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**UNECE FRAMEWORK CODE FOR GOOD AGRICULTURAL PRACTICE
FOR REDUCING AMMONIA */**

Prepared by the Expert Group on Ammonia Abatement

Introduction

1. On 1 December 1999, Environmental Ministers from Europe and North America met in Gothenburg (Sweden) and signed a new Protocol to the Convention. The Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone aims to reduce emissions of four pollutants e.g. sulphur, nitrogen oxides, volatile organic compounds (VOCs) and ammonia and sets stringent reduction targets for all of them for 2010.
2. The Gothenburg Protocol is probably the most sophisticated binding environmental agreement ever because of its multi-pollutant and multi-effect nature. Moreover, it is the first time that any international treaty has targeted ammonia emissions. Under the Protocol, ammonia emissions will be cut by almost 20 % by 2010 as compared with the 1990 level. Current ammonia emissions in the area covered by EMEP total about 6.5 million tonnes.

*/ This document has not been formally edited.

3. Ammonia is emitted mainly from agriculture, e.g. livestock farming systems and use of mineral fertilizers on crop land. Although some of the ammonia emitted will be deposited locally, it can be transported hundreds or even thousands of kilometres and so contributes to transboundary air pollution. When ammonia is deposited on land or water, it can cause acidification and eutrophication, two major environmentally damaging effects. Ammonia gas is released from the breakdown of urea in livestock manures (slurries and solid manures) or of uric acid in poultry manure. It is also emitted from nitrogen fertilizers, especially from urea fertilizer, from urine deposited by grazing stock and from crops. Deposition of ammonium compounds, following reaction with acidic compounds in the atmosphere, is a primary cause of acidification of certain soils. This can affect the availability of elements both essential and toxic to plant growth. In addition, ammonia as a source of nitrogen (N) contributes to eutrophication, or nitrogen enrichment of nutrient-poor soils. This process, which can also occur in surface waters, disrupts the balance of sensitive ecosystems, causing either excessive growth or disappearance of plant species. High ammonia emissions may also directly affect trees or vegetation by damaging foliage and retarding growth.

4. The abatement of ammonia emissions is of increasing importance in strategies to combat acidification and eutrophication. Emissions of sulphur have already been drastically reduced under the Convention so, by 2010 in Europe, ammonia is likely to be the largest contributor to acidifying and gaseous nitrogen emissions.

5. The Gothenburg Protocol contains a series of mandatory control measures that the Parties shall employ for the control of ammonia emissions from agricultural sources. It targets primarily those sources from the manure management cycle from which ammonia can easily escape. These include pig or poultry housing, where manure or slurry accumulate, manure and slurry stores, where manure may remain for a long-time, and finally manure and slurry application to land. It also targets ammonia emitted from using N fertilizers, particularly urea, and recommends measures to limit ammonia emissions from the use of solid fertilizers based on urea. It prohibits the use of ammonium carbonate fertilizers.

6. Nitrogen, together with other plant nutrients, is essential for plant growth and is needed to achieve optimum crop yields. Most of the plant available N in manure or slurry is in the form of ammonium-nitrogen, which can substitute directly for mineral fertilizers. Ammonia emissions, therefore, represent a loss of valuable N and so may increase the requirement for mineral fertilizers to maximize crop yields. For this reason, the Protocol firmly recommends that each Party shall take due account of the need to reduce ammonia losses from the whole N cycle in agriculture, including both livestock farming systems and use of mineral fertilizers on land. In addition, it provides guidance to the Parties in identifying best available options and techniques for preventing or reducing releases of ammonia from the sector.

7. Within one year of the date of entry into force of the Gothenburg Protocol, a Party to the Protocol shall establish, publish and disseminate, an advisory code of good agricultural practice to control ammonia emissions. The national code shall take into account the specific conditions within the territory of the Party, i.e. be tailor-made to local soil and geomorphological conditions, manure types and farm structure. However, in order to harmonize some basic requirements of national codes and to incorporate the best available control options and techniques, the Expert Group on Ammonia Abatement, led by the United Kingdom, was requested to prepare a framework advisory code of good agricultural practice based on the experience and knowledge of its members. A draft framework code was written by six experts from Germany (H. Döhler), the Netherlands (H. Hendriks), Switzerland (H. Menzi), the United Kingdom (B. Pain and J. Webb) and the secretariat for the Convention (A. Jagusiewicz). Agreement on the format and content of this code was reached at a meeting of the Expert Group on Ammonia Abatement held in Berne, Switzerland, from 18 to 20 September 2000 (summary report of the meeting: see EB.AIR/WG.5/2001/6). The framework code includes provisions on all major agricultural sources of ammonia and is intended to help Parties develop and/or elaborate their own national advisory codes of good agricultural practice to control emissions.

Annex

FRAMEWORK ADVISORY CODE OF GOOD AGRICULTURAL PRACTICE FOR REDUCING AMMONIA EMISSIONS

Introduction

1. The Code comprises six sections:
 - (a) Nitrogen (N) management that takes into account the entire N cycle;
 - (b) Livestock feeding strategies;
 - (c) Low emission manure spreading techniques;
 - (d) Low emission manure storage techniques;
 - (e) Low emission animal housing systems;
 - (f) Limiting ammonia emissions from the use of mineral N fertilizers.

2. The Code includes guidance on reducing ammonia emissions from all the major agricultural sources for which practical and widely applicable techniques are available. In addition to the publication and dissemination of a Code, the Protocol requires other mandatory measures that affect certain sectors of the agricultural industry. It is mandatory, for example, to introduce measures to reduce ammonia emissions from manure storage and animal housing on large pig (with 2000 or more fattening pigs or 750 or more sows) and poultry (with 40,000 or more poultry) farms. The thresholds for animal numbers are the same as those included in the European Community's (EC) Integrated Pollution Prevention and Control (IPPC) Directive. A timescale for the introduction of these measures is given in the Protocol and it is recognised that applicability of animal housing measures may be limited by animal welfare considerations.

3. Manures from housed animals contain appreciable quantities of plant nutrients and thus have value as fertilizers for crop production. Management strategies should ensure that the fertilizer value of manures is fully exploited and losses of nutrients to the wider environment are minimized. Losses of nitrogen as ammonia not only have an adverse effect on the environment but also decrease the fertilizer value of manures.

4. It is important to note that ammonia conserved by the introduction of an abatement measure at one stage of manure management can be readily lost at a "downstream" stage of management. Where abatement measures are used for housing and/or manure stores, it is essential to use a suitable, low emission technique for applying the manure to land. Although reducing ammonia emissions from applying manures to land should increase the amount of N available for uptake by plants, in some circumstances it may also increase the potential for N loss by other pathways, through nitrate leaching for example. It is important to consider this risk, and

take steps to minimize it where necessary, when planning and implementing ammonia abatement strategies.

A. Nitrogen management

Introduction

5. Nitrogen is readily lost from agriculture through a number of pathways including nitrate leaching to water and gaseous emissions. From the air pollution perspective, ammonia and nitrous oxide, a greenhouse gas, are of most concern. Although this Code is mainly about ammonia emission, there are interactions between this and other nitrogen transformations, losses and crop uptake. It is, therefore, important to consider the whole N-cycle in devising effective strategies for minimizing both water and atmospheric pollution, optimizing N use for crop production and taking into account the effects of ammonia abatement on other N losses. Ammonia emissions originate mainly from manures produced by housed livestock as slurries or solid manures and, to a lesser extent from N fertilizers, urine from grazing animals and from crops. Emissions from manures occur from livestock buildings, manure stores and following application to land. In most circumstances, the latter source and livestock feeding strategies offer the most cost-effective opportunities for reducing emissions.

Balanced N applications

6. To ensure effective utilization of N by crops and to reduce the risk of losses, it is essential to (a) avoid excess applications of both fertiliser and manure-nitrogen and, (b) apply at times of the year when nitrate leaching will be minimized and, where possible, crops are actively growing. Careful balancing of N inputs to crop requirements will save money by reducing the amount of purchased fertilizer needed and reduce the potential for nitrate leaching. The benefits of balanced fertilization for ammonia abatement are less immediate although good management of fertilizers and manures can make a useful contribution. Specific abatement techniques, which are described later in this Code, are needed to achieve large reductions in ammonia loss.

7. Ammonia emissions arise from the soil surface before the applied nitrogen enters the pool of mineral (plant-available) nitrogen in the soil. Balancing N applications to crop requirements therefore has less impact on ammonia emissions than on nitrate leaching. However, adopting measures to reduce ammonia emission following manure application will also contribute to better management by conserving N for crop uptake. In countries that limit annual N applications, ammonia abatement will provide an opportunity to utilize both the manure N as well as the fertilizer N more effectively.

Emissions from grassland

8. Balanced N fertilization avoids unnecessarily high concentrations of N in forage, especially grass. Excess N application can increase concentrations in grass and hence in the urine of grazing animals, leading to greater ammonia emissions from grazed grassland and manure management.

Emissions from arable crops

9. Ammonia is also emitted directly from arable crops, especially as they ripen before harvest. Emissions from crops are generally small but can be variable. The potential for loss increases as the N concentration in the plant increases. Avoiding over-fertilization with N (from manures and/or mineral fertiliser) will reduce the size of these losses.

Guidelines

10. To avoid the consequences of excess or untimely N application, the following guidelines should be adhered to:

- (a) Calculate the N in livestock manure applications that will become available for crop uptake in the following year;
- (b) Calculate the N left in residues of the previous crop, especially if grassland and field forage crops was ploughed up;
- (c) Take account of N mineralization in soils that have large (>6%) soil organic matter content, or where livestock manures have been applied in large amounts over several years;
- (d) Use acknowledged national methods for predicting plant-available soil nitrogen;
- (e) Where soil is well supplied with available N (for example because grassland has recently been ploughed) have the soil analysed for its mineral N content;
- (f) Nitrogen fertilizer and livestock manure applications should be timed according to periods of N uptake by the crop, i.e. shortly before the onset of rapid crop growth;
- (g) Avoid large application rates of manures that supply nitrogen (and other plant nutrients) in excess of crop requirements.

B. Livestock feeding strategies

Introduction

11. Ensuring that farm livestock are not fed more protein than that required for the target level of production can reduce the N excretion per livestock unit and per unit production. Decreasing the amount of N in manure will not only abate ammonia emissions but also other potential N losses (leaching, denitrification). N excretion by different types and classes of livestock is strongly dependent on the production system (Table 3.1). Standard excretion values

should therefore be calculated on a national or regional level.

12. Protein surplus in livestock rations is primarily excreted in the form of urea (uric acid in poultry manure). These compounds are rapidly degraded to ammonia and ammonium that have a high emission potential. Reducing N excretion by reducing the protein content of the ration, therefore, results in a disproportional decrease in ammonia losses. Furthermore, emission abatement is effective at all stages of manure management (houses, storage, application).

13. Even under optimal conditions, animals excrete more than half the protein intake in feed in the form of different N compounds. There are usually excesses in the protein supply for almost all livestock classes and production systems, the reduction of which could reduce N excretion.

Methods for decreasing N excretion

14. The following general methods can be used to decrease the amount of N excreted by livestock:

- (a) Better adjusting the composition of the diet to the requirements of the individual animal e.g. according to lactation stage, age and weight of animals, etc.;
- (b) Reducing excesses in the protein supply by ensuring that it does not exceed current feeding recommendations;
- (c) Reducing the crude protein content of the ration by optimization of the amino acid supply. For monogastric animals, the required amino acid supply can be controlled by addition of pure amino acids to the diet or by using a combination of different protein feeds in the diet;
- (d) Increasing the efficiency of N use by improving animal performance so that a diminishing proportion of the total protein requirement is used for maintenance.

Pigs and poultry

15. For pigs, N excretion can be reduced by matching more accurately the diet to the specific requirements of different growth and production stages. This can be achieved by:

- (a) Ensuring that the protein content of the feed or ration is not higher than the recommended level;
- (b) Using different diets for lactating and gestating sows;
- (c) Using different diets for different growth stages of fattening pigs (phase feeding).

16. In addition to the above options, the protein level of pig diets can be lowered by optimizing the essential amino acid content rather than the crude protein content. This can be achieved by adding pure amino acids, especially lysine, methionine and threonine, to the diet. Even though such strategies will result in somewhat higher feed prices, they are some of the cheapest measures to reduce ammonia emissions.

17. For poultry, the strategies to reduce N excretion are basically the same as for pigs.

Ruminants

18. Ruminants, protein surplus and N excretion strongly depend on the proportion of grass, grass silage and hay in the ration and the protein content of these feeds. The protein surplus and the resulting N excretion and ammonia losses will be highest for grass-only summer rations with young, intensively fertilized grass or grass legume mixtures. In such cases, a ration matched to the energy demand of the animals will always result in a high protein surplus. The following strategies can improve this situation:

- (a) Ensuring that N- fertiliser application rate on the grassland is not excessive;
- (b) Improving the energy/protein equilibrium by:
 - (i) substituting some of the fresh grass with roughage of lesser protein content (maize silage, hay, straw etc.);
 - (ii) using older grass or rationed amounts of grass and more high energy concentrates. Nevertheless, for livestock production systems predominantly based on grassland, the feasibility of this strategy is often limited because a full use of the grass production would no longer be guaranteed (under conditions of limited production, e.g. milk quotas) and the nutrient balance of the farms would not be in equilibrium.

19. A reduction of ammonia emissions from ruminants can also be achieved by increasing the proportion of grazing because much of the urine infiltrates into the soil before urea is degraded and lost as ammonia. Nevertheless, the total N efficiency of grazing systems tends to be lower than that of mown grassland due the uneven distribution of the excreta. Furthermore, grazing is often limited by climatic and soil conditions as well as farm structure. A minimum period of grazing per year may be required for animal welfare reasons.

20. A special form of reducing N excretion and losses per unit product is the improvement of the feed conversion efficiency through higher yields. Increasing the number of lactations per cow could also decrease ammonia emission per unit of milk production over the life of the animal.

Table 3.1. Nitrogen excretion by different classes of farm livestock

Animal type	Production level	N excretion		
		kg N place ⁻¹ year ⁻¹	per unit production	
			kg N per ...	
Dairy cows	less than 5000 kg milk cow ⁻¹ year ⁻¹	60-110	15-25	1000 kg milk
	5000-6000 kg milk cow ⁻¹ year ⁻¹ , low amount of concentrate	100-140	20-28	1000 kg milk
	5000-6000 kg milk cow ⁻¹ year ⁻¹ , >500 kg concentrate year ⁻¹	80-100	16-20	1000 kg milk
	9000-10000 kg milk cow ⁻¹ year ⁻¹	110-140	11-14	1000 kg milk
Beef cattle	Extensive: mainly grazing	40-50	10-20	100 kg growth
	Intensive: corn silage etc.	35-45	7-10	100 kg growth
Breeding sows	including piglets to 25 kg	30-40	1.4-2	per piglet
Fattening pigs	25-100 kg; no phase feeding	15-18	6-8	100 kg growth
	with phase feeding	12-15	5-7	100 kg growth
	phase feeding and pure amino acids	10-14	4-6	100 kg growth
Laying hens	1 bird	0.60-0.80	2.0-3.5	1000 eggs
Broilers	1 bird-place	0.35-0.50	2.0-4.0	100 kg growth

C. Low emission manure spreading techniques

Introduction

21. Ammonia emissions from the application of manures (slurries and solid manures such as farmyard manure and broiler litter) account for a large proportion of the emissions from agriculture. It is very important to minimize losses at this stage of management because any ammonia saved earlier, from livestock housing or manure storage, will be lost if it is not controlled by an appropriate field application technique. Reducing ammonia loss means that more nitrogen is potentially available for crop uptake. To gain maximum benefit from it and to

avoid increasing the risk of nitrate leaching, attention should be paid to the N content of the manure so that the rate and time of application is matched to crop requirements.

Low emission techniques for slurries and other liquid manures

22. The most effective means of reducing ammonia emissions from slurry application is to employ an appropriate application technique such as an injector or band spreader.

Injectors: These reduce emissions by placing the manure beneath the soil surface, thus decreasing the manure surface area exposed to the air and increasing infiltration into the soil. They are generally more effective than band spreaders. There are three types:

- (a) Shallow (or slot) injectors: these cut narrow slots (typically 4-6 cm deep and 25-30 cm apart) in the soil that are filled with slurry or liquid manure. They are most commonly used on grassland. Different abatement results are achieved depending on whether open or closed slot injectors are used;
- (b) Deep injectors: these apply slurry or liquid manure to a depth of 12 – 30 cm in the soil using injector tines space about 50 cm apart. The tines are often fitted with lateral wings to aid dispersion in the soil and to achieve high application rates. They are most suited for use on arable land because of the risk of mechanical damage to grass swards;
- (c) Arable injectors: these are based on spring or rigid tine cultivators and are for use on arable land only.

Band spreaders: These reduce emissions from slurries and liquid manures through decreasing the manure surface area exposed to the air and decreasing air flow over it. The efficiency of these machines can vary depending on the height of the grass. There are two main types of machine:

- (a) Trailing hoses: slurry is discharged at ground level to grass or arable land through a series of flexible hoses. Application between the rows of a growing crop is feasible;
- (b) Trailing shoes (or feet): slurry is normally discharged through rigid pipes which terminate in metal “shoes” designed to ride along the soil surface, parting the crop so that slurry is applied directly to the soil surface. Some types are designed to cut a shallow slit in the soil to aid infiltration.

Incorporation

23. The aim should be to incorporate slurry into the soil as rapidly as possible after spreading on the surface. It is normally recommended that incorporation should be completed within 6 hours of spreading to achieve worthwhile abatement. Completely burying the slurry by ploughing is

often considered to be the most effective method of incorporation. However, ploughing is a relatively slow operation and, in some circumstances, the use of a tine or disc cultivator may be as effective because the slurry will remain exposed on the surface for a shorter time.

Low emission techniques for solid manures

24. Although it can be used for all types of manure on arable soils, incorporation into the soil is the only practical technique for reducing emissions from solid manures. Most of the ammonia is released within a few hours of spreading. It is recommended, therefore, that incorporation should take place within 24 hours. The manure must be completely buried for maximum abatement and it is often more difficult to achieve this with some solid manures (e.g. those containing large amounts of straw) than with slurries. Ploughing is usually the most effective means of incorporation although other methods, such as disc or tine cultivators, may be as effective depending on the manure and soil characteristics.

Other techniques

25. The following techniques can also help to reduce ammonia emissions, although they may not be as effective or reliable as those outlined above:

- (a) Time of application: Spreading under cool, still, humid conditions, will help to minimize emissions;
- (b) Dilution of slurries: where soil conditions allow, diluted slurries infiltrate into the soil more readily than viscous slurries so emissions cease sooner after spreading. The need to spread a larger volume is a disadvantage. Similar results can be achieved by irrigation after application;
- (c) Mechanical separation of slurries: applying the liquid fraction from an efficient separating machine can give a similar reduction in emissions as diluting slurry.

26. Other techniques, for example the use of additives and acidification of slurry, are either not proven to be effective or have practical problems that severely limit their use.

Practical considerations

27. Effectiveness in reducing emissions, applicability and costs should be taken into account in selecting the most suitable techniques for reducing ammonia emissions. Guidance on the effectiveness and applicability of the different methods is given in Table 4.1. The reduction in emission is expressed as a percentage of the reference method. The reference for manure application method is defined as the emission from untreated slurry or solid manure spread over the whole soil surface ("broadcast"). For slurry, this would be with a tanker equipped with a discharge nozzle and splash plate. For solid manure, the method would be to leave the manure on the soil surface for a week or more.

28. The effectiveness of abatement achieved with band spreaders and injectors will vary with the dry matter content of the slurry, soil properties and crop characteristics. Similarly, the effectiveness of incorporation varies with the type of manure and the time since spreading. Band spreaders are, in general, more effective on arable than on grassland and when used with dilute pig slurries than with more viscous cattle slurries. Band spreaders and injectors are not suitable for use on steeply sloping land and sub-surface injection techniques do not work well on very stony or compacted soils. Open slot injectors are more applicable to a wider range of soil types and conditions than closed slot machines. Small, irregularly shaped fields present difficulties for large machines. Incorporation is restricted to land that is cultivated. Umbilical systems, where the applicator is mounted directly on the tractor and fed from a tank or pipe via a long flexible hose, offer an alternative to mounting the applicator on a tractor drawn tanker. They have the advantage of higher work rates and of lessening the risk of soil damage and can be preferably be used on farms with small distances between slurry store and the field. Capital and operating costs for low emission systems are likely to be more than for "broadcast" spreading techniques.

Table 4.1. Practical considerations in selection of ammonia abatement techniques for landspreading manures.

Abatement technique	Manure type	Land use	Reduction in emission	Restriction on applicability
Trailing hoses	Slurry and liquid manure	Grassland/ arable land	10–50%	Field slope, size and shape. Not viscous slurry. Width of tramlines for growing cereal crops. Height of crop is a factor on arable land
Trailing shoe	Slurry and liquid manure	Mainly grassland	40–70%	As above.
Shallow injection	Slurry and liquid manure	Mainly grassland	open slot 50-70% closed slot 70-90%	As above. Not stony or very compacted soils
Deep injection (including arable injectors)	Slurry and liquid manure	Arable land	70–90%	As above. Needs high powered tractor
Incorporation into soil	All manure types	Arable land including grass leys	20-90%	Land that is cultivated, preferably ploughed

D. Low emission manure storage techniques

Introduction

29. Ammonia losses from buildings and after spreading animal manures are usually the most important emission sources, however losses from stored slurries and solid manures can also make a significant contribution to the total emission of ammonia. Storage enables manures to be spread on to land at times of the year when the risk of water pollution (e.g. through nitrate leaching) is low. It also allows manures to be utilized for crop production.

Storage of slurry and other liquid manures

30. After removal from animal houses, slurry is stored either in concrete, steel or wooden tanks (or silos) or in lagoons. The latter usually have a relatively larger area per unit volume than the former and thus a greater potential for ammonia emissions. There may be national or regional regulations controlling the design, construction and management of manure stores.

31. Techniques for reducing ammonia emissions from manure stores include:

(a) Design of the store:

(i) Size. The store should be of sufficient size to avoid spreading on land at times of the year when there is a risk of water pollution (e.g. through nitrate leaching) and to allow application at the best time with regard to crop nitrogen demand. Frequent mixing and emptying should be avoided wherever possible because these operations increase ammonia emission. However, mixing and removal of slurry for spreading is likely to be more frequent on grass than on arable farms to ensure effective utilization of the slurry.

(ii) Surface area. Reduce the surface area (or emitting surface) of the store. For example, the surface area of a 1000 m³ slurry store can be reduced by more than one third, if the height of the sides is increased by 2 m from 3 to 5 m. Generally, for practical (mixing, reducing required volume for precipitation) and abatement reasons, the height of the store should be at least 3 m where feasible.

(b) Covers for slurry tanks or silos: Covers on slurry stores are an effective means of reducing ammonia emissions. The options for covering tanks or silos are summarized in Table 5.1. They include:

- (i) Roofs etc. These are the most effective techniques for reducing ammonia emissions but also the most expensive. Whilst it is important to guarantee that covers are well sealed to minimize air exchange, there must be small openings or a facility for venting to prevent the accumulation of inflammable methane gas, especially with tent structures;
- (ii) Floating covers. These are usually made from plastic sheets and are less effective than roofs, although they are usually less expensive. Double sheets with shrink-wrapped polystyrene are often used to avoid gas bubbles and sinking of parts of the sheet. The floating cover should be fixed to vertical ropes that are fastened to the store wall. This prevents the cover from turning during manure mixing and being lifted off by wind. Properly constructed roofs and some floating covers also exclude rainfall from the store and so increase the volume of slurry that can be stored;
- (iii) Natural crusts. Cattle slurries normally build up a natural crust of floating organic materials. The crust will only form if the dry matter is high enough (>7%) and stirring can be minimized. The crust should cover the whole of the surface area of the manure. The store must be filled from below the crust to avoid breaking it up;
- (iv) Floating crusts. The introduction of straw, LECA (light expanded clay aggregates) balls, peat, oil or other floating material on the slurry surface in tanks or lagoons can reduce emissions by creating an artificial crust.
- Straw. The most effective way is to introduce chopped straw with a self-propelled field chopper (forage harvester) at a length of about 4 cm. About 4 kg straw/m² should be blown into either the emptied or the filled tank by a well-instructed and experienced driver;
 - LECA balls. The introduction of LECA balls can be done very easily. It is more expensive than straw but only about one third as costly as a tent structure. About 10% of the material is usually lost yearly from emptying the store. Agitating one day before spreading and briefly just beforehand can help to reduce losses.

32. The use of oil and peat is not recommended because of practical difficulties due to a lack of experience under farm conditions.

33. It is more difficult to reduce ammonia emissions from lagoons than from tanks. The construction of new lagoons should be discouraged in favour of tanks. The replacement of existing lagoons with tanks can be considered to be an abatement technique. Covers for lagoons, however, are available and artificial crusts of straw or LECA balls have been used. About 7-12 kg/m² straw is needed. It may be difficult to retain these materials on large lagoons under windy conditions.

Table 5.1. Effectiveness and applicability of ammonia abatement techniques for slurry stores

Abatement Measure	Livestock Class	Emission reduction (%)	Applicability	Remarks
rigid lid or roof	all	70-95%	tanks and silos only	no additional capacity for rain water needed, limitation through static requirements
flexible cover (e.g. tent structure)	all	60	tanks and silos only	limitation through static requirements
floating cover	all	60	not practicable on lagoons due to high costs	
Natural crust	cattle, pig slurries with more than 5-7 % DM	35-50	not on farms with frequent spreading	
artificial crusts: straw	pig and cattle slurry	40-70	not practicable on thin liquid manures, not on farms with frequent spreading	increased N ₂ O and probably methane-emissions
artificial crusts: leca balls etc.	all	60-90%	also on thin liquid manures, not on farms with frequent spreading	increased N ₂ O and probably methane-emissions, loss of LECA through pumping
artificial crusts: peat	hardly any experience			increased N ₂ O and probably methane-emissions
artificial crusts: oil	practical difficulties and little experience			

Storage of solid manure

34. At present there are no proven techniques for reducing ammonia emissions from stored solid manures. After removal from animal houses, solid manure may be stacked on a concrete area, sometimes with walls, usually with drainage and a pit for collecting leachate. In some

countries, it is permitted to store manure in stacks on the soil in fields. Litter and manure from poultry, especially air-dried dung from laying-hens, is increasingly stored in bunkers. Management guidelines for limiting ammonia emissions are as follows:

- (a) Cover solid manure stores. This will reduce ammonia emissions but is impractical when manure has to be loaded frequently. Furthermore, the emission reduction is often neutralised by higher emissions at later stages of manure handling;
- (b) Make the surface area of the stack as small as possible (e.g. by constructing walls to increase the height);
- (c) Keep the manure as dry as possible, for example by:
 - (i) Storing under a roof, preferably on a concrete base;
 - (ii) Covering with a sheet;
 - (iii) Storing in narrow A-shaped heaps that shed water more readily, when no cover is used.

35. This is particularly important for litter from broilers and laying-hens and air-dried laying-hen excreta collected on manure belts that have a dry matter content of at least 60 to 70%, and thus emit very little ammonia. Excreta from deep pit battery-laying hen houses, which are often stored for a year beneath the surface of the house, emit high rates of ammonia due to their low dry matter content. To prevent ammonia emission, the dry matter content may be increased by passing exhaust air from the building over the manure heap.

36. Other techniques include maintaining the temperature of the heap below 50° C or increasing the C:N ratio to >25, e.g. by increasing the amount of straw or other bedding material used. The effectiveness of these techniques is not yet proven.

37. It is essential to take national or regional regulations concerning the avoidance of water pollution into account when locating manure stacks directly on the soil in fields.

E. Low emission animal housing systems

Introduction

38. Livestock housing, together with the application of manures to land, is one of the largest sources of ammonia emission from agriculture. This is due in large part to artificially ventilated pig houses. For all types of housing, the requirements of animal welfare codes must be taken into account in deciding stocking density, etc. Appropriate husbandry of the farm area can contribute to the reduction of ammonia emissions and other forms of pollution.

39. A range of emission abatement methods are available which vary from high to negligible cost and in their applicability to different housing systems.

Slurry based pig houses

40. For slatted floor systems, the following techniques can contribute to emission abatement:

- (a) Reduce the surface area of the slatted area, e.g. by using partially slatted floors. Slat design should facilitate maximum transfer of dung and urine to the channels. Solid floor areas should have provisions (e.g. a slight slope) for urine to drain to the channels. Channels should be emptied frequently to a suitable store outside the house. This can be achieved by the use of a vacuum system, by flushing with water, untreated liquid manure (under 5% dry matter) or separated and aerated slurry;
- (b) Reduce the exposed surface of the slurry beneath the slats, e.g. by constructing channels with inwardly sloping walls so that the channel is narrower at the bottom than at the top. The walls should be made of a smooth material to avoid manure sticking to them;
- (c) Lower slurry temperature. For existing houses, the temperature of the slurry in the channels can be lowered by pumping a coolant (e.g. groundwater) through a series of fins floating on the slurry (recycling groundwater may not be permitted in some countries or regions);
- (d) Improve animal behaviour and design of pens. Pens with partially slatted floors should be designed so that pigs can distinguish separate functional areas for lying, eating and dunging. The aim is to keep the solid part of the floor as free from dung and urine as possible to reduce ammonia emissions. For example, longer narrow pens help to ensure that the pigs do not dung on the solid part of the floor. The position of feeders and drinkers in the pen is also important. Feeders should be positioned in the front of the pen and drinkers at the back above the slatted part of the floor. High room temperatures encourage pigs to lie down on the slatted portion of the floor (the dunging area) rather than on the solid area. This can lead to a dirty solid floor area and an increase in emissions that make it necessary to take additional steps to achieve good abatement, (e.g. improved ventilation or controlling the temperature of the solid floor to encourage pigs to lie on it). Detailed design and management will vary from country to country and from region to region. In general it is more difficult to control the behaviour of the pigs in warmer climates;
- (e) Avoid ventilation directly above the surface of the slurry in the channels. The higher air velocity will increase ammonia emission from the manure surface. In pig houses where this is unavoidable, the gap between the slats and the manure surface should be sufficiently large to minimize air velocity.

Straw-based pig houses

41. In straw-based pig housing systems, i.e. with solid manure production, the following considerations are important:

- (a) Manage bedding to ensure pigs have a clean, dry bed;
- (b) Ensure that drinkers and troughs do not leak;
- (c) Prevent urine accumulation.

42. Straw-based systems are better for animal welfare but deep litter systems are also associated with high emissions of ammonia and nitrous oxide, especially during storage and composting (see section 5). A small amount of straw will provide more animal-friendly conditions for the pigs and will be better for the environment. An example is the straw-flow system. The eating of straw, however, can affect digestion in the pig so that a greater proportion of the N is excreted in the faeces.

Low emission systems for poultry buildings

43. Ammonia emissions are minimal when the dry matter content of manure or litter is 60% or above. For poultry litter and manure, abatement techniques should aim to increase the dry matter content by preventing spillage of water and, in new buildings, providing a drying mechanism.

44. Emission abating options for laying hen buildings include:

(a) Belt systems. Droppings are collected and regularly removed from the building on a belt fitted beneath the animals. Drying the manure on the belt gives a further reduction of ammonia emissions;

(b) Stilt houses. Droppings accumulate in a chamber beneath the tiered cages or aviary systems. The chamber has large openings to permit air to enter and assist drying. Existing buildings should be managed to maximize the drying of the manure.

45. In broiler and turkey buildings the quality of the litter is the main factor affecting ammonia emissions. In new buildings, ventilation systems should be designed to remove moisture under all weather and seasonal conditions and the house should be well insulated. In new and existing houses measures to avoid condensation should be taken and nipple type drinkers, which are less prone to spillage, should be provided for broilers.

Low emission systems for cattle buildings

46. Tied housing systems emit less ammonia than loose housing systems because of the reduced soiled area. Nevertheless such systems are now discouraged for animal welfare and labour reasons.

47. It is difficult to reduce ammonia emissions from naturally ventilated cattle buildings. Modifying the diet, as outlined in Section 3, offers some possibilities. Systems for frequently cleaning, by scraping or flushing, passageways used by the cattle may be possible in some buildings. Using water increases the volume of slurry that must be stored and managed. Adding acid or formalin to the flushing water improves ammonia emission abatement but is hazardous and not recommended. Designing the floors of passageways to minimize the exposed surface area of

the urine and to ensure that it drains rapidly to a pit can be considered for new buildings. This can be achieved by constructing ridged floors where urine collects in and drains from the narrow troughs. Good husbandry e.g. keeping passageways and yards used by cattle as clean as possible, can contribute to lower ammonia emissions on most farms.

48. For loose-housed cattle bedded on straw, increasing the amount of straw used per animal can reduce ammonia emissions from the building and during manure storage.

F. Limiting ammonia emissions from the use of mineral fertilizers

Ammonia losses from mineral nitrogen fertilizers

49. Most ammonia comes from livestock manures and slurries, but around 10% is emitted following nitrogen fertilizer application. Losses from ammonium nitrate (AN) are usually small, often less than 1% of the total nitrogen applied. Losses from other N fertilizers, e.g. MAP, ammonium sulphate and urea may be much greater. Losses from urea may range from 5% up to 30% under certain conditions which is why urea is often perceived to be a less efficient source of nitrogen.

Urea

50. To be useful as a fertilizer, urea needs to be broken down by the naturally occurring enzyme urease. Ammonia and carbon dioxide are released during this process. If this happens on the soil surface, then ammonia will be lost to the atmosphere. If the breakdown does not take place until the urea has been mixed into the soil then the ammonia can be 'captured' by clay and organic matter in the soil or form more stable compounds. Urea applications therefore need to be well managed to make most effective use as a fertilizer and to reduce the likelihood of ammonia emission. It is, therefore, important that urea is mixed or washed into the soil before such breakdown occurs.

51. Ammonia losses from urea application are often greatest on light, sandy soils due to their low clay content and limited capacity to absorb ammonium-N. Despite their high pH, losses on chalk soils may be less than on some other soil types because of their greater clay and calcium content and their capacity to retain ammonium-N.

52. In dry periods, ammonia losses may be greater from urea applied to grassland than to arable crops.

53. Ammonia emissions from aqueous solutions of urea are the same as for solid formulations. The amount of water applied in solution fertilizers is very small and not usually enough to wash the urea into the soil.

54. Foliar sprays of urea can increase the grain-N concentration of milling wheat but can result in emissions of ammonia.

G. Limiting ammonia emissions from mineral fertilizers

Urea

55. To minimize ammonia emissions from urea fertiliser, the following guidelines should be adhered to:

(a) Incorporate the urea into the soil. Quickly mix urea into the soil wherever possible. This option is not available where urea is top-dressed onto cereals or grassland but can be used where urea is applied to seedbeds. As for all nitrogen fertilizers, if seedbed applications are made, care must be taken to avoid large amounts of urea close to the seed because this may inhibit germination/sprouting;

(b) Spread urea during appropriate weather conditions. Apply urea just before there is sufficient rain to wash it directly into the soil. Where urea is used as a top dressing, the best time to apply is just before irrigation with water. Avoid applying urea when the soil is moist or when there are heavy dews at night but when the weather is changing to a dry or windy period. On grassland, it is particularly important that urea be applied only in the early season, for first-bite or first-cut silage, to increase the likelihood of rain occurring soon after application;

(c) Urease Inhibitors. Urease inhibitors can be used to delay the breakdown of urea until it has been washed deep enough into the soil to greatly reduce ammonia loss. They offer a potentially effective but costly method.

Ammonium sulphate

56. The potential for ammonia loss from ammonium sulphate will depend upon pH. Losses will be small with $\text{pH} < 7.0$ but above that level alternative sources of N and S should be sought.

Ammonium bicarbonate

57. Ammonium bicarbonate may be available in some UNECE areas. Gaseous N losses of up to 50% have been measured following its application. Ammonium bicarbonate should therefore not be used as N fertilizer.