production. Normally, 35% of the N present as ammonium and uric-acid N is lost over a 30-day period after spreading, although measurements showed a range of 15-95%.

Methods of ammonia abatement

The EU Directive on Integrated Pollution Prevention and Control (IPPC) covers poultry premises with more than 40,000 birds. It is estimated that there are 540 of these premises in the UK so the EU Directive makes it important to find practical ways to reduce ammonia emissions from poultry farming.

Feeding methods: Nitrogen excretion by poultry, and therefore their potential for ammonia emission, can be decreased by reducing the protein in their diet. This method could reduce the ammonia losses from housing and from manure storage and spreading.

Housing: Keeping the manure dry prevents the bacteria converting uric acid to ammonium-N. In practice, this can be done in the house by:

- preventing water spillages;
- using drinkers for the birds that do not leak or drip;
- using enough litter to soak up any liquid in droppings; and
- regularly cleaning manure belts to prevent a build-up of droppings.

Manure stored outdoors: As explained previously, it is good practice to keep manure as dry as possible by storing it under a roof, with sheeting over outdoor heaps, and making long, thin, steep-sided heaps that can easily shed rainwater. In some areas of the UK, litter with under 40% moisture content is used as a fuel for electricity generation and, at present, around one-third of all broiler litter is sold for this purpose.

Spreading manures on land: Mixing manures into the soil as quickly as possible after spreading, ideally by ploughing, reduces emissions. This should be done within 24 hours of spreading poultry manures. Cultivation with discs or tines will not mix in the manure as completely, but it is quicker and cheaper.

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Chapter 8

Other livestock: sheep, goats, farmed deer and horses

Steve Jarvis (IGER) and Mark Sutton (CEH)

Main Points

- Ammonia emissions from livestock other than cattle, pigs and poultry are small but significant and are mostly associated with the UK sheep population.
- So far, there have only been limited measurements of these emissions so present estimates are very uncertain, and tend to vary with weather and livestock management conditions.
- Emissions from this livestock group arise mainly from grazing, so opportunities for reducing emissions are mainly limited to restricting nitrogen inputs in feed and minimising livestock densities.

Introduction

Ammonia emission from this livestock group mostly takes place during grazing. There has been little experimental work on measuring emissions from these animals, and what there is relates almost entirely to sheep. The UK inventory assumes that emissions for goats and deer are similar to those for sheep. Apart from horses, these livestock groups spend little time indoors so overall emissions will be relatively small compared with the ammonia emissions from cattle, pigs and poultry manure production. The latest inventory estimate for emission from UK sheep is 18 kt of ammonia a year (of which more than 70% comes from grazing). Goats and deer each produce just less than 1 kt of ammonia each year, and agricultural horses produce just over 3 kt each year.

Emissions from sheep

Sheep are a major feature of the countryside, with about 42 million animals in the UK at present. If we assume that the average volume of urine produced by one sheep each day is 5.7 litres, and that this contains 1.14% N, this represents 1,200 kt of ammonium-N each year being recycled – mostly directly to pastures. As is the case with all urinary-N, this could be volatilized (released as a gas), although the extent of this depends on the nature of the environment in which the sheep are grazing. So, pastures providing feed and forage that contain little N will:

- reduce urinary-N production; and
- be able to recapture more ammonia in the soil system after volatilisation (see Chapter 3 on transport and deposition).

Figure 8.1 shows the large differences in the rates of ammonia emissions from sheep on different pasture. Nitrogen was introduced to these areas in fertilizer or through 'fixation' by clover (fixation is the conversion of the N in the atmosphere to N within the plant). These values are averages for ongoing measurements, made through two grazing seasons.

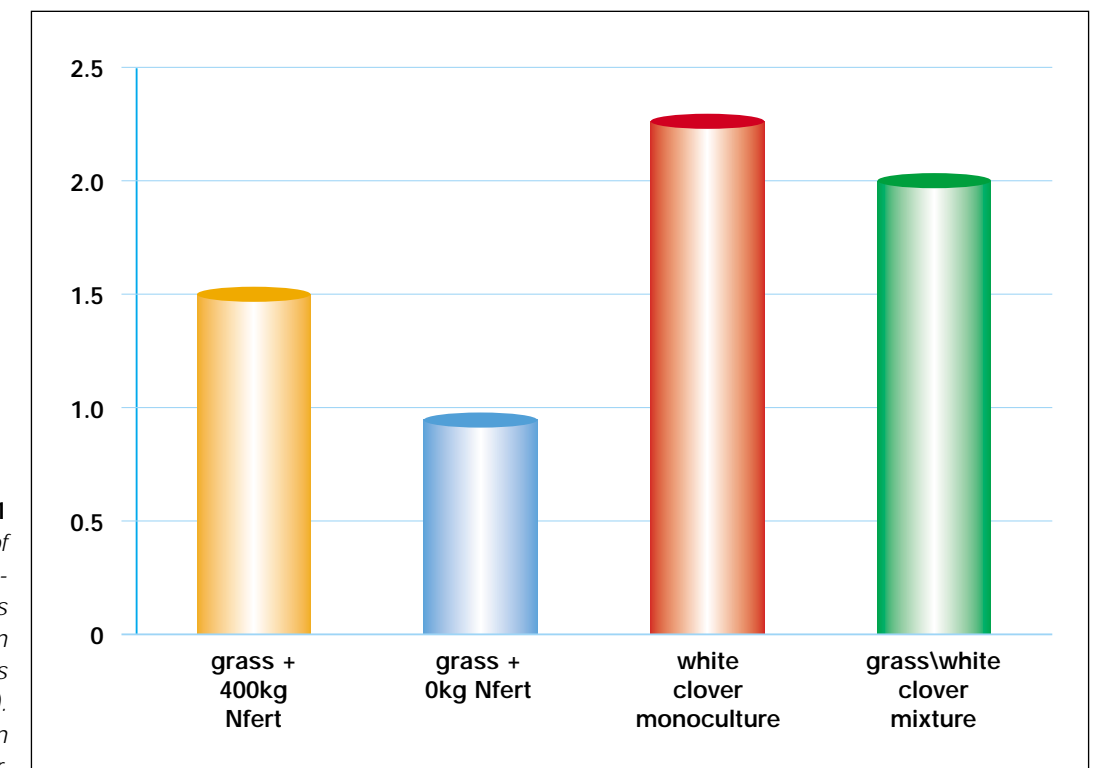


Figure 8.1
Daily emissions of ammonia from sheep-grazed pastures with different nitrogen (N) forms (g NH₃ sheep⁻¹ d⁻¹). Nfert = Nitrogen fertilizer.

A series of short-term experiments under different grazing situations showed the wide range of emissions that are found under different weather and management conditions. Emissions ranged from 0.05 to 3.94 g of ammonia per sheep, per day, for pastures, and up to 4.65 g of ammonia for each sheep, per day, for stubble turnips.

There is a great deal of geographical, and temporal, variation in ammonia emissions from sheep grazing. In most cases, emission is from soil to the atmosphere, but there are some opportunities for the land to absorb ammonia, especially during the winter period. Measurements have shown that after the sheep were removed, emissions always decreased but still continued for significant periods. Sometimes, both during and after grazing, ammonia deposition onto the grass took place. This did not appear to be related to environmental factors (such as windspeed, temperature and rainfall), although there was some evidence that the greater the concentration of N in the grass, the greater the ammonia emission. The lack of observed links to environmental factors may be from the fact that there is only a limited amount of data available.

Ammonia losses from grazing sheep, therefore, depend on the complicated relationships between:

- the grass and its management;
- background atmospheric ammonia concentrations;
- environmental conditions; and
- the grazing patterns of the sheep.

We know little about emissions when flocks are penned or housed. Results from the UK Ammonia Monitoring Network suggest that emissions from sheep may have been underestimated. In addition, the monitoring data in areas with many sheep show much larger ammonia concentrations in the atmosphere in summer than in winter. This suggests that overall ammonia emissions from sheep are largest in summer.

Emissions from other livestock

At present, we do not have enough information to estimate accurately the ammonia emissions from other livestock. Emission levels for sheep may be applied for goats and farmed deer, taking into account differences in body weight, because their diets are similar. There are not many of these animals so even large inaccuracies would not make much impression on the total national emission levels. Horses, however, have an uncertain but possibly significant effect on total emissions. Not only are there large numbers of horses in the UK, but the way their manure is managed will also contribute to emissions, mainly because most of it is composted. Ammonia emissions of 3 kt a

year have been estimated for the horses on farms in the UK (although this is uncertain).

Methods of ammonia abatement

There are few opportunities to reduce emissions from other livestock because most of their time, and often their entire husbandry, is based on grazing. One possible option is to reduce N inputs to sheep swards. However, much of the grassland grazed by sheep is extensively managed, with little or no N input, so the effectiveness of this option would be limited to those animals currently under intensive management. All management practices that:

- minimize the concentration of animals on small areas; and
- reduce 'camping' areas where animals gather;

will also help to reduce ammonia emissions.

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Chapter 9

Emissions from fertilizers and crops

Mark Sutton (CEH) and Roland Harrison (ADAS)

Main Points

- Using nitrogen-containing fertilizers on land accounts for around 11% of the total ammonia emission from UK agriculture and 8% of all UK ammonia emissions.
- Ammonia is emitted directly from the nitrogen fertilizer after spreading, and indirectly through plants.
- It is possible to reduce both direct and indirect emissions through fairly small changes in management such as the timing of fertilizer spreading.
- Since use of urea is a significant source of ammonia minimising its use by carefully controlling use to meet crop requirements or by switching to another fertilizer, such as ammonium nitrate, is one of the cheapest ammonia abatement options.

Introduction

Spreading N-containing fertilizers on land accounts for around 11% of the ammonia emission from UK agriculture. Emissions may come either directly from the fertilizer, or indirectly when some of the N taken up by crops is later emitted to the atmosphere as ammonia. This second effect happens both in the first few weeks after adding the fertilizer, when the growing crops are rich in N, and as plants age when stored N is released, such as during grain-filling of cereals.

The type of fertilizer used has a large influence on direct ammonia emissions, as does the way that the fertilizer is spread on the land. These effects are well established and they allow clear guidance to be given on how to reduce ammonia emissions. On the other hand, indirect ammonia emission from crops is only partly related to fertilizer type, and depends much more on the relationship between:

- plant metabolism (production, growth and so on);

- environmental conditions; and
- management (the type, amount and time of fertilizer application).

To develop ways of reducing indirect ammonia emissions from crops, we need a detailed understanding of these relationships.

Effect of fertilizer type

Direct emission of ammonia from fertilizers depends on the chemical form of N supplied and the way the fertilizer reacts with the crop-soil system. Ammonia gas exists in balance with ammonium-N dissolved in water, and emissions increase with higher temperature and pH.

In the UK, the largest ammonia emissions come from fertilizers containing urea. As a percentage of the N applied, between 5-40% of the N in urea is usually emitted to the atmosphere. By contrast, emission from ammonium nitrate fertilizer is usually only 0.3-3% of the total N applied. Emissions from other fertilizers, such as ammonium sulphate and di-ammonium phosphate, are somewhere between urea and ammonium nitrate, with greater emissions from calcareous (chalk) soils.

Urea produces large emissions of ammonia because it breaks down in the soil and on plant surfaces to form ammonium. This process is accompanied by an increase in pH to over 9 in the vicinity of fertilizer granules. As a result, soil pH does not have much effect on ammonia emissions after urea spreading, because the pH will always be high close to each granule of fertilizer. By contrast, with fertilizers such as ammonium sulphate and di-ammonium phosphate, chemical reactions in the soil do lead to larger ammonia emissions from calcareous soils. Where soil pH is more than 7, emissions from ammonium sulphate may be even greater than those from urea.

Mixing ammonium nitrate with calcium carbonate to form calcium ammonium nitrate, does not appear to increase ammonia emissions. This is because the added calcium carbonate is only slightly soluble and ammonium nitrate is quickly absorbed by the soil. Also, calcium nitrate is highly soluble so this limits the production of carbonate ions (which increase soil pH).

It had been suggested that applying urea dissolved in water might reduce emissions but more recent measurements do not support this suggestion. However, using urease inhibitors can significantly reduce ammonia emissions from urea. Urease inhibitors slow the breakdown of urea, so that the increases in pH are kept to a minimum and more of the ammonium produced is kept within the soil-plant system.

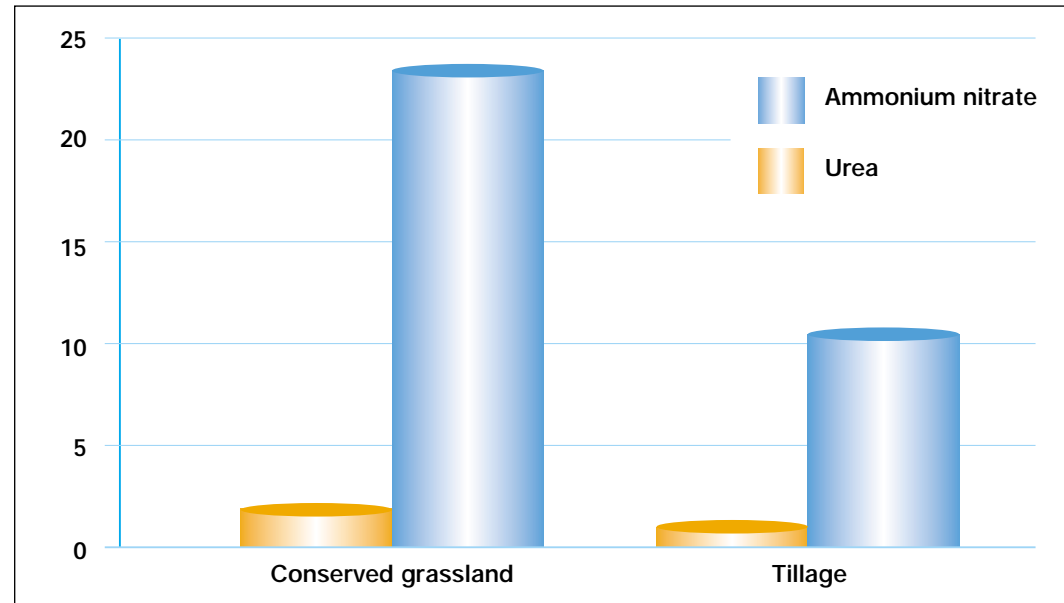


Figure 9.1
Estimated average rates of ammonia emission from ammonium nitrate and urea in the UK. The emission of ammonia is expressed as the percentage loss of the N applied.

The rate of ammonia emission from fertilizers also depends on environmental conditions, which partly explains the large range of estimates found in different experimental studies. In the UK ammonia emission inventory, it is estimated that ammonium nitrate spread on conserved grassland produces emissions equivalent to 1.6% of the N it contains. This can be contrasted with a value of 23% for urea (see Figure 9.1). For ammonium nitrate on arable land, the estimated percentage emission rates are halved as urease activity is much less in arable soils and most of the fertilizer-N applied to seedbeds is incorporated into the soil.

Uptake versus emission of ammonia by crops

It is now known that fertilizer N may be emitted as ammonia indirectly by crops. It is difficult to separate the direct emissions from those through crops. An extra complication is that crops may also absorb ammonia from the atmosphere or recapture emissions from the soil. So, at times the crop-soil system may emit ammonia, and at other times it may absorb ammonia.

Ammonium-N is found naturally in plant fluids and is present in leaves. The concentration of ammonium in the fluids surrounding cells is a major factor in determining plants' ammonia emissions. This concentration depends on the balance of inputs, such as roots absorbing ammonium versus outputs, such as the formation of plant proteins. The concentration of ammonia gas in balance with the ammonium concentration in these plant fluids is known as the '**ammonia compensation point**'. Where the compensation point is higher than the atmospheric concentration, ammonia is emitted from the stomata (pores) of leaves. Where the compensation point is lower than the atmospheric concentration, ammonia is absorbed through stomata. Leaf surfaces are another place where ammonia is absorbed. Also, decaying leaves may emit ammonia as the protein breakdown releases large amounts of ammonium.



Figure 9.2a
Equipment to measure ammonia exchange located over a managed grassland.

Grassland for hay and silage making

Measurements of ammonia exchange (emission and absorption) with grassland managed for hay and silage-making show that emissions following fertilizer application may last several weeks, although the direct emission only lasts a few days. Fertilizer N is taken up by plant roots, which increases the ammonium concentration in leaves. This results in a larger ammonia compensation point and emission from the leaves. Laboratory studies have shown that ammonium-based fertilizers result in greater ammonia emissions from grass than nitrate fertilizers, and suggest a direct transfer of some of the soil ammonium to the leaves.

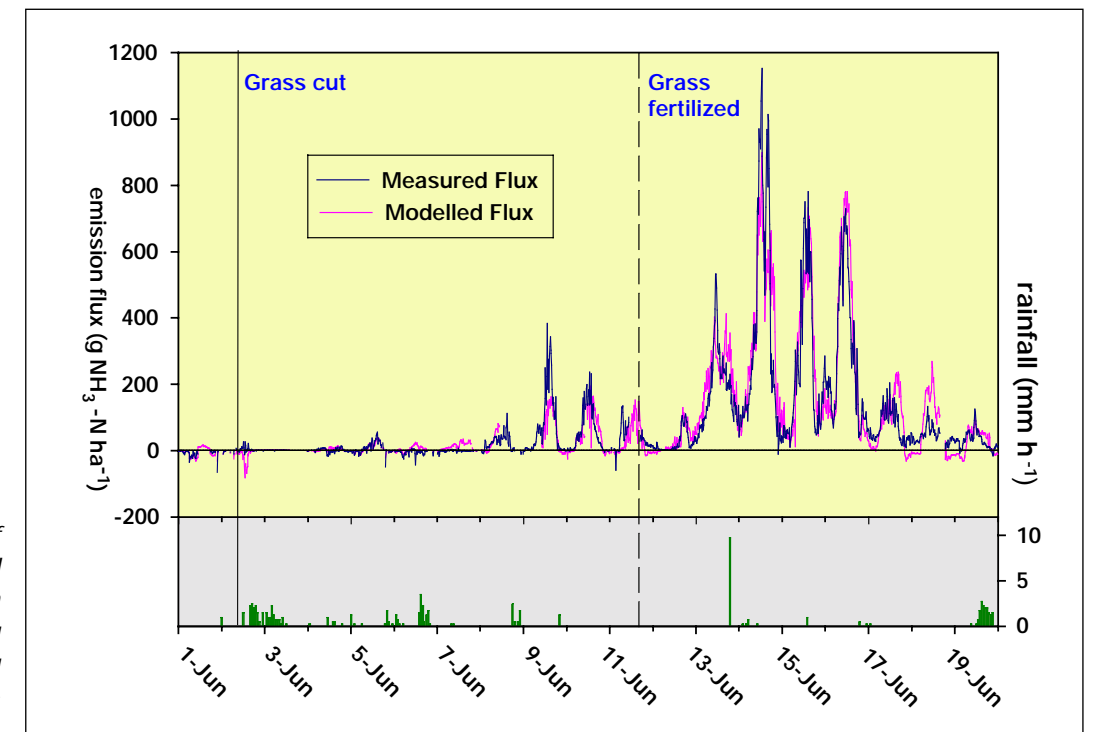


Figure 9.2b
Comparison of measured and modelled ammonia emission following cutting and fertilizing of an intensively-managed grassland.

Recent improvements in measurement methods now allow ammonia fluxes (exchanges) to be measured continuously at a field scale over many months. Figure 9.2b shows how emissions from grassland increased after ammonium nitrate was applied on the evening of 11 June, and lasted for over a week. Emissions did not increase immediately after application but this was probably because of dry weather conditions, as the presence of water increases the mobility of N. Compare this with the very wet conditions the week before, which reduced the initial emissions after the grass was cut because if there is plenty of water, the ammonium stays in solution. The normal increase in ammonia emissions after grass cutting therefore took several days to appear. Most of this emission comes from the re-growing plants, while emissions from cut silage or drying hay are small.

Advances have also been made in describing the ammonia-exchange process using mathematical models. Figure 9.2b also shows the output of such a model, which allows both ammonia emission and deposition to and from plant leaves and the soil surface, and deposition to leaf cuticles. The purpose of the model is to:

- explain the processes that lead to ammonia emission; and
- provide a tool to estimate changes in emission and absorption where no measurements are available.

In the model, the increased emissions following cutting and fertilization are explained by the increased ammonium in leaf tissues, while soil emissions last around four days.

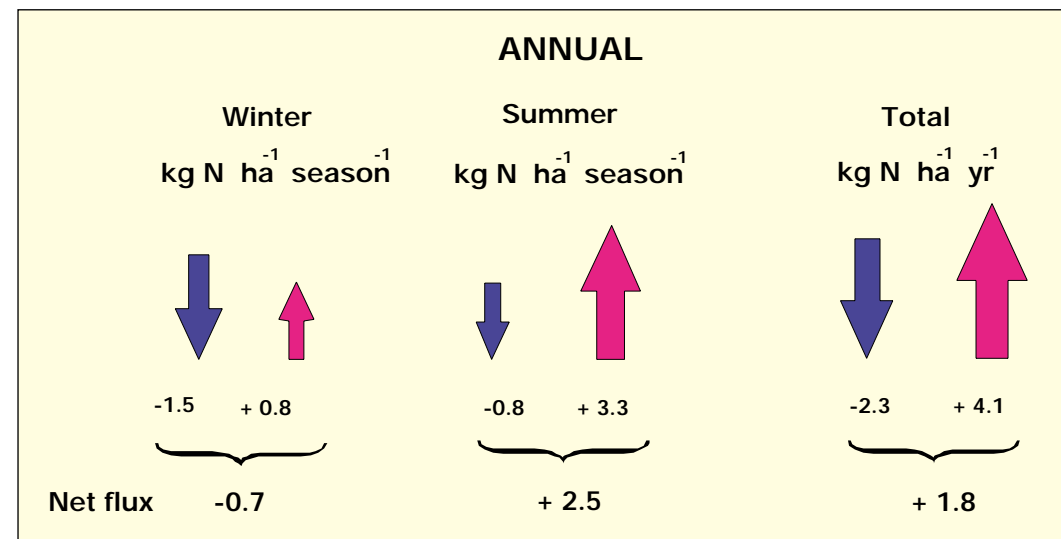


Figure 9.3
Annual level of ammonia exchange with an intensively-managed, conserved grassland. Values are the totals of continuous, half-hourly measurements.

The measurements may be used directly to build up a picture of ammonia exchange with the intensive grassland during the year (see Figure 9.3). By adding up the half-hourly average values, it can be calculated that the grassland emitted 3.3 kg N per hectare (ha) of land of ammonia during summer and absorbed 0.8 kg N per ha

from the atmosphere. During winter, the grassland absorbed 1.5 kg N per ha, but only emitted 0.8 kg N per ha. Over the whole year, the grassland emitted 4.1 kg N per ha, but the net emission was less than half this at 1.8 kg N per ha because of the periods when absorption occurred. These values are small in overall agronomic terms but, because of the large area of grassland, they make a significant contribution to national ammonia emissions. Also, the fact that such grasslands absorb only a small amount of ammonia is important as it means that much more ammonia is available in the atmosphere for deposition onto vulnerable ecosystems of conservation value, such as heath, moorland and forest.

Arable crops

As with grassland, large ammonia emissions occur after young plants emerge from the soil and fertilizer is applied. This is because the ammonia compensation point is large at this stage. As plant growth continues, the available N becomes diluted as more is incorporated into plant proteins, with the result that the compensation point is reduced. For cereal crops, a minimum compensation point is reached at flowering, and during this phase both ammonia emission and deposition occur, depending on plant temperature and background ammonia concentrations.

After flowering, crops start to use N from older leaves for seed growth. This leads to larger ammonia compensation points and net emissions from the canopy. This effect is largely due to the ageing of the older leaves, but there are also signs that high compensation points occur in the reproductive parts. Emissions from ageing leaves happen in many other crops, including potatoes, oilseed rape and other brassica (such as cabbage, turnip and mustard). With oilseed rape, the leaves fall to the ground during ripening of the seed, where they decay and provide a ground-level source of ammonia.

Changes in ammonia exchange above and within an oilseed rape canopy were measured to demonstrate this effect, and these measurements provide a useful case study to show how the canopy recycles ammonia. Figure 9.4 contrasts average daytime and nighttime fluxes (flows). Arrows show the size of individual fluxes. The decaying fallen leaves were a significant source of ammonia during both day and night, but at night most of this emission was re-absorbed by leaf cuticles. During daytime, the high compensation point of the seed cases led to emission from the top part of the canopy, supplemented by some emission from the decaying leaves on the ground. However, most of the emission from decaying leaves is recaptured by deposition within the canopy. The importance of these recycling processes was shown after the canopy was cut. Net emissions of ammonia to the atmosphere increased by more than a factor of 5, as much of the ammonia emission from decaying leaves was recaptured, while greater air flow at the ground surface also increased mixing with the atmosphere.

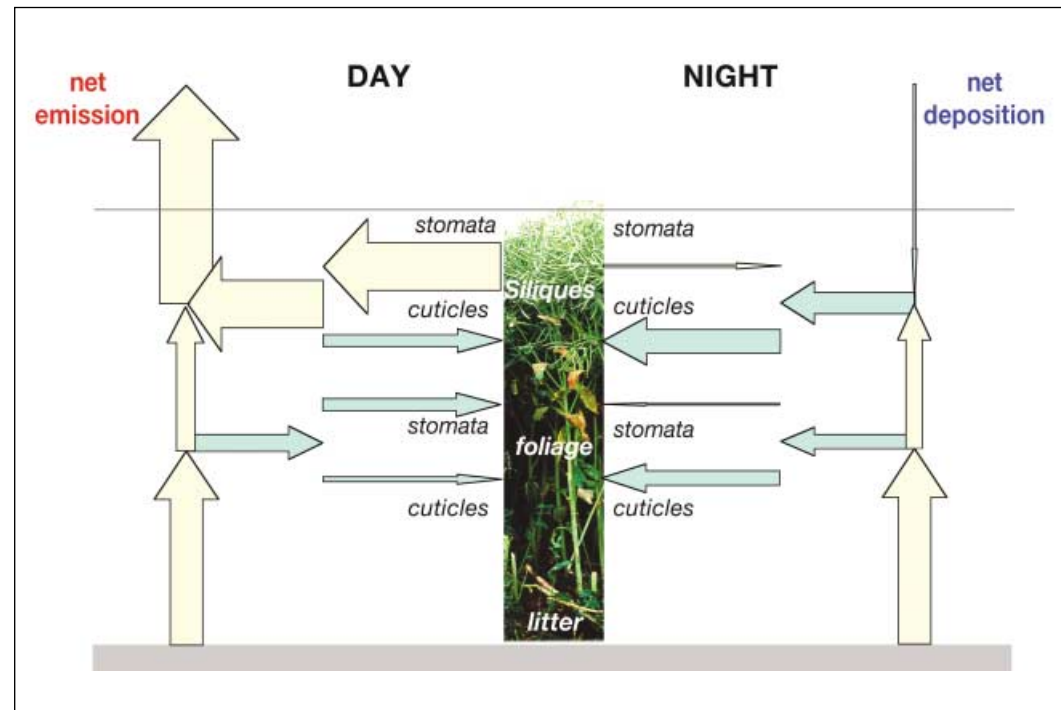


Figure 9.4 Recycling of ammonia within an oil-seed rape canopy.

Methods of ammonia abatement

There is potential to reduce the direct emissions from fertilizers, as well as the indirect emissions from crops. It is easier to estimate the potential to reduce direct fertilizer emissions. Since use of urea is a significant source of ammonia, minimising its use is a cheap option to reduce ammonia emissions, either by controlling use of urea to meet crop requirements or by switching to another fertilizer.

Switching from urea to ammonium nitrate or calcium ammonium nitrate throughout the UK would reduce ammonia emissions by 8.5kt each year.

Other measures include:

- wider use of urease inhibitors, which reduce ammonia emissions from urea by slowing the breakdown processes;
- mixing urea quickly into the soil; and
- not using ammonium sulphate fertilizers on alkaline soils (those with a pH of more than 7).

The potential to reduce the indirect emissions of ammonia from plant canopies is currently much more uncertain. However, studies suggest that emission reductions could be achieved by making rather simple changes to land management practice.

For example, grass takes up little N from the soil in the days after it is cut, and it emits increased amounts of ammonia. Ammonia is also emitted from the N fertilizer added at this time. Simply by delaying when the fertilizer is added may reduce net emission by allowing the plants some time to recover from cutting. Slow-release fertilizers will have similar benefits.

The recycling of ammonia within crop canopies also shows the potential to reduce ammonia emissions. In the same way the ammonia from oil-seed rape litter is recaptured, placing fertilizers or manures under a growing canopy can lead to a significant recapture of ammonia, so reducing net emissions to the atmosphere.

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Chapter 10

Emissions from non-agricultural sources

Mark Sutton and Ulrike Dragosits (CEH)

Main Points

- A wide range of non-agricultural sources contributes to ammonia emissions in the UK, including pets, wild animals, sewage sludge (industrial waste), industrial and combustion processes, and vehicles fitted with catalytic converters.
- In the UK, non-agricultural sources account for around 60 kilotonnes (kt) of ammonia emission each year, but this value is rather uncertain.
- Given the large number of source types, each containing a small amount of ammonia, achieving large reductions in ammonia from non-agricultural sources would require a wide range of different approaches. The source where there is the largest potential to reduce non-agricultural emissions are vehicles fitted with catalytic converters, sewage sludge and industrial processes.

Introduction

Ammonia is a waste product of normal biological-breakdown processes. It is also an important component of many manufactured products. So, while agricultural activities are the main source of ammonia emission to the atmosphere, there are many other sources. Most of these are very small, but added together they account for around 60 kilotonnes (kt) of ammonia each year, or around 20% of the UK's total ammonia emission. Because of the wide variety and small size of these sources, most have not been studied and estimates are rather uncertain.

Emissions from animals and birds

Much of the non-agricultural ammonia is emitted from urine and droppings from animals and birds, in the same process that gives rise to most agricultural emissions. Sources include dogs, cats, horses, wild animals and seabird colonies. Horses produce a large proportion of emissions in this group and account for around 13 kt of ammonia each year, including 3 kt a year from horses registered on

agricultural holdings. Estimates of emissions from pets and wild animals are based on N flow for each animal species, their environment and estimated rates of emission from their excreta. Seabird colonies can emit a large amount of the ammonia in their droppings to the atmosphere. Current studies suggest that a large bird colony may emit more than 5 tonnes of ammonia to the atmosphere in a year, which is a similar amount to that from a large poultry farm.



Figure 10.1
Seabird colonies are now recognized as sources of ammonia.

Emissions from humans

People are also sources of ammonia emissions. The largest sources are sewage treatment and disposal, although estimates here are particularly uncertain. Sewage treatment using anaerobic (oxygen-free) digestion methods form ammonia and so are thought to give rise to larger emissions than other methods. Dumping sewage at sea has now been banned to reduce pollution of the marine environment. This, however, has led to more treated sewage being spread on land, with the result that ammonia emissions from this source have increased. Other sources of ammonia from people include sweating, breathing, smoking and babies' nappies. The most reliably estimated of these is the emission from smoking, which is partly because ammonia is one of the additives in cigarettes.

Emissions from industry

The wide range of industrial sources of ammonia include:

- fertilizer manufacture;
- sugarbeet processing;
- ceramics and cement works; and
- combustion processes.

Although such industries have wide experience in measuring and reducing emissions to the atmosphere the industrial emissions of ammonia are much less certain, and priority has usually been given to other pollutants such as sulphur dioxide and nitrogen oxides. The effects of these industrial pollutants on the environment have been of greater concern so far and reducing emissions the subject of a number of international agreements. Ammonia is included in the Pollution Inventory of the Environment Agency, but it is likely that many sources have not yet been recognized and so are missing from such official inventories.

Emissions from vehicles

Vehicles are a major source of ammonia, which has been recognized in recent years. Increases in the fitting of catalytic converters, designed to reduce emissions of nitrogen oxides, have actually caused ammonia emissions from petrol vehicles to increase from 1 kt in 1990 to about 12 kt in 2000. Emissions depend on engine-combustion conditions and are largest in engines with high petrol consumption.



Figure 10.2
Cars are a more recently recognized source of ammonia.

Methods of ammonia abatement

It is obviously difficult to reduce 'natural' ammonia emissions (such as from the urine or droppings from wild animals and birds). However, humans affect even these emissions. For example, numbers of wild deer are closely managed by man while seabird numbers in the north Atlantic have doubled in the last 50 years because of changes caused by humans. However, most of the non-agricultural emission is from more direct man-made sources. Reducing emissions from non-agricultural sources is complicated by the fact that each source provides a

small fraction of the total emission for this group, so a wide range of approaches would be required to reduce emissions significantly.

Horses are one of the largest sources of 'non-agricultural' ammonia emission, and much of the emission results from the animal's stabling, and how its manure is stored and used. So, the same principles of good manure management that are recommended for agricultural sources could be used to reduce ammonia emissions from horses. Another major source of emission is sewage sludge, arising from the treatment of domestic and industrial waste, that has been spread on land. Already, much of this is injected or mixed into the soil for health reasons, rather than spread on the surface, and an increased use of these approaches would reduce emissions further.

In industry, equipment such as "wet scrubbers" already used in some processes to reduce ammonia emission by dissolving the gas in water. Such methods can give large reduction in ammonia emissions from a given source, but require substantial economic investment. Probably the largest potential for reducing non-agricultural ammonia emissions is from catalytic converters. New designs have the potential for more accurate fuel delivery to the engine, thereby reducing ammonia emission. Overall, current estimates suggest that it is possible to reduce non-agricultural ammonia emissions by around 12 kt in the next 10 years, with most of this due to improvements in vehicle technology.

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Chapter 11

Overview of research on methods for reducing emissions from agriculture

Brian Pain and J Webb (ADAS)

Main Points

- A wide range of possible ways to reduce ammonia emissions has been examined experimentally.
- The focus has been on reducing emissions from the largest sources, in ways that do not increase emissions from other sources on the farm and that are cost-effective, practical and easy to introduce.
- Research suggests that low-emission techniques for spreading manure on land have the greatest potential to reduce ammonia, and are among the most cost-effective. Covering slurry stores may also bring some benefits.
- It is important to consider ammonia emission and reduction within the wider context of using nitrogen in fertilizers and manures to grow crops on farms without causing pollution.
- The most promising methods to reduce emissions must be assessed on commercial farms in the UK, to see how practical they are, how much they benefit the environment and how much they cost. Some farms are already taking part in pilot studies.

Introduction

We have assessed a number of emission reduction options from the significant DEFRA research programme on ammonia. The main focus of this programme is on developing and assessing ways of reducing emissions from manures produced by livestock. This is because manures are not only the major source of ammonia emission, but are potentially the easiest source to reduce. Reducing ammonia emissions from manures has the added benefit of using the N that they contain more efficiently as a fertilizer for crop production.

Of the large number of methods that have been examined experimentally, table 11.1 lists the methods which current research suggests are likely to be effective in reducing ammonia emissions.

Table 11.1 Leading methods of ammonia abatement. The reduction in emissions are quoted against a reference of broadcast application.

Source	Abatement technique	Reduction in emission (%)	Applicability
Slurry storage	Cover store:		Mainly for above-ground, circular stores of steel or concrete.
	Engineered roof	70 – 90	
	Floating sheet	60	
	Floating crust	35 – 50	
Slurry application to land	Low emission application machinery:		Depending on soil type and conditions, topography, cropping limit.
	Injection		
	- deep	70 – 90	
	- shallow	50 – 90	
	Band spreader		
	- trailing hose	10 – 50	
	- trailing shoe	40 – 70	
Solid manure storage	Keep as dry as possible		Mainly for poultry.
Solid manure application to land	Incorporate into the soil, preferably by ploughing.	20 – 90	Arable land and grass leys.

* research ongoing.

Methods for reducing ammonia emissions from livestock housing

The largest emissions of ammonia come from:

- buildings that house livestock; and
- spreading of manures on land.

Research has been carried out by several of DEFRA's contractors on a variety of ways to reduce emissions from housing, particularly for pigs and poultry. For farms covered by the integrated Pollution Prevention and Control Directive, there are requirements to minimize ammonia emissions from new large housing for pigs or poultry.

Poultry

Minimizing the moisture content of manure can reduce emissions. This can be done by:

- preventing water spillage from the birds' drinkers;
- regularly cleaning conveyor belts (which remove the droppings); and
- blowing air over the manure to dry it quickly.

Pigs

In pig housing, floor design can help to reduce emissions. So far, there are no reliable and effective methods for reducing emissions from cattle housing, which tend to be ventilated naturally through gaps in the walls and roof. However, for loose-housed cattle (those kept in sheds with a deep layer of straw bedding covering the whole floor area), using more straw may reduce ammonia emissions from the building. The straw absorbs the ammonia, which means there will not be any increase in emissions from manure storage or spreading. Methods for reducing emissions from pig and poultry houses, that are commonly by mechanical means (such as extractor fans), has proved so far to be either expensive or impractical in existing houses.

Methods for reducing ammonia emissions from manure stores

Emissions from stored manure depend on the surface area of manure in contact with the air. Fitting specially made covers is an effective way of reducing ammonia emissions from slurry stores. The ammonia concentration in the air beneath the cover remains high because there is no flow of air across the slurry surface. This prevents more of the ammonia dissolved in the slurry being released as a gas and emitted from the store. Such covers are made from sheet steel or concrete and are best suited to above-ground, circular tanks. Using a slurry store cover can also have the benefit of keeping rainfall off the store, a particular advantage in high rainfall areas. Less rainfall on the store means less volume of slurry to spread on the land and could give farmers more opportunity to spread the manure at times of the year where ammonia emissions will be lower (such as in spring to a growing crop). Although it is possible, there are some practical difficulties in fitting a cover to a 'lagoon' type of store, as this has a large, possibly irregular, surface area.

Other methods to reduce ammonia from stored slurry, such as allowing a natural or artificial crust to form on the surface of the stored slurry are not as successful and

are more difficult to manage but cost less. Methods for reducing emissions from stored solid manures, such as farmyard manure FYM, are still being developed but generally involve covering the heaps. Although covering manure stores in the UK will have a much smaller effect than reducing emissions from housing or from spreading manures, it may be important where the store is near to a sensitive habitat.

Methods for reducing ammonia emissions from spreading manures on land

Most slurry and FYM is spread over the whole land surface 'broadcast' (figure 11.1A). Several techniques have been developed to reduce emissions from slurry spreading and these are described in Figure 11.1 A to D, respectively: spreading slurry over the whole land surface (broadcast), using a trailing hose, using a trailing hose, using a trailing shoe by injection.

Figure 11.1
Methods to reduce ammonia emissions after slurry spreading.

A Spreading slurry over the whole land surface ('broadcasting').



B Band spreading by trailing hose.



C Band spreading by trailing shoe.



D Injection, either by shallow, open-slot injection or deep, below-surface injection.



Against a reference of broadcasting.

Injecting the slurry puts it below the soil surface and so increases its contact with the soil. This leads to rapid absorption of ammonia on clay particles and soil organic matter. Depending on the depth of the injection, ammonia emissions may be reduced by up to 90%. However, the method is not practical on stony soils. If slurry is spread in narrow bands (band spreading) rather than over the entire soil or crop surface, this reduces emissions by decreasing the surface area of slurry exposed to the air. There are two machines for band spreading, which can minimize ammonia emissions by up to 70%: trailing hose, that places the slurry in bands, and trailing shoe that parts the crop canopy and places the slurry in bands on the soil beneath. On grassland, greater emission reductions can be achieved by using a trailing shoe machine because the grass leaves and stems above the slurry decrease the surface area, and the air flow over the slurry surface.

Emissions from slurries and solid manures are greatest immediately after spreading. Mixing solid FYM or slurry into cultivated land, preferably by ploughing, can reduce emissions by up to 90%, if it is done within a few hours of spreading. However, the longer this mixing is delayed, the less effective it becomes (see Figure 6.2). In practice, the plough should follow behind the manure spreader wherever possible, but emission reductions are still possible if manures and slurries are mixed in within 24 hours of spreading.

The spreading techniques described above are among the most cost-effective emission reduction methods. They also make sure that ammonia retained in the manure at an early stage of management (for instance, by covering the manure store) will not be emitted later when the manure is spread on land.

Other methods

A large number of additional methods have been investigated and are summarized in Table 11.2. Some methods have been tested in experiments and found to be unreliable or ineffective at reducing ammonia emissions. There are several methods that do show potential, but more work is required to develop the technique or quantify the cost effectiveness in reducing ammonia emissions.

Nutrient N input, which is over and above the needs of growing crops and livestock production, can be lost from the farming system in the form of 'diffuse' or widespread pollution. Taking steps to minimise the amount of surplus N within the farming system can help to reduce losses of N in the form of ammonia or other pollutants. These steps may include:

- reducing the protein in livestock diets, which in turn reduces the amount of N in their manure; and
- balancing the amounts of N used in both mineral fertilizers and manures to the requirements of the crop.

Table 11.2 Additional methods for ammonia abatement, and findings from DEFRA research to date.

Method	Mode of Action	Disadvantages
All stages of manure management.		
<i>Reduce crude protein in livestock diet.</i>	<i>Reduces amount of N excreted and hence potential for ammonia emission.</i>	<i>More research needed.</i>
<i>Use extra straw for bedding cattle.</i>	<i>Locks up ammonia.</i>	<i>Research ongoing.</i>
Livestock housing.		
<i>Modify design of livestock housing.</i>	<i>Reduces time and area of slurry exposed to air.</i>	<i>Mainly for pigs. More research needed. Difficult for existing houses.</i>
<i>Equip livestock houses with air scrubbers or filters.</i>	<i>Removes ammonia from air ventilated from houses.</i>	<i>Only for mechanically ventilated houses. Very expensive.</i>
Manure storage.		
<i>Cover surface of store with straw, plastic sheet, clay granules, oil etc.</i>	<i>Physical barrier to ammonia emission.</i>	<i>Can be unreliable. Granules or straw may block pumps etc.</i>
<i>Additives (eg zeolites)</i>	<i>Various. Physically lock up ammonia or form stable chemical compounds.</i>	<i>Large quantities needed, not reliable. Many commercially available products not tested independently.</i>
Spreading manures on land.		
<i>Dilute slurry with water.</i>	<i>Speeds up infiltration into the soil.</i>	<i>Effectiveness varies with soil conditions. Increases volume of slurry to be managed.</i>
<i>Add acid to slurry.</i>	<i>Lowers pH and so ammonia stays in solution.</i>	<i>Hazardous. May increase other emissions e.g. nitrous oxide, a greenhouse gas.</i>
<i>Remove proportion of solids from slurry with a mechanical separating machine.</i>	<i>More free-flowing liquid infiltrates into the soil more rapidly.</i>	<i>Specialist machinery required and there are ammonia emissions from the remaining solid material.</i>
<i>Irrigate with water after spreading slurry.</i>	<i>Washes slurry into the soil.</i>	<i>Needs large amounts of water and may cause run-off to surface waters.</i>
<i>Choose optimum time.</i>	<i>Cool, humid weather discourages ammonia release; rain washes slurry into the soil.</i>	<i>Difficult to quantify effectiveness. May cause odour problems.</i>
Nitrogen fertilizers.		
<i>Match fertilizer use to crop need. Switch to another fertilizer, such as, ammonium nitrate.</i>	<i>Urea is one of fertilizers with highest ammonia emissions.</i>	<i>Controlling its use can reduce emissions.</i>

Changing the livestock diet to convert as much N as possible in feeds to meat and milk appears to be the best solution to the loss of nutrient N, and so reduce diffuse pollution, because it tackles the problem at source. The animals excrete less N, so there is less possibility of ammonia emission from the whole manure-management system. It is sensible to make sure that protein, and therefore N, in the livestock diet is matched as closely as possible to the animals' needs at various stages of their growth. Although progress has been made, it is currently not easy to balance the need to achieve an acceptable level of animal production and farm profitability with less N in the diet, especially for dairy cows. More research is being proposed to address these issues, however, it is sensible to make sure that protein, and therefore N, in the livestock diet is matched as closely as possible to the animals' needs at various stages of their growth.

Among the other options for reducing ammonia emissions is, when using urea, to match the amount of urea and the timing of application to meet the requirements of the growing crop, or more effectively still, to switch to a different fertilizer with lower emission, such as ammonium nitrate.

Similarly, not spreading the N fertilizer until a few days after cutting grass (to make silage or hay) could reduce ammonia emissions from the crop, as suggested in Chapter 9. A similar benefit might be expected from slow release fertilizers. These methods do not require specialised machinery and could be very cost-effective, however, research is at an early stage.

At the local level, planting a belt of trees around poultry or pig houses could offer some protection from ammonia emissions nearby sensitive habitats. Good husbandry, for example keeping floors and walkways clean, and avoiding spillages should also bring small benefits in reducing ammonia emissions.

International research

The development and assessment of methods for reducing ammonia in the UK has taken full advantage of research in other countries, particularly those in Europe. Research on ammonia emission reduction has a longer history in countries such as the Netherlands and Denmark, where the environmental effects have been recognised earlier than in the UK. However, it is well established that there are significant differences between the UK and other countries in livestock management, soil types, climate, economics and so on. It follows that these differences affect how efficient, practical and easily introduced the emission reduction techniques might be. For example, although injecting slurry to below 15 cm is known to be a very effective emission reduction method, about 40% of UK soils are too stony for this method and some land is too steep for the machinery. So, we need to collect data under specific UK conditions to tackle these differences, and to make sure that the information is relevant to our farming community. Such data will come from experimentation, monitoring and modelling, which will involve laboratory, field and farm-scale studies. Alongside this work, improvements in how ammonia is measured outdoors in field scale experiments have greatly improved the accuracy of the data obtained.

Practicalities on farms

Until recently, our knowledge and experience of ammonia abatement was based on research done under experimental conditions. However, priorities and circumstances are likely to be very different on commercial farms and this will not only affect the efficiency and practicality of the technique, but will also have wider implications for manure management on the farm. As part of a DEFRA funded research project, dairy, beef, pig and poultry farmers were asked to 'pilot' the use of injectors, band spreaders and slurry store covers over three years. Manure contractors were also included because the relatively high cost of the injectors and band-spreaders could mean that more farmers use such contractors. The project is providing valuable information on the advantages and disadvantages of abatement methods on commercial farms, and on the true costs. For example, farmers have found that using shallow injectors has improved grass production by spreading slurry at the right time to grazing paddocks without the risk of cattle refusing to eat the grass. Covering stores has greatly reduced the amount of slurry in high rainfall areas. Covers may be a more cost-effective option than first thought because of the savings in slurry-spreading costs. On a less positive note, some farmers have found it impossible to get onto the land with heavy injection or band-spreading machinery during wet springs. However, the problem may not be widespread because new machines can have large flotation tyres so should be more versatile and less damaging on wet land than some more conventional manure spreaders.

Further reading

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Misselbrook T H, Chadwick D R, Pain B F and Headon D M (1998). Dietary manipulation as a means of reducing N losses and methane emissions and improving N uptake following application of pig slurry to grassland. *Journal of Agricultural Science*, Cambridge 130, 183-191.

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Annex 1

DEFRA inventory of annual ammonia emissions in the UK for 2000

Source of Ammonia	Ammonia emission (kt)
CATTLE	
Grazing	12.1
Housing	47.9
Storage	13.0
Land spreading	66.6
PIGS	
Outdoor pigs	1.1
Housing	19.1
Storage	1.9
Land spreading	7.7
POULTRY	
Outdoor poultry	1.5
Housing	23.6
Storage	0.3
Land Spreading	20.1
OTHER LIVESTOCK (including sheep, deer, goats)	
Grazing in the uplands	3.2
Grazing in the lowlands	11.4
Housing	1.8
Storage	0.07
Land Spreading	1.54
OTHER AGRICULTURAL SOURCES	
HORSES (on farms)	3.8
GRASSLAND	11.7
TILLAGE OF CROPS	14.6
BIOMASS BURNING	1.9

NON-AGRICULTURAL SOURCES	
ELECTRICITY GENERATION	0.03
RESIDENTIAL AND COMMERCIAL COMBUSTION	2.9
INDUSTRIAL COMBUSTION (CEMENT)	0.19
PRODUCTION PROCESSES	
Manufacture of coke and smokeless fuels	0.13
Fertiliser production	1.55
Non-agricultural fertilizers	0.28
Other chemical industry	1.14
Sugar beet processing	0.95
HOUSEHOLD PRODUCTS	1.14
ROAD TRANSPORT	
Cars	11.84
Other vehicles	0.41
WASTE TREATMENT	
Land fill	4.82
Sewage sludge incineration	0.02
Sewage treatment and spreading	6.10
HORSES (not on farms)	9.3
DOMESTIC CATS & DOGS	6.1
WILD BIRDS	4.2
OTHER WILD ANIMALS	2.2
CIGARETTE SMOKING	0.32
HUMAN BREATH & SWEAT	1.23
NAPPIES	0.06
TOTAL	320

The upper limit for annual ammonia emissions, to be achieved from 2010, applies to ‘anthropogenic’ emissions of ammonia (emissions derived from human activity). The ceiling is not applied to natural sources such as wild animals. However, all sources are included in the annual UK inventory, since total emissions are needed in order to assess the effects on the environment.

Annex 2 – Glossary

Glossary of Terms

Acidification: is the decrease in the soil reserves of basic cations (positively-charged ions such as those of calcium and magnesium) as a result of leaching by acids. In streams and lakes, run-off of acidic pollutants (such as nitrate and sulphate) from soils in the catchment (the area of land that provides the source of water for the stream or lake) removes basic cations, which leads to a decrease in the waters' ability to neutralise further acidity. Acidic cations, such as toxic aluminium, can be released into waters that cannot neutralize further acidity.

Ammonium-N: Ammonia is very soluble in water and readily reacts with other substances in the atmosphere to form ammonium (NH₄⁺) compounds

Ammonia gas: Ammonia is mainly emitted to (released into) the atmosphere as a gas (NH₃).

Critical level: is the concentration of a pollutant in the atmosphere, below which vegetation is unlikely to be damaged according to present knowledge.

Critical load: the critical load is the amount of pollutant deposited below which significant harmful effect on specified elements of the environment do not occur, according to current knowledge.

The idea of a critical load was developed to provide a receptor-based system for measuring emission reduction targets for pollutants, in the areas of acidification and nutrient over-enrichment. Critical loads of N for nitrogen **enrichment** have been based on the results of field monitoring experiments, and links between N deposition and changes in vegetation. Critical loads of acidity, which include the contributions from N and S (sulphur), are generally set to limit changes in the chemistry of soil or soil solution so that the biological system is protected. The critical limits have been set to prevent changes in the species present, or changes in the ecosystem

Deposition: Transfer of ammonia or other pollutants from the atmosphere to land

FRAME: the Fine Resolution AMmonia Exchange model has been developed to analyze the fate of ammonia emissions across the UK. The model uses emissions of ammonia, nitrogen oxides and sulphur dioxide to estimate concentrations and deposition at a resolution of 5 km.

Glossary of Terms

Leaching: the washing out of soluble ions and compounds by water draining through the soil.

Nitrogen enrichment: is an increase in nitrogen (N) available to plants above the amount that a given semi-natural plant community needs sometimes referred to as 'eutrophication'.

Particulate ammonium: ammonia gas reacts in the atmosphere to form fine particles containing ammonium (NH₄⁺). As these particles can dissolve in water, they are sometimes called 'aerosol'.

Reduced nitrogen: together, NH₃ and NH₄⁺ are often called 'reduced nitrogen' (NH_x). This can be compared with oxidized nitrogen, which includes nitrogen dioxide and nitrates.

Uric Acid: is the form of nitrogen excreted by poultry and other birds.