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How to half N-losses, improve N-efficiencies and maintain yields? The Danish case

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How to half N-losses, improve N-efficiencies and maintain yields? The Danish case

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Abstract
Denmark is one of the Worlds most intensively farmed countries and one of the largest exporters of animal products. This leads to significant N-losses from agriculture, and policies to mitigate environmental effects of N have high priority on the political agenda.
This paper presents the Danish measures to mitigate N-losses from agriculture, imposed since the early nineteen-eighties. These agro-environmental measures have shown remarkable results. However, accounting developments in N-losses on the national scale is difficult. Therefore, the development is described via three estimated, national level indicators: N-surplus (N-import minus N-export), N-efficiency (N-export per N-import), and N-leaching (simulated with the DAISY model and upscaled to the national level via the GNL-framework). N-surplus decreased from 490 x 10^6 kg in 1985 to 313 x 10^6 kg in 2002. N-efficiency increased from 27% to 36% in the same period, while the N-leaching was estimated to 334 and 187 x 10^6 kg N, respectively. In conclusion, N-leaching was almost halved from 1985 to 2002, while the crop yields sustained and the animal production, expressed in kg N exported, increased with around 30% in the same period. In line with the recommendations of the 2nd N-workshop in 2001, it is hoped that the presented measures to reduce N-pollution can inspire other countries with similar N-problems in the efforts to develop a more sustainable N-management.

Key words
N-surplus, nitrate leaching, upscaling, Danish agriculture, nitrogen policy

Introduction

Intensive farming and livestock production characterises large parts of Western Europe; including for example Denmark, The Netherlands, Belgium (The Flanders), Italy (The Po Valley), France (Brittany), and some parts of Germany. This has lead to significant N-losses from agriculture, and following environmental- and health effects (De Clercq et al., 2001; Wolfe & Patz, 2002). Consequently, The European Union has imposed two major directives to mitigate these effects of N. First, The Nitrates Directive (1991/696/EC) was imposed in 1991, aiming to reduce nitrate water pollution in the nitrate vulnerable zones of Europe. Secondly, The Water Framework Directive (2000/60/EC) was imposed in 2000. The aim is to protect groundwater resources, and all surface waters in a state close to that without anthropogenic interferences.

One of the first countries, to discover the nitrogen problems, was Denmark. In the 1970's and start of the 1980's, there was increasing concern at the effect of nutrient losses from agriculture. Elevated nitrogen concentrations were observed in groundwater extracted for household consumption, and surveys and monitoring of oxygen concentrations in the Danish marine waters indicated an increasing frequency of situations with serious oxygen depletion. However, the event that really kick-started the regulation of nutrient management in agriculture was a television report in the Danish channel 1 news of October 8th 1986. This showed dead lobsters in the sea area between Denmark and Sweden and was attributed to hypoxia resulting from an algal bloom stimulated by agricultural nutrient runoff. From 1985 till today, a series of radical, political action plans have been imposed (Table 1), with remarkable effects on the agricultural N-efficiency and the N-pollution. Consequently, Denmark has been one of the most successful among the EU countries, to reduce N-surpluses and N-losses (OECD, 2001). Moreover, these effects have been achieved while still increasing the animal production and the value of agricultural products produced. Therefore, elements from "The Danish Model" might be desirable to adopt in other countries throughout the World.

The aim of this paper is to document the effects of the N regulations in Denmark 1985-2002, and to discuss the potentials for further N pollution mitigation options. In line with the recommendations from The 2nd International N-conference (Cowling et al., 2001), the hope is to inspire countries, facing similar problems, in their efforts to develop a sustainable agricultural sector, and mitigate the effects of agricultural N-pollution.

Table 1. An outline of the Danish measures imposed to reduce nutrient losses from agriculture.

Danish Policy Actions	Policy measures imposed
1985: NPo Action Plan to reduce N- and P-pollution	• Minimum 6 months slurry storage capacity. • Ban on slurry spreading between harvest and 15 October on soil destined for spring cropping. • Maximum stock density equivalent to 2 LU ha^{-1}. (1 livestock unit = 1 LU corresponds to one large dairy cow) • Various measures to reduce runoff from silage clamps and manure heaps. • A floating barrier (natural crust or artificial cover) mandatory on slurry tanks.
1987: The First Action Plan for the Aquatic Environment (AP-I), aiming to half N-losses and reduce P-losses by 80%	• Minimum 9 months slurry storage capacity. • Ban on slurry spreading from harvest to 1 Nov on soil destined for spring crops. • Mandatory fertiliser and crop rotation plans. • Minimum proportion of area to be planted with winter crops. • Mandatory incorporation of manure within 12 hours of

	spreading.
1991: Action Plan for a Sustainable Agriculture, aiming to reduce N-losses from agricultural fields by 100×10^6 kg N	• Ban on slurry spreading from harvest until 1 Feb., except on grass and winter rape. • Obligatory fertiliser budgets. • Maximum limits on the plant-available N applied to different crops, equal to the economic optimum. The economic optimum is calculated annually, taking into account the mineral N in the soil (from a comprehensive soil sampling system). • Statutory norms for the proportion of manure N assumed to be plant-available. (Pig slurry: 60%, cattle slurry: 55%, deep litter: 25%, other types: 50%)
1998: The Second Action Plan for the Aquatic Environment (AP-II)	• Subsidies to establish 16,000 ha wetlands, designed to reduce nitrate leaching through denitrification and reduced demand for fertiliser. • Subsidies to enable reduced nutrient inputs to up to 88,000 ha of areas designated as being specially sensitive with regards the environment. • An expectation that animal feeding practice would be improved to reduce N excretion. • A reduction of the stock density maximum to 1.7 LU ha^{-1}. • Subsidies to encourage the conversion of 170,000 ha to organic agriculture. • The statutory norms for the proportion of manure N assumed to be plant-available were increased from 1999 (pig slurry: 65%, cattle slurry: 60%, deep litter: 35%, other types: 55%) • Maximum limits on the application of plant-available N to crops reduced to 10% below the economic optimum. • Mandatory 6% of the area with cereals, legumes and oil crops to be planted with catch crops. • Subsidies to encourage afforestation on up to 20,000 ha.
2000: AP-II Midterm Evaluation and Enforcement	• Increased economic incentives to establish wetlands. • The N assumed to be retained by catch crops must be included in the fertiliser plans. • Further tightening of the statutory norms for the proportion of assumed plant-available N in manure. From 2001; pig slurry: 70%, cattle slurry: 65%, deep litter: 40%, other types: 60%; from 2002 pig slurry: 75%, cattle slurry: 70%, deep litter: 45%, other types: 65% • Reduced fertilisation norms to grassland and restrictions on additional N-application to bread wheat.
2001: Ammonia Action Plan	• Subsidies to encourage good manure handling in animal housing and improved housing design.

	• Mandatory covering of all dung heaps. • Ban on slurry application by broadcast spreader. • Slurry spread on bare soil must be incorporated within 6 hours. • Ban on the treatment of straw with ammonia to improve its quality as an animal feed. • Options for planning authorities to restrict agricultural expansion near sensitive ecosystems.
2004: The Third Action Plan for the Aquatic Environment (AP-III). AP-III is very closely related to the EU-Water Framework Directive and the EU Habitat Directive. N-leaching must be reduced by further 13% by 2015. The agricultural P-balance of 32.7 × 10^6 kg yr^{-1} must be halved by 2015. *(First AP that regulate P handling in agriculture).* General reduction objectives will be laid down. In addition, regional objectives will be set for individual water bodies and natural habitats.	• Further tightening of the request for catch crops. • Further increase in the statutory norms for the proportion of manure N assumed to be plant-available based on research. • Establishment of further wetland areas (ca. 4,000 ha). • Afforestation is assumed on 20,000-25,000 ha. • Establishment of 50,000 ha of buffer zones along streams and around lakes before 2015 to reduce discharge of P. • Improved utilisation of N and P in feed is assumed to reduce losses of N and agricultural surplus of P. • A tax of DKK. 4 kg^{-1}. mineral P in feed. • Protection zones of 300 m around ammonia sensitive habitats such as raised bogs, lobelia lakes and heaths larger than 10 ha. • Strengthening of organic farming. • Evaluations of the effect of AP-III will be carried out in 2008 and 2011. • Based on the evaluations further initiatives will be implemented if necessary.

Materials and Methods

To account for the developments in N-losses, three national level indicators are defined: N-surplus, N-efficiency and N-leaching.

N-surplus is defined as N-import minus N-export to and from the agricultural sector, while N-efficiency is defined as N-export per N-import. Annual values for N-imports and N-exports are derived from national agricultural statistics (Statistics Denmark, 2002) according to Kyllingsbæk’s (2000) method. N imports include N in commercial fertilisers and waste materials spread to the fields, N in imported concentrate fodder stuffs like soy bean cakes, meat and bone meals (banned from year 2000), fodder urea, fish products etc., and N derived from the atmosphere. The latter includes estimated values for net N deposition and N fixation via legumes and free-living micro-organisms. N exports include N in 1) animal products, in the form of eggs, milk, meat, live animals or livestock received by offal destruction plants, and 2) vegetable products, in the form of cereals, seeds for manufacturing and sowing, beets for sugar production, potatoes and other fruits and vegetable products.

N-surplus indicates the potential for N-losses from farming, and covers a number of N-loss components. The largest N-loss component is leaching of nitrates. N-leaching is of special importance in relation to ground- and surface water pollution. Other N-loss components are gaseous N (ammonia, di-nitrogen, nitrous oxides etc.) and particular N (mainly organic matter). Some of the surpluses may temporarily accumulate as biomass or as humus in the soil, but as the soil system approaches steady state, N-surplus and N-loss will converge.

In this study, that part of the N-surplus, which results in N-leaching, is simulated with the DAISY model (Abrahamsen & Hansen, 2000) and upscaled to the national level via the GNL-framework (Børgesen et al., 2004). The GNL-framework to simulate and upscale N-leaching builds upon disaggregated results for each municipality in Denmark, represented with its own specific farm- and soil type distribution, irrigation practice, livestock manure production, fertilisation practice etc. Consequently, the N-leaching results can be distributed geographically, and reveal municipalities with "hot-spots" for N-leaching. To exclude effects of extreme weather situations in single years, the procedure includes an 11-years climate normalisation. For example, the leaching for year 2000 is calculated as the average of 11 simulations with the actual, agricultural practice in 2000 combined with whether data from each of the years 1990-2001. These simulations also give information on crop yields (Børgesen & Heidmann, 2002). In that way, the total N-harvest in the form of crops can be accounted.

Results and discussion

Developments in N-imports and N-exports are accounted for the last century (Figure 1). The gap between N-imports and N-exports corresponds to the N-surplus. With few exceptions during The Two World Wars (1914-18, 1940-45), and The Oil Crises (1972-1974), the N-surplus generally increased from year 1900 and until the mid nineteen-eighties. Here, the excess of N led to significant N-induced environmental problems, and the actions towards agricultural N-losses were politically initiated.

Figure 1

To follow the effects of these actions, the developments in the three indicators defined (N-surplus, N-efficiency and N-leaching) are accounted for the period 1985-2002 (Figure 2). Both the N-surplus and the N-leaching were reduced significantly in the period, while the N-efficiency raised. N-surplus decreased from 490 x 10^6 kg in 1985 to 313 x 10^6 kg in 2002. N-efficiency increased from 27% to 36% in the same period, while the N-leaching was estimated to 334 and 187 x 10^6 kg N, respectively.

Figure 2.

In comparison, the total N-export from the agricultural sector was stable in the same period (Table 2). From 1985 to 2002, the N in animal exports increased by 28%, while N in the total plant production seemed significantly reduced. However, in the same period the total agricultural area was also reduced from 2,85 × 10^6 ha to 2,67 × 10^6 ha. Moreover, set-aside of land was introduced by the EU reform in 1992, wherefore the actual agricultural area without set-aside land was lower in the years after 1992. For example, in 2002 it was 2,44 × 10^6 ha. Therefore, from the decreasing figures on N-exports of plant products (Table 2), it cannot be concluded whether the N-regulations have resulted in lower crop yields or not; partly because the reduced plant product N-export is caused by a reduced area, and partly because some of the plant production is used for fodder in the raised animal production, and therefore is not exported from the agricultural sector.

To investigate whether the N-regulations imposed from 1985 to 2002 (Table 1) have resulted in lower crop yields, the total crop N-harvest is derived from the GNL-framework model simulations (Table 2). Apparently, there is no trend from 1985-2002 in the modelled crops-yields per ha of agricultural land excl. set-aside. Consequently, it is concluded, that the general yield level in Danish Agriculture has not been reduced in the period.

Table 2. N-exports from the agricultural sector in Denmark 1985-2002, and the modelled crop yields (N-harvest) per ha of agricultural land excl. set-aside land.

	1985	1989	1995	1996	1997	1998	1999	2000	2001	2002
N-exports (10^6 kg N):										
Animal products	88	89	103	105	108	111	110	111	114	113
Plant products	86	106	92	73	84	76	65	74	69	61
Total	174	195	195	178	192	187	175	185	183	174
N-harvest (kg N/ha)	124	133	132	129	128	127	132	132	129	125

The two main instruments behind the N-regulation in Denmark are: 1) The mandatory fertiliser- and crop rotations plans, with limits on the plant-available N applied to different crops, and 2) The statutory norms for the proportion of manure N assumed to be plant available. These two instruments have been enforced in several rounds, for example with the 1991, 1998, 2000 and 2004 restrictions of the norms for the proportion of manure N to be plant available (Table 1). Throughout the period, N-regulations have been designed in close dialogue with researchers, farmers and farmers associations, and have been followed-up by information materials, extension and education. Also, extensive, strategic research programmes have been supported; for example on optimisation of manure utilisation and on organic farming production systems (Hansen et al., 2001). The ability to design the N-regulations in a manner, where crop and animal production is effected least possible (Table 2), is a main achievement of this bottom-up approach of continuous dialogue. Also, evaluation and documentation of the effects of the political initiatives are important. Among other results, the results of this paper have been used for such documentation (Grant &

Waagepetersen, 2003). It is recommended that other countries, which might feel inspired by the success of the Danish regulations, also learn the lesson of the importance of these processes for the development of a sustainable agriculture with acceptable low N-losses. For example, this message might be important in mitigating the effects of excess N in many Chinese provinces and in Asia as such (Shindo et al. 2003). Here, more than 60% of the Worlds fertiliser resources are used (Cowling et al., 2001), and a significant growth in N-uses and potential N-pollution problems are expected in the future (Zheng et al. 2002).

Until today, the N-regulation in Denmark has focussed on general measures, equal for all parts of the country (Table 1). The success of this regulation is undisputable and has reduced the N-leaching in all parts of the country (Figure 3). However, the average N-leaching in a whole municipality may cover local hot-spots within the municipality, with special needs for regulation.

Figure 3.

With The Third Action Plan for the Aquatic Environment (AP-III), Danish N-regulation is moving towards a more holistic approach, where the focus will no longer only be on the reduction of nitrate leaching. The aim is a more integrated approach, where protection of the aquatic environment is combined with regional development objectives and nature protection. The former is seen in relation to the new direction of EC agricultural policies towards rural development, while the later is seen in close relation to the national obligations according to the EC Habitat Directive (1997/62/EC) and The International Convention on Biological Diversity, signed at the Rio Earth Summit in 1992.

With the EC Water Framework Directive, the aims of the N-regulations will be set by specific goals for each water body, and both N-regulations and evaluations of the effects of these regulations must be designed for this regional- and local scale implementation. New methods are under development for such regional analyses (Børgensen et al. 2004), together with methodologies to combine N-regulation and water protection with the multiple other interests in the agricultural landscapes (Dalgaard et al. 2002).

Conclusions

In the intensive Danish agriculture it has proven possible to reduce N-leaching by almost 50% while maintaining crop yields and increasing livestock production by 30%. This has been achieved by a strong focus on improving nitrogen efficiency facilitated by regulatory measures and an innovative farming community.

Future agri-environmental initiatives will be based on a more holistic approach, integrating protection of the aquatic environment and natural habitats, and linking national N-regulations to EC-directives and other international obligations.

Further, the approach for general, national level regulation of nutrient losses will be supplemented with additional regional initiatives to meet the environmental objectives for individual water bodies and natural habitats.

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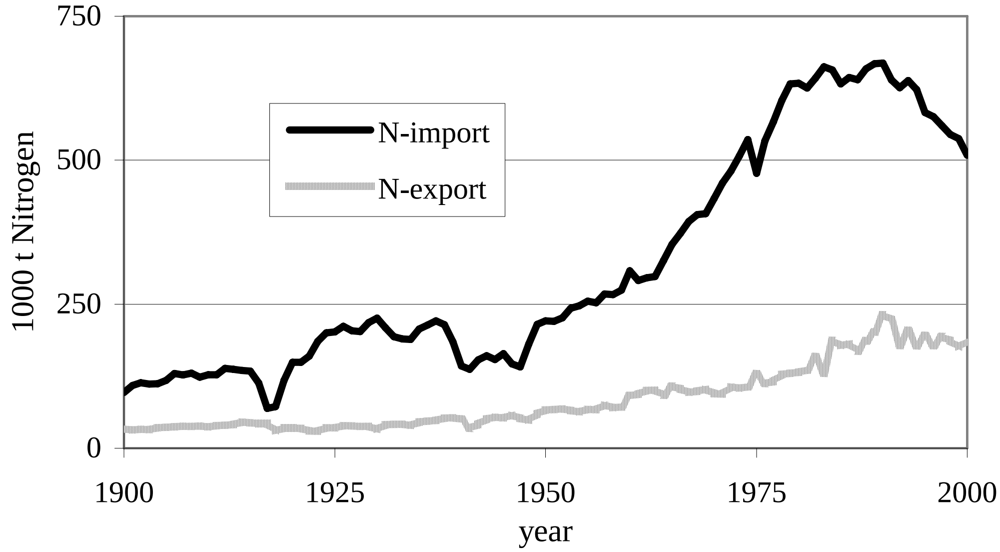

Figure 1. Developments in N-imports to- and N-exports from Danish Agriculture 1900-2000 (Modified from Dalgaard & Kyllingsbæk, 2004).

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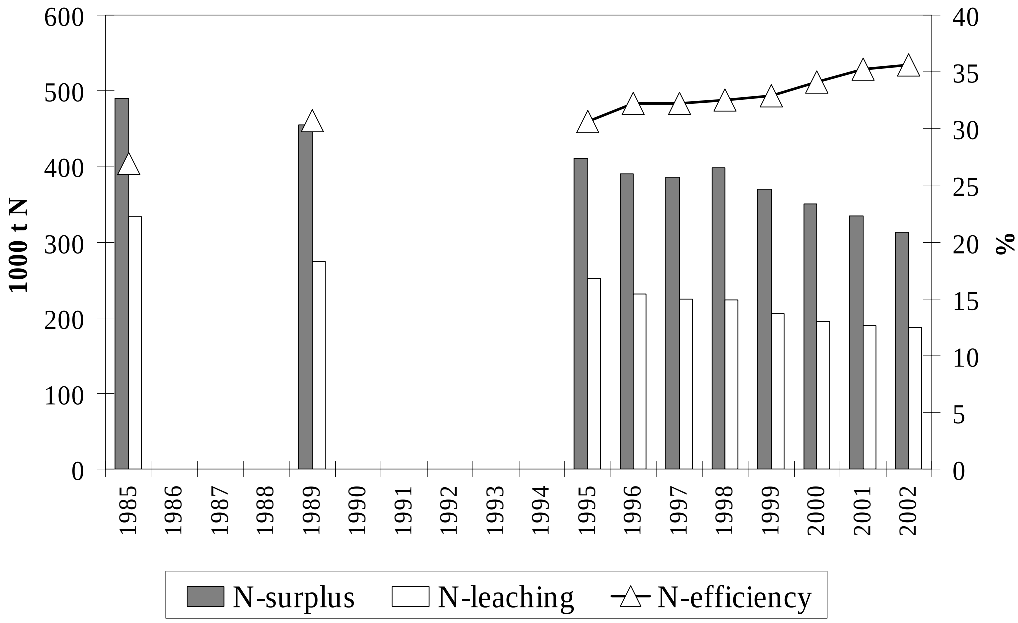

Figure 2. N-surplus, N-leaching (left axe) and N-efficiency (right axe) in Denmark 1985-2002.

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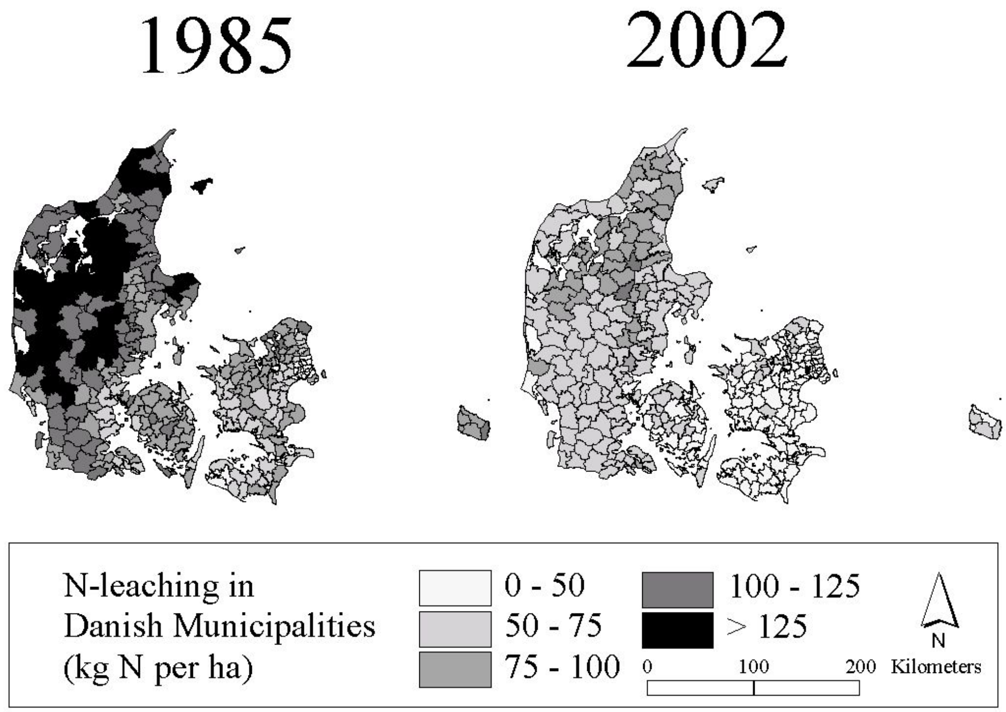

Figure 3. Geographic distribution of the simulated N-leaching 1985 and 2002

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