Chapter II: Technical overview

Integrating principles and measures for sustainable nitrogen management in the agrifood system

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36. The guidance provided in this document is structured around four main themes:

(a) **Principles of integrated sustainable nitrogen management.** Chapter III provides the background to help understand the integrated approach, including key points of nitrogen (N) cycling, dimensions of integration and principles of the measures;

(b) **Housed livestock, manure storage and manure processing.** Chapter IV explains the rationale for an integrated approach to manure management from excretion to storage, including opportunities for processing that treat manure as a valuable nitrogen and nutrient resource to be recycled. The core of the chapter is a summary of the main dietary, housing, manure and nutrient recovery measures;

(c) **Field application of organic and inorganic fertilizers.** Chapter V considers the field use of manure, setting this in relation to opportunities for improved management of manufactured inorganic fertilizers. Following established norms, the term "inorganic fertilizers" includes manufactured urea fertilizer. The core of the chapter is a summary of the main measures associated with field application;

(d) **Land-use and landscape management.** Chapter VI explains how opportunities for integrated nitrogen management are provided by decisions at the land-use and landscape scale. While the main focus is on mitigation of adverse effects, measures may also contribute to abatement of nitrogen emissions. The core of the chapter is a summary of the most important measures available at the landscape scale.

37. This Technical overview includes an indication of the performance of each measure for each nitrogen form (see figure II.1), according to the UNECE categories[3].

38. Further details on the performance of each measure, including a qualitative indication of the magnitude of effects, are provided in chapters IV, V and VI. A reduction in "Overall N loss" indicates potential for indirect reduction of all other N losses.

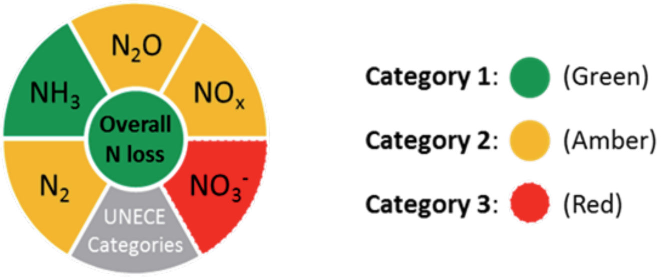
A. Principles of integrated sustainable nitrogen management

39. Nitrogen (N) provides substantial benefits to society by boosting crop productivity, allowing richer diets for humans, including with increased meat and dairy production and consumption. However, N losses present multifaceted problems affecting air, water, human health, climate, biodiversity and economy. To grasp the principles of sustainable nitrogen management, it is first necessary to consider the key points of nitrogen cycling (see box II.1).

40. Integrated sustainable nitrogen management in agriculture has a dual purpose: to decrease N emissions/losses, including to protect human health; the environment and climate; and to optimize the beneficial effects of N related to food production through balanced fertilization and circular economy principles.

41. Many environmental policies have a narrow scope concerning nitrogen management and would benefit from an integrated approach. For example, most NO_x and NH_3

Figure II.1: Illustration of the performance of each of the measures for each N form, according to UNECE categories assigned in this document



Source: The figure was created for the present document.

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[3] See chapter I, paras. 16–20, of the present document for a description of the UNECE categories and system for representing the magnitude of effect.

Box II.1: Ten Key Points of nitrogen cycling relevant for integrated sustainable nitrogen management

1) Nitrogen is essential for life. It is an element of chlorophyll in plants and of amino acids (protein), nucleic acids and adenosine triphosphate in living organisms (including bacteria, plants, animals and humans). Nitrogen is often a limiting factor for plant growth.

2) Excess nitrogen has a range of negative effects, especially on human health, ecosystem services, biodiversity, through air, water and climate change. The total amounts of N introduced into the global biosphere by human activities have significantly increased during the last century (more than doubled) and have now exceeded critical limits for the so-called safe operating space for humanity.

3) Nitrogen exists in multiple forms. Most N forms are "reactive" (N_r) because they are easily transformed from one form to another through biochemical processes mediated by microorganisms, plants and animals and chemical processes affected by climate. Dinitrogen (N_2) is unreactive, forming the main constituent of air (78 per cent). Nitrogen is "double mobile" because it is easily transported by both air and water in the environment.

4) The same atom of N can cause multiple effects in the atmosphere, in terrestrial ecosystems, in freshwater and marine systems and on human health. This phenomenon is termed the "nitrogen cascade", which has been defined as the sequential transfer of N_r through environmental systems.

5) Nitrogen moves from soil to plants and animals, to air and water bodies, and back again, with international transboundary pollution transport of most nitrogen forms. These flows are a result of natural drivers and human activities, which have to be understood for effective N management.

6) Human activities have greatly altered the natural N cycle and have made the N cycle more leaky. Main factors include: creation of synthetic inorganic N fertilizer; land-use change; urbanization; combustion processes; and transport of food and feed across the world. These have resulted in nitrogen depletion in crop food/feed exporting areas and regional nitrogen enrichment in urban areas and those areas with intensive livestock farming. Regional segregation of food and feed production and consumption is also one of the main factors why N use efficiency at whole food system level has decreased in the world during the last decades.

7) The nature and human alterations of the N cycle challenge the realization of both a circular economy and integrated sustainable nitrogen management. Sustainable nitrogen management provides the foundation to strengthen an emerging "nitrogen circular economy", reducing N losses and promoting recovery and reuse.

8) Nitrogen forms need to be near plant roots to be effective for plant growth. Nitrogen uptake depends on the N demand by the crop, the root length and density, and the availability of NO_3^- and NH_4^+ in the soil solution.

9) Some crop types are able to convert non-reactive N_2 into reactive N forms (NH_3, amine, protein) by using specialist bacteria in plant root nodules. This process of biological nitrogen fixation is an important source of reactive N in the biosphere including agriculture, which can also result in N pollution.

10) Humans and animals require small amounts of protein N and amino acids for growth, development and functioning, but only a minor fraction of the N intake is retained in the body weight and/or milk and egg. The remainder is excreted, mainly via urine and faeces, and this N can be recycled and reused.

sources have been included in the Gothenburg Protocol, but NO_x emissions from agricultural soils, (semi-)natural NO_x and NH_3 sources are excluded when assessing compliance with the Gothenburg Protocol emission reduction commitments, as are N_2O and N_2 emissions to air and N leaching to waters. Conversely, in the European Union Nitrates Directive[4], all N sources in agriculture must be considered for reducing NO_3^- leaching, but NH_3, NO_x, N_2O and N_2 emissions to air are not explicitly addressed.

1. Different dimensions of integration in nitrogen management

42. **Dimension 1: Cause and effect** are the basis for current N policies, as the effects on human health and the environment, caused by N emissions, drive policy measures to decrease these emissions.

43. **Dimension 2: Spatial and temporal integration** of all N forms and sources affecting a certain area and time scale in management plans are critical to ensure that multiple co-

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[4] Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC), *Official Journal of the European Communities*, L 375 (1991), pp. 1–8.

benefits of action are achieved, maximizing synergies while minimizing nitrogen trade-offs.

44. **Dimension 3: Multiple nutrients and pollutants** are brought together by nitrogen. As an element, N is unique in the diversity of its environment and sustainability relevance. Sustainable nitrogen management therefore encourages integration with other elements and compounds:

(a) Between NH_3 and NO_x, SO_2, VOCs and PM in air pollution;

(b) Between N and carbon, including CO_2 and CH_4 when considering climate effects;

(c) Between N, phosphorus (P), potassium (K) and silicon (Si) when considering freshwater and coastal eutrophication;

(d) Between N and all other essential plant nutrients (either macronutrients or micronutrients) when considering crop, livestock and human nutrition;

(e) Between N and irrigation water, when considering sustainable water management.

45. **Dimension 4: Integrating stakeholders' views** is an additional dimension and has to be done as early as possible during the design phase of nitrogen management plans and measures. Multiple stakeholder types ensure that policy measures are:

(a) Policy relevant by addressing the main issues;

(b) Scientifically and analytically sound;

(c) Cost-effective, with costs proportional to the objective to be achieved; and

(d) Fair to all actors/users.

46. **Dimension 5: Regional integration** aims at enhanced cooperation between regions and countries, incorporating the landscape scale. Arguments for regional integration are:

(a) Enhancement of markets;

(b) Creation of a "level playing field" for policy measures

(c) The transboundary nature of environmental pollution;

(d) Consideration of indirect pollution affects; and

(e) The increased effectiveness and efficiency of regional policies and related management measures.

47. The Gothenburg Protocol has demonstrated the benefits of developing an approach that integrates multiple pollutants and multiple effects. In the case of nitrogen, most NO_x and NH_3 sources are included when defining the emissions ceilings, while further efforts are needed to integrate NO_x emissions from agricultural soils, (semi-) natural NO_x and NH_3 sources, and the relationships to N_2O and N_2 emissions and NO_3^- leaching. The need to bring these issues together was recently recognized in United Nations Environment Assembly resolution 4/14 on sustainable nitrogen management and its follow-up in the Colombo Declaration. These texts emphasize the win-win opportunities for environment, health and economy, including air quality, water quality, climate, stratospheric ozone and biodiversity protection, together with the provision of sustainable food and energy.

2. Principles of integrated sustainable nitrogen management

48. Twenty-four principles of integrated sustainable nitrogen management are identified below:

(a) **Principle 1: The purpose of integrated sustainable nitrogen management in agriculture is to decrease nitrogen losses to the environment to protect human health, climate and ecosystems, while ensuring sufficient food production and nitrogen use efficiency, including through appropriately balanced nitrogen inputs;**

(b) **Principle 2: There are various actors in agriculture and the food chain, and all have a role in N management.** There is a joint responsibility for all actors in the food chain, including for policymakers at several levels, to support a decrease of N losses and to share the cost and benefits of N abatement/mitigation measures;

(c) **Principle 3: Specific measures are required to decrease pathway-specific N losses.** This is because the loss mechanisms differ between NH_3 volatilization, NO_3^- leaching, erosion of all Nr forms to surface waters, and gaseous emissions of NO_x, N_2O and N_2 related to nitrification-denitrification processes. Pathway-specific measures relate to pathway-specific controlling factors;

> **"Reduced N inputs or increased harvested outputs are thus an essential part of integrated nitrogen management while providing opportunities for increased economic performance."**
> *From principle 6*

(d) **Principle 4: Possible trade-offs in the effects of N loss abatement/mitigation measures may require priorities to be set, for example, which adverse effects should be addressed first.** Policy guidance is necessary to inform such priorities and properly weigh the options according to local to global context and impacts;

(e) **Principle 5: Nitrogen input control measures influence all N loss pathways.** These are attractive measures because reductions in N input (for example, by avoidance of excess fertilizer, of excess protein in animal diets, and of human foods with a high nitrogen footprint), lead to less nitrogen flow throughout the soil-feed-food system;

(f) **Principle 6: A measure to reduce one form of pollution leaves more N available in the farming system, so that more is available to meet crop and animal needs. In order to realize the benefit of a measure to reduce N loss (and to avoid pollution swapping), the nitrogen saved by the measure needs to be matched by either reduced N inputs, increased**

storage, or increased N in harvested outputs. Reduced N inputs or increased harvested outputs are thus an essential part of integrated nitrogen management while providing opportunities for increased economic performance;

(g) **Principle 7: The nitrogen input-output balance encapsulates the principle that what goes in must come out**, and that N input control and maximization of N storage pools (in manure, soil and plants) are main mechanisms to reduce N losses (see figure II.2).

(h) **Principle 8: Matching nitrogen inputs to crop needs (also termed "balanced fertilization") and to livestock needs offers opportunities to reduce all forms of N loss simultaneously, which can help to improve economic performance at the same time.** Natural differences between crop and animal systems similarly imply opportunities from integrating animal and crop production and optimizing the balance of food types;

(i) **Principle 9: Spatial variations in the vulnerability of agricultural land to N losses require spatially explicit N management measures in a field and/or landscape.** This principle is applicable to field application of both organic and inorganic fertilizer resources;

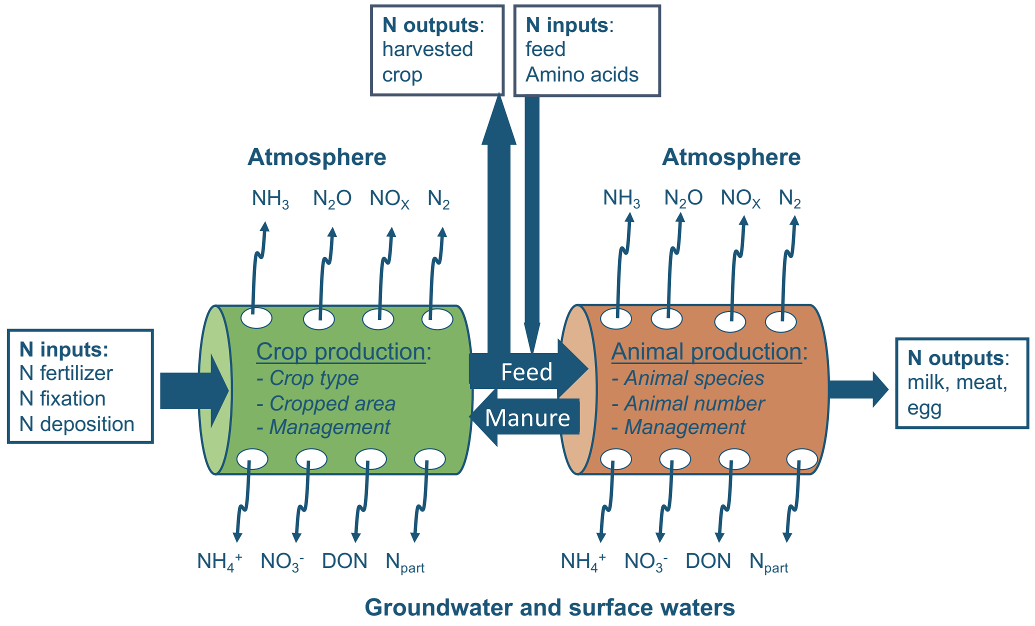
(j) **Principle 10: Spatial variations in the sensitivity of natural habitats to N loadings originating from agriculture highlight the need for site- and region-specific N management measures.** A source-pathway-receptor approach at landscape scale may help to target specific hot spots, specific N loss pathways, and specific sensitive or resilient areas;

(k) **Principle 11: The structure of landscape elements affects the capacity to store and buffer nitrogen flows. This means that ecosystems with high N storage capacity (for example, woodlands and unfertilized agricultural land) tend to buffer the effects of N compounds emitted to the atmosphere, so that less N is transferred to other locations.** In this way, woodlands, extensive agricultural land and other landscape features help absorb and utilize N inputs from atmospheric N deposition or N that would otherwise be lost through lateral water flow. This principle is the basis of planning to increase overall landscape resilience, where, for example, planting of new woodland (with the designated function of capturing N) may be used as part of a package of measures to help protect other habitats (including other woodland and ecosystems, where nature conservation objectives are an agreed priority);

(l) **Principle 12: In order to minimize pollution associated with N losses, all factors that define, limit and reduce crop growth have to be addressed simultaneously and in balance to optimize crop yield and N use efficiency.** Elements include: selecting crop varieties adapted to local climatic and environmental conditions; preparing an appropriate seedbed; ensuring adequate levels of all essential nutrient elements and water; and ensuring proper weed control, pest and disease management and pollution control.

(m) **Principle 13: In order to minimize pollution**

Figure II.2: Concept of the nitrogen input – output mass balance of mixed crop – livestock production systems



Source: Modified from Oenema and others (2009).

Note: Total inputs must balance total outputs, following corrections for possible changes in storage within the system. The concept is applicable at field, farm, regional and global scales for all farm types (chapter III).

Image 1: According to principle 12, all factors that limit crop growth have to be addressed simultaneously to reduce nitrogen pollution. The photograph shows trials of wheat for use as a winter cover crop. The middle variety was found to be sensitive to rust fungus infection, limiting its ability to take up nitrogen and reduce nitrogen pollution (photograph: © Shabtai Bittman).

associated with N losses, all factors that define, limit or reduce animal growth and welfare have to be addressed simultaneously and in balance to optimize animal production and N use efficiency, also to decrease N excretion per unit of animal produce. Elements include: selecting breeds adapted to the local climatic and environmental conditions; ensuring availability of high-quality feed and water; and ensuring proper disease, health, fertility and pollution control, including animal welfare;

(n) **Principle 14: Slowing down hydrolysis of urea and uric acid containing resources reduces NH_3 emissions.** Hydrolysis of these resources produces NH_3 in solution and locally increases soil pH, so slowing hydrolysis helps avoid the highest ammonium concentrations and pH, which can also reduce other N losses by avoiding short-term N surplus;

(o) **Principle 15: Reducing the exposure of ammonium-rich resources to the air is fundamental to reducing NH_3 emissions.** Hence, reducing the surface area, lowering the pH, temperature and wind speed above the emitting surface, and promoting rapid infiltration by dilution of slurries all reduce NH_3 emissions;

(p) **Principle 16: Slowing down nitrification (the biological oxidation of NH_4^+ to NO_3^-) may contribute to decreasing N losses and to increasing N use efficiency.** This is because NH_4^+ can be held in soil more effectively than NO_3^-, making it less vulnerable to losses via leaching and nitrification-denitrification processes than NO_3^-.

(q) **Principle 17: Some measures aimed at reducing N_2O emissions may also reduce losses of N_2 (and vice versa) since both are related to denitrification processes.** Measures aimed at jointly reducing N_2O and N_2 losses from nitrification-denitrification may therefore contribute to saving N resources within the system and reducing climate effects at the same time;

(r) **Principle 18: Achieving major N_2O reductions from agriculture necessitates a focus on improving N use efficiency across the entire agrifood system using all available measures.** The requirement for wider system change is because of the modest potential of specific technical measures to reduce N_2O emissions from agricultural sources compared with the scale of ambitious reduction targets for climate and stratospheric ozone. It implies a requirement to consider system-wide changes in all aspects of the agrifood system, including human and livestock diets and management of fertilizer, biological and recycled N resources;

(s) **Principle 19: Strategies aimed at decreasing N, P and other nutrient losses from agriculture are expected to offer added mitigation benefits compared with single nutrient emission-abatement strategies, because of coupling between nutrient cycles.** A nitrogen focus provides a pragmatic approach that encourages links between multiple threats and element cycles, thereby accelerating progress;

(t) **Principle 20: Strategies aimed at optimizing N and water use jointly are more effective than single N fertilization and irrigation strategies, especially in semi-arid and arid conditions.** This underlines the need for an integrated approach in which the availability of both N and water are considered jointly, especially in those regions of the world where food production is limited by the availability of both water and N. The joint coupling of N and water management also underlies the safe storage of solid manures to avoid run-off and leaching;

(u) **Principle 21: Strategies aimed at enhancing N use efficiency in crop production and at decreasing N losses from agricultural land have to consider possible changes in soil organic carbon (C) and soil quality over time and the impacts of soil carbon-sequestration strategies.** Carbon sequestration is associated with N sequestration in soil due to reasonably conservative ratios of C:N in soils. Protection of soil organic matter against degradation ("nitrogen mining") is vital to sustain agricultural productivity in regions with low N input;

(v) **Principle 22: Strategies aimed at reducing N emissions from animal manures through low-protein animal feeding have to consider the possible impacts of diet manipulations on enteric methane (CH_4) emissions from ruminants**. Low-protein diets in ruminants are conducive to low N excretion and NH_3 volatilization, but tend to increase fibre content and CH_4 emissions, pointing to the need for dietary optimization for N and C;

(w) **Principle 23: The cost and effectiveness of measures to reduce losses of N need to take account of the practical constraints and opportunities available to farmers in the region where implementation is intended.** The effectiveness and costs must be examined as much as possible under practical farm conditions and, in particular, taking account of farm size and basic environmental limitations. Cost-effectiveness analysis should consider implementation barriers, as well as the side effects of practices on other forms of N and greenhouse gases in order to promote co-benefits;

(x) **Principle 24: The whole farm-level is often a main integration level for emission-abatement/mitigation decisions, and the overall effects of emission-abatement/mitigation measures will have to be assessed at this level,** including consideration of wider landscape, regional and transboundary interactions.

3. Tools for integrated nitrogen management approaches

49. The toolbox for developing integrated approaches to N management contains both tools that are uniformly applicable and more specific tools, suitable for just one dimension of integration. Important common tools are:

(a) Systems analysis, used especially by the science-policy-practice interface;

(b) Nitrogen input-output budgeting tools to integrate N sources and N species for well-defined areas at various scales (from farms to continents) and that are easy for farmers and policymakers to understand (as well as being compatible with data privacy regulations);

(c) Integrated assessment modelling and cost-benefit analyses. The "Driver-Pressure-State-Impact-Response" (DPSIR) framework can be used as a starting point for analysing cause-effect relationships conceptually and cost-benefit analysis (CBA) goes a step further by expressing costs and benefits of policy measures in monetary terms;

(d) Food-chain assessment and management relates to the planning and management of activities and information between actors in the whole food production–consumption chain, including suppliers, processors, retail, waste-recycling companies and citizens;

(e) Stakeholder dialogue and communication are essential for exchanging views of actors on N management issues. These can help make the concepts transparent and facilitate adoption of targets, as well as helping in the implementation of measures in practice;

(f) Abatement/mitigation measures, including best management practices, which have been shown to reduce emissions and impacts, as described in chapters IV–VI of the present document.

B. Housed livestock, manure storage and manure processing

50. Measures to reduce N loss from housed livestock, manure storage and processing influence manure composition and the storage environment, with the result that conditions are unfavourable for emissions. The first crucial step is to adapt the N content in the livestock diet as closely as possible to the requirements of animals, for which five measures are identified.

51. NH_3 emissions will be small at low temperatures and low pH values if the contact of manure with ambient air is limited. Emissions of N_2O, NO_x and N_2 will be reduced by low organic C content, sufficient oxygen availability and low nitrate concentrations. Concepts for best practices to reduce adverse environmental impacts require integrated approaches, detailed understanding of emissions at the process level, and the development of flexible solutions that match regional needs.

52. The following priorities are identified to reduce nitrogen losses from livestock housing:

(a) Reduction of indoor temperature, including by optimized ventilation;

(b) Reduction of emitting surfaces and soiled areas;

(c) Reduction of air-flow over soiled surfaces;

(d) Use of additives (for example, urease inhibitors, acidification); and

(e) Regular removal of manure to an outside store. Overall, 18 Housing Measures are identified (see table II.1).

53. The following priorities are identified to reduce N losses and to mobilize N recovery/reuse from manure storage, treatment and processing:

(a) Storing outside the barn in a dry location;

(b) Covering slurry stores;

(c) Manure treatment/processing to reduce slurry dry matter content, increase slurry NH_4^+ content and lower pH;

(d) Anaerobic digestion, solid/liquid separation and slurry acidification;

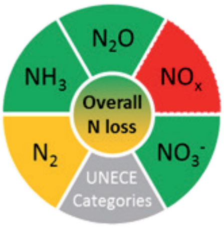
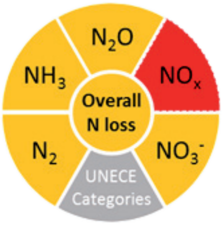
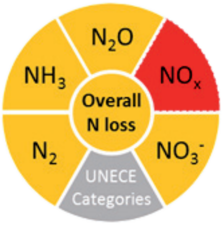
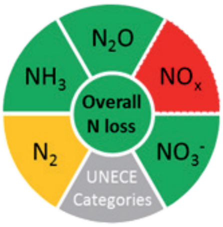
(e) Ensuring that all available nutrient resources are used effectively for crop growth;

(f) Improving nutrient recapture and recovery; and

(g) Production of value-added nutrient products from recycled manure N resources. In total, 12 Manure Measures related to storage/processing and 5 Nutrient Recovery Measures are identified (see table II.1).

54. Overall, measures related to livestock diets, housing, manure storage and manure reprocessing should be seen in relation to the flow of nitrogen and other nutrients, with significant synergy between the different stages. For example, N saved through optimized diets and low-emission stables provides an opportunity to increase N resources for manure recycling or direct application to fields (chapter V). It is important to remember the principles by which each measure works (chapter III) to maximize the synergies and avoid trade-offs. For example, in order to achieve the full benefit of reducing NH_3 emissions during animal housing, corresponding measures are needed during manure storage and manure spreading to avoid NH_3 emissions later in the system. The manure management chain provides a key example of an opportunity for circular economy thinking where reduced losses to the environment translate into increased resource availability (see figure I.2).

Table II.1 : Measures related to livestock diets, livestock housing, manure storage and processing, and nutrient recovery. For explanation of colours, see figure II.1.

Measures related to livestock diets		
Dietary Measure 1: Adapt protein intake in diet (dairy and beef cattle)	Adaptation of crude protein in the diet to match the needs of animals is the first and most efficient measure to mitigate N emissions. This measure decreases the excretion of excess N and thus reduces emissions along the whole manure management chain. Increasing the energy/protein ratio in the diet is a well-proven strategy to reduce levels of crude protein. For grassland-based ruminant production systems, the feasibility of this strategy may be limited, as older grass may reduce feeding quality.	
Dietary Measure 2: Increase productivity (dairy and beef cattle)	Increasing the productivity of dairy and beef cattle through an increase in milk yield or daily weight gain reduces CH_4 (and potentially N_2O) emissions per kg of product.[5] A balance must be found between emission reduction through productivity increase and the limited capacity of cattle to deal with concentrates. The ability of cattle to convert protein from roughage, which is inedible for humans, to high-value protein is valuable from a resource and biodiversity perspective.	
Dietary Measure 3: Increase longevity (dairy cattle)	Productivity can be increased though increasing milk production per year and through increasing the amount of milk production cycles. Optimized diet and housing conditions enable a higher longevity of dairy cattle, and therefore fewer replacement animals are needed, thereby reducing N losses per product.	
Dietary Measure 4: Adapt protein intake in diet (pigs)	Feeding measures in pig production include phase feeding, formulating diets based on digestible/available nutrients, using low-protein amino acid-supplemented diets, and feed additives/supplements. The crude protein content of the pig ration can be reduced if the amino acid supply is optimized through the addition of synthetic amino acids.	
Dietary Measure 5: Adapt protein intake in diet (poultry)	For poultry, the potential for reducing N excretion through feeding measures is more limited than for pigs because the conversion efficiency currently achieved on average is already high and the variability within a flock of birds is greater.	

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[5] This effect is noted without prejudice to any current or future agricultural policy (for example, the European Union Common Agricultural Policy) and other state aid measures oriented to conserving local traditional animal races, which emphasizes the need to consider the balance between issues.

Measures related to livestock housing

Housing Measure 1: Immediate segregation of urine and faeces (cattle)

A physical separation of faeces (which contain urease) and urine in the housing system reduces hydrolysis of urea, resulting in reduced NH_3 emissions from both housing and manure spreading. Solid-liquid separation will also reduce emissions during land-application, where urine infiltrates soil more easily than mixed slurry.

Housing Measure 2: Regular cleaning of floors in cattle houses by toothed scrapers (cattle)

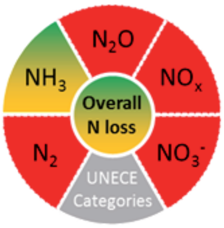
The emitting surface may be reduced by using "toothed" scrapers running over a grooved floor, thereby reducing NH_3 emissions. This also results in a cleaner floor surface with good traction for cattle to prevent slipping.

Housing Measure 3: Regular cleaning of floors in cattle houses

Thorough cleaning of walking areas in dairy cattle houses by mechanical scrapers or robots has the potential to substantially reduce NH_3 emissions.

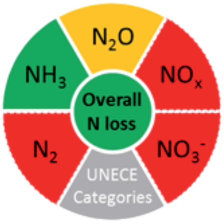
Housing Measure 4: Frequent slurry removal (cattle)

Regular removal of slurry from under the slats in an animal house to a (covered) outside store can substantially reduce NH_3 emissions by reducing the emitting surface and the slurry storage temperature. It also reduces CH_4 emissions as manure is stored outside, under cooler conditions.



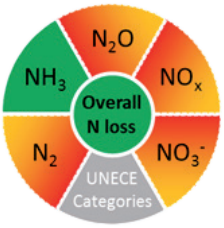
Housing Measure 5: Increase bedding material (cattle with solid manure)

Use of bedding material that absorbs urine in cattle housing can reduce NH_3 emissions by immobilizing nitrogen and may also reduce N_2O emissions.



Housing Measure 6: Barn climatization to reduce indoor temperature and air flow (cattle)

In houses with traditional slatted floors, barn climatization with slurry cooling, roof insulation and/or automatically controlled natural ventilation can reduce NH_3 emissions due to reduced temperature and air velocities and can also help reduce CH_4 emissions.



Housing Measure 7: Use of acid air-scrubbers (cattle)

In the few situations where cattle are housed with forced ventilation, this measure can be considered as category 1 to reduce NH_3 emissions. However, most cattle are housed in naturally ventilated buildings across the ECE region. Recent developments explore the use of air-scrubbers with naturally ventilated buildings (for example, by directly extracting and scrubbing air from the slurry pit).

Housing Measure 8: Slurry acidification (pig and cattle housing)

Emissions of NH_3 can be reduced by acidifying slurry to shift the balance from NH_3 to NH_4^+. Acidification in the livestock house will reduce NH_3 emissions throughout the manure management chain. Slurry acidified with sulphuric acid is not suitable as the sole feedstock for biogas production, only as a smaller proportion.

Housing Measure 9: Reduce emitting surface (pigs)

Ammonia emission can be reduced by limiting the emitting surface area through frequent and complete vacuum-assisted drainage of slurry from the floor of the pit. Other floor designs can be used, including partially slatted floors, use of inclined smoothly finished surfaces and use of V-shaped gutters.

Housing Measure 10: Regular cleaning of floors (pigs)

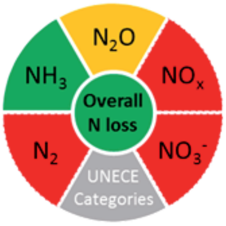
Thorough and regular cleaning of floors in pig houses by mechanical scrapers or robots has the potential to reduce NH_3 emissions substantially.

Housing Measure 11: Frequent slurry removal (pigs)

Regular removal of slurry from under the slats in the pig house to an outside store can reduce NH_3 emissions by reducing the emitting surface and the slurry storage temperature. It also reduces CH_4 emissions as manure is stored outside, under cooler conditions.

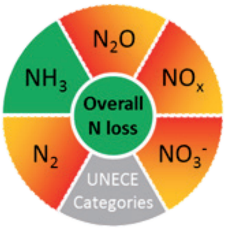
Housing Measure 12: Increase bedding material (pigs with solid manure)

Use of bedding material that absorbs urine in pig housing can reduce NH_3 emissions by immobilizing nitrogen and may also reduce N_2O emissions. The approach can have a positive interaction with animal welfare measures. Regular changes of bedding may be needed to avoid N_2O and N_2 emissions associated with deep-litter systems.



Housing Measure 13: Barn climatization to reduce indoor temperature and air flow (pigs)

Surface cooling of manure with fans using a closed heat exchange system can substantially reduce NH_3 emissions. In slurry systems, this technique can often be retrofitted into existing buildings.



Housing Measure 14: Use of acid air-scrubbers (pigs)

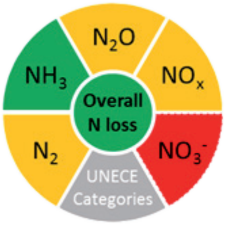
Treatment of exhaust air by acid scrubbers has proven to be practical and effective at least for large-scale operations. This is most economical when installed in new houses. The approach also helps reduce odour and PM emission and may also contribute to reducing N_2O and NO_x emissions if the N recovered is used to replace fresh fertilizer N inputs.

Housing Measure 15: Use of biological air-scrubbers (pigs)

Biological air-scrubbers operate with bacteria that remove NH_3 and odours from the exhaust air. Careful management is needed to ensure that NH_3 captured in biological air-scrubbers (for example, organic biofilters) is not nitrified/denitrified, leading to increased emissions of N_2O, NO_x and N_2. Recovery of the collected N_r in bioscrubbers may help offset any increase, with opportunities to recover N_r through use of biotrickling systems.

Housing Measure 16: Rapid drying of poultry litter

NH_3 emissions from battery deep-pit or channel systems can be lowered by ventilating the manure pit or by use of manure removal belts to dry manure. Keeping excreted N in the form of uric acid can also be expected to reduce N_2O, NO_x and N_2, since this will also reduce nitrification and denitrification.



Housing Measure 17: Use of acid air-scrubbers (poultry)

Treatment of exhaust air by acid scrubber has been successfully employed to reduce NH_3 emissions in several countries. The main difference from pig systems is that poultry houses typically emit a much larger amount of dust. To deal with dust loads, multistage air-scrubbers with pre-filtering of coarse particles have been developed.

Housing Measure 18: Use of biological air-scrubbers (poultry)

Treatment of exhaust air by use of biotrickling filters (biological air-scrubbers) has been successfully employed in several countries to reduce NH_3 emissions, fine dust and odour. Multistage scrubbers have been developed to deal with high dust loads, although use of biofilters may increase other N losses as N_2O, NO and N_2.

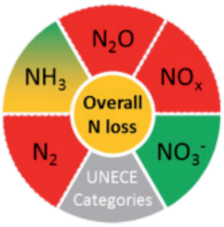
Measures related to manure storage and processing

Manure Measure 1: Covered storage of manure (solid cover and impermeable base)

Many options are available for covered storage of manure and biogas digestates, including use of metal or concrete tanks with solid lids, floating covers on lagoons and use of slurry bags, most of which are associated with negligible NH_3 emission if well operated. The impermeable base avoids nitrate leaching and must be maintained to avoid leakage.

Manure Measure 2: Covered storage of slurry (natural crust and impermeable base)

Where slurries have a high dry matter content, and stirring is minimized, these may form a natural crust during storage, which is associated with substantially reduced NH_3 emission, although N_2O production may be enhanced. The impermeable base avoids nitrate leaching and must be maintained to avoid leakage.



Manure Measure 3: Covered storage of solid manure (dispersed coverings)

Covering solid manures with dispersed coverings, such as peat, clay, zeolite and phosphogypsum or clay, can substantially reduce NH_3 emissions. The approach works by protecting manure surfaces from the air, while these materials also have a high affinity for ammonium. Sufficient thickness of the covering is required.

Manure Measure 4: Storage of solid manure under dry conditions

Simply storing solid manure in a dry place, out of the rain, can also reduce N emissions from a range of N_r compounds and N_2. This is even more important for poultry litter, where keeping manure dry limits hydrolysis of uric acid to form NH_3.

Manure Measure 5: Storage of solid manure on a solid concrete base with walls

Storage of manure on a walled solid base helps reduce nitrate leaching and other N_r leaching by avoiding run-off and infiltration into the soil. The approach costs less than installing a solid cover, but risks substantial NH_3, N_2O, NO_x and N_2 emissions.

Manure Measure 6: Slurry mixing (during storage)

Slurry mixing of stored manure prior to field application helps ensure a homogenous distribution of nutrients. There are no additional benefits to reduce emissions of N_2O, NO_x or N_2. The method may even increase NH_3 losses (for example, if mixing increases pH by promoting CO_2 loss from slurry), so mixing should only be done shortly before field application.

Manure Measure 7: Adsorption of slurry ammonium

Certain additives to slurry can be used to adsorb ammonium on a chemical, physical or biological basis. Mineral additives such as clay/zeolite require a high amount of additives, which can result in the measure being costly (for example, 25 kg of zeolite per m^3 slurry to adsorb 55 per cent of ammonium). However, experiments have shown only a small effect in reducing NH_3 emission. Addition of biochar may also reduce NH_3 emissions from stored manure.

Manure Measure 8: Slurry acidification (manure storage)

Ammonia emissions from stored slurry can be reduced by addition of acids. This is most commonly done just prior to spreading. The reduction in pH also reduces CH_4 and is expected to decrease N_2O and N_2 emissions. Acid may be added or produced in situ during storage (for example, by oxidation of atmospheric N_2 augmented using locally produced renewable energy). While feedstock for biogas production can only contain limited amounts of acidified slurry, acidification after anaerobic digestion can help to reduce subsequent NH_3 emissions.

Manure Measure 9: Slurry aeration

Slurry aeration introduces oxygen into the slurry in order to allow aerobic microbes to develop, so reducing odour. However, CO_2 and NH_3 emissions are increased. Emissions of NO_x are also expected to increase, while greater NO_3^- availability risks a subsequent increase in denitrification-related loss of N_2O and N_2. Therefore, slurry aeration is not recommended.

Manure Measure 10: Mechanical solid-liquid separation of slurry fractions

Mechanical separation of solid and liquid fractions of slurry produces an ammonium-rich liquid that degrades more slowly and infiltrates more effectively into soil, reducing NH_3 emissions, with more predictable fertilization benefits increasing crop yields and allowing reduction of mineral N fertilizer. Care is needed to avoid NH_3 and CH_4 losses from the solid fraction, which may serve as a slow-release fertilizer or feedstock for biogas production.

Manure Measure 11: Anaerobic digestion

Anaerobic digestion associated with production of CH_4 biogas reduces emissions of CH_4 from subsequent storage of the digestate, while substituting consumption of fossil energy. Ammonium content and pH in digested slurry are higher than in untreated slurry, increasing the potential for NH_3 emissions, requiring the use of covered stores and low-emission manure spreading. As part of an integrated package of measures, anaerobic digestion can reduce NH_3, N_2O and N_2 losses, while providing an opportunity for advanced forms of nutrient recovery (Nutrient Recovery Measures 3–5). The requirement for an impermeable base avoids nitrate leaching compared with storage of manure on permeable surfaces.

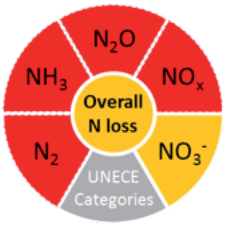
Manure Measure 12: Manure composting

Composting of manure creates a stable and odourless biobased fertilizer product, with lower moisture content, while containing most of the initial nutrients, free of pathogens and seeds. However, losses of NH_3, N_2O, NO_x, N_2, CO_2 and CH_4 tend to increase, also reducing N fertilizer value, while composting on porous substrates risks increasing N leaching. Use of covered composting can mitigate some of these effects. The UNECE categories shown assume open composting on an impermeable surface.

Measures related to nutrient recovery

Nutrient Recovery Measure 1: Drying and pelletizing of manure solids

Drying and pelleting of solid manures, slurry or digestate solids can be done to create a more stable and odourless biobased fertilizer product. Drying is energy intensive, while NH_3 emissions increase, unless exhaust air filtering or scrubbing and N recovery is applied, or the solids are acidified prior to drying.



Nutrient Recovery Measure 2: Combustion, gasification or pyrolysis

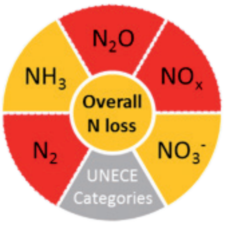
Combustion, thermal gasification or pyrolysis of manure and digestate solids can be used to generate a net energy output for heat and/or electricity production. However, the method wastes manure N, which is converted into gaseous N_2 and NO_x (category 3). Systems under development to minimize N_2 formation and recover the N_r gases can be considered as category 2 for abating overall N loss.

Nutrient Recovery Measure 3: Precipitation of nitrogen salts

Struvite ($MgNH_4PO_4 \cdot 6H_2O$) (as well as other phosphorus salts such as hydroxy apatite) can be precipitated from liquid manures, including anaerobically digested slurries and the liquid fraction from digestate separation. The main advantage of struvite compared with other approaches is its high concentration and similarity in physical-chemical properties to conventional mineral N fertilizer. The setting of UNECE category 2 reflects the need for further assessment of efficiencies.

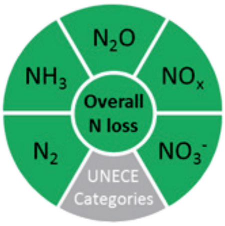
Nutrient Recovery Measure 4: Concentration of nitrogen salts and solutions

Mineral concentrates are highly nutrient-rich solutions that may be obtained via ultrafiltration, evaporation or reverse osmosis of the liquid fraction from separation of slurry or digestate. Provided that losses can be kept to a minimum (for example, use of acidification, soil injection), the mineral fertilizer replacement value of the mineral concentrates can be relatively high, as they resemble commercial liquid fertilizers.



Nutrient Recovery Measure 5: Ammonia stripping and recovery

In this method, the liquid fraction after manure separation is brought into contact with air, upon which NH_3 evaporates and is collected by a carrier gas. Use of membrane systems allows use of lower temperatures, if membrane fouling can be avoided. Ammonia released from an NH_3 stripping column or from a manure drying facility can be collected using wet scrubbing with an acid solution, such as sulphuric or nitric acid. The ammonium sulfate and nitrate produced can serve as raw materials for mineral fertilizers, providing the opportunity for circular economy development.



C. Field application of organic and inorganic fertilizers, including manures, urine and other organic materials

55. Measures to reduce nitrogen loss from field application of nitrogen resources are especially important as the benefits of improved nutrient use can be seen by farmers. Measures to reduce overall nitrogen losses thus have a dual aim: to improve resource efficiency (allowing a reduction in bought-in fertilizers and other nutrient resources); and to reduce pollution of air and water, with multiple environmental benefits.

56. According to principle 6 (chapter III) the nitrogen savings resulting from measures during housing and storage of manure must be accounted for. These actions increase the amounts of nitrogen resources available for field spreading, enabling reductions in newly produced nitrogen resources.

57. The most effective measures are listed below according to applicability:

(a) Measures applicable to both organic and inorganic fertilizers;

(b) Measures applicable to manures and other organic materials;

(c) Measures applicable to inorganic fertilizers;

(d) Measures applicable to livestock grazing; and

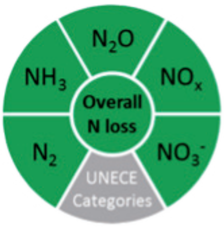
(e) Other cropping-related measures. Overall, 20 field measures are identified (see table II.2).

Table II.2 : Measures applicable to organic and inorganic fertilizers, manures and other organic materials and grazing livestock. For explanation of colours see figure II.1

Measures applicable to both organic and inorganic fertilizers

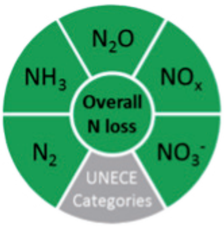
Field Measure 1: Integrated nutrient management plan

The approach focuses on integrating all the nutrient requirements of arable and forage crops on the farm, through use of all available organic and inorganic nutrient sources. Priority should be given to utilization of available organic nutrient sources first (for example, livestock manure), with the remainder to be supplied by inorganic fertilizers, in accordance with Field Measure 3. Recommendation systems can provide robust estimates of the amounts of N (and other nutrients) supplied by organic manure applications. Supported by soil nutrient testing and decision-support tools to assess crop needs (for example, leaf colour sensing), this information can be used to determine the amount and timing of any additional inorganic fertilizers, while allowing for further input reductions as a result of saved nitrogen from decreased pollution losses.



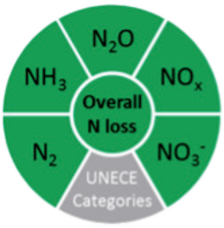
Field Measure 2: Apply nutrients at the appropriate rate

Under application of N will result in reduced crop yields and can lead to mining of soil N and organic matter. Over application of N can also result in reduced crop yields and profits, and surplus available soil N, increasing the risk of losses to air and water. Applying N to match crop requirement at an environmentally and economically sustainable level requires knowledge of the N content of the organic manure or fertilizer product and crop N demand. In-crop soil testing or leaf colour sensing may help with split applications.



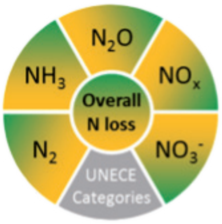
Field Measure 3: Apply nutrients at the appropriate time

Targeting N to the soil at times when it is required by an actively growing crop reduces the risks of nitrogen losses to air and water. Multiple (or split) applications reduce the risk of large leaching events and enable later additions to be fine-tuned according to adjustment of yield expectations. Appropriate timing should take account of climatic differences, as well as weather forecasts (for example, to favour manure spreading during cool weather). Combined application of organic slurries and inorganic fertilizer should be avoided where co-occurrence of water and carbon increases N_2O emissions.



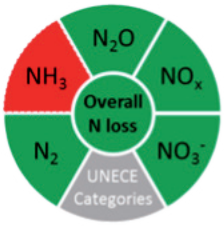
Field Measure 4: Apply nutrients in the appropriate form

This measure mainly targets NH_3 emissions, which are much lower from ammonium nitrate than from urea fertilizer. There is a risk of increased losses through denitrification and/or leaching and run-off because the N saved by decreasing NH_3 emission, unless N application rate is reduced to match the amounts saved (chapter III, principle 6). With organic materials, such as livestock manure, account should be taken of the relative content of inorganic forms of N (such as ammonium) compared with organic compounds, as this affects the N replacement value.



Field Measure 5: Limit or avoid fertilizer application in high-risk areas

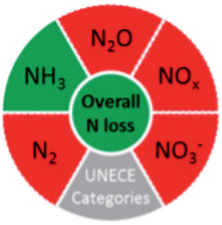
Certain areas on the farm can be classified as higher risk in terms of N losses to water, by direct run-off or leaching, or to air through denitrification. Pollution can be reduced by avoiding or limiting fertilizer application to these locations (for example, in the vicinity of ditches and streams and on steeply sloping areas).



Measures specific to the application of manures and other organic materials

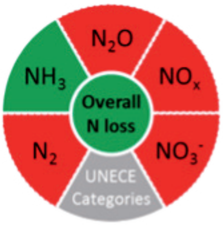
Field Measure 6: Band spreading and trailing shoe application of livestock slurry

Reducing the overall surface area of slurry, by application in narrow bands, will lead to a reduction in ammonia emissions of 30–35 per cent compared with surface broadcast application, particularly during the daytime when conditions are generally more favourable for volatilization. In addition, if slurry is placed beneath the crop canopy, the canopy will also provide a physical structure to reduce further the rate of ammonia loss (by 60 per cent).



Field Measure 7: Slurry injection

Placing slurry in narrow surface slots, via shallow or deep injection greatly reduces the exposed slurry surface area, thereby reducing NH_3 emissions (by 70–90 per cent). Emissions of N_2O (as well as NO_x and N_2 emissions) may be increased, though this risk can be reduced by compensating for the amount of nitrogen saved through NH_3 emission reductions by using reduced slurry applications rates.



Field Measure 8: Slurry dilution for field application

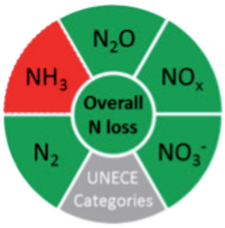
Ammonia losses following surface broadcast slurry application are less for slurries with lower dry matter, because of the more rapid infiltration into the soil. The reduction in ammonia emission will depend on the characteristics of the undiluted slurry and the soil and weather conditions at the time of application (c. 30 per cent emission reduction for 1:1 dilution of slurry in water).

Field Measure 9: Slurry acidification (during field application)

A lower pH favours ammoniacal N in solution to be in the form of ammonium rather than ammonia, thereby reducing ammonia volatilization. Typically, sulphuric acid is used to lower the pH, though other acids may be used. Acid addition during field application of slurry requires appropriate safety procedures.

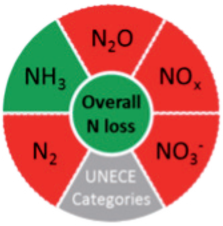
Field Measure 10: Nitrification inhibitors (addition to slurry

While more usually associated with mineral fertilizers, nitrification inhibitors can also be added to livestock slurries just prior to application to land with the aim of delaying the conversion of the slurry ammonium content to nitrate, which is more susceptible to N_r losses through denitrification, run-off and leaching.[6]



Field Measure 11: Rapid incorporation of manures into the soil

Rapid soil incorporation of applied manure (within a few hours after application) reduces the exposed surface area of manure from which NH_3 volatilization occurs and can also reduce N and P losses in run-off. The measure is only applicable to land that is being tilled and to which manure is being applied prior to crop establishment.



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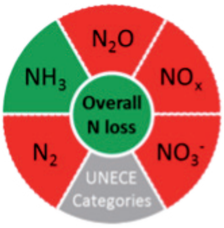
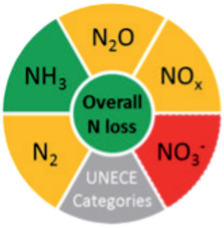
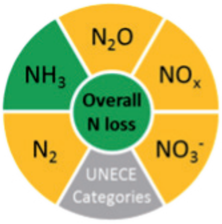
[6] No benefit is expected from using urease inhibitors in spreading cattle and pig manure, as most of the excreted urea will have already hydrolysed to form ammonium during livestock housing and manure storage. Potential long-term effect of nitrification inhibitors on non-target organisms should be considered.

Measures specific to the application of inorganic fertilizers

Field Measure 12: Replace urea with an alternative N fertilizer	Following land application, urea will undergo hydrolysis to form ammonium carbonate, locally increasing pH and favouring NH_3 emission. By contrast, for fertilizer forms such as ammonium nitrate, ammonium will be in equilibrium at a much lower pH, greatly reducing the potential for ammonia volatilization. In calcareous and semi-arid soils, the replacement of urea by ammonium nitrate or calcium ammonium nitrate usually also leads to the abatement of N_2O and NO_x, though the opposite can happen in other situations.	
Field Measure 13: Urease inhibitors	Urease inhibitors slow the hydrolysis of urea by inhibiting the urease enzyme in the soil. This allows more time for urea to be incorporated in the soil and for plant uptake, thereby reducing the potential for NH_3 emissions. In some studies (for example, under nitrifying conditions), urease inhibitors have also been found to decrease soil N_2O and NO_x emissions.[7]	
Field Measure 14: Nitrification inhibitors with inorganic fertilizers)	Nitrification inhibitors are chemicals (manufactured or natural) that can be incorporated into NH_3 or urea-based fertilizer products, to slow the rate of conversion of ammonium to nitrate. These have been shown to reduce emissions of N_2O and can also be expected to reduce emissions of NO_x and N_2, and leaching losses of nitrate, as they arise from the same process pathways. Potential long-term effects of nitrification inhibitors on non-target organisms should be considered. Field Measures 13 and 14 are complementary and can be combined.	
Field Measure 15: Controlled release fertilizers	Special coatings on fertilizers slow the release of nutrients to the soil over a period of several months (for example, sulphur or polymer coating). The gradual release of nutrients is associated with lower leaching and gaseous N losses. Organic N products with low water solubility, such as isobutylidene diurea (IBDU), crotonylidene diurea (CDU) and methylene-urea polymers, are also considered as slow-release fertilizers. Potential effects from the degradation of polymer coatings to form microplastics remain to be demonstrated.	
Field Measure 16: Fertigation	In areas subject to drought or limited soil water availability, the efficiency of water and N use should be managed in tandem. Drip irrigation combined with split application of fertilizer N dissolved in the irrigation water (for example, drip fertigation) provides precision application (in space and time), minimizing evaporative losses of water and losses of N to air and water, thereby greatly enhancing the N use efficiency.	

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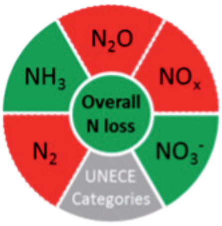
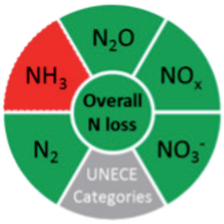
[7] See footnote 6.

Field Measure 17: Precision placement of fertilizers, including deep placement	Placement of N and P fertilizer directly into the soil close to the rooting zone of the crop can be associated with enhanced N and P uptake, lower losses of N to air and N and P to water and a lower overall N and P requirement compared with broadcast spreading. Placement within the soil reduces losses by NH_3 volatilization.	
Measures for grazing livestock		
Field Measure 18: Extend the grazing season	Ammonia emissions arising from grazing livestock are much smaller than for managed manure (for example, from housed animals) because of the rapid infiltration of urine into the soil. Where climate and soil conditions allow, extending the grazing season will result in a higher proportion of excreta being returned via dung and urine during grazing, thereby reducing NH_3 emissions. Risks of nitrate leaching and denitrification losses (as N_2O and N_2) may be increased unless additional actions are taken.	
Field Measure 19: Avoid grazing in high-risk areas	High-risk areas include those with high connectivity to vulnerable surface waters and/or groundwaters, and those subject to waterlogging, poaching and compaction. These include cases with both greatly enhanced potential for N, P and pathogen losses from dung and urine via run-off and denitrification. Such areas should be fenced, or carefully managed, to exclude livestock grazing.	
Field Measure 20: Nitrification inhibitors: addition to urine patches	Nitrification inhibitors, more commonly associated with mineral fertilizers, may also have an application in reducing leaching and denitrification from urine patches in grazed pastures. Risks of increased NH_3 emissions from urine patches associated with delays in nitrification are likely to be minimal because of the rapid urine infiltration.	

D. Land-use and landscape management

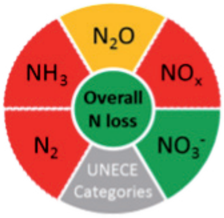
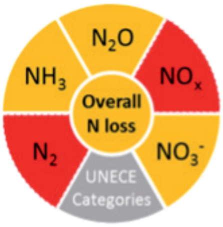
58. Landscape management enables N_r pollution problems to be addressed where they occur, both in space and time, helping to achieve the desired N mitigation effect.

59. Landscape measures can be economically favourable compared with other types of measures, especially as they can be placed outside agricultural areas, for example, retaining agricultural production, while creating new nature and recreational resources in the form of hedgerows, forests and extensive buffer-zones around fields, streams or wetlands.

60. For land-use and landscape-scale measures, the primary focus is on mitigation of adverse impacts, though there can also be benefits for emissions abatement. This means that measures focus on increasing overall landscape resilience so that there are fewer adverse impacts per unit of emission, in addition to a contribution to reducing emissions (for example, by local recapture within landscapes).

61. The most effective measures are listed in table II.3 according to their applicability. Overall, 16 Landscape Measures are identified.

Table II.3 : Measures related to land-use and landscape management. For explanation of colours see figure II.1.

Land-use measures for crops and crop rotations, including agroforestry		
Landscape Measure 1: Increasing land cover with perennial crops	Introducing perennial crops, such as grasslands, predominately grass or grass-clover mixtures, can reduce the risk of environmental N_r losses due to N_r immobilization in plant biomass and litter. They typically have a higher capacity for storage in biomass/ litter and have a longer N uptake period than annual plants. This approach also increases soil N (and C) stocks, with higher soil organic carbon contents providing increased N_r retention capacities.	
Landscape Measure 2: Use of cover crops in arable rotations	Cover crops (or "catch crops") that follow the main crop can help reduce available soil N levels during high-risk periods for nitrate leaching by taking up N originating from post-harvest decomposition and mineralization. Success in reducing emissions and in increasing N use efficiency over the whole cropping cycle depends on effective management of the cover crop residue and appropriate tuning of fertilization rates to the subsequent crop. The approach also reduces the risk of erosion and other soil/nutrient transport to streams.	
Landscape Measure 3: Inclusion of N_2-fixing plants in crop rotations (including intercropping)	Inclusion of plants such (for example, legumes) that fix atmospheric N_2 to produce organic nitrogen forms reduces the requirement for applied N (as fertilizer or manure) and the N losses associated with such applications. The approach can be implemented by including legumes as part of a crop rotation or by including legumes within a mixed crop ("intercropping", for example grass-clover sward). Incorporation of legumes into the soil as part of a crop rotation leads to a pulse of mineralization, which can lead to N_r emissions to air and nitrate leaching to water.	
Landscape Measure 4: Introducing agroforestry and trees in the landscape	Introducing agroforestry land-uses, with alternate rows of trees and annual crops or blocks of trees in the landscape, can help remove surplus N_r from neighbouring arable fields, minimizes erosion, provides wind shelter, and supports biodiversity provision.	
Landscape measures for management of riparian areas and waters		
Landscape Measure 5: Constructed wetlands for stimulating N_r removal	Constructed wetlands can help remove nutrients from water bodies or for wastewater treatment. The principle of operation of constructed wetlands is to encourage conditions that favour denitrification to N_2, while other nutrients accumulate. The approach is cheap but wastes N_r as N_2 and risks increased N_2O and CH_4 emissions, as well as dissolved organic C and N loss to watercourses.	

Landscape Measure 6: Planting of paludal cultures in riparian areas or constructed wetlands

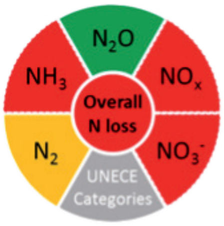
Wetland (paludal) plants are specifically planted to maximize biomass growth, thereby removing Nr from the water. The biomass can be harvested and used, for example, as source of bioenergy. Poorly managed systems may increase N_2O and N_2 emissions (as well as CH_4 emissions) if N_r is not fully used for plant growth. Performance is compared with Landscape Measure 5 as the reference.

Landscape Measure 7: Use of organic layers to promote nitrate removal

A layer of organic matter (for example, woodchips) is placed in trenches in soil at key points in the landscape to promote denitrification, enhancing the removal of nitrates from groundwaters and surface waters. The approach can help improve water quality but wastes N_r resources as N_2 emission while risking increased N_2O and CH_4 emissions.

Landscape Measure 8: Drainage management

Drainage measures (such as insertion of tile drains for water-table management) promote run-off and limit waterlogging, reducing residence times of nutrients. This can help abate emissions of CH_4 and N compounds relating to denitrification (N_2O, N_2), while shorter residence time may increase NO_3^- and carbon losses to stream waters.



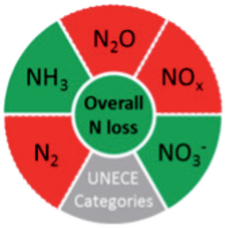
Landscape Measure 9: Stimulating N_r removal in coastal waters

It has been proposed that growing seaweed, eel grass, and oyster farming or shellfish aquaculture can help remove excess nutrients from coastal waters. Nitrogen is incorporated into the biomass, which is harvested. While the principle of encouraging N_r recovery into useful products is sound, further evidence of the quantitative performance of this system is needed before it can be used with confidence to mitigate coastal water pollution.

Afforestation, set-aside and hedgerow measures to mitigate N_r effects

Landscape Measure 10: Introducing trees for afforestation and hedgerows in the landscape

Afforestation and preservation and planting of strips of trees around agricultural fields can reduce NO_3^- leaching and has very positive effects on biodiversity. The efficacy of hedgerows for N_r retention will depend on size and placement of hedgerows, on the amount of NO_3^- in soil and groundwater, hydrological flow-paths and timing. With sufficient tree area, there can also be benefits for NH_3 mitigation (see Landscape Measure 12).



Landscape Measure 11: Set-aside and other unfertilized grassland

Unfertilized grasslands (for example, "set-aside" grassland) have the potential to remove NO_3^- from lateral soil water flows and can be used as buffers to protect adjacent natural land or streams. The effectiveness of the measure also depends on the extent to which overall N inputs are accordingly reduced in the landscape.

Mitigating the cascade of N_r effects from livestock hot spots

Landscape Measure 12: Shelterbelts around large point sources

Wide shelterbelts, such as woodland planted around point sources, can help mitigate landscape N_r dispersion from emission hot spots, such as manure storage areas or animal housing facilities, due to the function of trees as biofilters for NH_3 and the immobilization of N_r into plant biomass and soil organic N stocks. The approach may also reduce NO_3^- leaching losses but can risk increased N_2O emissions.

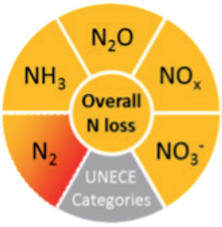
Landscape Measure 13: Environmentally smart placement of livestock facilities and outdoor animals

Placement of livestock facilities away from sensitive terrestrial habitats or waterbodies can reduce local N_r problems. The approach is most commonly used as part of planning procedures for new developments to expand existing farms.

Smart landscape farming in relation to mitigation of N_r effects

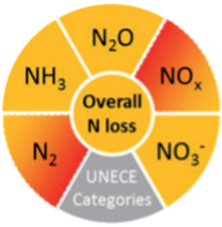
Landscape Measure 14: Digital planning of land-use on basis of a suitability assessment

Land-use and farm planning based on digital 3D precision maps of soil N retention can help to optimize fertilizer use and reduce N leaching and other losses. This can help to improve nutrient retention at landscape scale, improve water quality in surface waters and groundwaters and reduce gaseous N_r losses. The approach typically requires support through detailed modelling.



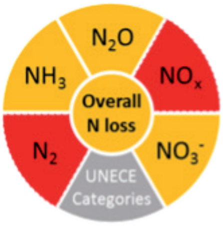
Landscape Measure 15: Towards mixed farming

Mixed farming combines livestock and cropping at farm and landscape scales. Crop and livestock integration provides opportunities to connect nitrogen inputs and surpluses so as to reduce overall levels of nitrogen pollution, while increasing farm- and landscape-scale nitrogen use efficiency. Emissions associated with long-distance feed and manure transport are reduced. Mixed cropping-livestock systems also provide the opportunity to develop free-range livestock production in combination with crops that mitigate N_r losses.



Landscape Measure 16: Landscape-level targeting of technical options to reduce N_r losses

Technical measures may be selectively applied at the landscape scale, where they are targeted to be used in specific sensitive areas. Analysis at the landscape scale can also allow for a more nuanced analysis of the potential trade-offs and synergies between emissions abatement and effects mitigation of different N compounds.



E. Overall priorities for policymakers

62. Policymakers may find it helpful to recognize that underlying every measure is one or more of the listed principles for integrated sustainable nitrogen management, as illustrated by table II.4.

63. The following priorities are identified linked to livestock housing and manure storage:

(a) Concepts for best practices to reduce adverse environmental impacts require integrated concepts including consideration of the interactions:

(i) Between pollutants;

(ii) With animal welfare aspects;

(iii) With climate change;

(iv) With biodiversity protection; and

(v) With region-specific characteristics.

(b) Concepts to reduce adverse environmental impacts require a detailed understanding at a process level to assess emissions, influencing factors and abatement/mitigation options;

(c) Concepts to reduce adverse environmental impacts depend on the development of flexible concepts that account for climate- and site-specific conditions, the three pillars of sustainability, potential conflicts of interest and whole-system solutions.

Table II.4 : Summary of measures to support integrated sustainable nitrogen management in agriculture and their linkage to underlying principles

Measure numbers	Description of measures	Principle numbers	Description and application of the principles
Livestock Diets, Housing, Manure Management & Nutrient Recovery			
Dietary Measures 1, 4 and 5	Adapt protein intake in diet (cattle, pigs, poultry)	Principle 5	Control of N inputs influences all N loss pathways.
		Principle 22	Dietary strategies for N consider C and CH_4 interactions.
		Principle 4	Trade-offs require policy priorities to be set.
Dietary Measure 2	Increase productivity (dairy and beef cattle)	Principle 13	Optimizing animal production requires that all factors be in balance.
Dietary Measure 3	Increase longevity (dairy cattle)	Principle 13	Optimizing animal production requires that all factors be in balance
Housing Measure 1 and Manure Measure 10	Immediate segregation of urine and faeces (cattle). Mechanical separation	Principle 14	Reduce rate of urea hydrolysis.
		Principle 15	Reduce exposure of NH_4^+-containing resources to air by increasing infiltration to soil.
Housing Measures 2, 3, 9 and 10	Reduce emitting surface and regular cleaning of floors (cattle, pigs)	Principle 15	Reduce exposure of NH_4^+-containing resources to air, including by reducing temperature.
Housing Measures 4 and 11	Frequent slurry removal (cattle, pigs)	Principle 15	Reduce exposure of NH_4^+-containing resources to air, plus benefits through reducing temperature and surface area.
Housing Measures 5 and 12	Increase bedding material (cattle and pigs with solid manure)	Principle 7	Nitrogen input-output balance, with increased storage from N absorbed in bedding.
Housing Measures 6 and 13	Barn climatization (cattle, pigs)	Principle 15	Reduce exposure of NH_4^+-containing resources to air, due to reduced temperature and airflow.

Measure numbers	Description of measures	Principle numbers	Description and application of the principles
Housing Measures 7, 14 and 17	Acid air-scrubbers (cattle, pigs, poultry)	Principle 7	Nitrogen input-output balance, with N captured by the scrubbers.
Housing Measure 8	Slurry acidification (pig and cattle)	Principle 15	Reduce exposure of NH_4^+-containing resources to air, due to reduced pH.
Housing Measures 15 and 18	Biological air-scrubbers (pigs and poultry)	Principle 7	Nitrogen input-output balance, with N captured by the scrubbers.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
		Principle 4	Trade-offs require policy priorities to be set.
Housing Measure 16	Rapid drying of poultry litter	Principle 14	Reduce rate of urea hydrolysis.
		Principle 16	Reduce rate of nitrification.
Manure Measure 1	Covered storage (solid cover and impermeable base)	Principle 15	Reduce exposure of NH_4^+-containing resources to air.
		Principle 20	Coupling N and water cycles: avoidance of rain driven leaching and run-off from stored manure.
Manure Measure 2	Covered slurry storage (natural crust and impermeable base)	Principle 15	Reduce exposure of NH_4^+-containing resources to air.
		Principle 20	Coupling N and water cycles: avoidance of rain driven leaching and run-off from stored manure.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
		Principle 4	Trade-offs require policy priorities to be set.
Manure Measure 3	Covered storage of solid manure (dispersed coverings)	Principle 15	Reduce exposure of NH_4^+-containing resources to air.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE. May be combined with Manure Measure 5.
Manure Measure 4	Storage of solid manure under dry conditions	Principle 16	Reduced rate of nitrification and denitrification.
		Principle 20	Coupling N and water cycles: avoidance of rain driven leaching and run-off from stored manure.
Manure Measure 5	Storage of manure on a concrete base with walls	Principle 20	Coupling N and water cycles: avoidance of rain driven leaching and run-off from stored manure.
		contra Principle 15	Exposure of NH_4^+ resources to air increases NH_3 emissions.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
		Principle 4	Trade-offs require policy priorities to be set.
Manure Measure 6	Slurry mixing	Principle 9	Managing spatial variations: better mixed slurry ensures more reliable application rate.
		contra Principle 15	Exposure of NH_4^+ resources to air increases NH_3 emissions.
Manure Measure 7	Additives to adsorb slurry ammonium	Principle 7	Nitrogen input-output balance, with increased storage from N absorbed in bedding.
Manure Measure 8	Slurry acidification	Principle 15	Reduce exposure of NH_4^+-containing resources to air, due to reduced pH.

Measure numbers	Description of measures	Principle numbers	Description and application of the principles
Manure Measure 9	Slurry aeration to reduce odour	contra Principle 15	Exposure of NH_4^+ resources to air increases NH_3 emissions.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
		Principle 4	Trade-offs require policy priorities to be set.
Manure Measure 11	Anaerobic digestion of manure	Principle 6	Measures to save N pollution leave more available in the farming system, which needs to be managed accordingly.
		Principle 15	Reduce exposure of NH_4^+-containing resources to air.
		Principle 16	Reduce rate of nitrification.
		Principle 18	Can increase whole system NUE by promoting N recovery and reuse.
		Principle 19	Co-benefits from reuse of other nutrients and CH_4.
Manure Measure 12	Manure composting for odourless fertilizer supply	Principle 19	Co-benefits from reuse of other nutrients.
		contra Principle 15	Exposure of NH_4^+ resources to air increases NH_3 emissions.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
		Principle 4	Trade-offs require policy priorities to be set.
Nutrient Recovery Measure 1	Drying and pelletizing of manure solids	Principle 19	Co-benefits from reuse of other nutrients.
		contra Principle 15	Exposure of NH_4^+ resources to air increases NH_3 emissions.
		Principle 4	Trade-offs require policy priorities to be set.
Nutrient Recovery Measure 2	Combustion, gasification or pyrolysis	Principle 4	Trade-offs require policy priorities to be set (for example, bioenergy or N pollution).
		contra Principle 6	Burning destroys N resources, reducing system-wide NUE (unless converted into a recoverable N_r form).
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
Nutrient Recovery Measures 3 and 4	Precipitation of N salts. Concentration of N solutions.	Principle 6	Measures to save N pollution leave more N available for the farming system, which needs to be managed accordingly.
		Principle 18	Increase whole-system NUE by promoting N recovery and reuse.
		Principle 19	Co-benefits from reuse of other nutrients.

Measure numbers	Description of measures	Principle numbers	Description and application of the principles
Nutrient Recovery Measure 5	Ammonia stripping and recovery	Principle 6	Measures to save N pollution leave more N available in the farming system, which needs to be managed accordingly.
		Controlled use of principle 15	Exposure of NH_4^+ resources to air with high pH and temperature increases emission of NH_3 (which is re-captured).
		Principle 18	Increase whole system NUE by promoting N recovery and reuse.
Field application			
Field Measure 1	Integrated nutrient management plan	All principles apply including:	
		Principle 2	Multiple actors have a role in N management: a clearly documented plan can support multi-actor agreement.
		Principle 5	Control of N inputs influences all N loss pathways.
		Principle 6	Measures to save N pollution leave more N available in the farming system, which needs to be managed accordingly.
		Principle 7	Nitrogen input-output balance provides a basis to optimize N and economics.
		Principle 8	Matching inputs to crop and livestock needs allows all N losses to be reduced.
		Principle 9	Spatially explicit management to match N needs and vulnerability within and between fields.
Field Measures 2 and 3	Apply nutrients at appropriate rate and time	Principle 5	Control of N inputs influences all N loss pathways.
		Principle 6	Measures to save N pollution leave more N available in the farming system, which needs to be managed accordingly.
		Principle 7	Nitrogen input-output balance provides a basis to optimize N and economics.
		Principle 8	Matching inputs to crop & livestock needs allows all N losses to be reduced.
Field Measure 4	Apply nutrients in the appropriate form	Principle 14	Reduce rate of urea hydrolysis.
		Principle 16	Reduce rate of nitrification.
		Principle 17	Nitrogen input forms reducing N_2O loss may also reduce N_2 loss, as both are controlled by denitrification.
Field Measure 5	Limit or avoid fertilizer use in high-risk areas	Principle 9	Spatial variations in agricultural land require spatially explicit N management.
		Principle 10	Spatial variations in natural habitat sensitivity require spatially explicit N management.
Field Measure 6	Band-spreading and trailing shoe application of slurry	Principle 15	Reduce exposure of NH_4^+-containing resources to air.
		Principle 6	Measures to save N pollution leave more N available in the farming system, which needs to be managed accordingly.

Measure numbers	Description of measures	Principle numbers	Description and application of the principles
Field Measures 7 and 11	Slurry injection Rapid incorporation of manure	Principle 15	Reduce exposure of NH_4^+-containing resources to air.
		Principle 6	Measures to save N pollution leave more N available in the farming system, which needs to be managed accordingly.
Field Measure 8	Slurry dilution for field application	Principle 15	Reduce exposure of NH_4^+-containing resources to air by increasing infiltration to soil.
		Principle 20	Coupling N and water cycles: may risk increased NO_3^- leaching unless integrated with irrigation management.
		Principle 4	Trade-offs require policy priorities to be set.
Field Measure 9	Slurry acidification (during spreading)	Principle 15	Reduce exposure of NH_4^+-containing resources to air by decreasing pH.
Field Measures 10, 14 and 20	Nitrification inhibitors (slurry, fertilizers and urine)	Principle 16	Reducing rate of nitrification and denitrification reduces N losses and increases NUE.
		Principle 17	Reducing N_2O loss may also reduce N_2 loss.
Field Measure 12	Replace urea with other N fertilizer	Principle 15	Reduce exposure of NH_4^+-containing resources to air by avoiding pH peaks associated with urea hydrolysis.
Field Measure 13	Urease inhibitors: addition to urea-based fertilizers	Principle 14	Reduce rate of urea hydrolysis.
Field Measure 15	Slow release fertilizers	Principle 8	Matching N inputs to crop needs, through improved timing of N availability.
Field Measure 16	Fertigation	Principle 20	Co-optimization of N and water increases effective nutrient uptake reducing N losses.
Field Measure 17	Precision placement of fertilizer including deep placement	Principle 12	Optimizing crop yield and NUE requires that all defining and limiting factors be addressed simultaneously.
		Principle 15	Reduce exposure of NH_4^+-containing resources to air.
Field Measure 18	Extended grazing season	Principle 15	Reduce exposure of NH_4^+-containing resources to air, as urine infiltrates soil more rapidly than manures and slurries.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
		Principle 4	Trade-offs require policy priorities to be set.
Field Measure 19	Avoid grazing high-risk areas for waterlogging and run-off	Principle 9	Spatial variations in agricultural land require spatially explicit N management.
		Principle 10	Spatial variations in natural habitat sensitivity require spatially explicit N management.

Measure numbers	Description of measures	Principle numbers	Description and application of the principles
Land-use and landscape management			
Landscape Measure 1	Increasing land cover with perennial crops	Principle 7	Perennial crops allow more C and N to be stored in biomass and soil, reducing N losses according to the mass balance of inputs-outputs.
		Principle 16	Reduction in soil inorganic N levels can reduce losses as NO_3^-, NO_x, N_2O and N_2.
		Principle 20	Better-developed root systems of perennial crops may offer co-benefits for N and water to reduce NO_3^- leaching.
Landscape Measure 2	Use of cover crops in arable rotations	Principle 7	Removing N using a cover crop (or catch crop) can reduce N loss during vulnerable periods.
		Principle 8	Matching N inputs to crop needs, offers opportunity to reduce all N losses.
		Principle 16	Cover crops remove N from the soil and can therefore reduce losses as NO_3^-, NO_x, N_2O and N_2.
		Principle 20	Co-optimizing N and water management can help reduce NO_3^- leaching.
Landscape Measure 3	Inclusion of N_2 fixing plants in crop rotations (including intercropping)	Principle 8	Matching N inputs to crop needs, offers opportunity to reduce all N losses.
		Principle 15	Reduce exposure of NH_4^+-containing resources to air, by provision of slow release biological N fixation.
		Principle 16	Decreasing denitrification reduces other N losses by a slow-release N source.
		contra Principle 16	Ploughing-in of N from legumes in crop-rotations manure may give N losses as NO_3^-, NO_x, N_2O and N_2
Landscape Measure 4	Introducing agroforestry and trees into the landscape	Principle 7	Perennial crops allow more C and N to be stored in biomass and soil, reducing N losses according to the mass balance of inputs-outputs.
		Principle 11	The structure of landscape elements affects the capacity to store and buffer nitrogen flows.
		Principle 20	Better-developed root systems of perennial crops may offer co-benefits for N and water to reduce NO_3^- leaching.
Landscape Measure 5	Constructed wetlands	Principle 11	Specially designed ecosystems may act as buffers of N pollution.
		Principle 19	Co-benefits if reuse of other nutrients.
		contra Principle 15	Exposure of NH_4^+ resources to air increases NH_3 emissions.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
		Principle 4	Trade-offs require policy priorities to be set.
Landscape Measure 6	Planting of paludal cultures in riparian areas or constructed wetlands	Principle 11	The structure of landscape elements affects the capacity to store and buffer nitrogen flows.
		contra Principle 15	Exposure to air increases NH_3 emissions.
		contra Principle 16	Increasing denitrification risks other N losses and reduced NUE.
		Principle 4	Trade-offs require policy priorities to be set.

Measure numbers	Description of measures	Principle numbers	Description and application of the principles
Landscape Measure 7	Use of organic layers to promote nitrate removal	contra Principle 16	Deliberately increasing denitrification reduces NO_3^- in water flows while increasing other N losses as N_2O and N_2, also reducing NUE.
		Principle 4	Trade-offs require policy priorities to be set.
Landscape Measure 8	Drainage management	Principle 16	Reduces denitrification related losses by reducing soil water residence times, but correspondingly likely to increase NO_3^- losses to stream-water.
		Principle 4	Trade-offs require policy priorities to be set.
Landscape Measure 9	Stimulating N_r removal in coastal waters	Principle 7	Cultivation and harvesting of biomass in coastal waters allows more N removed reducing coastal N pollution according to mass balance.
Landscape Measure 10	Introducing trees for afforestation and hedgerows	Principle 11	The structure of landscape elements affects the capacity to store and buffer nitrogen flows.
		Principle 20	Better-developed root systems of perennial crops may offer co-benefits for N and water management to reduce NO_3^- leaching.
Landscape Measure 11	Set-aside and other unfertilized grassland	Principle 11	The structure of landscape elements affects the capacity to store and buffer nitrogen flows. Unfertilized land may serve as a buffer to N compounds flowing to water, and physically separate emissions and vulnerable ecosystems.
Landscape Measure 12	Shelterbelts of trees around large point sources	Principle 11	The structure of landscape elements affects the capacity to store and buffer nitrogen flows. Tree belts planted around point sources of NH_3 emission help recapture and disperse NH_3 and particles, acting as buffers to protect nearby sensitive ecosystems.
Landscape Measure 13	Environmentally smart placement of livestock facilities	Principle 11	The structure of landscape elements affects the capacity to store and buffer nitrogen flows. Utilizes smart placement to maximize landscape buffering capability.
		Principle 16	Avoiding acute N inputs to semi-natural lands helps avoid local surpluses, reducing N losses.
Landscape Measure 14	Digital planning of land-use suitability	Principles 11, 12, 14, 16 and 20	Optimizing crop and livestock production according to all parameters including landscape structure and vulnerability, including interactions with water flows.
Landscape Measure 15	Towards mixed farming, including free-range systems	Principles 5, 7 and 8	Mixed farming allows manure flows to be reused more locally in cropping systems, allowing reduced N inputs according to mass balance with a broad opportunity to reduce N losses.
Landscape Measure 16	Landscape-level targeting of technical options to reduce N_r loss	Principle 4 and Principle 11	Based on agreed policy priorities, certain areas are designated as more vulnerable and requiring special protection, so more ambitious technical measures are applied in the vicinity of such sites.

Abbreviations: NUE, nitrogen use efficiency, which may be defined on a range of scales from crop and livestock scale to the full agrifood chain and across the entire economy.

64. The priority considerations for policymakers regarding integrated management of N to minimize pollution include:

(a) Integrated N planning at the farm, sectoral and regional levels (including addressing the trend towards concentration of intensive livestock and crop farms, often near cities), taking into account the fact that a healthy mix of food products is produced at low environmental burden;

(b) Minimizing nutrient applications to high-risk zones (water and N deposition-sensitive habitats, high-risk drainage basins), being aware of region-specific requirements and conditions;

(c) Integrating nutrients from recycling of organic residues to agriculture (this may require regional planning and adequate quality control of materials to be applied);

(d) Identifying cost-effective abatement measures for farmer implementation;

(e) Providing technical advice, guidance and adequate training to farm advisors and farmers relative to N use and management.

65. Priority considerations for policymakers regarding land-use and landscape actions for integrated nitrogen management include:

(a) Establishing pilots and demonstrations of sustainable land-use and landscape management to demonstrate how these approaches can utilize the nitrogen cycle to maximize overall resilience with reduced environmental impacts;

(b) Establishing evidence, scenarios and tools to demonstrate performance in reducing multiple adverse effects of nitrogen on sensitive landscapes, including analysis of costs and benefits;

(c) Demonstrating how land-use and landscape options support the development of production systems that are more resilient to climate change and with more diverse services delivered, at the same time as reducing environmental N_r footprint;

(d) Consideration of how benefits for nitrogen link to other issues; for example, woodlands in landscapes serve many functions, such as increasing landscape water retention to reduce flooding and providing wildlife habitats and shelter for livestock, in addition to their benefit as N management tools.

F. Priorities for practitioners

66. The following priorities are identified linked to livestock housing and manure storage:

(a) Match the N content of the animals' diet as closely as possible to the animals' requirements in order to avoid excess N input already at the feeding level;

(b) Keep livestock houses cool and clean and regularly remove manure to a covered outside storage;

(c) Store manure in a covered store, consider manure treatment for low emissions (for example, anaerobic digestion, separation, acidification);

(d) Recycle manure nutrients as valuable fertilizer in crop production.

67. For farmers, the main goals of implementing abatement measures are to increase the efficiency of N applied as fertilizer or manure to their crops, save costs on nitrogen inputs, and reduce pollution into air, water and soil. As such, the top field measures for farmers to improve N use efficiency are considered to be:

(a) Integrated farm-scale N management planning taking account of all available N sources;

(b) Precision nutrient management: appropriate rate, timing, form and placement of N;

(c) Use of the appropriate fertilizer product and form (including inhibitors, as relevant) in the appropriate context;

(d) Use of low-emission slurry-spreading technologies (accounting for the saved N in nutrient plans);

(e) Rapid soil incorporation of ammonia-rich organic amendments.

68. Top land-use and landscape management measures to be implemented in practice can be divided into two groups: those related to a geographically targeted land-use change, and those related to geographically adapted management practices at landscape/regional scale.

69. Key land-use change measures identified include:

(a) Set-aside/grassland (with no addition of fertilizers);

(b) Establishment of riparian buffer strips, or of biodiversity buffer strips around or within fields (the difference being the proximity to an aquatic environment;

(c) Hedgerows and afforestation;

(d) Changed crop rotation/perennial crops (for example, permanent grasslands);

(e) Agroforestry;

(f) Wetlands and watercourse restoration and/or constructed mini-wetlands.

70. Key management options for geographically oriented measures at landscape and regional scales include:

(a) Soil tillage and conservation (for example, no tillage of organic soils);

(b) Drainage measures and controlled drainage;

(c) Grassland management;

(d) Placement of livestock production;

(e) Spatial redistribution of manure;

(f) Fertigation and installation of proper irrigation system for dry cultivated areas;

(g) Placement of biogas plants and biorefineries for biomass redistribution.

71. It is recognized that more farmers are adopting practices referred to as "regenerative agriculture", with some practices

having potential to reduce different N losses, including no-till, “organic farming” (avoiding manufactured inorganic fertilizers and focusing on biological nitrogen fixation) and activities designed to increase carbon sequestration, etc. As with other agricultural approaches, such systems provide the opportunity to design bespoke “packages of measures” to foster sustainable nitrogen management. These require further assessment to quantify their effects for all forms of N loss, including emissions of NH_3, N_2O, NO_x and N_2 and leaching of NO_3^- and other N_r forms.