Chapter VII: Development of packages of measures for integrated sustainable nitrogen management

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A. Introduction

465. The material presented in this guidance document provides the basis for improving understanding of the connections across the nitrogen (N) cycle, together with a menu of options. Reflection on the listed principles (chapter III) can inform national and regional approaches based on understanding the key issues. Together, the descriptions of measures for the different parts (chapters IV–VI) indicate the benefits and limitations of the actions.

466. While consideration of the overall nitrogen flow through the agrifood system is a key element of bringing these parts together, there is also a need to visualize these connections more fully. The present chapter therefore examines selected case studies to illustrate possible "packages of measures". These represent coherent groups of measures according to the locality, farming system and environmental context. The examples may be useful to Governments, agencies, businesses and community groups as they consider how to fit together the different measures and principles.

467. At the heart of the approach is consideration of the N flow in the context of the nitrogen cycle. Nitrogen inputs for fertilizer and feed are directly connected to N outputs in crops and livestock for food and wasteful losses to the environment. This means that decisions by all actors have an effect on system efficiency, amounts of N wasted and levels of pollution. Measures taken earlier in the nitrogen chain therefore need to be followed up by complementary measures later in the chain if the full benefit is to be achieved. For example, measures to reduce NH_3 emissions from animal housing should be matched with actions for manure storage and land application, if earlier savings are not to be lost.

468. Inspection of the different measures listed in chapters IV–VI quickly shows how they are complementary – addressing different parts of the system. This means that it is essential to consider "packages of measures" as part of integrated sustainable nitrogen management, both to realize synergies between measures and to minimize trade-offs.

469. The following examples illustrate how packages of measures are needed:

(a) Ammonia emissions tend to occur quickly (hours-days), so measures that minimize contact of ammonium-rich resources with air (principle 15) are essential;

(b) Measures that reduce a large nitrogen loss (for example, NO_3^-, N_2 and NH_3) leave more N_r in the farming system. It is therefore essential to reduce additional N_r inputs (or increase outputs/storage) if the full benefits of the measures are to be realized in increasing nitrogen use efficiency (NUE) and reducing N losses (principle 6);

(c) Emissions of N_2O, NO and N_2 to air and leaching of NO_3^- and other N_r compounds to water tend to occur as a result of surplus ammonium and nitrate in soils, where these exceed plant needs. Therefore, reducing these emissions depends on knowing the amount and timing of plant N uptake (principle 7) in order to avoid soil N surplus;

(d) The different processes controlling oxidized N_r losses (N_2O, NO, NO_3^-) versus NH_3 emissions mean that measures for the first group are not necessarily helpful for the second (and vice versa). Measures must therefore be considered together;

(e) According to mass balance, all measures that allow an appropriate reduction in total N_r inputs, while maintaining productivity, will increase system-wide NUE and lead to a reduction in all N_r losses (principle 7);

(f) Wider land-use and landscape management strategies complement animal and crop abatement strategies by offering the opportunity to increase landscape resilience, mitigating environmental effects by managing temporal and spatial distribution (principles 11 and 15). This means that land-use/landscape measures are especially relevant to reduced local adverse impacts (for example, effects on nature and water).

470. Further issues of this kind are detailed in chapter III. The case studies here show how this thinking may be applied to design coherent packages of measures. The focus here is on agricultural examples, although the philosophy is relevant for all source sectors.

B. Case studies

Case Study 1: Measures package for an intensively managed dairy farm

471. Intensive dairy production typically includes both housed animals and animals grazing for part of the year. This means that measures will need to consider both systems. In this case study, a broad approach is taken with the objective of the illustrative measures package being to:

(a) Reduce total N losses to maximize N_r retention in the farming system, and reduce denitrification losses to N_2, while offering financial benefit by reducing the need for bought-in manufactured fertilizers;

(b) Reduce, as a priority, NH_3 emissions, given close location to certain protected natural habitats;

(c) Follow good practice to minimize nitrate leaching and avoid N pollution of watercourses according to basic national guidelines;

(d) Reduce N_2O and NO_x emissions, so long as this is consistent with other measures.

472. The context of this case study is a rural country with low vehicular NO_x emissions, but with high tropospheric ozone concentrations, so any reductions in soil NO_x will be considered a significant benefit. The location has a mild climate, where it may be possible to increase the grazing season from that currently implemented. The soils are impermeable, with low risk of NO_3^- leaching, but have a high risk of surface run-off to vulnerable watercourses. The farm buildings have natural ventilation, with cattle on slatted floors over a slurry pit. There is no possibility of investment to alter significantly the housing design, though targeted modifications may be feasible. The farm is grass-based, with insignificant arable area. Manure is currently surface broadcast on grassland using a traditional vacuum spreader (splash plate).

473. The following issues are worth considering related to grassland N flows:

(a) With impacts of ammonia being relevant, an increase in the grazing season (Field Measure 18) provides an obvious opportunity to reduce NH_3 emissions. However, special measures would be needed to ensure that this does not exacerbate N lateral run-off to nearby watercourses. This could be managed by using landscape features such as wooded buffer zones (Landscape Measure 10);

(b) While the impermeable soil means that nitrate leaching to groundwater may not be a priority in the case study, this soil type is also vulnerable to increased denitrification, wasting N_r resources as N_2 and increasing N_2O emissions;

(c) If winter rainfall is high, poor drainage in the impermeable soils risks "poaching" of the grassland by cattle, where grass is destroyed by trampling and fields become muddy. Such poaching damage reduces plant nutrient uptake and can increase N_2O and N_2. This may be a key limiting factor for extending the grazing season in this case study.

474. With these considerations, a possible package of measures for emissions related to grazing animals in this case study could be:

(a) An increase in the time animals spend grazing (Field Measure 18), for example, by extending the grazing season by one to two weeks at each end, while recognizing the limits to maintain a healthy soil and sward and using appropriate grazing. This can contribute to reducing total NH_3 emissions from the farm;

(b) Ensuring healthy sward development and avoid "poaching" by active herd management through rotational grazing. This minimizes the risk of surplus N not being taken up by plants, helping to reduce N_2O and N_2 losses. It will also help to reduce any nitrate leaching to the extent that this occurs;

(c) Ensuring that there is appropriate fencing to restrict grazing within recommended distances of watercourses (Field Measure 19), and consider use of growing vegetation in buffer areas near streams (Landscape Measure 10). This can contribute to reducing run-off of N_r into streams;

(d) Working with a local research partner to test application of nitrification inhibitors to urine patches (Field Measure 20) (for example, by use of drones or as part of grazing rotation management).

475. The following issues are worth considering in relation to emissions from housing and manure management:

(a) The diet of each animal group during the winter housing period should be reviewed to see if there are opportunities for the total mixed ration to be optimized in relation to protein needs, as minimizing unnecessary excess may offer opportunities to reduce wasteful nitrogen excretion (Dietary Measure 1);

(b) The existing slatted floor system is not well suited to immediate segregation of urine and faeces (Housing Measure 1). With realistically available finance in this case study, substantial redesign of the building is not feasible;

(c) Add-on measures may be feasible if targeted funding can be obtained that does not require major rebuilding of the animal house;

(d) Liquid manure (slurry) is currently stored in an open tank, liable to significant NH_3 emissions.

476. With these considerations in mind, a possible package of measures to reduce N emissions from the animal housing and manure management could consist of:

(a) Targeting the protein content of the housed diet of the cattle to match requirement, for example, 15–16 per cent crude protein for dairy cows on average. Consider phase-feeding according to animal age if cows are block calved or kept in age groups to give even more precision, while ensuring that energy needs are also met. Start regular testing of the forage component of the diet (for example, stored farm silage) as it is used, to help achieve the target crude-protein intake (Dietary Measure 1);

(b) Exploring options for grants for low-emission housing, storage and manure spreading, especially given the priority that the farm is near a protected natural habitat sensitive to ammonia;

(c) Installing an automatic system for washing of animal house floors (on a twice-daily basis) (Housing Measure 3);

(d) Installing a system to acidify slurry in the slurry pit (Housing Measure 7). This system will reduce NH_3 emissions from the housing itself, as well as having further benefits to reduce emissions during manure storage and spreading;

(e) Upgrading the vacuum spreader to include a trailing hose or trailing shoe system (Field Measure 6). This will further reduce NH_3 emissions in addition to the benefit of slurry acidification and also ensure accurate spreading of manure to enabling consistent delivery (and fertilization benefits for crops), while minimizing the spreading of slurry near vulnerable habitats (Landscape Measure 16). Consultation with nature agencies and use of online models (for example, http://www.scail.ceh.ac.uk) may be needed to agree minimum distances between slurry spreading and sensitive nature areas).

477. The overall package of field and housing measures should be reviewed in relation to local goals for nitrogen saving, emission reduction of different N_r forms and ecosystem protection. Use of an integrated nutrient management plan (Field Measure 1) informed by soil nutrient testing, combined with the low-emission measures identified, will help to reduce bought-in fertilizer inputs to save money and realize the benefit of the emissions reductions (principle 6). Monitoring of the farm-level N balance may prove a useful indicator to work out how fast to reduce purchased N inputs as part of improving farm level NUE and reducing N surplus. Further measures may be included if higher ambition is needed (for example, covering of slurry store, installing solid surfaces for animal holding and traffic areas).

Case Study 2: Measures package for an organic dairy farm

478. It is relevant to consider how the preceding case study might be different if the context were an organic dairy farm at the same location. The following general considerations should be noted:

(a) It is assumed that the environmental objectives for sustainable nitrogen management are the same as in the previous case study. The major differences are that manufactured inorganic fertilizers will not be used, nor will strong acids be purchased to acidify slurry (for example, sulphuric acid);

(b) On this organic farm, nitrogen inputs are provided by using clover-rich swards, which generate a sufficiently protein-rich ration for winter feeding of cattle during the winter housing period. Preliminary estimates for this case study show that it is still relatively intensive, with high milk production, although N inputs are 30 per cent lower than in Case Study 1, with half the overall nitrogen surplus, but these estimates need to be checked;

(c) As a livestock farm, production of liquid manure (slurry), emissions of NH_3 from animal housing will still be significant, including from the open manure storage and surface broadcast application of slurry to surrounding grass fields. Ammonia emissions from this organic farm and from the field application still pose a significant risk to adjacent protected natural habitats;

(d) Although no inorganic fertilizers are used, the activities still contribute significantly to N_2O, NO and N_2 emissions, especially following field application of liquid manure. Nitrate and other N_r run-off are similarly a concern;

(e) As there are no bought-in N sources to the farm in this organic system, the farmer is strongly motivated to reduce N losses to maximize the benefit of the limited N resources that are available.

479. All of the measures described in Case Study 1 would be available except for the following:

(a) Acidification of slurry (Housing Measure 7);

(b) (Chemical) nitrification inhibitors during grazing (Field Measure 20).

475 bis. To take account of the fact that some measures are not available in this organic context, the following package of measures may be considered:

(a) Extension of grazing season (Field Measure 18) – as per Case Study 1;

(b) Rotational grazing to avoid poaching – as per Case Study 1;

(c) Avoidance of grazing of sensitive areas near watercourses (Field Measure 19) and identify buffer areas (Landscape Measure 10) – as per Case Study 1;

(d) Working with local research partner to test application of a nitrification inhibitor to urine patches (Field Measure 20) – as per Case Study 1, but testing the use of an organic nitrification inhibitor, such as neem oil;

(e) Testing opportunities to fine-tune diet in relation to protein needs with a target crude protein content and consider the possibility of phase feeding (Dietary Measure 1) – as per Case Study 1;

(f) Exploring options for grants for low-emission housing, storage and manure spreading, given the priority that the farm is near a protected habitat sensitive to ammonia – as per Case Study 1, but opportunity for grants may be greater given the organic farm commitment of Case Study 2;

(g) Installing an automatic system for washing of animal house floors (Housing Measure 3) – as per Case Study 1;

(h) Undertaking work with a research partner to test a biotrickling system for capturing and recovering NH_3 from the slurry pit as an organic N resource (cf. Housing Measures 7 and 15), which reduces emissions from housing and manure storage;

(i) Investigating low-cost options for covering slurry stored outside the animal house. Consider whether natural crusting is feasible (Manure Measure 2) or whether it is possible to store manure with a solid cover (Manure Measure 1);

(j) Upgrading the vacuum spreader to include a trailing shoe system (Field Measure 6) – as per Case Study 1 – but with larger emission reductions than trailing hose and even better suited to grassland. This is especially important because no acidifying agent has been used in this organic farming case study;

(k) Minimizing the spreading of slurry near vulnerable habitats (Landscape Measure 16) – as per Case Study 1.

480. As with Case Study 1, the overall package should be reviewed in relation to local goals for nitrogen saving, emission reduction of different N_r forms and ecosystem protection. Use of an integrated nutrient management plan (Field Measure 1) informed by soil nutrient testing will be especially important to maximize efficient use of the limited available N resources, and to realize the benefit of savings through the emissions reductions (principle 6). Additional measures may be included if higher ambition is sought (for example: Field Measure 7 – manure injection; Manure Measure 8 – local manure acidification and nitrogen enrichment augmented by wind/solar energy).

Case Study 3: Measures package for production of Mediterranean processing tomato

481. Production of the processing tomato (*Lycopersicum esculentum* L) is among the most important in the

Mediterranean region (four Mediterranean countries are among the top 10 producers globally). It is a perennial crop, grown annually by transplanting seedlings at the beginning of spring and growing until the end of summer. This results in a superficial and widely spread root system that requires heavy irrigation and fertilization, especially with nitrogen. The measures package illustrated in this case study consists of a broad approach with the following objectives:

(a) Reduction of total N losses to maximize N_r retention in the cropping system, focusing in particular on the reduction of NO_3^- leaching losses, with soils located in vulnerable drainage basin areas;

(b) Reduction of N losses by surface run-off to vulnerable watercourses, given that irrigation is mostly done by drip systems on the soil surface;

(c) Reduction of soil N_2O and NO_x emissions, which are at risk of being substantial because of water availability and high temperatures. These nitrogen losses are also associated with the heavy tillage needed to prepare soil for tomato transplanting;

(d) Reduction and avoidance of possible increases in NH_3 emissions (if future markets increasingly favour urea-based fertilizer products);

(e) Reduction of the total amount and costs of bought-in fertilizer.

482. The context of tomato production in this case study is rural areas, where traffic is almost entirely restricted to agricultural vehicles. There are few NO_x emissions from traffic sources in the case study area. This means that reductions in soil NO_x will be considered a significant benefit for air quality. Manure is usually not currently used in this production system, which focuses on N and other nutrient inputs from manufactured inorganic fertilizers. Currently, the fertilizer formulations used in the case study are based on ammonium nitrate, augmented by other nutrients. Non-urea composite fertilizers are the most commonly used for basal dressing. This is followed by the application of diverse soluble compounds in fertigation, including urea solutions in the fertigation. The following issues should be considered in relation to N flows associated with production of processing tomato:

(a) The greatest risk of N loss relates to nitrate leaching to groundwater, due to the heavy irrigation demand for this crop in the Mediterranean climate. As irrigation is mostly done on the soil surface according to current practice, there is also potential for losses by run-off. An appropriate irrigation system and water management are necessary to ensure that irrigation does not exacerbate N leaching or surface run-off;

(b) The soil types are conducive to nitrate leaching to groundwater, with the farms of this case study located in vulnerable areas, which makes this loss a priority;

(c) Processing tomato is highly demanding for N fertilization, which results in farmers often applying more N fertilizer than is needed by the crop. Besides basal dressing with N and other nutrients, tomato fields are already "fertigated" (for example, fertilizer addition to irrigation water, Field Measure 16). The amounts of N added by fertigation are currently varied according to the crop-growth cycle, but lack of calibration according to the actual performance of crops increases the risk of N loss, with farmers typically using more N than is needed as part of their risk management (for example, in case of unfavourable weather or nitrogen losses);

(d) Soil preparation for tomato cropping before seedling transplantation is substantial and involves deep tillage and several machine transits. This increases N emission as N_2O and NO_x from soil, as well as fuel combustion from agricultural machinery. Increased mineralization of soil organic matter (SOM) from tillage increases NH_3 emissions in variable amounts, though the exact amounts lost are not well known. Significant losses of N through denitrification to N_2 are expected but are not currently well-quantified.

483. With these considerations, a possible package of measures for emissions related to production of processing tomato in the field could consist of:

(a) Installation of more accurate irrigation systems compatible with the crop management. These can contribute to reducing total N losses from the field, including leaching and surface run-off (principle 16);

(b) Adoption of better-controlled systems for water management (principle 20). This also maximizes tomato growth and production, increasing plant uptake of N, which then helps to reduce total N losses (especially N leaching);

(c) Recognizing the different watering needs of tomato plants over the growing cycle according to the actual conditions as they develop. This requires variable irrigation flow and N addition by fertigation to match crop needs, based on updatable calculation of crop needs. This can also lead to water savings, as well as savings in N and other nutrient inputs. This measure may be supported by computer estimates, updated in real time based on meteorological data and monitoring of crop-growth indicators;

(d) Ensuring that there is appropriate soil coverage with impervious sheeting to reduce evapotranspiration water losses. This can contribute to reducing the irrigation flow needed and thus losses of N_r into surface water and groundwater bodies. When using black sheeting, weed growth will be reduced to minimum, which will also help avoid pesticide use. Consideration should be given to plastic reuse and recycling;

(e) More carefully fine-tuning the amounts of N added during basal fertilization and fertigation, avoiding overapplication of nutrients (including N), as informed by soil nutrient testing and crop performance indicators (for example, leaf colour sensing). This can significantly reduce nitrate leaching and other N emissions depending on the extent of fertilizer overapplication in current practice (principle 5; Field Measures 2, 3, 4 and 16). Use of electronic tools to calculate feasible cost-savings by fine-tuning N inputs to match requirements may help mobilize change;

(f) Reducing the intensity of soil tillage for tomato bedding preparation can also contribute to reducing N emissions derived both from fuel combustion and from soil itself. Alternative solutions include planting the seedlings in mulched non-tilled soil, to reduce weed growth, the use of sheeting and the need for tillage;

(g) Including an awareness campaign targeting farmers in the case study area to highlight the risks of unabated urea use for NH_3 emissions. This should raise awareness among farmers of the likely N losses by emission from urea-based fertilizers, the economic value of N losses and the environmental consequences. This awareness can then be used to mobilize adoption of additional measures (for example, inclusion of a urease inhibitor, Field Measure 13).

484. This list of field measures should be considered in relation to local conditions and local goals for nitrogen saving, emission reductions of different N_r forms, human health and ecosystem protection. Using a nutrient management plan supported by soil testing is beneficial to optimization of the use of fertilizers, saving of money and reduction of pollution (Field Measure 1). Further measures may be included if higher ambition is needed to meet agreed goals (for example, actions related to soil preparation prior to seedling transplanting).

C. Considerations for developing packages of measures

485. It is for users of this guidance to develop their own case studies, informed by the principles and measures presented herein. The following is a summary of key points to consider when developing packages of measures for integrated sustainable nitrogen management:

(a) **Consider which are the priority nitrogen threats** being managed in the area/country of concern (for example, air pollution, water pollution, climate change, biodiversity) and whether there are particular local risks (for example, designated sensitive nature areas or water bodies);

(b) **Consider whether there are other priority issues** that need to be considered at the same time concerning element flows (for example, carbon, phosphorus, sulphur) and other threats (for example, water scarcity);

(c) **Consider the level of ambition relevant for the situation**, for example, in relation to local or international commitments to reduce emissions and impacts;

(d) **Consider which principles are most applicable for the situation** (chapter III) according to the emission sources, local and regional context and priority nitrogen forms;

(e) **Identify relevant measures** needed to address the different nitrogen forms according to context and the relevant issues faced (drawing on chapters IV–VI).

486. Based on these actions, a draft package of measures may be proposed. This should be reviewed to consider what it might achieve for abatement of emissions to air and losses to water of different nitrogen forms. The following questions are relevant concerning each proposed package of measures:

(a) Does the package cover all important **nitrogen forms** according to agreed targets and priorities?;

(b) Are the measures in the package **complementary in achieving the overall goals**, for example, in relation to control of multiple nitrogen forms, and consistent with the principles of overall nitrogen flow?;

(c) What would the **overall outcome of the package** be, in terms of emissions reduction to air and losses to water, and is it sufficiently ambitious to meet agreed goals?;

(d) What would the **overall amount of nitrogen saved** from the measures package be that would otherwise have been wasted to air and water pollution and denitrification to N_2?;

(e) **By how much is wasted nitrogen to the environment reduced** compared with unabated practice? How does it compare with the Colombo Declaration ambition to "halve nitrogen waste" by 2030 (considering the sum of all loss pathways of N_r and N_2 emission)?; [35]

(f) What are the **initial implementation and running costs** of the package of measures, and what is the potential for reducing these costs?;

(g) What are the **initial and running benefits** of the package of measures, including monetary value of nitrogen saved in moving towards a circular economy for nitrogen?;

(h) What are the **wider societal benefits** of the package of measures, including valuation of the multiple benefits to environment, economy, health and well-being in the wider context of sustainability?;

(i) What is the **relationship to the Sustainable Development Goals**? How many of the Goals does the measures package help achieve and in what way?

487. As illustrated in chapter VII, multi-actor review of proposed packages of measures can serve to fine-tune the approach, building consensus on the way forward, including the need to highlight opportunities (for example, cost savings, environmental improvement, sustainability of resources) and discuss potential barriers (for example, implementation costs, need for harmonization, regulatory tools and opportunity for investment to catalyse action).

488. The above shortlist does not address all issues. Rather, it is intended to help support countries by illustrating how the different principles and measures described in this guidance document can be fitted together. The next step is for countries, regions and local communities to start considering their own packages of measures.

489. It is anticipated that feedback will be gathered through activities under the Air Convention and in partnership with other international processes, especially through the developing Inter-convention Nitrogen Coordination Mechanism (INCOM). This feedback will be essential as guidance is further developed for other United Nations regions within the context of the International Nitrogen Management System (INMS), as well as to evaluate progress in relation to achieving the Sustainable Development Goals.

35 See https://apps1.unep.org/resolution/?q=node/286.