LIFE Ammonia

Sustainable milk production through reduction of on-farm ammonia losses

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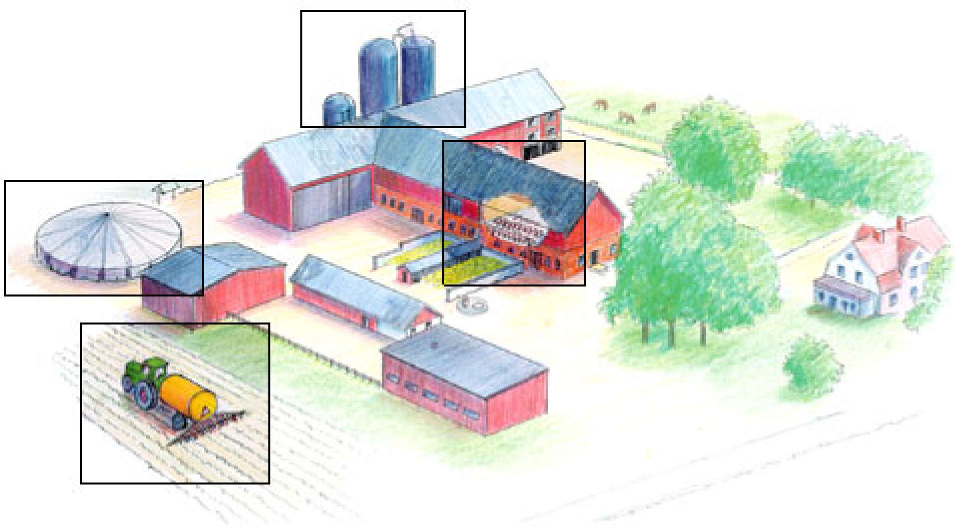
Ammonia is a gas which can cause damage to the environment through eutrophication and acidification of the ground and water. This causes changes in the composition between species in sensitive habitats such as meadows and heaths. Farming causes around nine tenths of ammonia emissions to the atmosphere.



Project objectives were to:

- Demonstrate an effective and innovative combination of techniques to reduce ammonia losses in milk production at farm lavel, by improving stalls, fittings, vantilation, manure handling and management, by adjusting the feeding to minimize ammonia emission from the manure, and by introducing slurry manure which was stored in a roof-covered container and later spread in growing crops, using a band spreading technique and incorporation, or direct ground injection,
- Increase knowledge in this area among farmers, advisers, authorities and agricultural students,
- Create a basis for future policies and legislation.

The project lasted from 1999 to 2004 and was carried out in cooperation with Lantmännen, Arla Foods, DeLaval, Svenska Foder, the Swedish Dairy Association, JTI – Swedish Institute of Agricultural and Environmental Engineering, and the Dept. of Agricultural Biosystems and Technology, SLU. The farm Brogården in Skara, with 40 Swedish Red cows, was used for demonstration purposes. The project was financed through funding from EU LIFE Environment, Swedish Farmers' Foundation for Agricultural Research and the Municipality of Skara. Project Manager was Jan-Olof Sannö.

For further information, please contact Jan Hultgren (jan.hultgren@slu.se).

Ammonia - an environmental threat

Background

Ammonia is a colorless and irritating gas made up of the elements nitrogen and hydrogen in the chemical formula of NH_3. In the wrong place, it can cause environmental harm. The ultimate impact of ammonia on the environment is difficult to predict because it can have both acidifying and eutrophying effects. It becomes a problem in the environment when it is lost to the atmosphere and then deposited on nearby or distant land. Ammonia does not naturally cycle in large quantities through the atmosphere, but as a result of human activities, particularly farming activities, significant quantities now follow this pathway.

The presence of ammonia in the atmosphere is not natural, but a result of human activities. Farming causes 90% of ammonia emissions. Ammonia, which is water soluble, can deposit as rain. In Sweden, the ammonia deposition is about 58 800 tonnes per year (1997). The ammonia deposition affects the environment through eutrophication and acidification of the ground and water. This causes changes in the composition between species in sensitive areas such as meadows and heaths.

The acidifying effects on soil and water take place when ammonia ions are transformed into nitrate by micro-organisms, a so-called nitrification. If the nitrate is not absorbed by plants, and instead reaches the surface or groundwater, the acidifying effects increase.

Handling of manure causes emissions of ammonia. Large emissions take place during spreading of manure. The greatest losses occur when the manure does not have contact with the soil and the climatic conditions are warm, dry and windy.Emissions also take place in the stable and during the storage of manure. Losses also occur when animals are on pasture. The manure may then be spread under conditions when the losses are the greatest. There are several ways to reduce ammonia losses on a farm.

There are also ammonia losses from the crops, especially when harvesting ley. The ammonia emissions from plants depend on several factors such as intensity of fertilising, percentage of clover at harvest and climatic conditions at times of harvest. The use of mineral fertilisers can also cause losses of ammonia, but these are generally small. Looking at the usage of mineral fertilisers, urea causes the greatest losses.

The ammonia accumulating in the atmosphere can be directly absorbed through the stomata in plant leaves, or dissolved in water droplets to form ammonium ion (NH_4+) and deposited in rain, or deposited on soil and plant surfaces as dry deposition. As a gas, ammonia does not remain in the atmosphere for long and is deposited fairly close to its source. This is particularly true for ammonia sources such as urine patches on pasture (Asman, 1997). Ammonia dissolved in water droplets can return to the earth as rain, snow or hail (Bertils and Hanneberg, 1995).

When air-borne ammonia dissolves in water particles, it can form salts with sulphate or nitrate ions, producing compounds such as $(NH_4)_2SO_4$. These compounds can remain airborne for much longer than ammonia itself, and can be transported long distances by the prevailing winds before they are deposited (Berge et al, 1999).

About half of the ammonia deposition in Sweden comes from Swedish sources. The rest is transported to Sweden by winds mainly from Denmark, Germany and Poland. Sweden also exports ammonia. Most of the Swedish ammonia export is deposited in the ocean, but some of it also reaches Finland, Russia and Norway.

Deposition of ammonia is an international problem since a country can only partly affect the deposition within its borders. In Europe there are two international agreements (conventions) which aim at reducing the deposition of ammonia.

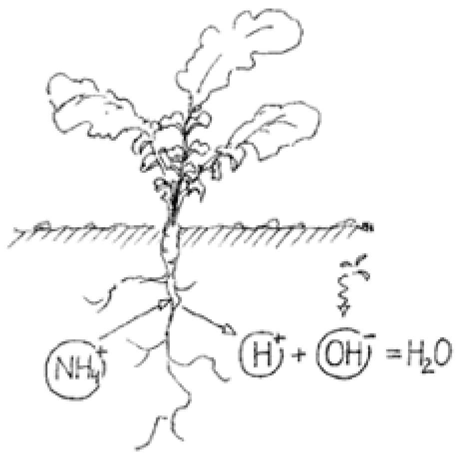
- Acidifying effects
- Eutrophicating effects
- National and international discharge
- Sources of discharge
- Environmental goals in Sweden
- References

Acidifying effects

The chemical reaction between ammonia and water forms an ammonium ion (NH4+) and a hydroxide ion (OH-). The hydroxide ion is alkaline in nature.

$$NH_3 + H_2O \longrightarrow NH_4^+ + OH^-$$

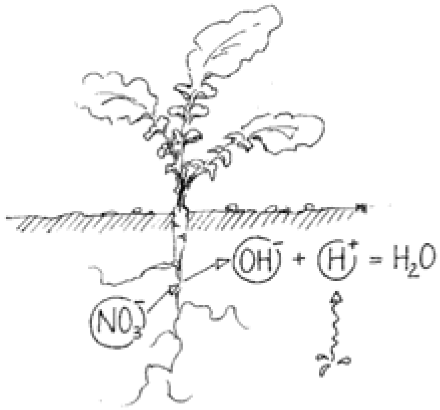
Ammonia is deposited primarily as the ammonium ion NH4+. In the soil, plants absorb the ammonium ion to utilise the nitrogen. As the absorption process involves the release of a hydrogen ion from the plant root, it neutralises the alkaline hydroxide ion and the net acidification is therefore zero.



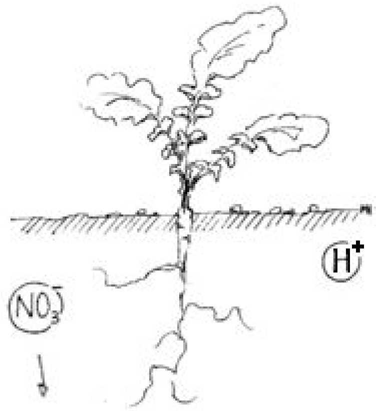
In well aerated (oxygen rich) soil or water, ammonium ions can be transformed into nitrate ions by microorganisms. This reaction is called nitrification in which energy is released and utilised by the microorganisms.

$$NH_4^+ + 2\ O_2 + H_2O \longrightarrow NO_3^- + 2\ H_2O + \mathbf{2\ H^+} + \text{energi}$$

When an ammonium ion is converted to a nitrate ion (that is, nitrified), two hydrogen ions are produced, which are acidic in nature. Nitrate ions formed in this way are either absorbed by plant roots or leached beyond the reach of roots to the ground water. When plants absorb a nitrate ion, a hydroxide or carbonate ion is released from the roots, and neutralises the hydrogen ions produced by the nitrification step. If all nitrate ions are absorbed by plants, the net acidification effect is zero.



If, however, all the nitrate ions are leached, no hydrogen ions are neutralised and the net acidification is one hydrogen ion.

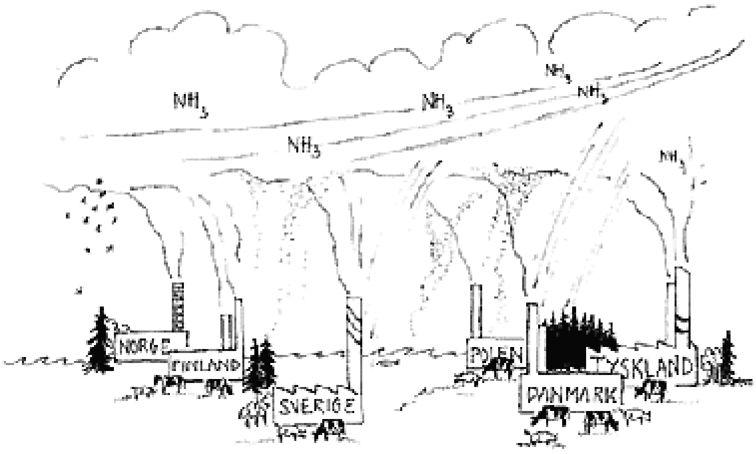


Thus, the potential for the ammonium ion to acidify the soil is dependent on whether it or the nitrate ion is absorbed by plants or leached to the ground water. The total acidifying effect is therefore 0 to 1 hydrogen ions per ammonium molecule.

If the ammonium ion is deposited in water, the same chemical reactions as in the soil take place, but usually a larger proportion is nitrified and less is taken up by plants, with an end result of a greater acidifying effect (The Swedish Board of Agriculture, 1999).

Acidification involves the leaching of nutrients from the surface layers of soil. To varying degrees, the weathering of soil minerals can counteract this process. And yet the net effect is probably only to slow the rate of acidification. For example, the Swedish Environmental Protection Agency (1995) has estimated that the concentrations of available nutrients in forest soils have decreased by 50 % over the last 50 years. In some soils, for instance in coniferous forests, the weathering process is slower and these soils are less able to counteract the acidification process. As a soil acidifies, pH values decline and toxic metals like aluminium come into solution. Excess levels of soluble aluminium can slow the growth rates of microorganisms, plants and animals.

The acidification of soils leads to the acidification of surrounding lakes and watercourses. In acidic waters, fewer species of mussels, water plants and fish persist, which is a major problem in Sweden, such that about Swedish 14 000 lakes and rivers are now regularly limed.


NH3
NH3
NH3
NH3
NH3
NH3
NORGE
FINLAND
SVERIGE
POLEN
DANMARK
TYSKLAND

Eutrophicating effects

In natural systems, nitrogen is commonly in short supply and is the key nutrient that limits plant growth. When nutrients, particularly nitrogen, accumulate in natural systems such as water bodies, they stimulate excessive growth of water plants, which in turn depletes the oxygen levels in the water. The net result is massive plant death and eutrophication of the water body.

Some plants species can scavenge the nitrogen better than others, and when the soil nitrogen availability increase these species can out-compete other species. An increased level of nitrogen in the soil can markedly change the composition of species.

Eutrophication of forestland, heathlands and bogs are primarily caused by large depositions of nitrogen as ammonia. Poor soils have less capacity to retain the additional nitrogen and are at risk of exceeding the "critical load" for nitrogen. When this critical limit is reached, soil profiles become "saturated" with nitrogen, and the excess is leached into lakes and watercourses. In Sweden, the deposition of nitrogen exceeds the critical load for forest land in the whole southern region of Sweden to a borderline between Gävle and Värmland (The Swedish Environmental Protection Agency 1999a). Additionally, the increased leaching of nitrogen from these soils accelerates their acidification rates (The Swedish Board of Agriculture, 1999).

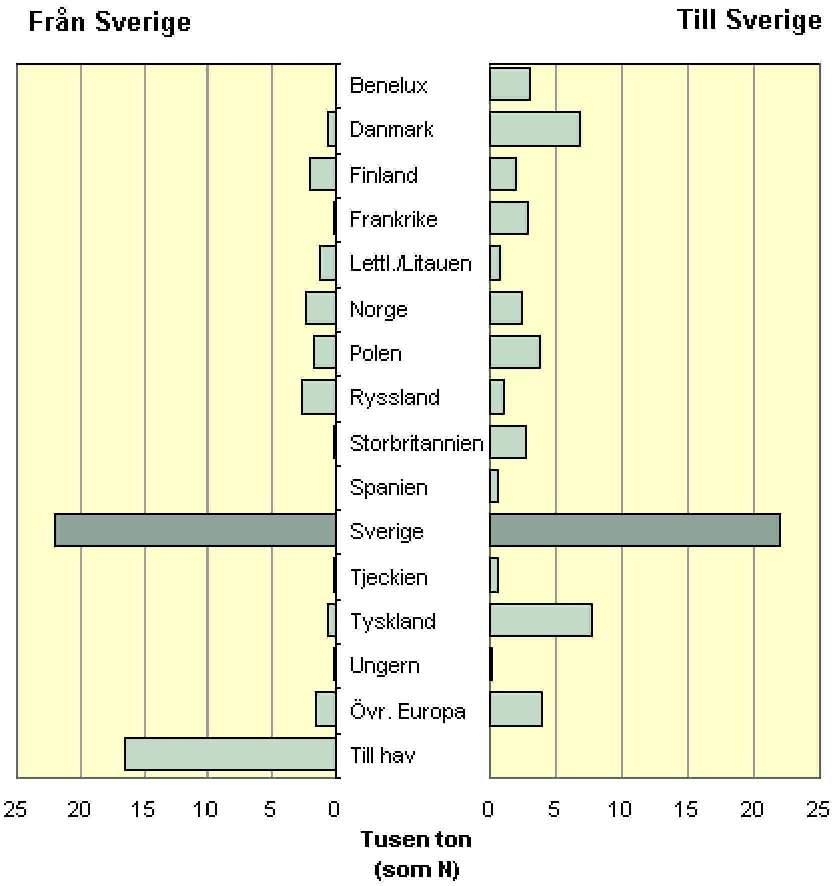
Rates of nitrogen deposition and "critical loads" for nitrogen on forest land in southern, central and northern Sweden (The Swedish Environmental Protection Agency).

Area	Nitrogen deposition rates in 1995 (kg/ha/year)	*Critical load for nitrogen on forest land* (kg /ha/year)
South west southern Sweden	9-18	3-5
North east southern Sweden	6-9	3-5
Central Sweden	3-5	2,5-4
Northern Sweden	1-3	1,5-4

In total, the deposition of nitrogen is estimated to exceed the critical load for eutrophication on 30% of the land area of Europe (Berge et al., 1999).

National and international discharge

The sources of deposited ammonia can be quite localized, with almost half of the ammonia deposited on Sweden originating from within Sweden (The Swedish Environmental Protection Agency, 1999 a). Ammonia can however remain airborne for several days and depending on the prevailing winds can be transported far from its source of origin. A large proportion of the ammonia deposited in Sweden originates from outside the country, even though about 40% of Swedish emissions are deposited beyond its borders.



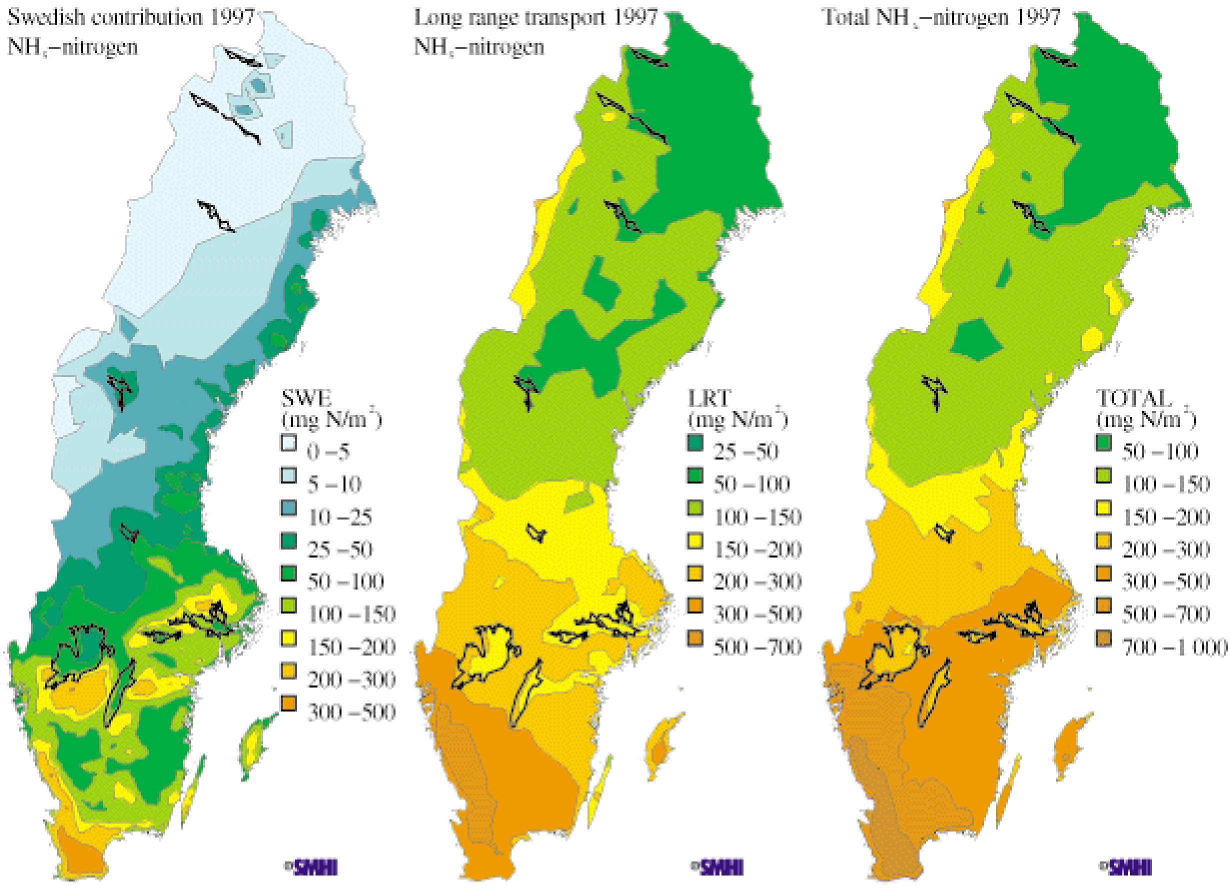
Sources of ammonia deposited in Sweden, and destinations of Swedish sources of ammonia 1997 (Swedish Environmental Protection Agency).

In Sweden, between 0.5 and 10kg nitrogen/ha as ammonia was deposited in 1997 (SMHI). The rates of nitrogen deposited in Holland are among the highest in Europe (40 kg/ha/yr) and included nitrogen oxides, as well as ammonia which contributes about 60% of the total nitrogen (Eerden, Vries och Dobben, 1998). In Holland, ambitious programs to reduce nitrogen emissions have been in place for several years.

The maps below show the rates of ammonia deposition in milligrams per square metre per year (mg/m2/yr), which is the same as kilograms per square kilometre per year (kg/km2/yr). To convert either of these units to kilograms per hectare per year (kg/ha/yr), divide the values by 100.

The emission and deposition of ammonia is an international problem, as only a proportion of any air-borne ammonia is deposited close to its source. Ammonia emissions are therefore regulated through a number of international conventions.

It is possible that some ammonia is blown between continents. Prediction from a computer model used by EMEP (European Monitoring and Evaluation Program) suggest, for example, that the Arctic receives a small amount of ammonia. Even though the amounts deposited are relatively small, it is predicted that environmentally sensitive areas in the Arctic could be detrimentally affected in the long-term (Galperin och Sofiev, 1998).

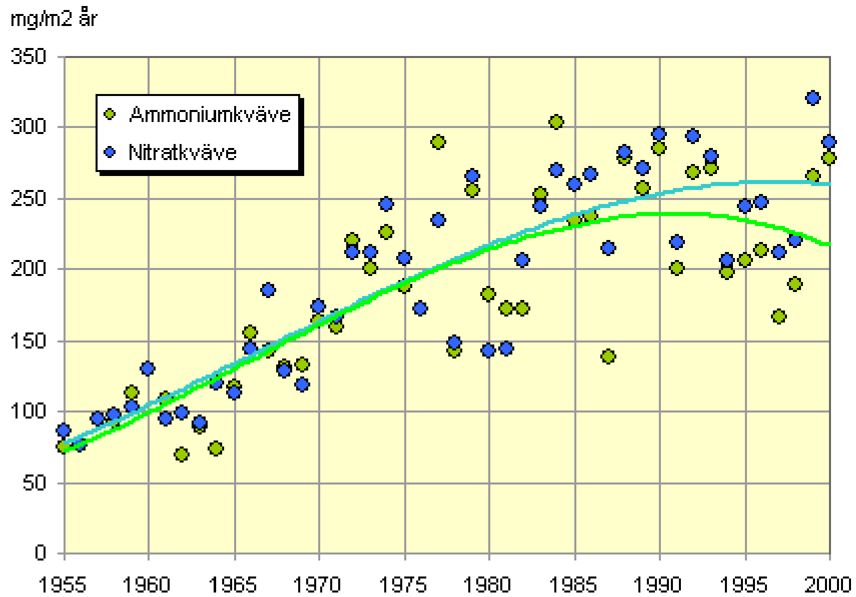


Deposition of ammonia in Sweden 1997 from Swedish sources, from foreign sources and totally (SMHI, 2000).

Ammonia - an environmental threat

Sources of discharge

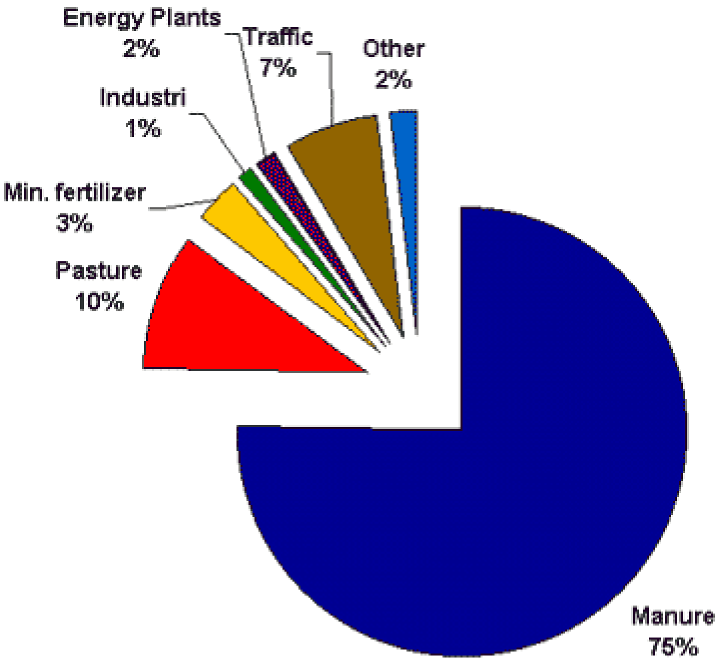
In 1997, an estimated 58,800 tons of ammonia came from Swedish sources (SCB, 1999); these sources include farming, forestry, industry, domestic and wild animals, sludge and land-fill materials, motor vehicles, etc (SCB, 1999). While the total amount of ammonia lost from these sources has slowly decreased, emissions from traffic are expected to increase in coming years because of the greater use of catalytic converters that produce more ammonia (Sutton et al., 1999). The amounts of ammonia emitted from eastern European countries are likely to increase as agricultural development moves to more-intensive, larger-scale animal farming enterprises. However, across all of Europe, total ammonia emissions have decreased by 15% between 1990 and 1995 (Berge et al., 1999).



Wet ammonia deposition in middle part of Sweden (Swedish Environmental Protection Agency).

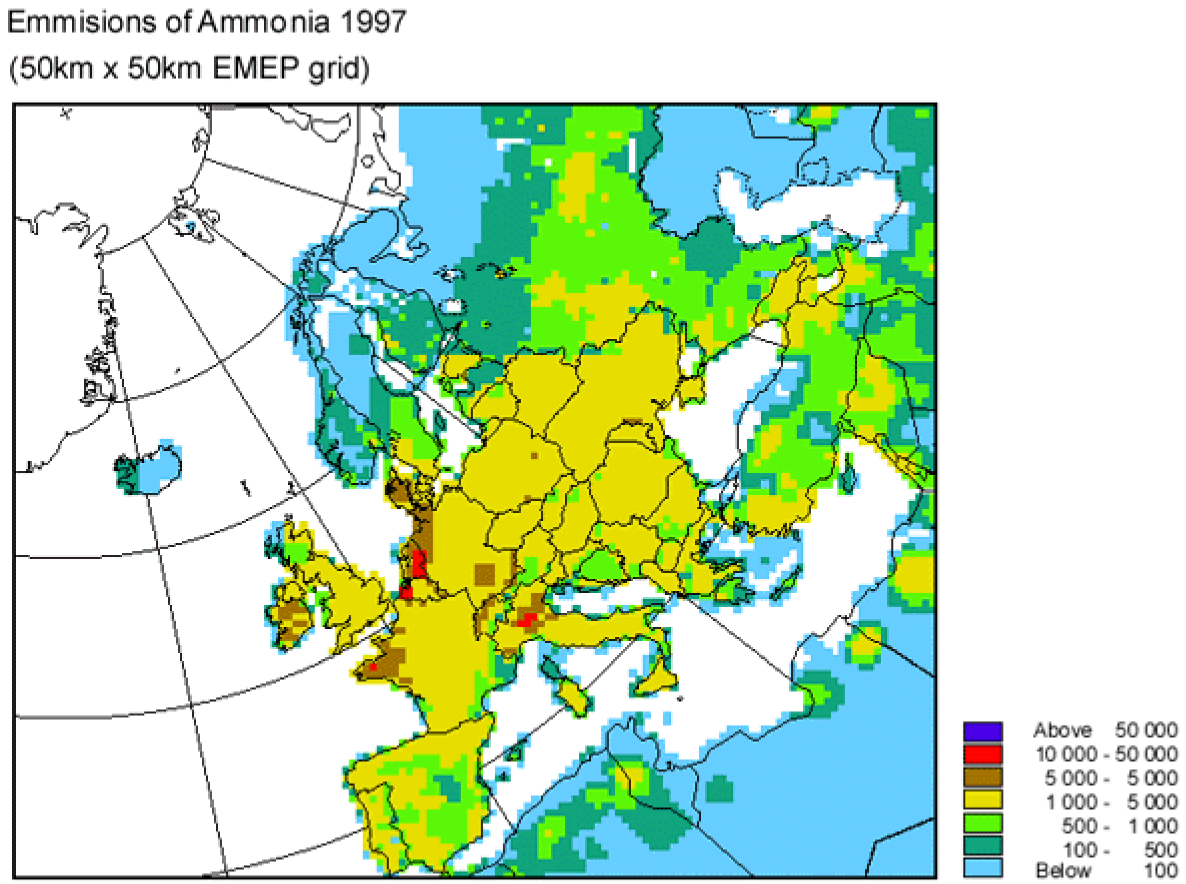
The total amount of ammonia derived from European sources has been estimated from calculations by EMEP, an organisation that seeks international co-operation to resolve and manage the problems of air-borne pollutants crossing national borders. EMEP´s website, provides information on the emission and deposition of several air pollutants, including ammonia, for a number of different European countries.

Farming industries are collectively the single largest source of ammonia emissions representing about 90% of the ammonia emission of both Sweden (SCB, 1999) and Europe (Hoek, 1998).



Sources of ammonia emissions (% of total) in Sweden 1999 (SCB, 1999).

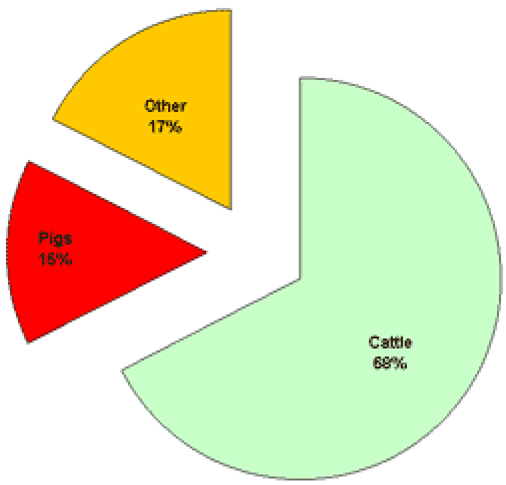
The major source of ammonia lost from farming enterprises is from animal manure. This can occur from manure in the barn, during the storage and spreading of manure, and when animals are at pasture. Significant losses of ammonia occur when manure is handled, particularly in enterprises where animal densities are high.



Ammonia emissions in Europe 1997 (EMEP).

Ammonia losses from livestock

The largest ammonia losses from farming are associated with livestock management. Cattle manure represents the single largest source of ammonia because of the high volumes/animal and the high densities of animals. The greatest losses occur when manure is mechanically spread, although the losses from within the barn and from stored manure are still significant. The greatest losses of ammonia from pig production systems are from within the barn (Pain et al., 1998). The figure shows the distribution of emissions from different animal species (SCB, 1999).



Ammonia losses from livestock farming are influenced by several factors:
1. protein content of the feed,
2. nitrogen content of the manure,
3. species, age and weight of the animals,
4. barn system and the system used to manage and remove manure from the barn,
5. the system used to store the manure (open or covered storage tanker),
6. temperatures in barn and storage tanker,
7. length of time animals spend in the barn and on the pasture, and
8. factors associated with the spreading of the manure.

1. Feeding more protein than is needed for optimum production results in increased urea concentrations in the urine. This urea is often rapidly hydrolysed into ammonia in the soil, increasing the risk of ammonia losses directly from the soil. A Danish study has shown that it was possible to reduce ammonia losses from dairy farms by 55 % without any losses in milk production (Petersen et al. 1998).

7. Ammonia losses from urine patches deposited by livestock held on pasture can vary greatly. Losses ranging from 3 to 52% of the nitrogen in the urine have been reported. Losses from bovine manure deposited in the field are lower, perhaps because of the sealing effect from the manure drying from the outside (Petersen et al. 1998).

8. Ammonia losses from the spreading of manure depend on:

- the condition of the manure (dry matter and nitrogen content, pH value),
- key properties of the soil (pH value, CEC = cat ion exchange capacity, lime and moisture content, porosity and buffering capacity),
- the weather conditions (temperature, wind velocity, humidity, rainfall) at the time of spreading,
- the application or spreading technique,
- the length of time between spreading and incorporating the manure into the soil, and
- the height of the crop or pasture

To calculate the ammonia losses from farming, prescribed standard values must be used. The Swedish Boars of Agriculture has established a data model, STANK, which is uses the following standards to calculate ammonia losses from the barn from the storage and from spreading of manure.

Ammonia losses from different forms of manure of different livestock classes within the barn (% of total nitrogen content of the manure) (STANK, 1999).

Livestock class	**Solid manure**	**Urin**	**Deep litter manure**	**Liquid manure**	**Semi-liquid manure**
Cattle	4	4	20	4	4
Sows	10	10	25	14	10
Weaned pigs/year	10	10	25	14	10
Boars, growing- fattening pigs	10	10	25	14	10
Laying hens	10	0	35	10	10
Pullets	10	0	20	10	10
Broilers	0	0	10	0	0
Horses	4	4	15	0	4
Sheep	4	4	15	0	4

Ammonia losses from different forms of manure storage (% of annual total nitrogen content of the manure, after losses in the barn) (STANK, 1999).

Livestock class	**Solid**	**Semi-liquid**	**Deep-litter**	**Urine**			**Liquid manure, filled from the bottom**				**Liquid manure, filled from the top**			
				Open	Roof	Other cover	Open	Surface crust	Roof	Other cover	Open	Surface crust	Roof	Other cover
Cattle	20	10	30	40	5	10	6	3	1	2	7	4	1	3
Sows	20	10	30	40	5	10	8	3	1	2	9	5	1	3
Weaned pigs/yr	20	10	30	40	5	10	8	3	1	2	9	5	1	3
Boars, growing-fattening pigs	20	10	30	40	5	10	8	3	1	2	9	5	1	3
Laying hens	12	12	20				8	4	1	2	9	5	1	3
Pullets	12	12	20				8	4	1	2	9	5	1	3
Broilers	12	12	5				8	4	1	2	9	5	1	3
Horses	25	20	33	40	5	10								
Sheep	25	20	33	40	5	10								

Ammonia losses following the spreading of manure (% of ammonium content in the manure at the time of spreading) (STANK, 1999).

Time and manner of spreading and incorporation	Solid manure	Urine	Deep litter manure	Liquid manure
Late winter, broadcasting	20	40	20	30
Late winter, row spreading	-	30	-	20
Spring, broadcasting, incorporation within 1 hour	15	8	15	10
Spring, broadcasting, incorporation within 12 hours	50	20	50	20
Spring, broadcasting on ley, no incorporation	70	35	70	40
Spring, row spreading, incorporation within 1 hour	-	7	-	5
Spring, row spreading, incorporation within 12 hours	-	20	-	10
Spring, row spreading on ley, no incorporation	-	25	-	30
Early summer, summer, broadcasting on ley, no incorporation	90	60	90	70
Early summer, summer , row spreading on ley, no incorporation	-	40	-	50
Early summer, summer , row spreading in cereals, no incorporation	-	10	-	7
Early autumn, broadcasting, incorporation within 1 hour	20	15	20	5
Early autumn, broadcasting, incorporation within 12 hours	50	30	50	30
Early autumn, broadcasting, no incorporation	70	45	70	70
Early autumn, row spreading, incorporation within 1 hour	-	10	-	3
Early autumn, row spreading, incorporation within 12 hours	-	25	-	15
Early autumn, row spreading, no incorporation	-	30	-	40
Late autumn, broadcasting, incorporation within 1 hour	10	10	10	5
Late autumn, broadcasting, incorporation within 12 hours	20	20	20	10
Late autumn, broadcasting, no incorporation	30	25	30	30
Late autumn, row spreading, incorporation within 1 hour	-	4	-	3
Late autumn, row spreading, incorporation within 12 hours	-	18	-	5
Late autumn, row spreading, no incorporation	-	25	-	15

The choice of spreading technique can have a critical impact on the ammonia losses, and even when techniques designed to minimise losses are used, ammonia losses can still be substantial due to climatic factors, the nature of manure, etc. Studies carried out by The Swedish Institute of Agricultural Engineering have shown that the amounts of ammonia lost after the manure has been spread can vary between 55 and 100 % of the ammonium-nitrogen in liquid manure, even when it was spread in a way that minimise losses on ley land during the summertime.

In Holland, spreading techniques to minimise ammonia losses have been used for a longer time, but ammonia losses have not been reduced to the extent that was expected. The reason for this unexpected result is not known (Erisman and Monteny, 1998).

Ammonia losses from crops fertilized with nitrogen

The spreading of nitrogenous commercial fertilizers can directly contribute to the ammonia lost to the atmosphere. As well, they can contribute to indirect losses, as more ammonia is lost from well-fertilized crops than from poorly fertilized crops. The amount of ammonia lost from this source is not known but is estimated to be 10 to 20 % of the total ammonia lost from farming (EMEP, 1999).

The ammonia losses from commercial nitrogenous fertilizer are affected by:

1. The type of fertilizer,
2. The soil type (especially the pH-value),
3. The weather conditions at spreading, and
4. The stage of development of the crop at spreading.

The most important factor is the choice of nitrogenous fertilizer. Those containing urea contribute the largest losses, since the urea can be transformed directly into ammonia in the soil. Ammonium sulphate may also contribute to the ammonia losses, particularly on calcareous soils, but these losses are considerably smaller when compared with the losses from urea. No ammonia is directly lost from fertilizers containing nitrate-nitrogen, although crops well fertilized with this fertilizer can indirectly lose ammonia, and the greater the application rates, the greater the losses of ammonia (EMEP, 1999).

Ammonia losses from nitrogenous fertilizers reach a maximum rate within days after spreading, with the exception of urea. During extremely dry conditions, the degradation of urea can take much longer and ammonia losses can occur for more than a month (EMEP, 1999). Urea is estimated to contribute 50% of the ammonia derived from commercial nitrogenous fertilizers in western Europe. The use of combine drilling to apply nitrogenous fertilizer, or mulching once applied reduces ammonia losses to almost negligible levels (EMEP, 1999). To calculate the ammonia lost from applied commercial nitrogenous fertilizers, van der Hoek (1998) and others have suggested the following percentages.

Estimated losses of nitrogen as ammonia from application of commercial nitrogenous fertilizer, including indirect losses from canopy of the crops (Van der Hoek, 1998).

Nitrogenous Fertilizer	Lost as ammonia (% of applied nitrogen)
Ammonium sulphate	8
Ammonium nitrate	2
Calcium ammonium nitrate	2
Liquid ammonia	4
Urea	15
Mono-ammonium-phosphate	2
Di-ammonium-phosphate	5
Other composed NK- and NPK fertilizers	2
Nitrogen solutions (urea mixed with ammonium nitrate)	8

Other sources of ammonia losses from crops can come from the microbial degradation of soil organic matter; the amount is however not known.

It is likely that ammonia also is emitted from cereal plants during the grain-ripening process, although again the extent of these losses is not known. Ammonia may also be lost from a harvested pasture ley, particularly where the green mass remains on the field for some time. The amounts lost via this mechanism are not known as they depend on local variations in weather and temperature (EMEP, 1999). Again the amounts of ammonia lost via this process reflect the levels of fertilizer nitrogen applied to the crop or pasture (EMEP, 1999). The clover content of a ley also affects the magnitude of ammonia losses. Petersen et al. (1998) reported similar ammonia losses from both a moderately fertilized clover/grass ley and a heavily fertilized grass ley.

Ammonia losses from crops grown without nitrogenous fertilizers

Ammonia losses from crops grown without nitrogenous fertilizers are estimated to be very small. However where the crop is a legume, ammonia emissions are estimated to be as high as that from a nitrogen fertilized cereal crop; that is from 0 to 15 kg/ha/yr (EMEP, 1999).

Few measurements of the ammonia losses from clover/grass leys, and from pure clover or grass leys have been reported. It is therefore difficult to draw any general conclusions about the magnitude of these losses. A review of published literature by EMEP (1999) suggested that ammonia losses from leys grown without nitrogenous fertilizers are likely to be of the order of 2 to 15 kg ammonia/ha/yr. Pure clover leys that have not been grown with nitrogenous fertilizers are likely to have slightly higher ammonia emissions than mixed clover/grass leys.

Ammonia - an environmental threat

Environmental goals in Sweden

In April 1999 the Swedish Parliament established 15 national objectives (goals) for environmental quality. These objectives describe the quality of our environment, and the qualities that our common natural and cultural resources must have to be ecologically sustainable. The objectives are defined and explained as targets. Ammonia emissions are included in the objectives ”No Eutrophication” and ”Natural Acidification Only”.

The concept of ”**critical load**” is an essential part of setting benchmarks to establish and achieve environmental goals, both nationally and internationally. A “critical load” is defined as the value at which there are no significant harmful effects on “sensitive elements” in the environment, as defined by the current best knowledge (The Swedish Board of Agriculture, 1999). Obviously critical loads vary with different materials and natural environments. It is difficult to determine the critical load for ammonia since it can have both acidification and eutrophication effects.

Environmental Quality Objective "No eutrophication"

The “No Eutrophication” objective states that ”Nutrient levels in soil and water must not adversely affect human health, the prerequisites for biological diversity or versatile land and water use.”

This environmental quality objective means that:

- Nutrient loads must not adversely affect human health or the conditions for biological diversity.
- Groundwater must not contribute to increase eutrophication of surface waters.
- Lakes and watercourses in forest and mountain areas must remain in their natural nutrient state.
- The nutrient status of lakes and watercourses in agricultural areas is natural, i. e. nutrient-rich or moderately nutrient-rich.
- Nutrient levels in coastal and marine areas should be approximately the same as those in the 1940s, and that the release of any nutrients into these areas must not cause eutrophication.
- The condition of forest and agricultural land is to be managed in such a way that it preserves the natural distribution of species.

It is proposed that the environmental quality objectives shall be achieved within one generation.

The Swedish Environment Protection Agency has as targets proposed, among other things, that the deposition of nitrogen compounds does not exceed the critical loads for eutrophication of soil and water anywhere in Sweden. This implies that:

- the deposition of nitrogen compounds must not exceed the critical loads for forests, bogs, heathlands and lakes in Sweden,
- the deposition of nitrogen compounds must not cause eutrophication of unfertilized meadows and pastures in the agricultural landscape,

by 2010, Swedish emissions of ammonia should have declined by at least 15 % relative to 1995 levels (that is; from 61,000 to 52 000 tonnes per annum). This target will be reviewed in 2005.

Environmental Quality Objective "Natural acidification only"

The objective states that ”The acidifying effects of acid deposition and land use must not exceed limits that can be tolerated by land and water. In addition, deposition of acidifying substances must not accelerate the corrosion of technical materials, cultural artefacts and buildings.”

This environmental quality objective means that:

- The rates of acidification of the soil that exceed the natural rate must be combated to preserve the soils inherent natural capacity to produce, as well as the soil's biodiversity.
- Sweden must ensure that deposition rates of acidifying substances over the long term do not exceed the critical loads for soil and water.

The Swedish Environment Protection Agency has proposed the following targets:

- By 2010, the current rates of increased acidification of forest soil, in areas affected by human activity, to have decreased to zero (that is, back to the natural rates), or even been reversed, so that recovery will have started.
- By 2010, the current rates of increased acidification of forest soil, in areas affected by human activity, to have decreased to zero (that is, back to the natural rates), or even been reversed, so that recovery will have started.
- By 2010, Swedish air emissions of ammonia to have decreased by at least 15 % relative to 1995 levels (from 61,000 to 52 000 tonnes per year).

Land-use practices that increase the natural acidification rates of soil and water are to be modified or managed so that their contributions to acidification processes are neutral.

CLRTAP

The **C**onvention on **L**ong **R**ange **T**ransboundary **A**ir **P**ollution (CLRTP) is the international convention for dealing with air pollutants. It was drafted in 1979 by UN/ECE (United Nation's Economic Commission for Europe) after the link between sulphur emissions in continental Europe and the acidification of Scandinavian lakes had been clearly established.

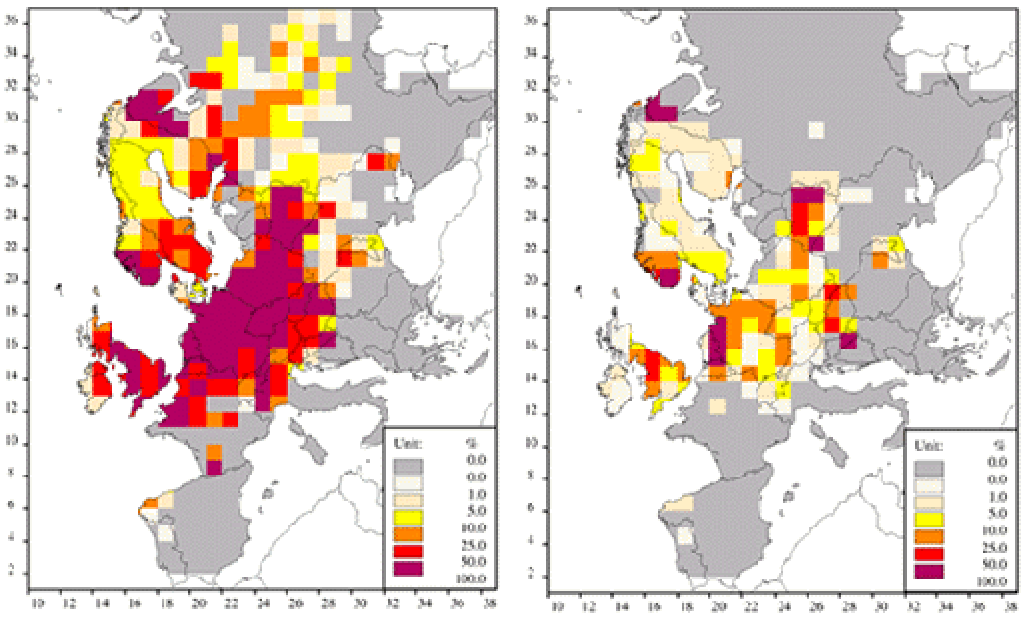
Almost all European countries, as well as the USA and Canada, are signatories to this convention, in contrast to the Ceiling Emissions Convention (see the next section for details) which is only valid for EU countries.

The convention is currently made up of five separate protocols (for further information visit CLRTAP's website www.unece.org/env/lrtap/). The latest protocol, the Gothenburg Protocol, was signed in December 1999 and deals with acidification, eutrophication and increased levels of ozone at ground level. It sets country-by-country emission ceilings for the four pollutants sulphur dioxide, nitrogen oxides, ammonia and volatile organic compounds.

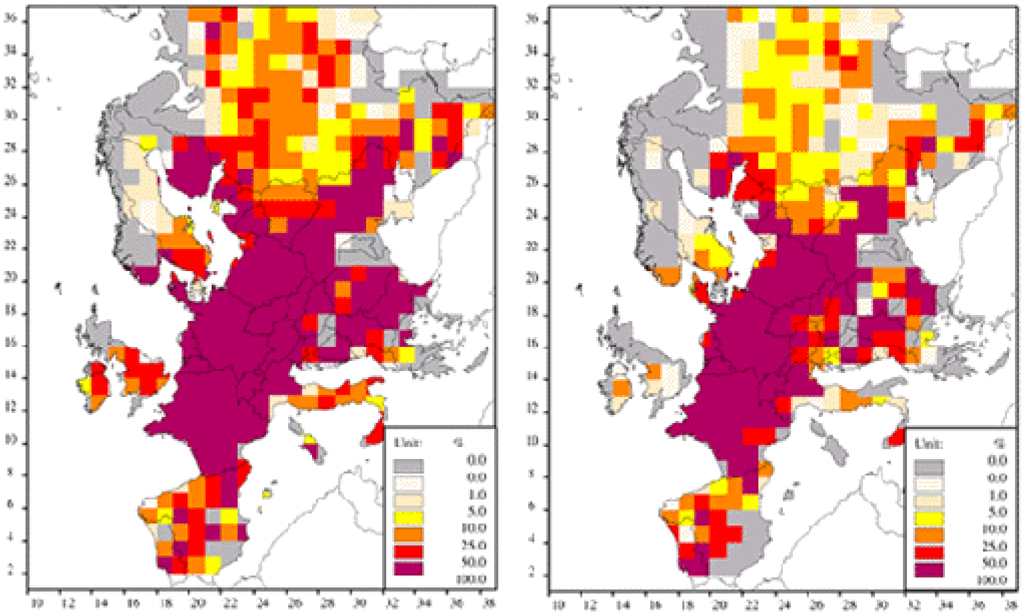
The aim of this last protocol was to maximize potential environmental gains for the lowest possible cost. In effect, this has lead to an agreement among signatories that countries whose emissions have the greatest impact on the environment, and that countries whose emissions are relatively inexpensive to reduce, should make the most effort to do so. For Sweden, this means a 7% decrease in ammonia emissions (from 61,000 to 57 000 tonnes/yr) relative to 1990 levels. If the targets set in this protocol are accomplished by 2010, overall ammonia emissions from European countries will have decreased by 15%, relative to 1990 levels (UNECE).

In summary, CLRTAP is a convention between almost all European countries, the USA and Canada. The convention currently consists of five so-called protocols. The latest one, the so-called Gothenburg Protocol, resembles the EU's Ceiling Convention, although the emission limits are slightly more generous than those defined in the EU Ceiling Convention.

The predictions of the likely outcomes of the Gothenburg Protocol for the acidification and eutrophication rates of natural ecosystems, as illustrated in Figures 5 and 6, have been criticized as far too optimistic (Alveteg och Sverdrup, 2000).



Model used to calculate the environmental impacts of the Gothenburg Protocol for the proportion of ecosystems sensitive to acidification in 1990 and 2010 (IIASA).



Model used to calculate the environmental impacts of the Gothenburg Protocol for the proportion of ecosystems sensitive to eutrophication in 1990 and 2010 (IIASA).Det har framförts kritik över att modellberäkningarna ger en alltför optimistisk bild av protokollets effekt (Alveteg och Sverdrup, 2000).

The directive on National Emission Ceilings

On 9 June 1999 the EU Commission adopted a proposal for a new directive that sets national emission ceilings for each of four air pollutants – ammonia, sulphur dioxide, nitrogen oxides and ground-level ozone. The long-term aim of this directive is to ensure that the critical loads for each of the pollutants are not exceeded anywhere in the EU. As this outcome is unlikely to be achieved in the foreseeable future, a number of shorter-term targets have been suggested.

The directive on National Emission Ceilings includes, like the Gothenburg Protocol, targets for reductions in acidification and ground levels of ozone to be achieved by 2010. Each country has been given a national emission ceiling for each pollutant. It will be up to each country to decide on how it will reach its targets, and to present it's plan of action to the EU Commission by no later than 2002.

Like CLRTAP, the focus is on achieving overall targets, through a commitment by all countries to achieve maximum possible environmental gains with minimal cost for the union as a whole. The National Emission Ceilings directive has more restrictive targets than the CLRTAP.

If the Commission's proposal is adopted and all country targets are reached, the following outcomes will be achieved:

The area of the EU that receives more acid deposition than it can tolerate in the long-term will decrease from 37 to approximately 4 million hectares between 1990 and 2010.
The area of natural ecosystems that is at risk from eutrophication from excess levels of nitrogen will decrease by 30 %.
The area of Sweden that currently receives more acid deposition than it can tolerate in the long-term will decrease from 6,3 million hectares (16,4 % of Sweden's area) in 1990 to 1,4 million hectares (3,7 % of Sweden's area) in 2010. The Swedish Environmental Protection

Agency estimates that it may be difficult for Sweden to reach it's emission target on ammonia.

The National Emission Ceilings targets for Sweden are similar to those in CLRTAP; that is 57,000 tonnes ammonia/year by 2010, of which farming contributes 47, 900 tonnes or 84% (Persson, 2000). By comparison, Sweden emitted 58,800 tonnes of ammonia in 1997, of which 52,800 tonnes (90%) originated from farming (SMHI, 1999).

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Internet

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Internationella försurningssekretaiatet: www.forsurning.nu and www.acidrain.org

The green lane: www.ec.gc.ca/envhome.html

Swedish Environmental Protection Agency: www.naturvardsverket.se

SMHI: www.smhi.se

SCB, ammonia emissions to the air in Sweden 2001: www.scb.se

Project organization

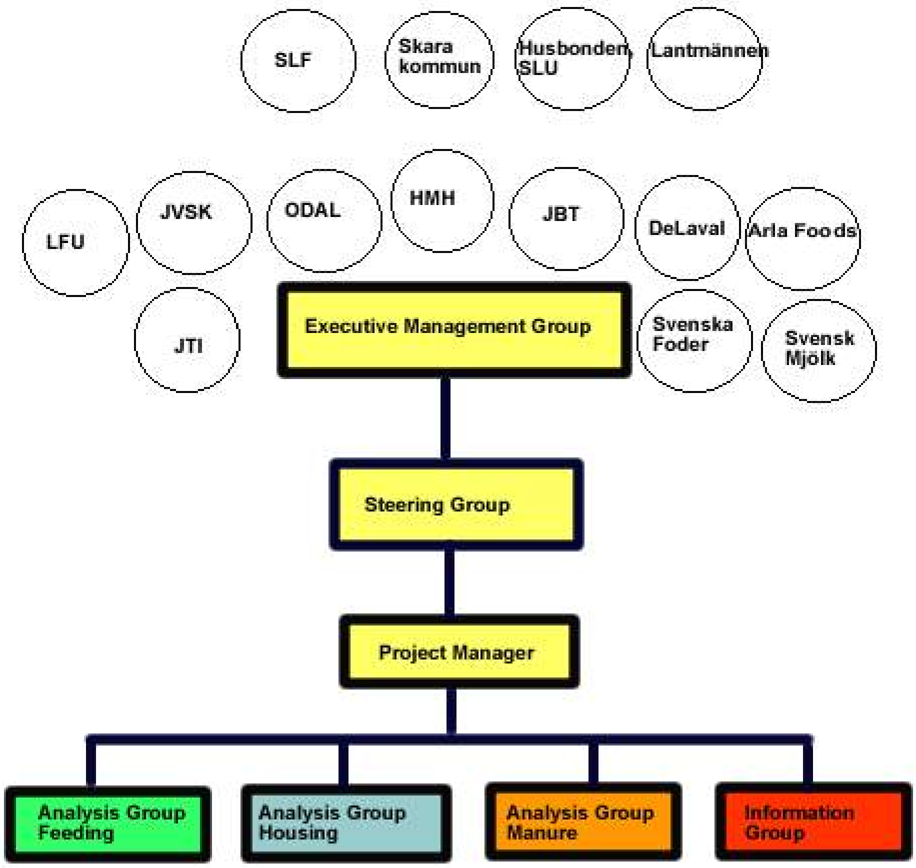
Financing

Project Participiants Evaluation

Management

Co-ordination Information

Analysis Evaluation Documantation



Analysis Group Housing
Department for Animal and Environment and Health (HMH), SLU, Skara
Department of Agricultural Biosystems and Technology, SLU
DeLaval
Chairman: Jan Hultgren

Analysis Group Feeding
Department of Agricultural Sciences, SLU, Skara
ODAL(LFU incl.)
Svensk Mjölk
Svenska Foder
Chairman: Elisabet Nadeau

Analysis Group Manure
JTI- Swedish Institute of Agricultural and Environmental Engineering

ODAL
Department of Agricultural Sciences, SLU, Skara
Chairman: Stig Karlsson

Information Group
Svensk Mjölk on behalf of Arla Foods
DeLaval
Department for Animal and Environment and Health (HMH), the project manager
Chairman: Christel Cederberg

Practical advice

Housing

Measure: Reducing air leakage in the manure handling system

Why are ammonia losses reduced?: There are very high concentrations of ammonia in the manure gutters and in the urine drainage system. If air is leaking into the barn via cross channels or urine drains the ammonia evaporation will increase.

Where is this measure suitable?: In all barns.

How is nitrogen efficiency and the sustainability of your farm affected by this measure?: Reduction of the direct losses of ammonia in the barn. This is an important measure for good barn environment. Uncontrolled air leakage via the manure channels is unfortunately very common.

How much are ammonia losses reduced?: It is difficult to predict as the reduction depends on how big the air leakage was from the beginning.

What can be done?: Efficient barriers in the gutters or cross channels are very important. If these cannot be closed or sealed the outdoor air will enter the barn through these openings and cause ammonia evaporation into the building. This kind of leakage can be eliminated by sealed doors, water traps (slurry systems) or by an exhaust fan, taking air from the cross channels. Urine drains must be carefully sealed.

What are the costs for this measure?: A trap in a slurry channel cost about SEK 2500 and an exhaust fan costs about SEK 6000 - 10000, depending on type and size.

Measure: Avoiding unnecessarily high temperatures in the barn

Why are ammonia losses reduced?: Ammonia evaporation is strongly related to the temperature and is reduced by lower temperature in the air and in the manure.

Where is this measure suitable?: Cows need for temperature is moderate and lowering the temperature in a cow barn is a simple and efficient method for reducing ammonia losses..

How is nitrogen efficiency and the sustainability of your farm affected by this measure?: Reduction of the direct losses to the air.

How much are ammonia losses reduced?: In a study recently carried out in Sweden, the ammonia evaporation was reduced by 40 % when the temperature in the manure was lowered from 15ºC to 10ºC.

What can be done?: Avoid higher temperature than necessary for efficient production and good comfort. During the winter season the amount of ventilated air can normally be increased without any negative effects on cows

What are the costs for this measure?: This measure does not result in any additional investment. In fan ventilated barns some additional operation cost for electricity might occur.

Measure: Reducing surfaces covered by manure

Why are ammonia losses reduced?: Ammonia evaporation is related to the size of exposed dirty surface, the bigger the area the more evaporation. The main part of ammonia evaporation originates from urine.

Where is this measure suitable?: To be considered when planning the layout of a barn.

How is nitrogen efficiency and the sustainability of your farm affected by this measure?: Reduction of direct losses to the air.

How much are ammonia losses reduced?: The reduction is directly related to the size of exposed area. Calculations made indicate that by reducing manure covered areas by 20 % in cubicle barns the ammonia evaporation is reduced by 15 %. In Holland tests have been carried out comparing different slopes in the manure alley and frequency of scraping.

The influence of scraping frequency and sloope of the floor on solid floors in a Dutch istudy.

Slope and scraping frequency	Reduction of ammonia evaporation, %
Solid floor, scraping 12 times per 24 hours	0 (baselevel)
Solid floor, scraping 96 times per 24 hours	5
Solid floor, 3% slope to one side, scraping 12 times per 24 hours	21
Solid floor, 3% slope to one side, scraping 96 times per 24 hours	26
Solid floor, 3% slope to the center, scraping 12 times per 24 hours	50
Solid floor, 3% slope to the center, scraping 12 times per 24 hours, cleaning with 6 litres of water per cow and day	65

What can be done?: The main goal is to reduce the dirty surface per cow and to keep the animals clean. Stanchion barns in general have less dirty areas than cubicle sheds do. In stanchion barns a number of details need to be considered: correct measurement of the stanchion, stalls correctly adjusted, design of the feed alley, partitions between cows, management routines, barn climate, feeding, etc. In loose housing systems the hygiene in scraped alleys can be improved by adding rubber to the scraper blades, by scraping more frequently and by designing and rebuilding, making the alley slope to the center and providing them with efficient urine drainage.

What are the costs for these measures?: The costs for these measures are very difficult to predict as they vary considerably, depending of the conditions in each case.

Feeding

Measure: Analyzing the forage and preferably the grain

Why are ammonia losses reduced?: By analyzing the nutritional content, such as the crude protein, NDF, energy, and starch (grain), of the feedstuff, we get more precision in the ration formulations. We can control the amount of feed offered more efficiently and, thereby, minimize the losses of ammonia.

Where is this measure suitable?: In all dairy herds.

How is nitrogen efficiency and the sustainability of your farm affected by this measure?: By improved control of the feed offered, the nitrogen in the ration is utilized more efficiently and the nitrogen utilization by the dairy cows is improved. The sustainability in farming is improved by lower losses of nitrogen in feces and urine by ammonia emissions, which decrease the acidification in the surrounding environment and eutrophication of the water sources.

How much are ammonia losses reduced?: It is difficult to estimate the decrease of ammonia losses that can be done by analyzing the feedstuff because there are a few other factors, such as the composition of the ration, feeding routines, and lactation stage that also influence the losses. Generally, we can conclude that if the ration formulation is controlled by feed analyses and with regard to feeding routines and lactation stage, the farmer has used all possible tools on the farm to decrease the losses of ammonia. Swedish investigations show that it is realistic to have about 12-13 kg of nitrogen in manure per 1000 kg of milk from a cow per year (Gustafsson, 2000).

What can be done?: Take representative samples during the forage harvest and send them to a feed lab for analysis of dry matter, crude protein, NDF, and energy*. It also is desirable to sample the grain during harvest and have it analyzed for crude protein, energy, starch and NDF. Additionally, there will be calculated values for amino acids absorbed in the intestine, protein balance in the rumen, effective protein degradation (tabulated value), and effective fiber degradation. Use these analyses and calculated values as a basis for ration formulations on the farm.

What are the costs for this measure?: A fresh forage sample, including the analyses mentioned above, costs about 350 SEK, whereas a grain sample costs about 375 SEK.

**Reference:* Provtagning och Analys av Foder. Kvalitetssäkrad Mjölkproduktion. T2686-13. SHS Butiken, Svensk Mjölk.

Measure: Decreasing the crude protein content of the ration

Why are ammonia losses reduced?: Traditionally, there has been an overfeeding of protein in many dairy herds in order to have a wide margin against factors that affect the crude protein concentration but cannot be adjusted for in the ration formulations. As a result, the amount of nitrogen in the feed that is not used for milk production, growth, and pregnancy, but is excreted in feces and urine, has become relatively high. Because there is a clear correlation between the crude protein concentration of the ration and the amount of nitrogen in the feces and urine, decreased crude protein concentration is an effective method to improve nitrogen utilization by and decrease ammonia losses from Swedish dairy cows.

Where is this measure suitable?: First and foremost in all dairy herds that have high protein levels, over 18% crude protein of DM during early lactation, but also on farms with 17-18% crude protein in early lactation and have a good control of feeding and follow-up of milk yield and milk quality. It also is important to keep the protein level low for middle- and low-producing cows that often consume excess protein.

How is nitrogen efficiency and the sustainability of your farm affected by this measure?: A decreased crude protein concentration by one percentage unit can improve the nitrogen utilization (nitrogen in milk/nitrogen in feed) of a cow by 1.5 to 2.0 percentage units (Gustafsson, 2000). An average nitrogen utilization between 28 and 30% on an annual basis seems to be a realistic level for a dairy cow. Farming becomes more sustainable on a long-term basis through decreased risk of acidification of lakes and soils and decreased eutrophication of our water sources due to lower ammonia losses from dairy farms.

How much are ammonia losses reduced?: A decrease of the crude protein concentration by one percentage unit in the dietary dry matter is estimated to decrease the amount of nitrogen in feces and urine by 11 kg per cow each year. A decreased dietary crude protein concentration by one to two percentage units may decrease the annual ammonia losses by 500 to 1700 tonnes of ammonium-nitrogen in Sweden (Gustafsson, 2000).

What can be done?: Decrease the crude protein concentration stepwise and follow up with milk yield and milk protein percentage. In this way you will find a protein level in the ration that improves the nitrogen utilization without decreasing the milk production .

What are the costs for this measure?: Naturally, there will not be any costs associated with a decrease in the dietary crude protein concentration as long as the milk yield is maintained. The feed costs will be lowered because the proportion of protein concentrate in the ration can be decreased.

Measure: Decreasing the proportion and improve the utilization of rumen degradable protein in the ration

Why are ammonia losses reduced?: The feed protein that is degraded in the rumen into ammonia can be used for the microbial protein synthesis only in the presence of available energy that is produced in the rumen during fermentation of fiber (NDF and pectin) and starch. In the absence of energy, the ammonia will be lost in the manure. If the proportion of rumen degradable protein is decreased, the ruminal ammonia production and, consequently, the ammonia losses will decrease.

Where is this measure suitable?: On farms that use early-cut forage or have a large proportion of legumes in the sward.

How is nitrogen efficiency and the sustainability of your farm affected by this measure?: Because a larger proportion of the crude protein passes the rumen without being degraded when the proportion of rumen degradable protein is decreased, nitrogen utilization and milk production will increase. Formulating the ration with NDF and starch results in a better utilization of the ammonia produced in the rumen and, thereby, a better nitrogen utilization. The sustainability of agriculture is improved by decreased ammonia emissions from dairy herds. This results in decreased acidification of the environment and decreased eutrophication of lakes, rivers, and creeks.

How much are ammonia losses reduced?: How much the ammonia losses will decrease depends on the size of the initial proportion of rumen degradable protein and how efficiently we use the ammonia that is produced in the rumen by supplementing with feedstuffs rich in fiber or starch and follow up of the feeding routines on the farm.

What can be done?: The proportion of rumen degradable protein can be decreased in the long term by altering the composition of the ley through the use of different forage species and in the short term by nitrogen fertilization. You can decrease the proportion of clover in a grass/clover ley by increasing the nitrogen fertilization application rate. The rumen degradable protein can be utilized better for the microbial synthesis if the ration is formulated with feeds rich in fiber and starch, such as whole-crop small grain silage and maize silage. The proportion of rumen degradable protein in the ration will cover the need for the microbial synthesis in the rumen. Several international investigations show that the concentration of rumen-degradable protein should be 10-11.5% of the dietary DM, which agrees with the recommendations by Lindgren (1997).

What are the costs for this measure?: The costs are not particularly large but involve a change of crop rotation to include whole-crop small grain silage and maize silage. There will be added costs for nitrogen fertilizing the ley and changing the forage seed mixture.

Reference: Lindgren, E. 1997. LFU-systemet för värdering av foder till mjölkkor. Stencil. Lantmännen Foderutveckling AB. Sverige.

Manure storage and spreading

Measure: Covering the storage

Why are the ammonia losses reduced?: The contact between the slurry in the store and the surrounding atmosphere is reduced as well as the exchange of air over the surface.

Where is this measure suitable?: Storage for slurry and urine

How is the nitrogen efficiency and the sustainability of your farm affected by this measure?: Reduction of the direct losses of ammonia from the storage during the storage period.

How much are the ammonia losses reduced?: During the storage period the losses are expected to be reduced 50 - 95% depending of which kind of cover is used.

What can be done?: A floating crust is normally established on slurry from milk cows, especially when straw is used as bedding material. In order to be efficient the crust must cover the entire store and be stable enough. In some cases solid manure, straw or peat has been added, the slurry has been mixed and the added material has formed a good crust. Sometimes leca-pebbles or floating plastic cover are used. Note that straw is best suited for slurry from cows. Used in urine stores the straw becomes wet and sinks to the bottom. Leca-pebbles are the opposite, they stay floating on thin slurry and urine, but mix easily with thick manure.

Another type of cover is a different kind of roof built on the store, sometimes resting on a central pole. The cover can be built in concrete or made of a lighter construction. It should in any case be as tight as possible.

What are the costs for this measure?: The lifetime of a cover varies, which means that its depreciation time varies as well. Floating crusts may also require additional work.

Kind of cover	Yearly cost SEK/m3
Floating crust	*
- Chopped straw, peat	5-13*
- Leca-pebbles	14
- Floating plastic cover	20
Fixed roof	25-40

** cost for manpower to be added*

Measure: Choosing the right spreading technique

Why are ammonia losses reduced?: By direct injection or incorporation of the slurry into the soil directly after spreading, or alternatively by using drop boom in growing crops the ammonia is the better protected than when spread on the surface. In the soil the nitrogen is bound to the soil and a growing crop stops blowing winds. This is very important in warm, dry and windy weather.

Where is this measure suitable?: Many injection devices are suitable for spreading on grassland after e.g. the first cut. Drop boom is preferred when spreading in growing crops, 10-15 cm high, but also reduces the losses when spreading on stubble-field. Plowing or harrowing directly after other types of spreading is recommended.

How is nitrogen efficiency and the sustainability of your farm affected by this measure?: Reduction of direct losses of ammonia at spreading. Furthermore unpleasant smell is reduced and the control of spread amount and accurancy is improved.

How much are ammonia losses reduced?: Direct injection or quick incorporation into the soil are the most efficient ways to reduce ammonia losses. By using these methods the ammonia losses can be reduced by as much as 80-95% compared with traditional surface spreading. Drop boom can reduce the losses by 30-50% compared with traditional techniques. The effect, however, depends on a number of other factors, such as weather, soil type, crop, time of the year, etc.

What can be done?: To incorporate the slurry into the soil directly after spreading does not normally require additional investment but does need careful planning and possibly more personnel. Technique for injection or drop boom means additional investment but can be solved by using a Contractor.

What are the costs for this measure?: A drop boom instead of a traditional surface spreader costs in the range of SEK 120,000. Equipment for injection costs about SEK 200,000. Price and design can vary a great deal between different suppliers. Using a contractor or working together with other farms might reduce the total cost considerably.

Measure: Choosing the right spreading time

Why are ammonia losses reduced?: Weather conditions such as air temperature, air moisture and wind speed have a strong influence on the amount of losses.

Where is this measure suitable?: At all times when manure is to be spread on surface by traditional spreading or by drop boom. Choosing the right spreading time also include other concerns such as the risk for tracks in the growing crops, leaking or runoff, delaying other jobs etc. It is very difficult to optimize all these parameters at the same time.

How is nitrogen efficiency and the sustainability of your farm affected by this measure?: Reduction of the direct losses when spreading.

How much are ammonia losses reduced?: Losses can easily be reduced by 50%. As weather parameters can vary within wide ranges ammonia losses can vary accordingly. Best effect is achieved at low temperature, high humidity and low wind speed.

What can be done?: Plan spreading in two steps. Crop rotation and size of storage determine when during the year the manure should be spread. From the ammonia losses point of view early spring, spring or even late autumn is preferred to spreading during the summer. When the period for spreading approaches, be sure to follow the weather forecasts and avoid spreading on warm, dry and windy days. If possible try to spread just before rain.

What are the costs for this measure?: In many cases this is a matter of planning the work, but in some cases changes in the plan can lead to increased risk for soil compaction during the spring and spreading in growing crops means more expensive equipment.

Project report

This project report is in Swedish with the title: "LIFE Ammoniak. Bärkraftig mjölkproduktion genom minskning av ammoniakförluster på gårdsnivå".
(LIFE Ammonia. Sustainable milk production through reduction of on-farm ammonia losses. Project report)
Sannö J.-O., Cederberg C., Gustafsson G., Hultgren J., Jeppsson K.-H., Karlsson S., Nadeau E.

Report 5, 2003, 84 pages, Sveriges lantbruksuniversitet, Institutionen för husdjurens miljö och hälsa, Skara (Swedish University of Agricultural Sciences, Dept. of Animal Enrivonment and Health)
ISBN 91-576-6605-9
ISSN 1402-3334

You can order the report from Gunilla Jacobsson (gunilla.jacobsson@slu.se).

List of publications

Gustafsson, G., Jeppsson, K.-H., Hultgren, J., Sannö, J.-O., 2003. Techniques to reduce the ammonia release from a cowshed with tied dairy cattle. In: Gaseous and odour emissions from animal production facilities, Proceedings of Research Center Bygholm, CIGR, EurAgEng, NJF, Denmark, p. 239–248.

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