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**Supporting documents**

**to the revised 1999 Protocol to**

**Abate Acidification, Eutrophication and Ground-level Ozone**

**DRAFT REVISION OF THE UNECE FRAMEWORK CODE FOR GOOD AGRICULTURAL PRACTICE FOR REDUCING AMMONIA EMISSIONS**

Submitted by the Co-chairs of the Task Force on Reactive Nitrogen

Draft 12-6-14

*Summary*

In implementing its Work Plan as agreed by the Executive Body (ECE/EB.AIR/109/Add.2, para 1.6), the Task Force on Reactive Nitrogen has worked on updating the ‘Framework Code on Good Agricultural Practice for Reducing Ammonia’ (EB.AIR/WG.5/2001/7) (hereafter the ‘Ammonia Framework Code’). The draft revision takes account of latest scientific knowledge and experience in ammonia abatement, as described in the recent update of the ECE Guidance Document for Preventing and Abating Ammonia Emissions from Agricultural Sources (ECE/EB.AIR/2012/L.9, the ‘Ammonia Guidance Document’), and takes account of the relevant European Commission’s reference documents on Best Available Techniques (BREFs).

Annex IX, paragraph 3 of the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone requires each Party to “establish, publish and disseminate an advisory code of good agricultural practice to control ammonia emissions”, noting that Parties should “give a title to the code with a view to avoiding confusion with other codes of guidance.” The Framework Code is designed to support Parties in preparing their National Ammonia Codes, as required by the Protocol. Following the revision of the Gothenburg Protocol and the Ammonia Guidance Document, the present revision of the Ammonia Framework Code may serve as a further stimulus for Parties to update their own National Ammonia Code or to establish such a code where this has not yet been accomplished.

The Working Group on Strategies and Review is invited to review this revision of the Ammonia Framework Code and to provide guidance to the Task Force on its finalization. In particular, the Working Group should advise on whether the Ammonia Framework Code represents a suitable level of ambition. Subject to necessary further amendments, the Working Group may recommend the revised Ammonia Framework Code to the Executive Body for adoption.

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[For transparency, the order of these sections has been retained from the previous Ammonia Framework Code. Once the revised text is agreed, it is proposed to re-order these sections, in line with the Ammonia Guidance Document, to follow the sequence of emission: feeding strategies, housing, storage, manure spreading, mineral fertilizers.]

**INTRODUCTION**

1. The purpose of this document is to provide guidance to the Parties to the Convention on Long-range Transboundary Air Pollution in identifying ammonia (NH3) control options and techniques for reducing emissions from agricultural sources in the implementation of their obligations under the Protocol.
2. The document has been prepared by the Task Force on Reactive Nitrogen (TFRN) through its Expert Panel on Mitigation of Agricultural Nitrogen (EPMAN).
3. The UNECE ‘Framework Code for Good Agricultural Practice for Reducing Ammonia’ (hereafter, the Ammonia Framework Code) provides a foundation to support Parties to establish, publish and disseminate their own advisory code of good agricultural practice to control ammonia emissions (hereafter, National Ammonia Code), as required under paragraph 3 of Annex IX to the 1999 Gothenburg Protocol on Long-range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level Ozone.
4. The Ammonia Framework Code was first established in 2001 (EB.AIR/WG.5/2001), two years after signature of the Gothenburg Protocol. Since that time substantial progress has been made in further developing and reducing the costs of ammonia abatement techniques. A review of ammonia mitigation costs in 2010 indicated that many options now show a net financial benefit to farmers if they are conducted effectively, where the economic value of nitrogen saved can exceed the cost of implementing the measure, as illustrated in the Ammonia Guidance Document (ECE/EB.AIR/2012/L.9). [[1]](#footnote-1) With these developments, the overall cost of ammonia mitigation across the UNECE according to the GAINS model is now estimated to be much less than previously estimated.[[2]](#footnote-2) Ammonia mitigation options are also now increasingly seen as part of strategies to improve overall nitrogen use efficiency of the food system, thereby providing wider benefits to the Green Economy.[[3]](#footnote-3)
5. Since the Gothenburg Protocol entered into force on 17 May 2005, some Parties have established their own National Ammonia Codes. However, by 2010, the experience of the TFRN “highlighted that many Parties to the Gothenburg Protocol had not produced an unambiguously named code of practice, as required under annex IX. By contrast, several Parties had elements of ammonia codes embedded within several other codes of practice” (ECE/EB.AIR/WG.5/2010/13, paragraph 33). This finding highlights the opportunity for the present revision of the Ammonia Framework Code to stimulate Parties to establish, revise and more widely disseminate their own National Ammonia Codes.
6. For convenience, this revision of the Framework Ammonia Code follows the same headings of Annex IX, paragraph 3, of the Gothenburg Protocol, which specifies that the Ammonia Code of each Party “shall take into account the specific conditions within the territory of the Party and shall include provisions on”:
   1. Nitrogen management, taking account of the whole nitrogen cycle;
   2. Livestock feeding strategies;
   3. Low-emission manure spreading techniques;
   4. Low-emission manure storage systems;
   5. Low-emission animal housing systems; and
   6. Possibilities for limiting ammonia emissions from the use of mineral fertilizers.
7. The present revision of the Ammonia Framework Code has been led by Mr Shabtai Bittman (Canada), Mr Martin Dedina (Czech Republic) and Ms Barbara Amon (Germany) as co-chairs of the TFRN Expert Panel on Mitigation of Agricultural Nitrogen. The section Lead Authors are Mr Harald Menzie (Switzerland) (Sections A and B), Mr J. Webb (Section C), Ms Barbara Amon (Section D), Ms Karin Groenestein (Netherlands) (Section E) and Mr Tom Misselbrook (UK) (Section F). The TFRN co-chairs thank each of the lead authors and the other contributing authors for their work. As with the Ammonia Guidance Document (see note 1), it is planned that the finalized Ammonia Framework Code will be published in a form that recognizes the wide contribution of experts and stakeholders to the preparation of this document.
8. This document is based on the original Ammonia Framework Code (EB.AIR/WG.5/2001) updated mainly using information described in the revised Ammonia Guidance Document (see note 1), where further details and references to the primary literature can be found.

## **Annex: UNECE Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions.**

**Section A: Nitrogen management, taking account of the whole nitrogen cycle**

### **Introduction**

1. Nitrogen, together with other plant nutrients, is essential for plant growth and sufficient amounts must be available for plants to achieve optimum crop yields. Nitrogen is readily lost from agriculture through a number of pathways including leaching and runoff of nitrate and organic N to water and gaseous emissions to air. From the perspective of agriculture’s role in air pollution, ammonia (NH3) and the greenhouse gas nitrous oxide (N2O) 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 which must be considered together. It is, therefore, important to consider the whole N-cycle in devising effective strategies for:

a) minimising both water and atmospheric pollution;

b) optimising N use for crop production; and

c) taking into account the effects of ammonia abatement on other N losses.

1. Most of the plant available N in manure or slurry is in the form of ammonium-nitrogen, which can substitute directly for mineral fertilisers. Ammonia emissions from organic and inorganic fertilizers represent a loss of valuable N and thus increase the requirement for commercial fertilisers to optimize crop yields. For this reason, the pre-amble and Annex IX of the Gothenburg Protocol firmly recommend that each Party shall take due account of the need to reduce ammonia losses from the whole N cycle. In agriculture, this applies especially in livestock, crop and mixed farming systems. In particular, the Protocol provides guidance to the Parties in identifying the best available options for reducing the release of ammonia from agriculture.[[4]](#footnote-4)
2. Ammonia emissions originate mainly from manures produced by housed livestock as slurries or solid manures and from applied mineral N fertilisers, and to a lesser extent from urine excreted by grazing animals and directly from crops. Emissions from manures occur sequentially from livestock buildings, manure stores and following application to land. Because the losses are sequential, the percent savings of ammonia from measures employed at each production stage are compounded rather than additive. This also means that measures to reduce ammonia emissions at an early stage (i.e. during housing and storage) should be followed by measures at a later stage (i.e. during manure spreading) to fully profit from the early savings if early savings are not to be lost. In many circumstances, optimised land application of slurry and livestock feeding strategies offer the greatest and most cost-effective opportunities for reducing emissions.

### **Elements of good N management**

1. Nitrogen management varies greatly across the UN-ECE region, and NH3 emissions vary accordingly. In general, emissions of nitrogen tend to decrease when:

a) All nitrogen sources on the farm are managed considering fully the ‘whole farm’ and ‘whole nitrogen cycle’ perspectives;

b) Amounts of nitrogen used are matched to the needs of growing plants and animals, including considerations of local breeds/ varieties, soil conditions, climate etc.;

c) Other limitations to production (such as other nutrient limitations, pests, stress) are minimized to the extent that is practical;

d) Nitrogen sources are stored effectively, then used in a timely manner, and applied with appropriate techniques, in the appropriate amounts, and in the appropriate places;

e) All important nitrogen loss pathways are considered in a coherent manner.

1. Ammonia from applied manure and fertilizer is mainly emitted from the soil surface before it enters the pool of mineral (plant-available) nitrogen in the soil. Matching N applications to crop uptake therefore has less direct impact on ammonia emissions than on nitrate leaching and denitrification losses. However, reducing the overall amount of ammonia applied will reduce losses; for example, application rates and losses may be reduced if N excretion is reduced by better matching feed N to animal requirements. Adopting measures to reduce ammonia emission following manure and fertilizer application will directly contribute to better management by conserving N for crop uptake. In countries that limit annual N applications, ammonia abatement from both manure and fertiliser will also improve crop yields and protein concentration.

**Aids to optimize N management**

1. Good N management on farms is a challenging task that requires knowledge, technology, experience, planning and monitoring. Tools for predicting optimum fertilizer rates and tools to calculate the N balance and N use efficiency are valuable aids for managing N on farms.
2. Fertilizer recommendations based on soil and crop testing provide indicative values on the nutrient requirements of crops and grassland. They are calibrated for local conditions and economic considerations and are therefore provided at the national or regional level in most countries. This helps farmers to dose appropriately their crops with manure, other organic amendments and mineral fertilizer to optimize yields and avoid nutrient surplus. However, this technology is still an inexact and an active area of research in many countries. On farm testing can be very helpful.
3. N balance tools compare N inputs with N outputs. The N **input-output balance** (also referred to as the **farm-gate balance**) is the total, at the farm level, of all nitrogen inputs coming into the farm (fertilizer, feed, bedding, animals, and should also account for N fixation by legumes and atmospheric N deposition) minus all nitrogen outputs in products (crops, animals products, manure) leaving the farms. The **field balance** is the total of field nitrogen inputs including manure and fertilizer (should include N fixations, deposition and irrigation) minus harvested products such as grain, fodder or fruit. In all nitrogen balances, the difference between nitrogen inputs and nitrogen outputs may be positive (surplus) or negative (deficit). An N surplus is an indicator for pressure on the environment while a deficit indicates nutrient depletion; both are expressed in terms of kg of nitrogen per ha per year.
4. The total nitrogen outputs divided by total nitrogen inputs is a measure of **Nitrogen Use Efficiency** (NUE) (amount of exported nitrogen per nitrogen input, expressed as kg per kg). Note that crop or animal yield per nitrogen input provides another important measure of nitrogen use efficiency.
5. Decreases in N surplus and increases of Nitrogen Use Efficiency over a period of years indicate improvement in nitrogen management. For this purpose, it is recommended that 5 years represents a suitable evaluation period. Nitrogen management can be improved until a ‘best management practice’ level is approached. Both nitrogen surplus and NUE values can be used to assess farms relative to one another or for comparison with model farms. However, different farm types vary in their characteristic NUE and N surpluses. Tools to calculate the nitrogen balance and nitrogen use efficiency are available in many countries.

10 bis. A wide range of options to reduce ammonia emission is described in the following sections, where the effectiveness is mainly described as a percentage reduction compared with a reference method. In general, while all emission reductions represent helpful contributions, achievement of a 30% reduction in emissions from a component source can be considered as a suitable performance benchmark for good practice. Many methods are available that offer more ambitious reduction opportunities.

**Section B: Livestock feeding strategies**

**Introduction**

11. Ensuring that farm livestock are not fed more protein than required for the target level of production can reduce the N excretion per livestock unit and per unit production. This should include maximizing the fraction of protein in the diet that can be metabolized, and minimizing the fraction that cannot be metabolized. Decreasing the amount of N in manure will not only abate ammonia emissions at all manure stages, but also other potential N losses (leaching, denitrification). N excretion by different livestock categories is strongly dependent on the production system. Hence, standard excretion values should be calculated on a national or regional level.

12. Protein surplus in livestock rations is primarily excreted in the form of urea (or as uric acid in the case of 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, the consequent emission abatement is effective at all stages of manure management (houses, storage, treatment, 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 often excesses in the protein supply for almost all livestock classes and production systems, the reduction of which can therefore 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) Reducing excesses in the protein supply by ensuring that it does not exceed current feeding recommendations. Table 1 gives indicative target levels for the crude protein (CP) content of the diet of different livestock species and production stages.

b) Better adjustment of the composition of the diet to the requirements of the individual animal, e.g. according to lactation stage, age and weight of animals, etc.

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 (milk yield, growth rate, feed conversion efficiency etc.), 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).

d) Considering the within- and between feed variability of the precaecal (or “ileal”) digestibility of crude protein and individual amino acids.

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. For ruminants protein surplus and N excretion strongly depend on the proportion of grass, grass silage, hay. grain and concentrates in the ration and the crude protein content of these feeds. The crude 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 a feed of lesser protein content (maize silage, hay harvested at advanced stages of maturity, straw etc.);

(ii) using more mature grass (wider cutting intervals) or rationed amounts of grass and more high energy concentrates and providing the appropriate amount of rumen-bypass protein

Nevertheless, for livestock production systems predominantly based on grassland, the feasibility of strategy b) (ii) 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 time that the animals spend grazing. This is 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 cut grassland due the uneven distribution of the excreta. The extent of grazing is typically 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. One strategy for 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 may also decrease ammonia emission per unit of milk production over the life of the animal.

21. The conversion of grass and legume N into ruminant protein could be improved by maintaining the quality of crude protein when making silage for winter feeding. Minimizing degradation of true protein in grass silage can be achieved by:

a) Ensiling grass as fast as possible after cutting;

b) Excluding oxygen from the silo quickly after filling;

c) Avoiding heat damage.

**Table 1. Indicative target levels for the Crude Protein (CP) content of the diet (in the Dry Matter, DM) of different livestock species, categories and production phases.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Species** | **Category** | **Production phase** | **CP content  (g/kg DM)** |
| Cattle | Dairy cows | early lactation | 150-160 |
|  | Dairy cows | late lactation | 120-140 |
|  | Replacement (heifers) |  | 120-130 |
|  | Fattening | Calf (veal production) | 170-190 |
|  |  | Beef <3 months | 150-160 |
|  |  | Beef >6 months | 120 |
| Pigs | Piglets | < 10 kg | 19–21 |
|  |  | < 25 kg | 17–19 |
|  | Fattening pigs | 25–50 kg | 15–17 |
|  |  | 50–110 kg | 14–15 |
|  | Sows | Gestation | 13–15 |
|  |  | Lactation | 15–17 |
| Poultry | Broilers | Starter | 20–22 |
|  |  | Grower | 19–21 |
|  |  | Finisher | 18–20 |
|  | Layers | 18–40 weeks | 15.5– 16.5 |
|  |  | 40+ weeks | 14.5– 15.5 |
|  | Turkeys | < 4 weeks | 24–27 |
|  |  | 5–8 weeks | 22–24 |
|  |  | 9–12 weeks | 19 –21 |
|  |  | 13+ weeks | 16-19 |
|  |  | 16+ weeks | 14 –17 |

**Section 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 ammonia 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, might 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 the maximum agronomic benefit from manures, and to avoid increasing the risk of nitrate leaching, attention should be paid to the N content of the manure so that the rate, method and time of application is matched to crop requirements, taking account of the amount of N saved when using low-emission practices.

21. bis The techniques summarized below reduce emissions of ammonia by reducing exposure of the manure to the atmosphere. Hence the methods are effective for all climates. Although absolute ammonia emissions will be influenced by climate, tending to increase with increasing temperature, the proportion of the ammonia emission abated by reduced-emission techniques has not been found to depend on climate. Emission reductions are shown in Table 2.

**A. Reduced 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. Such approaches also have the agronomic benefit of a more consistent application of slurry, with a more precise placement that can reduce the risk of slurry run-off.

Injectors: These reduce ammonia 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 for reduction of ammonia emission 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. Application volumes may be limited by the volume of the slots.

(b) Deep injectors: these apply slurry or liquid manure to a depth of 10-30 cm in the soil using injector tines spaced about 50 cm or even 75 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 of ammonia from slurries and liquid manures through decreasing the manure surface area exposed to the air and decreasing exposure to the air flow over it. The efficiency of these machines can vary depending on the height of the crop. 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 arable 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 and below the crop canopy. Some types of trailing shoes are designed to cut a shallow slit in the soil to aid infiltration.

**Rapid 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, at most, 6 hours of spreading to achieve worthwhile abatement. The most effective abatement is achieved by incorporation immediately after spreading. Completely burying the slurry by ploughing is a slow operation and, in many cases, 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 before being well mixed with the soil by cultivation. Incorporation of solid manures is discussed below.

**Dilution of slurry**

23 bis. Ammonia emissions from dilute slurry with low Dry Matter (DM) content are generally less than for undiluted slurry because of faster infiltration into the soil.

Two options are available:

1. Slurry can be added to irrigation water to be applied onto grassland or growing crops on arable land. This is best done by injecting slurry into the irrigation water pipeline and pumping under low pressure to the sprinkler or travelling irrigator (not under high pressure to a big gun which sprays the mix onto land). Dilution rates may be up to 50:1 water: slurry, but at least 1:1, resulting in an estimated emission reduction of 30%.[[5]](#footnote-5)
2. Water can be added to viscous slurries before application, either in the slurry store or in the tank wagon. For viscous cattle slurries even dilution rates of 0.5:1 water: slurry can contribute to loss reduction. However, the extra costs for the transportation of water are considerable and it is important, that the slurry application rate is increased proportionally to the reduction of the Total Ammonia Nitrogen (TAN) content.

**Application Timing Management Systems (ATMS)**

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

(a) Time of application: spreading under cool, windless and humid conditions, will help to reduce ammonia emissions.

(b) Application shortly before rainfall (only effective if at least 10 mm of rainfall occurs immediately after spreading). This measure is only applicable on flat land and away from surface waterways, otherwise there will be a risk of run-off.

(c ) Spreading in the evening, when wind speed and air temperature are decreasing.

(d) Spreading on freshly cultivated soils, provided that there is more rapid manure infiltration.

**Acidification of slurry**

23 quater. Low pH reduces loss of ammonia from manure. Lowering the pH of slurries to a stable level of 6 or less is commonly sufficient to reduce ammonia emission by 50% or more. This can be achieved by adding sulphuric acid to slurry. A technique which automatically doses sulphuric acid during the application of slurry is now on the market and practiced on farms in Denmark with considerable success.

**Other Additives**

23 pent. The use of other additives to slurry, apart from acids, is either not proven to be effective in reducing ammonia emissions or have practical problems that limit their use.

**B. Reduced emission techniques for solid manures**

24. Rapid incorporation into the soil is the only practical technique for reducing ammonia emissions from solid manure, although recently there has been some success in the USA with slot injectors for poultry litter. Most of the ammonia is released from solid manure within a few hours of spreading. It is recommended, therefore, that incorporation should take place within a few hours after spreading. The manure must be completely mixed with soil or 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.

24 bis. Reductions of 60-90% of ammonia emissions can be achieved when solid manures are incorporated into arable land by plough within 4 h of application. In contrast to slurry, studies have shown that incorporation of solid manures by plough is always more effective than incorporation by disc or tine despite the slower work rate of ploughing.

25-26. [These paragraphs are replaced by the new provisions following paragraph 23.]

**C. 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 2. The reduction of ammonia emissions is expressed as a percentage of the reference method. The reference for manure application method is defined as the ammonia 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 following considerations are relevant in working to reduce ammonia emissions from manure spreading:

1. The amount of abatement achieved with band spreaders and injectors will vary with the dry matter content of the slurry, soil properties, neatness of work and crop characteristics;
2. The effectiveness of incorporation varies with the type of manure and the time since spreading; immediate incorporation is most effective;
3. Band spreaders (trailing hoses) are, in general, more effective on arable than on grassland and when used with dilute pig slurries than with more viscous cattle slurries;
4. Band spreaders and open slot injectors are not always suitable for use on steeply sloping land due to runoff potential. Slurry application to such land should be avoided to minimize the risk of run-off. Sub-surface injection techniques do not work well on very stony or compacted soils;
5. Open slot injectors are more applicable to a wider range of soil types and conditions than closed slot machines;
6. Small, irregularly shaped fields present difficulties for large machines; low-emission equipment should be chosen that is most suitable to local terrain;
7. Incorporation is restricted to land that is cultivated; on grassland, band spreading and injection methods are most appropriate;
8. 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 or tanker truck. They have the advantage of greater work rates and of lessening the risk of soil damage by compaction and can preferably be used on farms with small distances between slurry store and fields. However, it is time consuming to roll out hoses and roll them back in again;
9. Dilution in irrigation systems is limited to situations where irrigation is practiced, in which case this can be a very effective measure for abating ammonia emissions;
10. Diluting slurry in mobile systems is only practical on small farms, since additional water to be spread reduces the spreading performance and increases spreading costs;
11. Capital and operating costs for reduced emission systems are likely to be more than for broadcast spreading techniques, but savings of mineral nitrogen fertilizer can more than compensate these extra costs when the most effective options are used;
12. Applying the liquid fraction from an efficient separating machine can give a significant reduction in ammonia emissions of 20-30%, due to more rapid infiltration associated with lower dry matter content. To achieve the benefit of this approach, the liquid fraction should as far as possible be applied under soil conditions that support infiltration (e.g. not saturated or very compacted). If no action is taken, emissions from the solid fraction will be larger (due to higher dry matter content, which limits infiltration into the soil). Emissions from the solid fraction should therefore be reduced during storage and during spreading (i.e. by rapid incorporation into the soil), or the solid fraction should be applied for other uses (e.g. anaerobic digestion);
13. The liquid digestate remaining after anaerobic digestion has a low dry matter content allowing it to infiltrate quickly on application to well draining soils. However, it also has a high pH making it liable to high ammonia emissions unless low-emission techniques are used (e.g. injection, band spreading or acidification).
14. The working width is limited for injectors, while band-spreading methods offer a much wider working width. Because of the narrower working width, an increased amount of damage from the wheels should be considered when using manure injector systems;
15. Acidification is normally done by mixing concentrated sulphuric acid into the slurry prior to or during application. However, sulphuric acid is a dangerous chemical, and must be handled with care.

**Table 2. Practical considerations in the selection of ammonia abatement techniques for land spreading of manures.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Abatement**  **technique** | **Manure type** | **Land use** | **Typical reduction in** **ammonia emission %1** | **Restriction on applicability** |
| Trailing hoses | Slurry and other liquid manure | Grassland/  arable land | 30-35% | Field slope, size and shape. Not highly viscous slurry. Width of tramlines for growing cereal crops.  On arable land, emission reduction increases with crop height. |
| Trailing shoe | Slurry and liquid manure | Grassland and arable land (pre-seeding) and row crops | 30-60% | As above. Not usually suitable for use in arable crops but may be suitable for rosette stage of row crops. |
| Shallow injection | Slurry and liquid manure | Grassland and arable land. Also on growing cereals | open slot 70%;  closed slot 80% at 10 cm depth; | As above. Not for very dry, stony or very compacted soils |
| Deep injection  (including arable injectors) | Slurry and liquid manure | Arable land | 90% | As above. Needs high powered tractor. Not suitable on shallow soils, high clay soils (>35%) in very dry conditions, on peat soils (>25% organic matter content) and perforated-tile drained soils that are susceptible to leaching. |
| Active dilution of slurry for use in water irrigation systems | Slurry | Arable land and grassland | 50% dilution (i.e. 1 slurry : 1 water) = 30% reduction | Only where irrigation is practiced. Only for low pressure irrigation systems. |
| Dilution before spreading with mobile spreading systems | Particularly viscous cattle slurry | Arable land and grassland | Up to 50% for viscous cattle slurries (50% dilution = 30% reduction) | Extra volume needed to be spread. Only for small farms and for irrigation. Dose must be increased proportionally to the reduction of the TAN content. |
| Application timing management systems (ATMS). | All manure types | Arable land and grassland |  | This technique requires local validation |
| Incorporation into soil | Slurry | Arable land including new grass leys, seedings. Only effective, if incorporation occurs right after application. | Immediate ploughing 90%; Immediate non-inversion cultivation 70%; incorporation within 4 h =45-65%; incorporation within 24 h =30% | Land that is cultivated. |
| Incorporation into soil | Solid manure | Arable land including grass leys. Only effective, if incorporation occurs right after application | Immediate ploughing 90% Immediate non-inversion cultivation 60%; incorporation within 4 h =45-65%;  incorporation within 12 h =50%; incorporation within 24 h =30% | Land that is cultivated. |

**1Relative to reference system, see paragraph 27**

**Section D:** **Low-emission manure storage systems**

**Introduction**

29. Ammonia losses from buildings and after spreading livestock 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 there is a crop nutrient requirement and the risk of water pollution (e.g. through nitrate leaching) is low.

**Storage of slurry and other liquid manures**

30. After removal from livestock buildings, slurry is stored either in concrete, steel or wooden tanks (or silos), in lagoons or in bags. Lagoons have a larger area per unit volume 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:

1. 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.
2. 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.

(a bis.) Management and surroundings of slurry tanks

1. Frequent mixing and emptying should be avoided wherever possible because these operations increase ammonia emissions. 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.
2. Reduction in the air velocity on the slurry surface can be achieved by a sufficiently high freeboard and by planting a tree shelterbelt.
3. Both below ground tanks outdoors and shadowing of stores may reduce the temperature of the slurry in the storage tank and thus result in a significant reduction of ammonia (and methane) emissions.

(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 3. They include:

(i) Solid covers*.* 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. In areas with heavy rainfall solid covers have the advantage of preventing rain from entering the store and thus avoid an increase in transport volume from rainwater.

(ii) Floating covers*.* These are usually made from plastic sheets and are less effective than roofs. 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. Some floating covers also exclude rainfall from the store and so increase the volume of slurry that can be stored;

(ii bis) Floating plastic bodies (hexacovers). Floating hexagonal plastic bodies form a closed floating cover on the slurry surface. The vertical ribs in the bodies prevent the elements from being pushed one on top of the other. They may be used only in pig slurry or other liquid manures without natural crust. They are not suitable for slurries rich in organic matter, because they will become part of a crust which will be difficult to break.

(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, granulates (light expanded clay aggregates or perlite) 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 use a self-propelled field chopper (forage harvester) to introduce chopped straw of about 4 cm length. About 4 kg straw/m2 should be blown into either the emptied or the filled tank by a well-instructed and experienced driver. Straw covers are likely to increase CH4 and N2O emissions because of the increased carbon added. The slurry dry matter is also increased which as a consequence raises NH3 emissions after slurry application.

- Granulates (LECA balls / Perlite). The introduction of granulates can be done very easily. It is more expensive than straw, but only about one third as costly as a compared with 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 of its use and lacking experience under farm conditions and because it is likely to lead to a strong increase in CH4 emissions.

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 or other low-emission solutions (see below). 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, LECA balls, plastic bodies and foils have been successfully used. About 7-12 kg/m2 straw is needed in this case. It may be difficult to retain these materials on large lagoons under windy conditions.

33 bis. Storage bagsare suitable for reducing emissions from slurry. Interest in this approach is growing because such systems can be implemented at significantly lower cost than building an elevated slurry store with solid roof. There may be a risk of water pollution if not correctly maintained.

**Table 3. Effectiveness and applicability of ammonia abatement techniques for slurry stores**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Abatement**  **Measure** | **Livestock**  **Class** | **Emission reduction (%)** | **Applicability** | **Remarks** |
| Rigid lid or roof | all | 80 | tanks and silos only | no additional capacity for rain water needed,  limitation through static requirements |
| Flexible cover (e.g. tent structure) | all | 80 | tanks and silos only | limitation through static requirements |
| Floating foil | all | 60 |  |  |
| Floating plastic bodies | all | c. 60 | Not on crusting manures | Further data on emission reduction needed |
| Natural crust | cattle, pig slurries with more than 7  % DM | 40 | not on farms with frequent spreading |  |
| Artificial crusts:  straw | pig and cattle slurry | 40 | not practicable on thin liquid manures, not on farms with frequent spreading | May lead to increased N2O and CH4 emissions |
| Artificial crusts:  leca balls etc. | pig slurry, liquid manures | 60 | also on thin liquid manures, not on farms with  frequent spreading | loss of some LECA through pumping |
| Replacement of lagoons with covered/open tanks | all | 30-60 |  | The reference in this situation is reflects the higher emission rate from open lagoons. |
| Storage bag | all | 100 |  | Most experience so far with small pig farms, but has also been used in larger dairy farms. |

Storage of solid manure

34. At present there are few options for reducing ammonia emissions from stored solid manures. Clear good-practice guidelines nevertheless apply. 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 – at least over a limited period. However this can lead to significant losses through ammonia emissions, denitrification and leaching. 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. While the use of solid covers may not always be practical, the use of plastic sheeting has been shown to reduce ammonia emissions substantially without significantly increasing methane or nitrous oxide emissions. As with reduced emission storage of slurry, it is important that covered storage of solid manure is followed by low-emission spreading techniques (i.e. immediate incorporation), otherwise the nitrogen savings may be lost at this later stage;

(b) Add an increased amount of straw to the manure. This approach can be considered as less effective than covering solid manure, with variable performance depending on the type of manure, conditions and possible increase in nitrous oxide and methane emissions;

(b) Make the surface area of the stack as small as possible (e.g. by constructing walls to increase the height). This approach can also be considered as less effective than covering manure.

(c) Keep the manure as dry as possible. This is particularly important for poultry litter (broilers and laying hens) and belt dried poultry manure, where the availability of moisture allows uric acid to breakdown to produce ammonia. Measures to keep poultry manure dry include:

(i) Covering with a sheet;

(ii) Storing under a roof, preferably on a concrete base;

(iii) If it is not possible to cover poultry manure, storage in narrow A-shaped heaps may help shed water more readily, although the extent of benefits from this approach remain poorly quanitified.

35. Air-dried laying-hen excreta collected on manure belts that have a dry matter content of at least 60% to 70%, emit very little ammonia. These manures must be kept dry and prevented from remoistening. Therefore storing under a roof (34.(c)) is the most appropriate option.

35 bis. 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 (i.e. high moisture content). To reduce 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 50o C or increasing the C:N ratio to >25, e.g. by increasing the amount of straw or other bedding material used.

37. It is essential to take national or regional regulations concerning the avoidance of water pollution into account if locating manure stacks directly on the soil in fields, given the significant risks of leaching and run-off associated with this practice.

**Section 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. 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.

## 39 bis. Several general principles should be adhered to for the housing of livestock in order to reduce ammonia emissions:

1. Keep all areas (activity, lying, exercise area) inside and outside the animal house dry and clean;
2. Keep manure surfaces in pits as small as possible (for instance with partly slatted floors, sloped pit walls);
3. Remove excreta from the livestock building as soon as possible;
4. Keep air velocity and temperature of air over surfaces that are fouled with excreta as low as possible, except where manure is being dried, e.g. by cooling incoming air or, in the case of natural ventilation, considering prevailing wind direction;
5. Offer the animals functional areas (for lying/sitting, feeding, defecating, exercising);
6. Clean the exhaust air in the case of artificially ventilated buildings.

**Low emission systems for cattle buildings**

[Paragraphs 46 to 48 have been moved forward]

46. The cubicle house is the most common housing system and considered to be the reference. In some countries dairy cattle are still held in tied stalls, however they are not recommended in consideration of animal welfare and –health, unless daily exercise is applied. Because of maintaining continuity in emissions inventories, tied stalls are considered the traditional reference systems.

47. It is difficult to reduce ammonia emissions from Naturally Ventilated Buildings (NVB) that house cattle. Modifying the diet, as outlined in Section 3, offers some possibilities. Systems for frequently cleaning, by scraping or flushing may be possible in some buildings. Using water for cleaning reduces emissions, while increasing the volume of slurry that must be stored and managed. There is some ongoing research in the possibilities to reduce emissions from NVBs by reducing the air velocity over emitting surfaces (through changes in the openings, application of wind shielding nets, etc.), but the work is in its beginning and no recommendations are available so far.

47 bis. In houses with traditional slats, optimal barn climatization with roof insulation and/or automatically controlled natural ventilation can achieve a moderate emission reduction (20% compared to conventional system), due to the decreased temperature (especially in summer) and reduced air velocities.

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. The appropriate amount of straw depends on breed, feeding system, housing system and climate conditions.

48 bis. There is no evidence of significantly higher losses from houses with well managed straw systems compared with slurry systems, provided that the floor space per animal is similar.  More research is needed on relative emissions between these systems. Management of straw systems takes more effort than slurry based systems.

48 ter. The following approaches can be used to reduce ammonia emissions from dairy and beef cattle housing:

a) Good husbandry e.g. keeping passageways and yards used by cattle as clean as possible, can contribute to lower ammonia emissions on most farms.

b) The "grooved floor" systemfor dairy and beef cattle housing employing “toothed” scrapers running over a grooved floor is a reliable technique to abate ammonia emissions. Grooves should be equipped with perforations to allow drainage of urine. An ammonia emission reduction of 25% to over 40% can be achieved relative to conventional system.

c) Adding acid to the flushing water can significantly reduce ammonia emissions from buildings. Further assessment is necessary.

d) Although adding formalin to slurry improves the effectiveness of ammonia emission abatement, it is hazardous and therefore not recommended.

**Slurry based pig buildings**

[the original paragraph numbering continues here]

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 scrapers or of a vacuum system, by flushing with water, untreated liquid manure (under 5% dry matter) or separated slurry;

Partly slatted floors covering 50% of floor area generally emit 20-50% less ammonia than fully slatted floors, particularly if the slats are less sticky for manure than concrete (e.g., metal or plastic-coated slats).

(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. Reducing the emitting surface area with shallow V-shaped gutters (max. 60 cm wide, 20 cm deep) can reduce emission in pig houses by 40 to 65%, depending on pig category and the presence of partly slatted floors. The gutters should be flushed twice a day with the liquid (thin) fraction of the slurry rather than water;

For lactating sows, emission reduction of up to 65% can be achieved by reducing the emitting area by means of constructing a pan under the slatted floor of the pen. The pan is a sloped subfloor (at least 3°) with manure drainage at the lowest point.

(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); Surface cooling of manure with fins using a closed heat exchange system can reduce emissions by 45-75% depending on animal category. This technique is most economical if the collected heat can be exchanged to warm other facilities such as weaner houses.

(c bis.) NH3 emission reduction can be achieved by acidifying the slurry to shift the chemical balance from NH3 to NH4+. The manure (especially the liquid fraction) is collected into a tank with acidified liquid (usually sulphuric acid, but organic acids can be used as well) maintaining a pH of less than 6. In piglet housing emission reduction of 60% has been observed.

(d) Improve animal behaviour and design of pens. Pens with partially slatted floors must 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. This can be done by using the nature of the pig to avoid dunging in eating and lying area’s by optimizing pen layout and climatic control.

For example, longer narrow pens with feeders in the front of the pen and drinkers at the back above the slatted part of the floor can avoid dunging on solid 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, controlling the temperature of the solid floor to encourage pigs to lie on it or installation of automatic sprinklers for cooling during hot summer periods). 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.

(e bis.) Clean the air from NH3 with acid scrubbers or biotrickling filters. Although more expensive, such scrubbing approaches offer the highest potential for mitigation of artificially ventilated buildings and may be considered appropriate where there is a strong national, regional or local imperative to reduce NH3 emissions (e.g., in the European Union when in the vicinity of an adversely affected Special Area of Conservation).

40 bis. In principle, many of the methods for reducing ammonia emissions from slurry-based pig buildings could also be applied to slurry-based cattle houses. Although these are generally naturally ventilated, preventing the easy application of scrubbers to clean exhaust air, strategies to reduce exposed surfaces, lower slurry temperature, acidify slurry, and minimize ventilation over the slurry surface, are all applicable.

**Straw based pig systems**

41. In straw-based systems use fresh, clean, dry and hygienic bedding material. Use sufficient bedding material in order to allow complete adsorption of urine. Apply bedding frequently if necessary. If complete adsorption of urine is not possible, sloped floors and gutters should allow rapid drainage and removal of urine. Leakages of drinking systems must be avoided at any time in order to avoid additional moistening of the bedding.

42. Straw-based systems are better for animal welfare than slurry-based systems. There is no evidence of significantly higher losses from houses with well managed straw systems than those with slurry, provided that the floor space per animal is similar. For animal welfare and environmental reasons, systems should be used where the pigs differentiate a lying and a dunging area. This is according to the pigs´ natural behaviour and at the same time reduces emissions. Management of straw systems takes more effort than slurry based systems.

42 bis. Kennel houses combine free ventilation systems and the realization of functional areas. Ammonia emissions may be reduced by 20%. More space is needed compared with forced ventilated buildings. Building costs are similar.

**Low emission systems for poultry buildings**

43. Ammonia emissions are minimal when the dry matter content of poultry manure or litter is 60% or above. Under these conditions insufficient moisture is available to allow the breakdown of uric acid to liberate ammonia. This means that further drying will not increase ammonia emissions. By contrast, drying of poultry manure that has already become wet, and in which uric acid breakdown has already occurred, will lead to increased NH3 emissions. For poultry litter and manure, abatement techniques should therefore aim to increase the dry matter content by preventing spillage of water and, in new buildings, by providing a drying mechanism that maintains litter dry matter content above 60%.

44. In buildings for laying hens, ammonia emissions from *battery deep-pit or channel systems* can be lowered by reducing the moisture content of the manure by ventilating the manure pit. Other emission abatement options for laying hen buildings include:

a) Belt systems in *cage housing systems (cage battery, enriched cage)*: The collection of manure on belts and the subsequent removal of manure to covered storage outside the building can reduce NH3 emissions, particularly if the manure has been dried on the belts through forced ventilation. Manure collected from the belts into intensively ventilated drying tunnels, inside or outside the building, can reach 60–80% dry matter content in less than 48 hours. Belt drying would be expected to prevent substantial hydrolysis, but heating up manure that is only infrequently removed, and allowed to become wet, should be avoided. An increase of the removal frequency from once per week to two or three times per week reduces NH3 emissions.

b) *Aviary systems (non cage housing system)* with manure belts for frequent collection and removal of manure to closed storages reduce emission by more than 70% compared with a deep litter housing system.

44 bis. Exhaust air from poultry houses can be cleaned from NH3 with acid scrubbers or biotrickling filters. Because air from poultry barns contains much large dust particles that can clog the scrubber, a multistage scrubber is recommended which removes the large particles in the first stage. Such multistage scrubbers offer co-benefits in reducing ammonia and other particulate matter emission, which also contains substantial amounts of phosphorus and other elements, allowing these to be recycled as plant nutrients.

45. In broiler and turkey buildings the quality of the litter is the main factor affecting ammonia emissions as in other poultry systems, since this affects the extent of uric acid breakdown. 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 (insulation) should be taken and nipple type drinkers, which are less prone to spillage, must be provided for broilers.

[Paragraphs 46 to 48 have been moved to follow Paragraph 39]

**Section F: Limiting ammonia emissions from the use of mineral fertilizers**

**Introduction**

49. Most ammonia comes from livestock manures and slurries, but in many temperate countries around 10% or more is emitted following nitrogen fertilizer application, when large areas are used for crops. Losses from ammonium nitrate are usually small, typically in the range 0.5-5% of the total nitrogen applied. Losses from other N fertilizers, e.g. ammonium phosphate, ammonium sulphate, urea and Urea Ammonium Nitrate (UAN) may be much greater, in the range 5-40% depending on conditions.

49 bis. Favourable conditions for the efficient absorption of ammonium ions in the soil include: i) when fertilizer is incorporated into the soil, ii) when the soil has a high absorption capacity, (iii) when the soil is sufficiently moist, (iv) when the soil has a low pH, (v) when the temperature is low.

**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 (and carbon dioxide) 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 application therefore needs to be well managed to maximize its effectiveness 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 it begins to break down.

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. Hydrolysis of urea placed in bands tends to cause a local increase in pH which can lead to high emissions unless the urea bands are injected or well incorporated into the soil which will trap the volatilized ammonia.

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

53. Ammonia emissions from aqueous solutions containing urea are similar to those from solid formulations. The amount of water applied in solution fertilizers is very small and not usually enough to wash the urea into the soil. However, absolute losses may be less if the application rates are significantly smaller.

54. Foliar sprays of urea can increase the grain-protein concentration of milling wheat and other cereals but can result in high emissions of ammonia.

**Reducing ammonia emissions from urea**

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

a) Incorporate the urea into the soil.Quickly mix urea into the soil wherever possible. This option reduces emissions for urea by around 50-80%. This option is not available where urea is top-dressed onto cereals or grassland, but can be used where urea is applied to seedbeds or between seed rows.

b) Inject urea into the soil. The closed slot injection of the solid and liquid urea is more effective than shallow incorporation, with emission reduction of up to 90 %. Improperly closed or incorporated bands of urea are prone to very high emissions due to a rise in pH within the band when the urea hydrolyzes. The rise in pH is mitigated by slow release urea products and urease inhibitors. 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. Risk of crop injury is reduced by products that slow urea hydrolysis.

c) Urease Inhibitors*.* Urease inhibitors can be used to delay the breakdown of urea until it has been washed deep enough into the soil, and to prevent sharp increases in pH especially in bands, giving emission reductions of 40 % for liquid urea ammonium nitrate and 70 % for solid urea.

d) Irrigate the field after urea application.Irrigation of at least 5 mm immediately after application of urea leads to an emission reduction of 40-70%. This technique is only considered to be practical where there is a water need for irrigation.

e) Polymer coated urea granules provide a slow release fertilizer that may reduce emissions by about 30% by delaying hydrolysis. There is not much practical experience is available to date.

f) Switching from urea to ammonium nitrate fertilizer can reduce ammonia emissions. A possible negative side effect is the potential increase in direct nitrous oxide emissions, but this effect occurs mainly under wet conditions and on fine textured soils (and should be offset against the reduction in indirect nitrous oxide emissions resulting from ammonia emissions). Ammonium nitrate fertilizers can be more expensive (10-30% higher costs) than urea but the net cost may be negligible because of the lower N losses. In some countries ammonium nitrate is not readily available.

**Ammonium sulphate and ammonium phosphate**

56. The potential for ammonia losses from ammonium sulphate and ammonium phosphate largely depend upon soil pH. Losses will be smaller from soils with pH < 7.0.

56 bis. On calcareous soils (pH > 7.5), do not use ammonium phosphate, or ammonium sulphate fertilizers if rapid incorporation, injection into the soil, immediate irrigation or the use of polymer coated fertilizer is not possible, but seek alternative sources of N, P and S.

**Reducing ammonia emissions from ammonium-based mineral fertilizers**

56 ter. Several of the techniques described above for urea, including incorporation, injection, immediate irrigation and the use of slow-release fertilizers, can also be used to reduce ammonia emissions from ammonium sulphate, ammonium phosphate and ammonium nitrate based fertilizers.

**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. Although emissions may be reduced during field application of ammonium bicarbonate by appropriate placement (para 56 ter.), substantial losses also occur during storage of ammonium bicarbonate. Given the very high rates of ammonia emission, ammonium bicarbonate should therefore not be used as N fertilizer.

1. Now published as: Bittman, S., Dedina, M., Howard C.M., Oenema, O. and Sutton, M.A. (2014) (eds.) *Options for ammonia mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen.* TFRN-CLRTAP, Centre for Ecology and Hydrology, UK. [ISBN: 978-1-906698-46-1] [↑](#footnote-ref-1)
2. Winiwarter W. and Klimont Z. in: Reis S., Sutton M.A., Howard C.M. (eds) (2014) *Costs of ammonia abatement and the climate co-benefits*. Springer Publishers (in preparation). [↑](#footnote-ref-2)
3. See: Sutton M.A., Bleeker A., Howard C.M., Bekunda M., Grizzetti B., de Vries W., van Grinsven H.J.M., Abrol Y.P., Adhya T.K., Billen G.,. Davidson E.A, Datta A., Diaz R., Erisman J.W., Liu X.J., Oenema O., Palm C., Raghuram N., Reis S., Scholz R.W., Sims T., Westhoek H. & Zhang F.S., with contributions from 25 others (2013) *Our Nutrient World: The challenge to produce more food and energy with less pollution.* Global Overview of Nutrient Management. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative. 114 pp. <http://initrogen.org/index.php/publications/our-nutrient-world/> [↑](#footnote-ref-3)
4. The UNECE Ammonia Guidance Document (ECE/EB.AIR/2012/L.9; Bittman et al. 2014, see note 1) [↑](#footnote-ref-4)
5. Ammonia Guidance Document (note 1), paragraph 146 and Figure 1. [↑](#footnote-ref-5)