Closing the mineral cycles at farm level

Good practices to reduce nutrient loss in the Central Denmark region
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Nutrient loss – Why does it matter?

Nitrogen, phosphorus and potassium are essential for agricultural production as they nourish the crops and support soil productivity. However, if these nutrients are not taken up by plants, they run the risk of being lost in various ways (e.g., leaching, run-off, emissions) and causing unnecessary costs for the farming business. Finding the right amount required by the plants and optimising the timing and application of the nutrients to match these needs can result in an economic gain and a positive effect on human health and the environment, including soil health and fertility.

This leaflet was developed in the framework of the project “Resource Efficiency in Practice – Closing Mineral Cycles”. It aims at providing practical information to farmers on how the risk of nutrient loss can best be minimised or prevented. In particular, the leaflet addresses the effects of nutrient loss in Denmark, with a specific focus on the Central Denmark region. The leaflet also provides practical information to farmers on how resource use efficiency can be maximised through good practices at farm level.
Agricultural structure in Central Denmark

Central Denmark is one of the main agricultural regions of the country, accounting for 30% of all Danish agricultural land and generating over 30% of the national agricultural revenue in 2013. In the region, more than 60% of the land is used for agriculture, where the main crops are barley, wheat and fodder crops, mostly consisting of grass and maize for silage. Farming in Central Denmark is dominated by livestock production; in particular, the western municipalities of the region have a high concentration of livestock farms. Pig production is dominant, but dairy cattle farming is also significant in Central Denmark.
How does nutrient loss affect farming business?

Nutrients are valuable and vital resources, which can nourish productive grazing lands and crops. From an economical point of view, it therefore makes sense to match the nutrient application to the grassland and crop requirements, thus limiting nutrient loss as much as possible. This in turn could limit the additional costs (e.g., tractor fuel, spreading equipment, labour, etc.) incurred when nutrients are applied beyond the crop and grass requirements. In addition, nutrient loss can create other costs for the farmer; for instance, in order to prevent soil acidification (which can increase with the application of fertilisers), farmers may have to lime their soils. Avoiding the impacts that may result from nutrient loss provides benefits to farming businesses, such as maintaining soil health and fertility and crop yields.

How does nutrient loss affect the Central Denmark region and what are the causes?

The Central Denmark region faces a number of environmental pressures mainly arising from nitrogen and phosphorus losses. Best management practices can help farming businesses use these nutrients more effectively, thereby reducing losses. High levels of livestock production result in a high volume of manure in comparison to the nutrient demand of the crops in the region. In addition to this manure, mineral fertilisers are also applied to crop fields, from which some of the nutrients are lost. Thus, part of the resources applied are not being utilised by the plants.

Different types of soils throughout the region also contribute to nutrient losses through nitrate leaching, which causes problems such as contamination of groundwater used for human consumption. Additionally, the soils in the region are moderately vulnerable to water erosion, which carries phosphorus along as run-off into streams, lakes and estuaries where it, together with nitrate, causes eutrophication and algae blooms.
What has already been done to address the problem in the region?

The Danish Action Programme for the Aquatic Environment III, adopted for the period 2005-2015, put a strong emphasis on phosphorus levels in agriculture. The aim was to halve phosphorus surplus by 2015 and to reduce nitrogen leaching by a minimum of 13% (compared to 2003). A mid-term review in 2008 showed that phosphorus surpluses were reduced, but nitrogen leaching had not decreased, even though farmers were required to use a nitrogen fertiliser rate around 15% below the economic optimum level. (1) Some of the measures implemented to reduce the eutrophication of water bodies included:

- Establishment of buffer zones along certain watercourses and lakes;
- Increased area of catch crops;
- Re-establishment of wetlands, which stimulate nitrate removal by microbial conversion;
- Ban on certain forms of soil cultivation during autumn and winter.

Ammonia emissions associated with livestock production pose a risk to natural ecosystems and may affect human health by forming fine particulate air pollutants, which can be inhaled. Danish legislation has therefore mandated that new livestock production facilities implement the best available techniques to reduce ammonia emissions. Existing livestock farms can only be expanded if the neighbouring ecosystem’s maximum capacity for nitrogen deposition will not be exceeded. Liquid manure used as fertiliser on bare soil or grass must be directly injected or acidified to reduce ammonia volatilisation.

The national Rural Development Programme under the EU Common Agricultural Policy has also promoted actions that decrease nutrient losses on-farm and increase resource efficiency. Specific measures have provided financial support to adopt new technology, update equipment, change crop rotations, plough using different methods, etc. Additionally, initiatives at the regional, state, and local level have supported farmers in implementing farm management practices to close mineral cycles. For instance, the Danish AgriFish Agency developed an environmental technology programme supporting new green technologies on farms.
Set of region-specific good practices

Several examples of ‘good practice’ measures to reduce nutrient loss and increase resource efficiency in the Central Denmark region have been identified (see Figure 2) and will be described in more detail in the following tables. The measures were selected based on their impacts on the agro-ecosystem in terms of reduced losses through improved nutrient utilisation. Thus, the selected measures provide some economic advantages for the farmer and at the same time reduce nutrient loss from the farming system, benefitting both the environment and society. Emphasis was placed on measures that have not yet been exploited to their full potential within the Central Denmark region. Further selection criteria were whether the measure might be feasibly implemented and whether the measure offers benefits which balance (or outweigh) the costs. The graphic below highlights various drivers of nutrient loss which exist in the Central Denmark region and problems related to those drivers. The final column presents the good practices that were identified as ways to potentially solve the problems associated with nutrient loss.

Figure 2: Selection of good practice measures for the Central Denmark region

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# Adjusting feeding strategies and techniques

The quality of livestock feed can be improved by adding enzymes, which increase the digestibility and nutritional value of the feed, especially concerning phosphorus availability. Furthermore, common fodder crops tend to be deficient in certain amino acids, causing inefficient use of the feed by the livestock during digestion. By adding the lacking amino acids, the feed composition will better match the livestock’s needs and the nutrients will be better assimilated by the animal, leading to fewer nutrients lost through excretion (i.e., less nitrogen in the manure). Overall, these measures result in significant reductions of the nutrient excretion per produced kg of meat, milk or eggs.

## Technical implementation
- Test or assess the nutrient content of non-manufactured animal feeds, especially forages;
- Consider animal nutritional advice as part of an overall nutrient management plan.

## Technical requirements
- Calculate the animals’ nutrient needs and the appropriate amount of enzymes or amino acids to add to the feed mixture. Group animals, if necessary, to facilitate diverse feeding strategies and obtain assistance from animal dieticians, if necessary, to determine appropriate amounts.

## Effects, benefits and costs

### Benefits for farming business
- Use of synthetic amino acids may reduce the need for protein feed as well as the amount of land needed to grow protein fodder.

### Costs for farming business
- Purchase of enzymes and amino acids to add to the feed; regular analyses of fodder; initial labour to re-group animals.

### Co-benefits
- When the nutrient content of animal manure is reduced, less nitrous oxide will result, for example, when it is applied as fertiliser. Also, a lower amount of ammonia will be released into the atmosphere and reduce N deposition, which also affects remote ecosystems. Additionally, potentially less land will be needed for fodder production.

### Environmental effects
- **Air**: Decreased ammonia emissions leading to less particulate matter, odour, and ozone formation, which lowers risks to human health (e.g., aggravated asthma and respiratory problems);
  - Reduced greenhouse gas emissions (methane and nitrous oxide), thereby decreasing the impact on climate.
- **Water**: Reduced leaching and run-off of nutrients (N and P), decreasing eutrophication and improving surface and groundwater quality, thereby lowering risks to human health and biodiversity.
- **Soil**: Improved soil fertility and health through reduced potential for acidification.
- **Biodiversity**: Positive effects from reduced N deposition in natural ecosystems.
## Improving manure processing: Slurry separation

### Definition of the measure
Livestock manure is separated into a liquid N-rich fraction (slurry) and a solid P-rich fraction. The solid fraction is subsequently exported away from the livestock intensive farm, thereby decreasing the P load on the farm where it originated. Slurry separation enables improved utilisation of the nutrients in livestock slurry, especially concerning P, thereby reducing the losses and the associated environmental impacts.

### Technical implementation
Due to the relatively high investment and operating costs for slurry separation systems, this measure has a significant economy of scale. Farmers with manure quantities less than 5,000 tonnes per year will probably not benefit economically from slurry separation, but at 10,000 tonnes manure annually the profitability increases. Mobile solutions, where a group of farmers share a slurry separation system, may be an option. For instance, six farmers on the island of Bornholm have established a manure separation co-operative, in which they share a mobile separator and regularly deliver the solid slurry fraction to the island’s biogas plant.

### Technical requirements
Source separation of slurry requires specific livestock housing designs and is therefore mainly suitable when constructing new stables. Alternatively, separation may take place using a separator after the manure has been removed from the stable. To limit ammonia emissions, the solid fraction should be separated shortly before it is applied or covered with an airtight cover during storage and incorporated rapidly following application in the field.

### Effects, benefits and costs

#### Benefits for farming business
Slurry separation will reduce the transportation costs because the liquid fraction stays on the exporting farm. Improved crop utilisation reduces the need for purchase and application of additional mineral fertiliser.

#### Costs for farming business
Initial investment in livestock housing designed for manure separation or an external separator. Additional costs include significant operating expenses.

#### Co-benefits
Slurry separation enables acidification of the liquid fraction, thereby reducing ammonia emissions. A further benefit is the reduction of greenhouse gas emissions during the production of fertilisers if less additional inorganic fertiliser is applied. In addition, the solid fraction is well suited for biogas production.

#### Environmental effects
- **Water**: Reduced losses of nutrients (P and potentially N), decreasing eutrophication and improving surface and groundwater quality, thereby lowering risks to human health and biodiversity.
- **Air**: Potentially decreased ammonia emissions depending on management (e.g., airtight cover on the stored solid fraction), leading to less particulate matter, odour, and ozone formation, which lowers risks to human health (e.g., aggravated asthma and respiratory problems); Potentially reduced methane emissions if the solid fraction is used for biogas production and carbon dioxide from less fertiliser production, thereby decreasing the impact on climate.
- **Soil**: Improved soil fertility through use of the liquid fraction as a fertiliser.
- **Biodiversity**: Positive effects from reduced N deposition in natural ecosystems.
## Improving manure cover

### Definition of the measure
Reducing nutrient losses from manure storage by covering manure. For slurry tanks established before 2007 or situated more than 300 m away from neighbouring houses, Danish legislation requires a floating cover layer (natural or artificial) to limit the emission of ammonia, methane, and odour to the atmosphere. The use of solid cover systems (e.g. “tent cover”) instead of floating cover layers can further enhance the effectiveness in terms of avoided ammonia emissions, which can be reduced by about 50%.

### Technical implementation
About 7% of the Danish slurry tanks have a solid cover, e.g., a tent cover. A tent cover is made of dense synthetic fabric material, which is stretched like a tent over the slurry tank. The slurry tank is equipped with a tall metal or wooden mast in the center.

### Technical requirements
It is easiest to install the mast when the tank is empty and clean, but some suppliers can also mount the mast and cover while there is slurry in the tank.

### Effects, benefits and costs

#### Benefits for farming business
Cost-savings from reduced mineral fertiliser purchase and application due to higher nutrient content of stored manure (obtained by covering with a semi-permeable or impermeable cover). Cost-savings from reduced storage capacity requirements and transport volumes if impermeable covers are used, which reduces rainwater dilution.

#### Costs for farming business
Construction and increased operating costs for maintenance and handling of the covered manure storage facilities. Fixed covers are more expensive than flexible covers, especially if not foreseen in the storage design. On cattle and mink farms, a solid cover on the slurry tank will cause additional costs for removal of sediments that accumulate at the bottom of the tank.

#### Co-benefits
Manure nutrient levels need to be calculated to match the crop needs; otherwise, application of the same quantity of manure would result in higher nutrient levels and potential losses.

#### Environmental effects
Decreased ammonia emissions leading to less particulate matter, odour, and ozone formation, which lowers risks to human health (e.g., aggravated asthma and respiratory problems); decreased ammonia emissions will also result in benefits to water and natural ecosystems. Reduced greenhouse gas emissions (methane), thereby decreasing the impact on climate.
**Improving manure processing: Slurry acidification**

**Definition of the measure**
By adding acid to livestock slurry, the pH of the slurry is reduced and the equilibrium between ammonia and ammonium is shifted towards ammonium, thereby reducing ammonia emissions to the air.

**Technical implementation**
Acidification of slurry is a commonly used technique in Denmark. During the period 2010-2013, the Danish AgriFish Agency has supported investments in slurry acidification equipment at 318 Danish livestock farms. By adding acid (usually sulphuric acid), the pH of the slurry is lowered to around 5.5, and thereby the ammonia volatilisation is limited. It is possible to acidify the slurry under the slats in the barn, in the slurry tank during storage, or at the time of field application using a system mounted on the slurry trailer. Standard spreading equipment can be used to handle the acidified slurry.

**Technical requirements**
Commercial equipment is available for acidification under the slats in the barn, in the slurry tank during storage, or on the slurry trailer during field application.

**Effects, benefits and costs**

| Benefits for farming business | Higher amount of nitrogen available for the crop, which may increase crop yields and reduce the amount of additional mineral fertiliser needing to be purchased and applied. |
| Costs for farming business | Initial investment in acidification equipment for use in stables, slurry tanks, or during field application. Additional expenses include running costs for sulphuric acid and extra costs for liming due to soil acidification. (3) |
| Co-benefits and trade-offs | Acidification of slurry results in a long-lasting decrease of methane production. The greatest effect is achieved by acidifying the slurry already in the stable, whereas there will be no effect on methane emissions if acidification takes place immediately before field application. One drawback is that acidified slurry cannot be used for biogas production. |
| Environmental effects | **Air**: Decreased ammonia emissions leading to less particulate matter, odour, and ozone formation, which lowers risks to human health (e.g., aggravated asthma and respiratory problems); Reduced greenhouse gas emissions (methane), thereby decreasing the impact on climate. **Biodiversity**: Positive effects from reduced N deposition in natural ecosystems. |
Using legumes in grasslands

**Definition of the measure**
Biological nitrogen fixation in grasslands could be increased by including more legumes in the mixture, which would reduce the need for mineral fertilisers. Fixed nitrogen is being mineralised after the plant dies, releasing nitrogen which can be absorbed by other non-legume plants.

**Technical implementation**
The species composition of grasses and legumes in the mixture should be selected based on the purpose of the grassland (e.g., whether it will mainly be used for grazing or cutting). Be aware that nitrogen fertilisation will stimulate grass growth at the expense of legume growth, thereby limiting biological nitrogen fixation and the legumes’ ability to provide fodder protein during the growing season.

**Technical requirements**
Following the final soil incorporation of the sward, a considerable amount of organically bound N is mineralised in the soil. This could potentially lead to nitrate leaching and nitrous oxide emissions, though this may also result from mineral fertiliser application. Therefore, the soil type and the timing of incorporation (e.g., avoiding soils saturated with water) should be considered carefully before implementing this measure.

**Effects, benefits and costs**

**Benefits for farming business**
Cost-savings due to reduced use of mineral fertiliser; potentially reduced costs for livestock fodder purchase due to a higher nutrient content.

**Costs for farming business**
Costs for purchase of legume seeds

**Co-benefits and trade-offs**
Multi-species grasslands with flowering forbs may improve the living conditions for bees and other pollinators on the farm. Reduced mineral fertiliser purchase also results in less greenhouse gas emissions from production. One drawback of legume-rich swards is the high risk of nitrate leaching and increased nitrous oxide emissions after ploughing. Therefore, a higher positive impact is expected for permanent grasslands, which are not ploughed regularly.

**Environmental effects**
- **Soil**: Improved soil fertility and nutrients available for the plant through N-fixation, also contributing to carbon sequestration and storage in the soil, less acidification due to reduced fertilisation
- **Water**: Reduced risk of run-off and leaching of nutrients in case of fertilisation, decreasing eutrophication and improving surface water quality, thereby lowering risks to human health and biodiversity.
- **Air**: Reduced greenhouse gas emissions (nitrous oxide and carbon dioxide – less fertiliser production and use), thereby decreasing the impact on climate.
### Cultivating perennial energy crops

#### Definition of the measure
Perennial crops are established and bloom over at least a two-year period and have a permanent, deep root system, which ensures efficient nutrient utilisation. The Danish Ministry of Food, Agriculture and Fisheries has found that willow crops could reduce N leaching by up to 70% compared to annual cereal production. (5) Cultivating perennial energy crops instead of annual crops may therefore reduce nutrient losses.

#### Technical implementation
When cultivating perennial crops, there is a long time span between establishment and harvest of the crop. In principle, the choice of perennial cropping is not much different from investing in stables, machinery, etc. When calculating the economic balance of a perennial crop, the farmer needs to include assumptions on when to expect expenses and revenues and the expected magnitude of such investments and proceeds.

#### Technical requirements
Examples of perennial energy crops are willow, poplar and miscanthus. The farmer should consider whether there will be a market for the perennial crop that s/he wishes to establish. In terms of the potential for nutrient leaching reductions, lowland soils are more variable than upland soils due to differences in drainage rates, mineralisation potential and hydrological conditions.

### Effects, benefits and costs

#### Benefits for farming business
Cost-savings due to reduced low running costs.

#### Costs for farming business
Initial investments in new field machinery. Initial loss of income due to the time lag between seeding/planting and harvest.

#### Co-benefits and trade-offs
Changing crop choice to perennial energy crops may result in land use change to supplement the loss of food production, potentially resulting in conversion of non-cropped land and more overall nutrient application.

#### Environmental effects
- **Soil**: Improved soil fertility and structure (due to reduced soil management) through increased soil organic matter and reduced risk of soil erosion, contributing to carbon sequestration and storage in the soil.
- **Water**: Reduced risk of leaching (due to better nutrient uptake and root retention) and run-off of nutrients (P and N), decreasing eutrophication and improving surface and groundwater quality, thereby lowering risks to human health and biodiversity.
- **Air**: Reduced greenhouse gas emissions (nitrous oxide) through better soil structure and microbial function, thereby decreasing the impact on climate.
- **Biodiversity**: Increased availability of wildlife habitats on the farm and reduced disturbance by management could potentially increase the number of wildlife and benefit biodiversity.
Further good practices to reduce nutrient losses

**Using digested manure from biogas production**

Anaerobic digestion of manure in a biogas reactor\(^1\) mineralises organically bound nitrogen into inorganic nitrogen. Therefore, slightly lower nitrogen leaching can be expected in the long term when fertilising crops with digested manure instead of untreated manure, (6) indirectly leading to reductions in nitrous oxide emissions, ammonia emissions and nitrate leaching from applied fertilisers. However, reductions in these environmental impacts will depend on whether farmers take the greater nitrogen availability in the digested manure into account when calculating fertilisation rates. Currently, Denmark does not differentiate the nitrogen availability in the digested manure from undigested manure, so the same amount of total nitrogen is applied whether digested or untreated manures are used. Individual farms will most likely find the costs of establishing a biogas plant prohibitive, but a co-operative of farms may decide to set up and operate a biogas plant in order to use the slurry produced and generate some revenue from energy production.

**Better implementation of buffer strips near watercourses**

Denmark uses the whole territory approach to implement the EU Nitrates Directive and has, therefore, adopted a Nitrates Action Programme which applies to the whole country. As a result, a range of measures regarding timing and conditions for fertiliser application are already established. However, the use of buffer strips could be further implemented. Since September 2012, a buffer zone must be created for fields next to open water streams and lakes larger than 100 square metres. The implementation of this measure has been complicated due to incorrect electronic mapping and malfunctions in official reporting websites. There is also not clear consensus on what constitutes a natural open water stream. Better implementation of this measure could reduce run-off of soil and nutrients to nearby water bodies, which would help reduce the extent to which the Central Denmark region is affected by eutrophication.

**Using partly slatted floors**

Better manure collection systems within livestock housing avoid losses of nutrients to volatilisation. At the national level, 97% of the ammonia emissions are from agriculture. Given the high amount of livestock production in the Central Denmark region, this measure could help reduce the amount of ammonia emissions and result in benefits to human health and biodiversity. Furthermore, these techniques are more suited for larger units, which is appropriate for Central Denmark where there are many large-scale intensive livestock farms.

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\(^1\)A biogas reactor is an anaerobic treatment technique that produces digested organic matter and biogas.
Border hills in Kolindsund, region of Central Denmark
Further relevant links

Further information (links) on the issue of reducing nutrient losses in agriculture which are relevant for the Central Denmark region can be found below. This information entails links to legal documents, programmes, initiatives, institutions and studies.

### EU level

DG Environment - Nitrates Directive:

The study "Resource Efficiency in Practice - Closing Mineral Cycles" is available at the following link:

DG Environment - Sustainable use of phosphorus:
http://ec.europa.eu/environment/natres/phosphorus.htm

Contacts:
ENV-NITRATES@ec.europa.eu;
ENV-USE-OF-PHOSPHORUS@ec.europa.eu

### National and regional level

Danish Nitrate Action Programme 2008-2015:
http://eng.mst.dk/topics/agriculture/nitrates-directive/nitrate-action-programme-2008-2015/

Danish AgriFish Agency:
http://agrifish.dk/

Environmental Affairs division:
http://agrifish.dk/agriculture/environmental-affairs/
(contributes to the Danish Aquatic Environment Scheme)

DNMARK Research Alliance for innovative sustainable nitrogen management solutions:
http://dnmark.org

### Studies and projects

'The Moon Pig' initiative for "low emission" pig-housing units:
http://naturerhverv.dk/tvaergaende/maanegrisen

http://dce2.au.dk/pub/5R78.pdf

Udvikling i kvælstofudvaskning og næringsstofoverskud fra dansk landbrug for perioden 2007-2011 - Evaluering af implementerede virkemidler til reduktion af kvælstofudvaskning samt en fremskrivning af planlagte virkemidlers effekt frem til 2015, Aarhus Universitet, Nationalt Center for Fødevarer og Jordbrug (Change in nitrogen leaching and nutrient surpluses from Danish agriculture for the period 2007-2011 - Evaluation of measures which have been applied to reduce nitrogen leaching, and a forecast of the expected effects of the planned measures until 2015. Aarhus University, National Centre for Food and Agriculture), DCA rapport nr. 031:

Windolf, J. et al. (2012) Changes in nitrogen loads to estuaries following implementation of governmental action plans in Denmark: A paired catchment and estuary approach for analysing regional responses. Environmental Science & Policy 24: 24-33. Available at:
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