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Nutrient management at farm scale

How to attain policy objectives in regions with intensive dairy farming?

First workshop of the EGF Working Group 'Dairy Farming Systems and Environment'
Quimper, France, 23-25 June 2003

Jules Bos, André Pflimlin, Frans Aarts & Françoise Vertès (Eds.)

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Summary

A large part of total milk production within the European Union (EU) is produced in regions with rather large and specialised dairy farms. The use of feeds and fertilisers on these farms has strongly increased over time, enabling increased stocking rates of high yielding cows. The increase in nutrient inputs was associated with an increase of nutrient surpluses, which largely contribute to environmental pollution due to emissions of ammonia and nitrous oxide to the air, and nitrate and phosphate to groundwater and surface waters. Increased pollution in Europe has led to increased policy efforts. Objectives and legislation regarding the state of the environment have been formulated in, for example, the Nitrates Directive (in 1991), the Water Framework Directive (2000) and the National Emission Ceilings Directive (2001).
From 23 to 25 June 2003, an international scientific workshop was held in Quimper, France, with as main objectives to inventory the implementation of European and national policies in different EU Member States and to discuss views among European scientists about the possibilities to comply with the policy objectives in regions with intensive dairy farming.
Part I of this workshop report schematically portrays the European scene, describing EU nutrient policies in relation to dairy farming and characterizing the main dairy farming systems in the EU and their nutrient cycling features.
Part II is the core of the report and consists of eight country reports (I, UK, DK, F, IRL, Flanders, NL, D). Each country report is a detailed national account of:

- key figures on intensive dairy farms (number, size, crops, climate, stocking rates, milk production per ha and per cow);
- key figures on nutrient cycles, balances and losses of dairy farming systems;
- key figures on (trends in) environmental quality, in particular nitrate concentrations in surface and groundwater and gaseous N losses from dairy farming systems;
- strong and weak points of the prevailing dairy farming systems;
- the implementation of European and national nutrient policies affecting dairy farming systems;
- implemented or proposed measures and their (expected) agricultural and environmental effects;
- actual and intended research in search for more sustainable dairy farming systems.

The workshop ended with a synthesis and plenary discussion about environmental problems related to intensive dairy farming systems, possibilities to solve these problems, research methodologies (diagnosis, indicators and farm scale nutrient fluxes modelling) and ideas about scientific collaboration in the future. The synthesis and plenary discussion are reported in the final Part III.

One of the findings during the workshop was the lack of uniformity in calculation methods between countries. This especially applies to farm gate nutrient balance calculations and calculation methods to relate animal manure applied to farmland to a corresponding number of animals. Therefore two sub-groups were initiated:

1. The sub-group 'Nutrient Balances' will work on uniformity of nutrient balance calculations, focussing on input and output terms to be included in balances, the fate of nutrient surpluses and questions related to interpretation of nutrient balance calculations.
2. The sub-group 'Livestock Unit Definitions' will begin by compiling an overview of the different methods applied in the different EU Member States to relate animal manure applied to farmland to a corresponding number of animals.

All workshop participants would like to participate in a follow-up to this workshop, for instance by starting a Working Group 'Dairy Farming Systems and Environment' within the European Grassland Federation. Scope of the working group is 'to improve environmental quality by improving nutrient cycling in dairy farming systems, taking into account the consequences for other sustainability issues, notably farm-economics, animal welfare and nature and landscape'.

Acknowledgements

We wish to thank all those that made the Quimper workshop possible. First of all, this applies to Patricia De Clercq, Patrick Durand, Michael Kelm, Friedhelm Taube and all country team members, who have put so much effort in timely preparation of their papers and country reports. Thanks also to Friedhelm Taube and Steve Jarvis for their willingness to act as chairman. And of course also thanks to all other participants for their useful contributions during the workshop.
This workshop was supported by INRA (Research Department Environnement et Agronomie) and by the Conseil Régional de Bretagne. We thank them for their financial help. We also thank M. Guyot, director, and Mme Quélen from the CEMPAMA Beg Meil, where we could work under the most favourable conditions.
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Jules Bos, André Pflimlin, Frans Aarts and Françoise Vertès

Introduction

Environmental problems in European regions with intensive dairy farming

A large part of total milk production within the European Union is taking place on rather large and specialised dairy farms in England, West and Southwest France, Northern Italy, Denmark, Germany, Belgium, Ireland and The Netherlands. In most of these regions, the use of fertilisers and feeds has strongly increased over time, especially because of the declining costs of these production factors relative to the production factors land and labour, but also through technological developments resulting from research. Thus, today, most dairy farms in these regions rely on large inputs of fertilisers and feeds, enabling increased stocking rates of high yielding cows. The increase in nutrient inputs was associated with an increase in nutrient outputs with milk and meat, but to a far lesser extent. As a result, efficiency of utilisation of nutrients at farm level, defined as output/input ratio, decreased. The surpluses largely contribute to environmental pollution due to emissions of ammonia and nitrous oxide to the air, and nitrate and phosphate to groundwater and surface waters. The water monitoring networks set up by EU Member States show that many water bodies contain high nitrate concentrations, with in some cases still increasing trends, particularly in areas with intensive livestock. Besides causing pollution, nutrient losses represent an economic loss and a waste of energy.
Increased pollution in Europe has led to increased policy efforts. Objectives and legislation regarding the state of the environment have been formulated in, for example, the Nitrates Directive (in 1991), the Water Framework Directive (2000) and the National Emission Ceilings Directive (2001). The objective of the Nitrates Directive is to reduce water pollution caused or induced by nitrates from agricultural sources, in order to protect human health, living resources and aquatic ecosystems. The Directive includes rules for the use of animal manure and mineral fertilisers. Although the rules at first sight seem rather global, they require Member States to include in their national legislation many detailed rules. The core of the Directive is that a balance should be reached between N supply from soils and fertilisers and N demand of the crop. Standards have been identified for the maximum doses of animal manure. Member States should guarantee that the annual application of N in the form of animal manure at farm scale does not exceed 170 kg per ha. This value corresponds with a stocking rate of about one dairy cow per ha (young stock included). In European regions with relatively intensive dairy farming, stocking rates are often much higher. Reducing these stocking rates is in general an expensive measure to comply with the Nitrates Directive. Manure application rates in excess of 170 kg N per ha, hence higher stocking rates, can be allowed for specific situations, provided that the objectives of the Nitrates Directive will still be realised and the higher rate can be justified on the basis of objective criteria as laid down in the Directive (e.g. high precipitation surpluses, high N uptake by crops, high proportion of grassland in farm area).

In dairy farming systems, nitrogen is transferred in a cyclic way from the soil compartment via crops, animals and manure back to the soil again. Single flows of nitrogen within farming systems can be influenced by changing management. However, intervening in one step of the cycle may affect nitrogen flows elsewhere, i.e. covering a slurry storage reduces direct ammonia emissions, but most of that ammonia will volatilise soon after slurry application, unless a low-emission technique is applied. Injection of slurry into the soil may indeed considerably reduce ammonia emissions, but will lead to increased leaching of nitrate if the input of mineral N fertilisers is not reduced. Therefore, losses of N compounds should be controlled simultaneously in all stages of the cycle. In addition, measures to reduce N losses may well be associated with negative trade-offs on other environmental issues (e.g. energy use, P losses). Hence, when proposing and implementing measures to reduce N losses, it is important to take into account these side effects, calling for a systems approach.

A workshop to share relevant knowledge

Workshop objectives

Addressing the issues described above, an international scientific workshop was held in Quimper (France), from 23 to 25 June 2003, with the following main objectives: (1) to inventory the implementation of European and national policies in regions with intensive dairy farming across Europe and (2) to discuss views among European scientists about the possibilities to comply with the objectives regarding water and air quality in these regions. The workshop objectives should be achieved by:

1. the exchange of information about the current agricultural and environmental situation in European regions with intensive dairy farming systems;
2. the exchange of 'European' opinions about how to comply with European and national policy objectives in an effective and efficient way;
3. discussing the expected agricultural and environmental effects of proposed measures, including possible side effects on other indicators for sustainable dairy farming;
4. the choice for a systemic approach at farm scale.

A metaphor as shared reference

To guide discussions during the workshop, a metaphor was used (see Box). Applying the metaphor to dairy farming systems, the mountain denotes the fixed climatological, physical and other circumstances which cannot be influenced by human activities in the short term. The peak of the mountain is smaller and the slopes of the mountain are steeper as the environment surrounding the dairy farming system is more sensitive to nutrient losses. The shape of the mountain is thus determined by, e.g., regional hydrological characteristics (determining nutrient transport pathways), soil characteristics (determining nitrate and phosphorus leaching sensitivity) and location (proximity of nature reserves and villages/cities). The ball and the props denote factors which can be influenced by human activities. The ball symbolises the intensity of the farming system: its size is larger as the intensity (expressed in kg milk per ha) is higher. Stabilisation of the ball is arranged by management factors. A higher quality of management is required as the size of the ball is larger and the slopes of the mountain are steeper.

Workshop plan

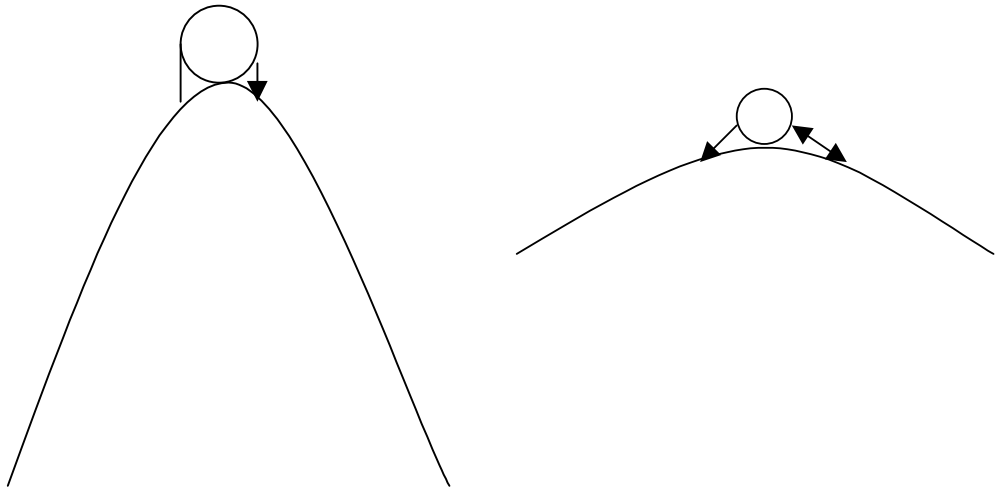
Country representatives of eight countries were asked by the organising committee to form a 'country team' of about five scientists, to participate in the workshop (for a list of delegates see Appendix I). Each team was asked to prepare for its own country a written report and an oral presentation about the implementation of European and national policies in relation to nutrient emissions in intensive dairy farming systems existing in the country, according to a prescribed format. All eight country reports were made available to each participant before the start of the workshop. They form Part II of this report.

Country teams were additionally asked to prepare an oral presentation of a 'case study' farm (size, crops, fertilisation, performance, etc.), typical for the country. By explicit consideration of a case study farm from each country, workshop participants were given an overview of the very different farm situations in each country and different ways to tackle problems.

Oral presentations of country reports during the workshop served to stimulate discussion. From that perspective, asking all European countries with intensive dairy farming systems to present country reports was unnecessary and too time-consuming. Therefore, representatives of additional, eligible countries, but without country report, were invited to participate in the discussions.

The first day of the workshop was devoted to plenary presentations: three introductory presentations by invited speakers and presentations of all country reports. As invited speaker, Patricia de Clercq (Ministry of the Flemish Communities, Belgium) presented an overview of EU nutrient policies. Patrick Durand (INRA, France) discussed the relationships between agriculture and water quality at watershed level. Friedhelm Taube (University of Kiel, Germany) characterised main dairy farming systems in the EU and their nutrient cycles. The presentations of Patricia de Clercq and Friedhelm Taube form Part I of this report.

On top of a mountain, there is a ball. In some situations, the top of the mountain is very narrow and the slopes are steep. In that case, the ball can be pushed out of balance rather easily, with dramatic consequences for the village in the valley. Therefore precautionary measures need to be taken, for example by propping up the ball (preventing its movement) or by attaching a sensor that registers every single movement of the ball and simultaneously assesses the danger arising from these movements (stopping the movement of the ball by immediate action and re-establishment of the old situation). In case the top is somewhat broader and the slopes are less steep, then a more expectant ('passive') attitude suffices: it is more difficult to get the ball rolling off the slopes, its speed will be moderate and there is sufficient time to prevent a catastrophe in the village, for example by evacuating the inhabitants.



The morning of the second day was devoted to discussions in small groups. Each group discussed two case study dairy farms from two different and rather 'contrasting' countries, focusing on environmental problems and potential measures to improve farm performance. Group results (see Appendix II) were reported in a plenary session. In the afternoon there was a visit to one experimental farm (Trévarez) and one commercial farm in the Brittany region. During the morning of the third day a plenary discussion was held on the basis of an overview of presented information and discussion statements, derived from country reports and group discussions. The workshop resulted in agreements about a follow-up (exchange of research results, collaboration, establishment of a working group 'Dairy Farming Systems and Environment' within the European Grassland Federation). The plenary discussion and agreements about follow-up activities are reported in Part III.

Part I. European situation

1. European nutrient policies in relation to dairy farming

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1.1 Background

The objective of this paper is to provide an overview of European policies concerning nutrients in agriculture in relation to dairy farming. After a general introduction on European environmental legislation, the focus will be on a few aspects of the current European nutrient policy and its links with the Common Agricultural Policy.

In the Treaty of Rome, by which the European Union was established in 1957, environmental protection was not an issue. It was not until the seventies that the general public and policy makers within the EU became aware of environmental problems. In 1973, the first Environmental Action Plan (EAP) was established for a period of 5 years. Other multi-annual programs followed this first EAP and resulted in various Directives. The most crucial change for European environmental issues was The European Act of 1987 which gave the Community explicit legal competence in environmental matters by introducing a new Title called 'Environment' in the Treaty. This treaty also introduced the idea that 'environmental protection concerns must be integrated in other policy areas of the European Community'. In 1993, this principle was confirmed by The treaty of Maastricht which also introduced the concept of sustainability (De Clercq & Sinabell, 2001).

The overall aim of the Community's environmental policy is to preserve, protect and improve the quality of the environment and to protect people's health. The environmental policy is based on three main principles:

- the precautionary principle;
- the principal of preventive action; and
- the polluter pays principle.

As indicated above the EAPs form the basis of the environmental policy and result in many directives. The first four EAPs were based on a vertical and sectoral approach of environmental concerns. The fifth EAP called 'Towards sustainability' ran from 1992 to 2000 and was aimed at the reduction of pollution, the implementation of the European regulations, and the integration of the environmental dimension in all policy areas of the Community. The sixth EAP is called 'Environment 2010: Our future, our choice'. It started in 2001 and runs until 2010 and it puts forward four priority areas: climate change, nature and biodiversity, environment, health care and welfare, and natural energy resources and waste.
The actions that should be taken to tackle these problems are based on 5 pillars (EP and EC, 2002):

- enhanced implementation of the existing environmental policy;
- integration of the environmental concerns in all other policy areas;
- close co-operation with trade and industry and consumers;
- enhancement of the quality and accessibility of environmental information to the public; and
- development of a more environmental minded attitude towards spatial planning.

1.2 EU nutrient policy and dairy farming

Dairy farming in the EU, as well as other agricultural branches, became more intensive and more specialized over the last years, which led to a concentrated production on fewer, lager farms. With increasing intensity in production, negative environmental impacts also tend to increase. Dairy farming, more specifically, has environmental implications in different areas, for example:

- the increased use of fertilizers affects soil integrity;
- the pollution of groundwater with nitrate and pesticides and eutrophication of surface waters;
- atmospheric pollution arising from denitrification, production of methane and ammonia volatilization.

1.2.1 The Nitrate Directive

A directive that has a large effect on dairy farming is the Directive concerning the protection of waters against pollution caused by nitrate from agricultural sources, or simply 'the Nitrate Directive' which was issued in 1991. Its main objective is to reduce water pollution caused or induced by nitrate from agricultural sources and prevent further such pollution.

The process to implement the nitrate directive consists of four steps:

1. designation of so-called nitrate vulnerable zones (i.e. agricultural land with a significant contribution to nitrate pollution);
2. development of Codes of Good Agricultural Practices (to be implemented by farmers on a voluntary basis in the whole territory of the Member State and compulsory in the nitrate vulnerable zones);
3. development of action programs for nitrate vulnerable zones;
4. national control on for example NO_3 concentrations and eutrophication.

The action programs must contain some mandatory measures relating to:

- periods when the land application of certain types of fertilisers is prohibited;
- the capacity of storage vessels for livestock manure; and
- limitation of the land application of fertilisers, consistent with good agricultural practice and taking into account the characteristics of the vulnerable zone concerned.

These measures must ensure that, for each farm or livestock unit in the vulnerable zones, the amount of N applied in livestock manure to the land each year, including that deposited directly by grazing animals does not exceed 170 kg N per hectare.

Member States are also compelled to evaluate the effects of their action programs and if necessary adjust their designation of vulnerable zones and/or action programs (EC, 1991).

In 2002, the Commission published a report based on the information received from Member States in 2000. An important aspect of the fulfilment of the Nitrate Directive is the control of pollution in ground- and surface waters. The Commission report states that there are still high and stagnating nitrate concentration levels in groundwater. This is due to a delay in transport of nitrate from soil to groundwater, an incomplete designation of vulnerable zones and an unsatisfactory application of measures at that time. Based on the available information on water pollution levels and eutrophication, the Commission feels that a larger part of EU territory needs to be designated. At the time of publication of the report, 38% of the land area was designated as vulnerable zone and the Commission indicated that another 9% needed to be designated, divided over Belgium, France, Greece, Ireland, Italy, Spain, Portugal, Sweden and the UK. At that time, a few countries had already planned to designate additional vulnerable zones, such as Flanders (Belgium), which proposed to the Commission a considerable enlargement of its vulnerable zones.

There are almost 200 different action programs throughout the EU Member States. A representative selection was evaluated and some general remarks of the Commission were that:

- most Member States fail to comply with the demand to set restricted periods for fertilizer application. More particularly, the measures are often well in compliance for organic nitrogen (manure), but not for mineral fertilisers;
- in many cases the minimum storage capacity for animal manure is not obligatory or not sufficient to overcome the period in which spreading on the land is forbidden;
- there are no well-defined measures for fertilizer application near water courses and ditches.

The action programs that were evaluated were meanwhile in many cases also reviewed by the Member States, and it appears that the renewed programs contain more preventive measures and more frequent controls at farm and field level.

In a preliminary assessment of the economic consequences, the Commission reasons that direct costs and a reduced harvest are often cited as the most important bottlenecks for the implementation of an improved nitrogen management but that the accessible information leads to believe that the reduction in harvest is probably minimal and that the extra costs are reasonable. Of the possible extra costs a few are pointed out, such as:

- extra costs for additional storage capacity for manure to cover the period in which fertilization is forbidden;
- costs resulting from a shift of N source from mineral to organic fertilizers. This is mainly due to extra costs for transport. For dairy farms this will be significantly lower than for pig farms since dairy farms have more land at their disposal than pig farms;
- extra costs for soil analyses to adjust N application to the crop's need, a method that is frequently used to limit nitrogen losses.

According to the Commission, some studies show that the limited availability of manpower is a main cause of the reluctance to change production methods. But since the area of economic consequences is not well studied for the moment, they rather suggest that in the near future more studies must be carried out in which socio-economic aspects and cost-effective analyses of programs and measures are better integrated (EC, 2002a).

1.2.3 Water pollution

Water pollution policy was the first area in which the Commission developed its environmental legislation. In October 2000, the Water Framework Directive was published and came into force. The Water Framework Directive sets as goal to protect all waters and to obtain 'good condition' in 2015. These 'good conditions' are dependent on the characterization of the water body and on a number of quality elements. The Water Framework Directive also sets clear deadlines for the implementation of the various actions.

In 2003 all Member States must transpose the Water Framework Directive into national legislation and identify river basin districts and river basin authorities. Before setting up action programs, a thorough analysis of the current situation is needed. The analysis of each river basin district, which is to be finalized by 2004, must contain information on the characteristics of the river basin district, an assessment of the impact of human activities on the condition of ground- and surface waters and an economic analysis of the water use.

In 2006, an operational monitoring network must be established in each Member State. For surface water this network will in the first place monitor the ecological and chemical characteristics. For groundwater the monitoring network will focus more on the quantitative and chemical condition. In 2009 the river basin management plans, including programs on implementation of measures, must be finalized. The management plans must contain a wide range of information, for example on:

- measures for the control of point source discharges and non-point pollution;
- measures to prevent or limit the leakage from technical installations; and
- measures to promote sustainable and efficient water use.

The programs of measures must help to obtain the environmental targets for a specific river basin district and the measures must be based on the analyses that are conducted in the previous stage. The Water Framework Directive describes a range of European directives of which the implementation needs to be considered as the basic and compulsory part of each measures program. Some examples of such basic directives are the Birds Directive, the Sewage Sludge Directive, the Plant Protection Products Directive, the Nitrate Directive, the Habitats Directive, and the Integrated Pollution and Prevention Control Directive. All measures must be operational at last by the end of 2012. By 2015, all waters in the European Union must have reached 'good conditions' and water must be a sustainable good. All river basin districts must be evaluated and adjusted, if necessary, every six years (EP and EC, 2000).

Since this rather complex Directive has a demanding timetable and a diverse range of possible solutions, the Member States and the European Commission agreed on a common strategy for implementation.
The common strategy can be divided into three phases:

- phase I from 2001 until 2002 for the preparation of guidance documents by working groups;
- phase II from 2003 until 2004 for testing of the guidance documents in pilot river basins; and
- phase III from 2004 until 2005 for establishing a manual for integrated river basin management which can be used to prepare the river basin management plans before 2009.

Results from these processes, for example in terms of guidance documents, have an informal and non-legally binding nature, creating a common working basis for the implementation.
The result from the first phase is the publication of 13 guidance documents concerning, *inter alia*, the economic analysis, the identification of river basin districts, the identification of water bodies, monitoring and analysis of pressure and impact. In 2003, the second phase or the testing of the guidance documents in pilot river basins (PRB) started. About 14 PRBs were submitted by the Member States, and several have been chosen to test the guidance documents. One example is the SCALDIT project or the Integrated testing of the Scheldt; a co-operation between France, Belgium and The Netherlands (Anonymous, 2001).

1.2.4 Air Quality

The EU, the Candidate countries, the USA and Canada have negotiated a multi-pollutant protocol under the convention on long-range transboundary air pollution. In this protocol national emission ceilings are set for sulfur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOC) and ammonia (NH_3). This protocol was agreed upon in 1999, but is still not ratified by all signatories (Anonymous, 1999). In the meantime, the EU has published Directive 2001/81/EC on national emission ceilings for certain atmospheric pollutants. The aim of this Directive is to limit emissions of acidifying and eutrophying pollutants and ozone precursors in order to reduce the adverse effects from acidification, soil eutrophication and ground-level ozone. The long-term objectives are set by means of national emission ceilings taking the year 2010 as a benchmark and with 1990 as reference year. By 2010 at the latest, Member States must limit their annual national emissions for nitrogen oxide and ammonia (Table 1). The table also shows the percentage of emission reduction that needs to be accomplished in comparison to the emission levels of 1990. For some Member States, these ceilings are more ambitious than those set in the protocol on long-range transboundary air pollution, but less stringent than what the Commission initially proposed. It is up to the Member States to decide which measure to take in order to comply with the Directive (EP and EC, 2001). An annex of the protocol is a list with measures for control of emissions of ammonia from agricultural sources that could be used as a guideline.

Table 1. Emission ceilings for NOx and NH_3 (kton) to be attained by 2010 and percentage reduction in comparison to emission levels of 1990.

Country	NOx (kton)		NH_3 (kton)	
Belgium	176	- 48%	74	- 31%
Denmark	127	- 55%	69	- 43%
France	810	- 57%	780	- 4%
Germany	1 051	- 61%	550	- 28%
Ireland	65	- 43%	116	- 8%
The Netherlands	260	- 55%	128	- 43%
Sweden	148	- 56%	57	- 7%
UK	1 167	- 56%	297	- 11%
EU-15	6 519	- 50%	3 110	- 10%

Source: EP and EC, 2001.

1.3 Midterm review of the CAP

An aspect that is not directly related to nutrient policy as such but that is of great importance to the dairy sector, is the mid-term review of the Common Agricultural Practice (CAP) that was agreed in Luxembourg on June 26th 2003. In order to provide a stable perspective for dairy farmers, the Council decided the prolongation of a reformed dairy quota system until the 2014/15 season. The general quota increases decided under Agenda 2000 will take place from 2006 onwards.
Dairy direct aids will be introduced in stages (11.81 Euro/ton in 2004, 23.65 Euro/ton in 2005 and 35.5 Euro/ton from 2006 onwards) and fully implemented by 2007. Generally, dairy payments will form part of the Single Payment Scheme from 2006/07 onwards. In the meantime, the target price for milk will be abolished.
The Council also decided on asymmetric price cuts in the milk sector. The intervention price for butter will gradually be reduced by 25%, which is an additional price cut of 10% to what was already foreseen in Agenda 2000. For skimmed milk powder prices will gradually be cut by 15% as agreed in Agenda 2000.
Intervention purchases of butter will be suspended above a limit of 70 000 tonnes in 2004, falling in annual steps of 10 000 tonnes to arrive at 30 000 tonnes from 2007 onwards. Above that limit, purchases may be carried out only under a tender procedure.

In the first part of this paper it was pointed out that the impacts of regulations on dairy farming arose from the environmental policy that was executed. With the mid-term review of the CAP, the stress on environmental issues in agriculture is now also arising from the agricultural policy itself by putting greater emphasis on cross-compliance. Up until now, cross-compliance, or enforcing farmers to comply with environmental standards, was an optional issue for Member States. The mid-term review made cross-compliance compulsory for all farmers receiving direct payments. A priority list of 18 statutory European standards in the fields of environment, food safety, and animal and health and welfare has been established, and farmers will be sanctioned for non-respect of these standards, through cuts in direct payments. Moreover, beneficiaries of direct payments will also be obliged to maintain all agricultural land in good agricultural condition, in order to avoid land abandonment and subsequent environmental problems. Where a farmer fails to comply with such requirements, reductions in his payments will be applied as a sanction (EC, 2002b, EC, 2003)

References

Anonymous (1999)
Protocol to the 1979 convention on long-range transboundary air pollution to abate acidification, eutrophication and ground-level ozone, United Nations Economic and social Council, Gothenburg, Sweden.

Anonymous (2001)
Strategic Document – Common strategy on the Implementation of the Water Framework Directive. At: http://www.europa.eu.int/comm/environment/water/water-framework/implementation.html, 69 pp.

Anonymous (2003)
Nature and biodiversity. At http://www.europa.eu.int/comm/environment/nature_biodiversity/index_en.htm.

De Clercq, P. & Sinabell, F. (2001)
EU legislation and multinational environmental legislation with respect to nutrient management. In: De Clercq, P., Gertsis, A.C., Hofman, G., Jarvis, S.C., Neeteson, J.J. & Sinabell, F. (eds.), Nutrient Management Legislation in European Countries. Department of Soil Management and Soil Care, Faculty of Agricultural and Applied Biological Sciences, Belgium, pp. 15-31.

The European Commission, Directorate-General for Environment (2002a)
Implementation of Council Directive 91/676/EC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Office for Official Publications of the European Communities, Report Com (2002) 407, Italy, 51 pp.

The European Commission, Directorate-General for Agriculture (2002b)
CAP Reform summary. Newsletter, Special Edition, 8 pp.

The European Council (1991)
Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal, L 375, 1-8.

The European Council (2003)
CAP Reform – Presidency Compromise (in agreement with the Commission). At http://europa.eu.int/comm/agriculture/mtr/index_en.htm, 35 pp.

The European Parliament and the European Council (2000)
Directive 2000/60/EC of The European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities, L327, 1-72.

The European Parliament and the European Council (2001)
Directive 2001/81/EC of The European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants. Official Journal of the European Communities, L309, 22-30.

The European Parliament and the European Council (2002)
Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programmes, Official Journal of the European Communities, L242, 1-15.

2. Characterization of dairy farming systems in the European Union and nutrient cycles

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2.1 Introduction

Since the introduction of the EU Nitrates Directive there has been increasing pressure on all those involved in agriculture to reconsider and improve their nutrient management practices. Both politics and scientists have reacted by either national action plans as required by the Nitrates Directive or research projects to identify problems, define alternative management options and develop 'sustainable' farming systems. Both the interpretation of the Nitrates Directive and approaches for reducing nutrient emissions to the environment differ considerably amongst European countries. At the European level, however, no consistent decline can be observed for nitrates in groundwater and surface water since the 1980s (CEC, 2002*b*).

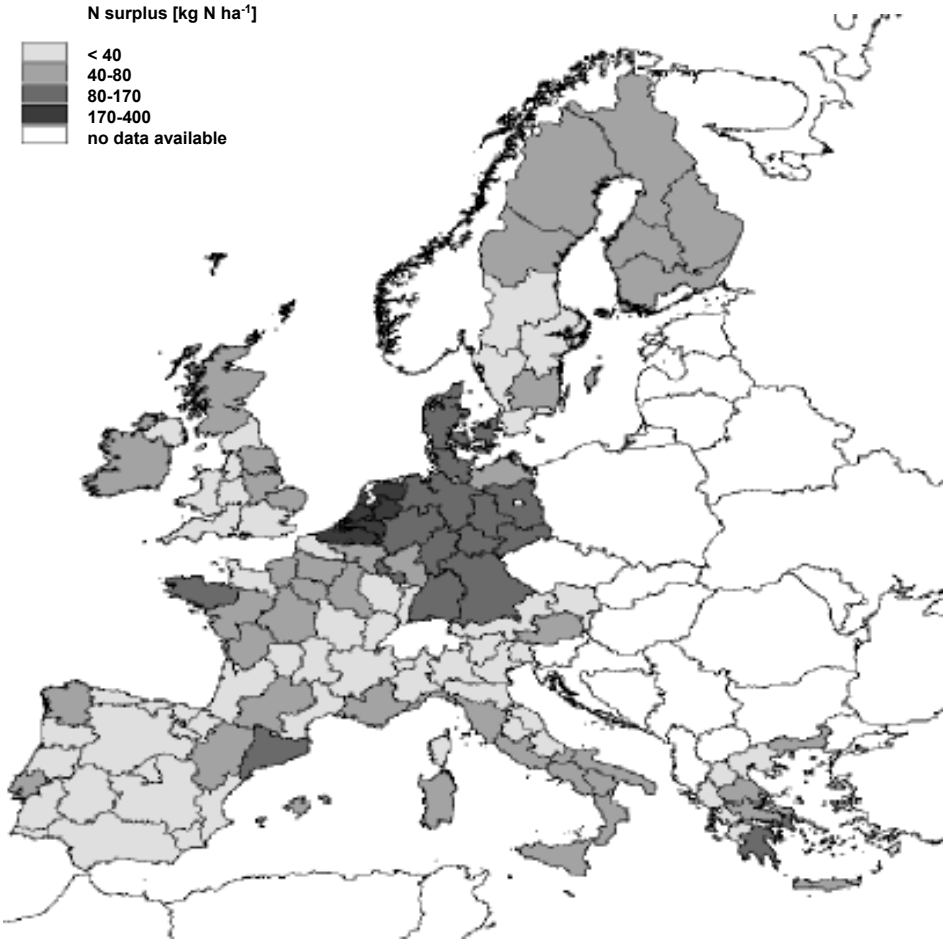

Figure 1. Nitrogen surpluses in EU regions in 1997 (CEC, 2002b).

Concerning ammonia losses, a 14% reduction between 1990 and 1996 was reported; a further declining trend is expected due to a reduction in the number of livestock in the EU and a more widespread use of emission-reducing techniques in livestock production and manure utilization (EEA, 1999). The phosphorus load in European surface waters is declining since the mid 1980s, but this is mainly due to lower emissions from non-agricultural sources (CEC, 2002*b*).
Within the agricultural sector, livestock production is the main source of nutrient emissions to the environment. Especially dairy farms are complex in terms of their management structure and the way in which nutrients are utilized and recycled (Jarvis & Aarts, 2000). The aim of this paper is to characterize and compare different dairy farming systems in Europe. It is not the objective of this paper to give information that is already present in the country reports. It is intended to give an overview of representative dairy farming systems with particular regard to nitrogen balances. Some relationships were found to be valid for all dairy farming systems in Europe. In other cases it is necessary to differentiate more than in the past when referring to aspects such as 'intensity', 'productivity' or 'environmental damage'. Future nutrient policy should aim at clearly defined goals that hold for every production system within the European Union, but should account for regional conditions and system-immanent characteristics.

2.2 Characterization of representative dairy farming regions in Europe

This section gives a characterization of some dairy farming regions in Europe. These regions were selected because (i) dairy farming is the most important agricultural activity in the respective regions (or at least as important as other farming enterprises such as pig, beef or arable farming), and (ii) dairy farming in these regions is considered being representative for a particular way of producing milk. The following dairy farming regions are regarded in this paper:

- Denmark
- The Netherlands
- Ireland
- The alpine regions

Of course there are other important dairy farming regions in Europe (for instance, parts of England, France and Belgium, the Po plain in Italy, Galicia/Northwest Spain, Northern Germany, and others). But it is believed that the characteristics of dairy farming in those regions can be addressed as somewhat 'in-between' with regard to the selected four 'characteristic' dairy farming regions. For instance, dairy farming in Ireland and in the alpine regions is based on grazing on permanent grassland, whereas ley farming is the predominant system in Denmark. In most other parts of central Europe both leys and permanent grassland are of importance in dairy farming.

2.2.1 Systems characterization and nutrient fluxes

In order to understand *why* milk is produced in a particular way in a given country (for instance, *why* is a high milk yield per cow not desirable under Irish conditions?) it is important to consider environmental, structural and economic constraints that vary considerably between countries and regions. This section gives a brief characterization of dairying systems (Tables 1 and 2) and tries to explain some of the *whys*. Detailed information on the addressed dairy farming regions can be found in the respective country reports.
Two general types of dairy farming can be distinguished with regard to climatic conditions. In Northern Germany, Denmark and Sweden the predominant strategy is to increase milk yields per cow. A high level of concentrate feeding strongly contributes to high milk yields. This strategy is mainly due to the relatively short growing season (5-7 months) which limits the grazing period. Furthermore, rainfall is not always sufficient for high grassland yields. Where climate is characterized by mild winters and high amounts of precipitation (Ireland, Western England, Brittany), milk production is based on a long grazing period on permanent grassland. Also the alpine regions are characterized by permanent grassland, but this is because arable farming is not possible in mountainous areas. In these grassland-based dairy farming systems, the achievement of high milk yields per cow by means of concentrate feeding and breeding for high milk yield is generally a less important objective than maximizing milk yields from grassland.

Table 1. Main characteristics of dairy farming systems in the European Union.

	Denmark	The Netherlands	Ireland	The alpine regions
General characterization	Ley farming	Intensive grassland-based dairy farming	N-intensive but low-cost grassland-based dairy farming	Extensive grassland-based mountain farming
Soils	Sandy, partly loamy	Sand (SE), clay/loam (W), peat (N)	Light loam or loam, partly sandy	Sandy – loamy
Climate	Temperate humid, dry periods in summer	Temperate humid	Mild humid, high amounts of rainfall	Temperate, mountain climate
Milk production system	Summer grazing/winter housing or year-round confinement	Summer grazing/winter housing or year-round confinement	Long grazing season, spring calving	Mountain grazing/winter housing
Livestock units per ha	1.5	2.6-2.9	1.9-2.5	1.2-1.7
Supplementation on pasture	yes	yes	no	no
Concentrates [t cow^{-1} yr^{-1}]	1.6-1.7	2.2-2.3	0.6	0.5-0.8
Milk yield [kg cow^{-1} yr^{-1}]	7 000-7 500	7 400-7 700	4 500-5 700	4 500-6 000
Forage crops	Crop rotations of grass/ clover, cereals and maize	Permanent and temporary grassland, maize	Permanent grassland	Permanent grassland
Grassland characteristics	Perennial ryegrass (tetraploid) + white clover	Perennial ryegrass	Perennial ryegrass	Perennial ryegrass + white clover, richness in species
N intensity on grassland [kg N ha^{-1}] *	60-210 **	340-450	180-330	0-70
Grassland management	Mixed cutting/grazing, two-thirds grazed, 2-3 cuts	Priority to grazing, 2-3 cuts	Priority to grazing, 1-2 cuts	Mixed cutting/grazing (2-3 cuts), hay pasture

* *Including plant-available N in slurry and manure.*

** *To established grass/clover (dependent on the clover content); 285-300 kg N ha^{-1} to pure grass swards.*

Table 2. Typical N surpluses, risk of N losses and general appraisal of dairying systems in the EU.

	Denmark	The Netherlands	Ireland	The alpine regions
Farm-gate N surplus [kg N ha^{-1}]	170-240	375-405	230-290	50-110
Risk of NO_3 leaching	Moderate-high	High-very high	Low-moderate	Low
Risk of gaseous N losses	High	High-very high	High	Moderate
Strong points	Sophisticated crop rotation practices, N transfer from ley to subsequent crops	High level of production per unit land area	Low-cost system, low labour requirements	Well-adapted to alpine conditions, low nutrient losses
Weak points	Labor-intensive, high level of skills required	High pressure on land, capital and biotic resources, high level of skills required	High N intensity, often N application until late autumn	Small farms, highly dependent on subsidies
Trends	Continuing structural change towards larger farms, increasing milk yields, no further increase in organic dairy farming	Tightening of nutrient policy regulations by MINAS or EU, maybe even further specialization and concentration of farms	Strong decline in the number of farms, concentration in the South-East, remaining dairy farms increase their stocking rate while reducing beef cattle	Decline or stagnation of the number of organic dairy farms, viability of most dairy farms will be highly dependent on future subsidy levels and rural environment programs

In countries such as Ireland or Switzerland there is currently an intensive discussion about the road dairy farming should follow in the future. Many farmers aim to minimize costs of milk production by minimizing winter feed requirement, concentrate input and replacement rate ('New Zealand Approach'). However, there are also farmers in these countries who aim at a maximum utilization of the high genetic merit of Holstein cows by means of increased concentrate input.
In a situation of decoupled direct payments and declining milk prices low-cost production will be a key factor for economically viable milk production throughout the EU. There are different strategies towards reduced costs, for instance a reduction of costs without any increase in milk yield or individual quota, or an increase in herd size and management for maximum milk yields. The consequences for nutrient management are still not clear. It is, however, likely that stricter regulations on nutrient management will cushion against increasing pressure on land, biotic and abiotic resources as a result of increasing concentration of dairying in some regions.

Table 3 indicates farm-gate N balances of the respective dairying systems. In order to make the different data sources comparable, if necessary, farm-gate balances were re-calculated by the following scheme:
N input = mineral N fertilizer (N1) + purchased manure (N2) + purchased feedstuffs (N3) + animals (N4) + atmospheric deposition (N5) + biological N_2 fixation (BNF) (N6)
N output = milk (N7) + meat (N8) + cash crops (N9) + sold manure (N10)
The efficiency of N use in dairying systems was calculated in three ways:
N efficiency total (NE_{tot}) = $\Sigma_{N7\text{-}N10} / \Sigma_{N1\text{-}N6}$
N efficiency external inputs (NE_{ext}) = $\Sigma_{N7\text{-}N10} / \Sigma_{N1\text{-}N3}$
N efficiency of milk production ($NE_{animals}$)* = $\Sigma_{N7\text{-}N8} / ((N3\text{-}N9) + N1 + N2 + N5 + N6)$

* after Kristensen (2002)

2.2.1.1 Denmark

In Denmark, forage production is typically part of a crop rotation scheme. This system is frequently addressed as 'ley farming'. Some of the reasons that explain the preference of crop rotation systems at the expense of permanent grassland are:

- Grassland yields are limited by a short growing season and water shortage in summer (sometimes drought periods)
- Water shortage is reinforced by sandy soils upon which most dairy farms are located; under these circumstances permanent grassland would have to be renewed regularly due to sward deterioration, yield decline and increase of weeds
- Cultivation is always possible on sandy soils
- As a consequence, it is a short way from regular grassland renewal to a ley system; newly established grassland provides a higher yield level and higher forage quality than permanent grassland
- N transfer from the ley phase to subsequent crops (cereals) is another advantage0

Typical crop rotations consist of spring barley for whole-crop silage with undersown grass/clover, 1-2 years grass/clover for conservation and/or grazing, and two years of cereals. Cultivation of maize is restricted by the short growing season and cool summers. Silage maize is grown only in the southern parts of Jutland where it replaces whole-crop silage of cereals.
White clover has successfully been re-introduced in Denmark, which was facilitated by the crop rotation system with short-lasting leys and, on many farms, irrigation facilities. Furthermore, Danish regulations strictly limit the use of mineral N fertilizer by a 'nitrogen quota'. Farms without irrigation facilities sometimes rely on red clover/grass because red clover is less susceptible to water shortage. Leys are predominantly used by mixed cutting and grazing. On average, two-thirds of the grass/clover area are grazed. However, with increasing farm and herd size there is a tendency towards year-round indoor feeding. N application rates to established grass/clover range between 50 and 200 kg N ha^{-1}, depending on the clover content.
Since the mid 1990s there has been a strong increase in organic dairy farming, which was supported by a general consensus between the government, the Farmer's Union, the dairy industry, retail companies and consumers. Organic milk currently accounts for 8% (380 million kg) of the total Danish milk production (Fødevareministeriet, 2003).

Table 3. Farm-gate nitrogen balances and nitrogen losses [kg N ha^{-1}] of commercial dairy farms in European countries (data sources: Danish country report – Part II, AARTS et al. (1999), Irish country report, Poetsch (2000)).

		Denmark		NL	Ireland	Austria	
		conventional	organic			conventional	organic
N inputs							
Mineral fertilizer	N1	89	0	242	287	18	0
Manure, straw for bedding	N2	3	11	50	0	1	1
Feedstuffs total	N3	97	49	145	20	21	4.4
Concentrates		79	29	125	20	18	4
Cereals, forage		18	20	20	0	3	0.4
Animals	N4	1	1	0	1	0.3	0.6
Atmospheric deposition	N5	16	16	49	10	10	10
Biological N_2 fixation	N6	23	70	0	0	25	38
N outputs							
Milk	N7	36	31	64	45	18	15
Meat	N8	9	6	14	16	10	6
Cash crops	N9	9	3	0	0	1	0
Manure	N10	3	0	0	0	0	0
N input total		**229**	**147**	**486**	**318**	**75.3**	**54**
N output total		**57**	**40**	**78**	**61**	**29**	**21**
N surplus		**172**	**107**	**408**	**257**	**46.3**	**33**
NE tot. [%]		**25**	**27**	**16**	**19**	**39**	**39**
NE ext. [%]		**30**	**66**	**18**	**20**	**72**	**350**
NE animals [%]		**21**	**26**	**16**	**19**	**38**	**39**
N losses							
NH_3 losses (storage)		15	10	51	— 212 —	–29–	–19–
NH_3 losses (manure spreading, grazing, crops)		26	18	16			
Denitrification		25	23	214			
Δ soil organic N		4	6	0		–17–	–14–
NO_3 leaching		112	62	124	45 ?		
Farm information							
Stocking rate [LSU ha^{-1}] *		1.5	1.3	2.7	2.5	1.7	1.1
Milk yield [kg cow^{-1} yr^{-1}]		7 373	6 860	7 250	5 680	6 095	4 710
Concentrates [kg cow^{-1} yr^{-1}]		1 650	600	2 200	600	806	276

* *Not corrected for different national livestock unit (LSU) expressions.*

Nutrient balances (Table 3) are therefore indicated for both conventional and organic dairy faming because organic farming is not as marginal as in other countries.

The risk of both nitrate leaching and ammonia emissions is quite high because (i) sandy soil texture and precipitation surpluses during winter favour NO_3 leaching, and (ii) pig production is another important enterprise in the central and western parts of Jutland, causing an intense pressure on land to apply manure.

The ley farming system practiced in Denmark has both advantages and disadvantages with regard to nitrate leaching losses. During the ley phase of the crop rotation, considerable amounts of soil-N are built up, especially on grazed leys. Less than 10 kg NO_3-N ha^{-1} are lost via leaching during the ley phase, irrespective of grazing or cutting (Eriksen & Vinther, 2002). After ploughing of grass/clover, however, leaching losses under cereals of 45 kg NO_3-N ha^{-1} were found in the first year and 60 kg NO_3-N ha^{-1} in the second year (Eriksen *et al.*, 1999). In spite of relatively high leaching losses after ploughing, there is evidence that the crop rotation system bears a lower risk of nitrate leaching than a permanent grassland – maize monoculture – cereal/cash crop system. As it may take 10-25 years or even longer until the soil organic matter pool of permanent grassland reaches an equilibrium (Johnston, 1986), a large part of the N input into the sward can be lost via leaching during the first years after establishment. Under soil and climatic conditions similar to Danish dairy regions, Büchter *et al.* (2002) determined for a Northern German sandy site NO_3 losses under permanent grassland of 30-50 kg NO_3-N ha^{-1} in mixed cutting/grazing systems and 40 - >100 kg NO_3-N ha^{-1} on grazed-only plots. However, sophisticated cropping practices (design of crop rotations, timing of ploughing, efficient use of fertilizer and manure, use of catch crops) are a prerequisite for obtaining an optimal economic and environmental performance with the Danish crop rotation system.
At a stocking rate of 1.5 LSU ha^{-1} the farm-gate N surplus is about 170 kg N ha^{-1}. Organic dairy farming reduces the N surplus by 65 kg N ha^{-1} (Table 3). At the same stocking rate, the advantage of organic dairy farming is about 50 kg N ha^{-1} (see Danish country report Part II: *N turnover on Danish mixed dairy farms*).

2.2.1.2 The Netherlands

The Netherlands have the highest population density within the European Union. More than in any other country there is an intense pressure on land due to the requirements of industry, infrastructure, housing, agriculture and nature reserves. Consequently, land and quota prices are higher than in other European countries. This structural frame-work explains why Dutch agriculture is characterized by an exceptionally high intensity with regard to the use of external inputs such as mineral fertilizer and concentrates. High N emissions per unit land and high levels of P accumulation in agricultural soils are the consequential drawbacks.
Climatic conditions favour grass growth, which is the dominant forage crop on Dutch dairy farms. Silage maize is grown particularly on sandy soils in the southern and eastern parts of the country. Grassland is predominantly used as permanent grassland dominated by *Lolium perenne* L., temporary grassland is of minor importance. Grassland utilization gives priority to grazing as this is the cheapest way to convert grass into milk. On the major part of the grassland area, rotational grazing at the stage of maximum herbage digestibility is integrated with cutting of the surpluses for silage. Especially in the Southeast, where dairy farming is most intensive, restricted or zero-grazing systems are becoming more important.
Typical N surpluses in the early 1990s on specialized commercial dairy farms were in the range of 400 kg N ha^{-1} (Aarts *et al.*, 1999). Nitrate concentrations in the upper groundwater were frequently found up to 250 mg NO_3 l^{-1}, especially in the sandy regions of The Netherlands (Fraters *et al.*, 1998). Approaches for improved nutrient management (Aarts *et al.*, 1992) have been tested and evaluated at 'De Marke' during the 1990s and are now being introduced on a (limited) number of commercial farms. These approaches, however, are 'high-intensity' approaches. In spite of a reduction of nutrient surpluses by up to 50%, surpluses are still at a relatively high level compared to other European regions. The structural framework with its intense pressure on land and capital makes it unlikely that approaches aiming at moderate intensities can be realized in The Netherlands. Under these circumstances it is comprehensible that the Dutch prefer the MINAS system which allows for a more flexible interpretation compared to EU regulations.

2.2.1.3 Ireland

Dairy farming in Ireland is characterized by N-intensive but capital-extensive grassland-based production systems. Climatic and soil conditions (750-1500 mm rainfall per annum, long grass growing season of 250-330 days per year, heavy and poorly drained soils especially in the North and West of Ireland) largely dictate the reliance on permanent grassland. Consequently, dairy farming in Ireland aims at a maximum milk production from grazed grass. This is facilitated by relatively cool summers which help to maintain highly digestible swards throughout the grazing season. The Irish system is based on compact spring-calving between February and April. Grass silage is fed in the winter period between October and March, of which a considerable part falls within the dry period. Concentrates are

supplemented only in the early lactation (February-May). Milk production is thus highly seasonal with most of the milk produced between March and November. The most commercial, economically viable dairy farming enterprises are located in the South-West of Ireland. These farms also have the highest input of organic N to agricultural soils. On most Irish dairy farms beef production is a major second enterprise.
Grassland management gives priority to grazing. Depending on the intensity of a farm, one or two silage cuts are included in spring or summer. The Irish low-cost system, aiming at minimum winter feeding, concentrate supplementation and replacement, depends strongly on seasonal calving in spring. This, in turn, requires a calving interval of around 365 days, which can be achieved only with milking cows of high fertility and body condition. As a consequence, the genetic merit of the Irish dairy herd (mostly British Friesian) is relatively low for milk production. Milk output per cow remained almost constant since 1997 apart from a slight but progressive increase on farms at the upper end of the range.
The highly seasonal scheme of milk production, which limits the development of value-added consumer-orientated products for EU markets, is surely an important reason for the lack of capital in the Irish dairy sector. It is, however, expected that dairying will concentrate in the South-East of Ireland at the expense of smaller non-viable farms in other parts of the country.
Water quality (both groundwater and surface water) is generally good. Where eutrophication of inland freshwaters occurs (mainly in the Northern parts of Ireland), this can be attributed to P losses from intensive pig and poultry farming on heavy clay soils prone to run-off. A number of studies of intensive grassland-based dairy production systems on heavier soils in Ireland have shown that large farm-gate surpluses of N (> 300 kg N ha^{-1}) are not associated with excessively elevated nitrate levels in drainage and groundwater (Bartley *et al.*, 2002; Humphreys *et al.*, 2002). Ryan *et al.* (2001) determined annual leaching losses in the range of 24-53 kg NO_3-N ha^{-1}, depending on N intensity and precipitation surplus. This indicates that much of the surplus N is being lost in gaseous form, either as N_2 or as environmentally harmful gases such as NH_3, N_2O *etc*.
A potential risk for undesired nutrient losses to water arises from dirty wash water management. There is further evidence that slurry storage capacity, storage management and application dates and techniques do not correspond to the codes of good agricultural practice. Limited storage capacity and the need to extend the grazing season until November/December often causes slurry application in autumn and winter, which strongly increases the risk of nitrate leaching losses (Mounsey *et al.*, 1998). Especially smaller farms cannot afford the required investments, or do not apply for extension or capital spending programs (Crosse *et al.*, 1999).

2.2.1.4 The alpine regions

In the alpine regions of Austria, Switzerland, Southern Germany and parts of France and Italy, agriculture can be characterized as dairy farming on permanent grassland in the mountainous areas, with arable farming on the less sloped soils in the valleys. On most of the sloped fields tilling is either not possible or not recommendable due to the risk of soil erosion. Permanent grassland is thus the only possible crop. Generally, dairy farms are relatively small compared to other European regions. Average farm sizes are in the range of 15 ha, with a considerable proportion of part-time farms. Conservation of landscape elements and tourism are important in the alpine regions and often provide a considerable part of the farmer's income. Similar to grassland-based systems in other European regions such as Ireland, maximizing milk production from permanent grassland is a major objective. However, the growing season is relatively short, which implies a higher amount of winter feeding than in other permanent grassland regions. Usually, 2-3 cuts are included in a rotational grazing system. Since cheese production is an important enterprise of the alpine dairy sector, hay is fed instead of grass silage on many farms in order to meet the requirements for cheese production. At higher altitudes permanent grazing during the summer months ('alp grazing') is still a common feature.
In contrast to most other regions in Europe arable farming contributes to a relatively greater extent to nutrient emissions than dairy farming. For typical alpine dairy production systems it is unlikely that nitrate leaching exceeds 5 kg NO_3-N ha^{-1} irrespective of the management intensity (Poetsch, 1998). Reasons are (i) that arable farms are located in valleys and river basins where soils are permeable and sandy, whereas dairy farming takes place in more mountainous areas, (ii) that nutrient intensity is traditionally low in alpine dairy farming systems, and (iii) that there is a high rate of acceptance of agri-environment programs (for instance, the 'ÖPUL' program in Austria) and organic farming especially amongst dairy farms. In Austria, more than 70% of the agricultural area is managed under the regulations of agri-environment programs. The number of organic dairy farms, however, is currently declining due to

both economic and agronomic reasons (Poetsch, 2000). Average N fertilizer rates to grassland are about 50 kg N ha^{-1}; there is, however, also a considerable proportion of conventional farms that do not apply any N fertilizer at all due to their participation in agri-environment programs. At the other end of the range there are also more intensive dairy farming systems in alpine countries than presented in Table 3 for Austria. For instance, Thomet and Koller (1996) found an average nitrogen surplus of 109 kg N ha^{-1} on commercial dairy farms in Switzerland.
Alpine grasslands are generally rich in species. Wetterich & Haas (1999) found between 20 and 30 species in swards of commercial farms. As legumes make up 20-30% of the grassland dry matter production under typical management intensities (Poetsch, 1998), biological N_2 fixation is the major source of N input into alpine production systems. From a survey on more than 200 commercial dairy farms Poetsch (2000) determined only a weak relationship (r^2 = 0.23) between N fertilizer use and milk production per hectare. The amount of concentrates fed did not explain much of the variation in milk production per hectare either (r^2 = 0.26).
It can be summarized that alpine grassland-based production systems are well adapted to the prevailing environmental conditions. The risk of nutrient losses to the environment is very low while the level of milk production is only slightly lower (due to a lower stocking rate) compared to other European grassland-based dairy systems (for instance, in Ireland). As the costs of milk production are much higher in the alpine countries than in other European dairy farming regions (0.50-0.60 €; IFCN, 2002), direct payments and agri-environment programs are a prerequisite for the economic viability of most farms in alpine countries.

2.2.2 Summary and generalization

Even though the regarded dairy farming systems are very different, some general trends can be observed. The following paragraphs refer only to conventional dairy farming, as well as Figures 2-4. It should be remembered that milk production in The Netherlands and in the alpine regions takes place on strongly specialized dairy farms. In Ireland, beef cattle production is a major second enterprise on most dairy farms. In Denmark, milk production takes place on mixed farms with cash crops and dairy cattle.
With regard to productivity there is a positive relationship between concentrate input and milk production per hectare in farming systems without cash crop production. The Danish mixed farming system falls not within this relationship. Milk production in permanent grassland-based systems (Ireland and the alpine regions) is almost comparable with regard to these parameters (Figure 2, top).
Between N fertilizer input and productivity no generalization can be drawn (Figure 2, bottom). Permanent grassland-based systems (Ireland and the alpine regions) have almost the same level of production, but N fertilizer input in Irish dairy farming is seven times higher. From this comparison it becomes very questionable whether high rates of N fertilizer input are justified in the Irish system. This is even reinforced by the fact that climatic conditions are more favourable in Ireland than in the alpine regions. In Denmark, milk production per cow is in the same range as in The Netherlands, but N fertilizer input is much lower due to stricter environmental regulations and possibly due to the more N-efficient crop rotation system.
The N surplus per hectare is strongly determined by concentrate input irrespective of mixed or specialized farms, and irrespective of grassland-based or crop rotation systems. Only the Irish system cannot be included in this general trend (Figure 3, top). The same holds for the relationship between N fertilizer input and N surpluses (Figure 3, bottom).
These observations show that different strategies of milk production under quite different climatic conditions can be compared and generalized. As N fertilizer input shows only a weak relationship with milk production per hectare but with a strong effect on N surpluses, high N application rates as present in some countries have to be questioned. This is illustrated by the consistently declining efficiency of nitrogen utilization with increasing total N input into the farming system (Table 3). As the level of concentrate input shows a stronger relationship with milk yields, a reduction in N fertilization seems to be the more promising road towards reduced N surpluses while maintaining an economically viable milk production. This is supported by Kühbauch & Anger (1999) who showed that the conversion of nitrogen into animal products is much more efficient if applied as concentrate compared to the application of mineral N fertilizer.
It seems obvious that high rates of N fertilizer application in the Irish system are not necessarily related to a high level of production. A significant reduction in N fertilization seems possible without considerable yield losses, especially under the favourable environmental conditions in the southern counties of Ireland.

From the large variation in stocking rates the relationship between stocking rate and N surplus was calculated over the different production systems (Figure 4, top). The relationship was even stronger than determined for Danish conventional mixed dairy farms (see Danish country report - Part II). Even though the stocking rate explained only a smaller part of the variation in N surpluses in a number of surveys on commercial farms (for instance, Scheringer, 2002), the present observation shows that, in the absence of variation between individual farms, a general conclusion can be drawn over different farming systems.
As a consequence of the facts discussed above, there is a very close relationship between total N input into farming systems and N surplus (Figure 4, bottom). Total N input is determined by N fertilizer levels, concentrate input and stocking rate. A reduction in total N input is thus a prerequisite for reduced N surpluses. As mentioned above, a reduction in N fertilization seems to be a more promising way than reducing concentrate inputs, as N fertilization levels are not necessarily related to the level of milk production.

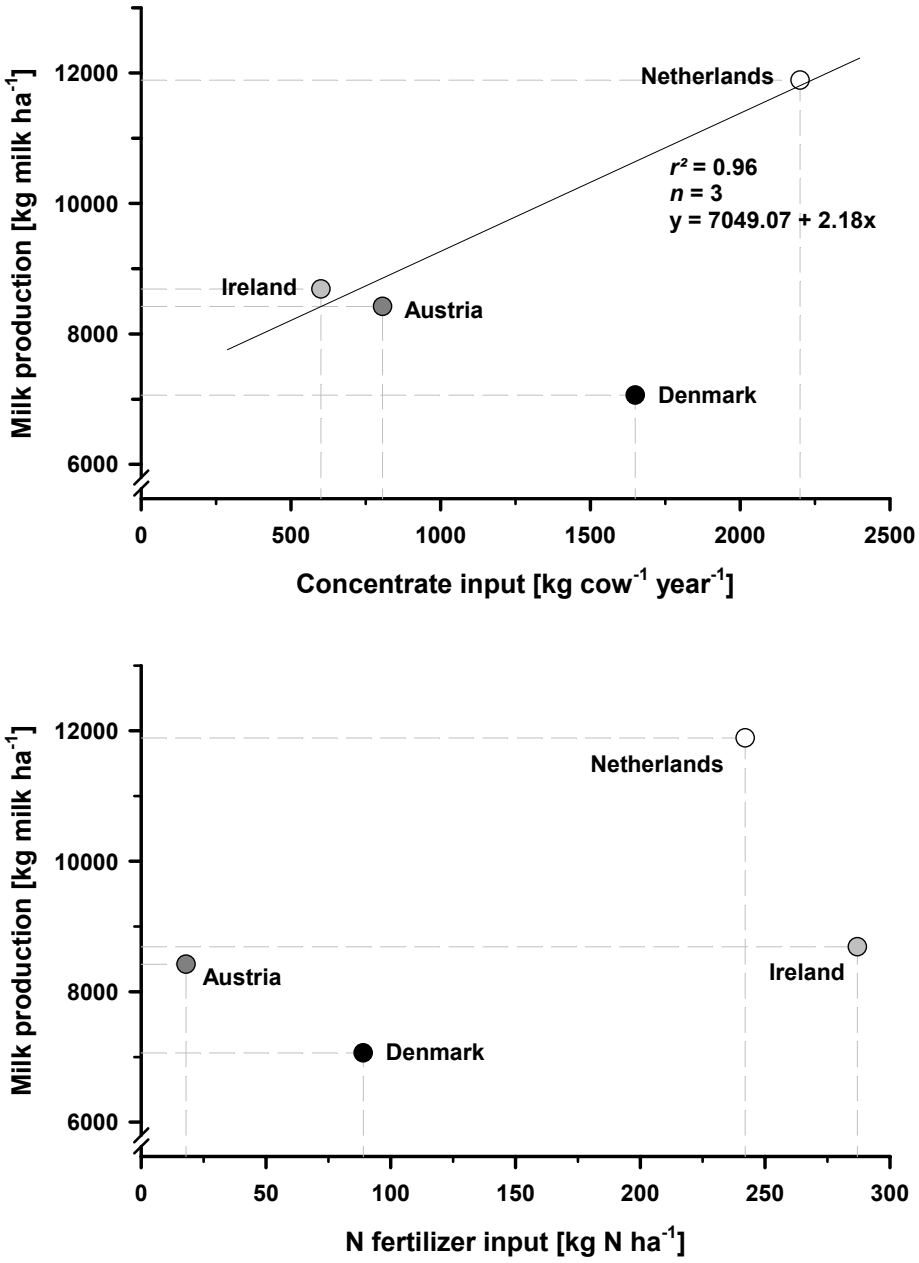

Figure 2. Relationship between concentrate input and milk production per hectare (top) and between N fertilizer input and milk production per hectare (bottom) in European dairy farming systems.

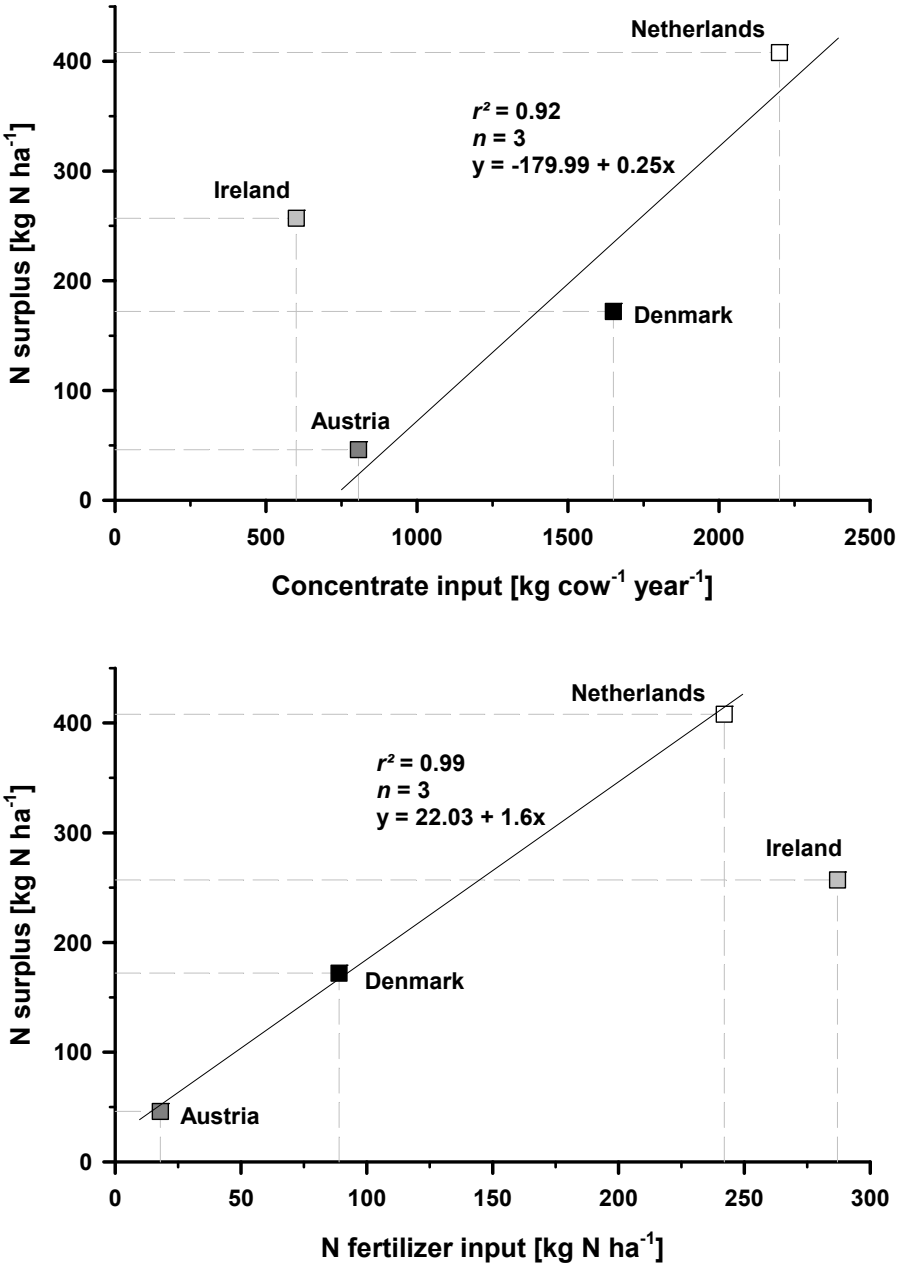

Figure 3. *Relationship between concentrate input and N surplus (top) and between N fertilizer input and N surplus (bottom) in European dairy farming systems.*

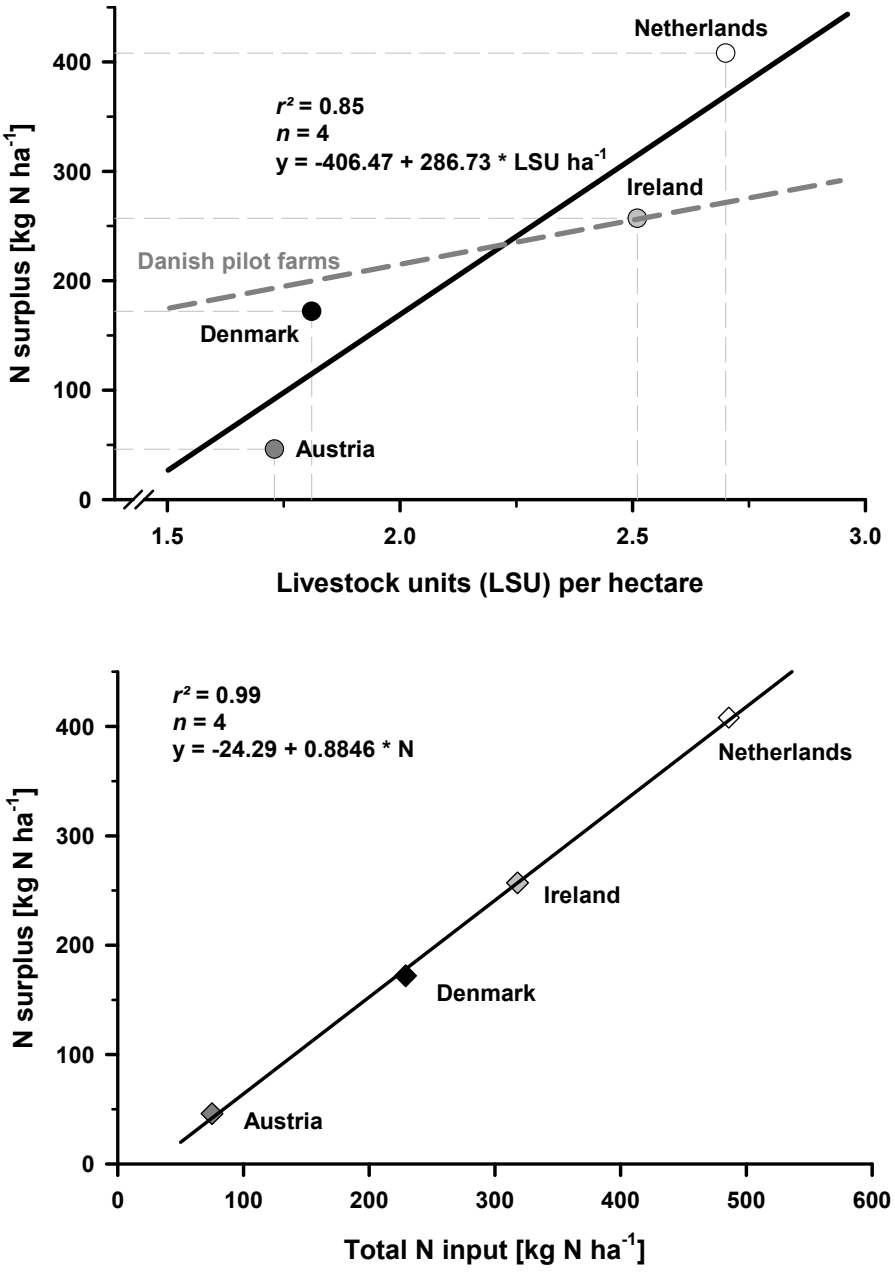

Figure 4. *Relationship between stocking rate (1 LSU = 1 dairy cow) and N surplus (solid line: regression; dashed gray line: relationship on Danish pilot farms, see Danish country report Part II) (top), and relationship between total N input and N surplus (bottom) in European dairy farming systems.*

2.3 Searching for indicators

2.3.1 Nutrient balances

It remains questionable whether nutrient balances are reliable indicators for potential nutrient losses. Generally, agri-environmental indicators should (i) be correlated with both environmental problems and farming practices, (ii) encourage farmers to improve their management practices, and (iii) fulfil the requirements of policy (low cost for data acquisition, efficient control, reliability). The nitrogen surplus is not an account of the actual loss over a given period, but expresses the potential loss from a farm over time if stocking rate and cropping practices are not changed significantly (Halberg, 1999). One important question addresses possible scale effects and the availability of accurate data. Field balances have been determined for a number of management intensities by scientific investigations. For instance, Wachendorf *et al.* (2003) found a significant positive relationship between total N input and NO_3-N load, and between N surplus and NO_3-N load on permanent grassland on sandy soils. For individual farms, however, limited data availability often hampers the drawing up of field balances. Farm-gate balances cost less in data acquisition, account for the systems character of a farm and for inter-relationships between farming enterprises (crop production, animal production), but do not allow an optimization of particular management factors if no breakdown into herd and crop-subsystems is conducted. It is also important to consider site-specific effects such as the nitrogen release from the soil, soil texture, growth conditions as affected by soil fertility and climate, *etc*. Some methodological aspects also need to be reconsidered when comparing nutrient balances. For instance, biological N_2 fixation (BNF) by legumes can be estimated by a number of more or less accurate methods, which can lead to significantly different results (Ledgard and Steele, 1992). Nevertheless some authors concluded that the farm-gate N surplus is a good indicator for potential and actual N losses to the environment (Fraters *et al.*, 1998; Taube & Poetsch, 2001; Vellinga *et al.*, 2001). This does not mean that there is no need for a harmonization of methodologies. Furthermore, it is necessary to formulate threshold values of nutrient surpluses that are acceptable from an environmental point of view without endangering the economic viability of farms. The formulation of such threshold values should account for site-specific factors as mentioned above, and for the farming system that is predominant in a given region.

2.3.2 Stocking rate

Irrespective of the large variation frequently found in on-farm surveys with a large number of farms, there is a positive relationship between stocking rate and nitrogen surpluses as shown in Figure 4 (top). This holds both when comparing highly different dairy farming systems as well as within similar farming systems, as shown for the Danish example. However, the strength of this relationship is much stronger between systems than within the indicated Danish example. As there is no accurate data available for most countries, the following thesis may be formulated:

The relationship between stocking rate and N surpluses is stronger in relatively N-inefficient dairy farming systems (for instance, Ireland and The Netherlands) than in N-efficient systems (the Danish example).

If a strong relationship between stocking rate and N surpluses could be determined for a given milk production system, the consequential second thesis is:

Given a close relationship between N surplus and nitrate leaching as found in many field experiments, it should be possible to calculate the amount of nitrate leached from the stocking rate.

These theses cannot be verified here due to the lack of accurate and sufficiently large data sets for the respective dairy farming regions. However, the investigation of these relationships could be of great value for future nutrient policy recommendations.
A restriction on stocking rate has already been implemented in some countries (for instance, in Denmark). This option is currently discussed in other countries. This is mainly because of ammonia emissions, which are directly related to the amount of livestock in a given region. As shown above, a positive effect on nitrate leaching losses can also be expected by a reduction of the stocking rate in dairy farming. If nutrient policy would focus more than in the

past on livestock density, 'critical loads' (on a regional basis) and the extent to which emission-reducing measures are set off have to be defined as a prerequisite. In regions where arable farming is dominating, a restriction of the stocking rate on individual livestock farms does not seem adequate. The acceptance of areas for slurry deposition outside the farm (e. g. on all-arable farms) can contribute to a greater flexibility.
In this context it is important to use an adequate expression of the livestock density. Unfortunately, the way of calculating livestock units differs between European countries. In order to reduce nutrient emissions by means of restricted stocking rates, livestock units should be expressed by the amount of nutrients excreted. This is already the case in some European countries. Additionally, management factors that affect the nutrient excretion of cattle should be recognized (for instance, the milk yield per cow, or the adjustment of concentrate and protein supplementation).

2.3.3 Other indicators and indicator-based systems

The development of sustainable dairy farming systems should also account for other agri-environmental indicators than nutrient emissions. Without discussing them in detail, the following aspects need to be considered:

- Productivity
- Product quality (quality of forage, crops, milk, meat, *etc.*)
- Biotic resources (biodiversity)
- Soil protection, soil fertility
- Fossil energy use, energy efficiency
- Greenhouse gas emissions (N_2O, CH_4, CO_2)
- Socio-economic impacts

Indicator-based systems (a recent overview on indicator-based systems in Europe is given by Van der Werf & Petit, 2002) provide efficient tools for evaluating dairy production systems in terms of productivity as well as in terms of environmental impacts. As most of the established indicator-based methods have been developed for arable farming systems rather than for livestock farming, there is still a need for research. Especially the complex interactions between animals, soils and crops have to be investigated by a systems approach at the farm scale.

2.3.4 Organic farming

It is intensively being discussed whether organic farming might be a promising option for reduced nutrient losses to the environment. The key factors for low N surpluses in conventional and organic dairy farming systems are similar:

- reduction in the use of external inputs (biologically fixed N_2 can be regarded as a substitute for mineral N fertilizer (Taube *et al.*, 1997); an efficient use of fixed N_2 is thus of major importance in organic farming systems)
- efficient use of high-quality forage
- efficient use of manure
- adjusted stocking rate

Stocking rate and use of purchased feedstuffs are restricted by the EU Organic Farming Directive and by the stricter regulations of organic grower's associations. The use of mineral N fertilizer is generally forbidden. With regard to the other aspects, however, it is not clear whether organic farming provides a more environmentally-sound management or not. For instance, the cultivation and feeding of silage maize has frequently been shown to increase the nitrogen efficiency of both dairy cows and the entire farming system (for instance, Aarts *et al.*, 1999). Organic farming, however, relies on pasture, grass silage and cereal whole-crop silage. Maize cultivation is quite scarce in organic farming due to limited nutrient availability and weed control. Concerning manure utilization it might be assumed that there are no consistent differences between conventional and organic dairy farms.
Thus, different nutrient surpluses between conventional and organic dairy farms reflect the systems characteristics in a given region rather than a consistent relationship. The nitrogen surplus differs only marginally between conventional and organic dairy farms in regions where farming is generally extensive (for instance, in Austria

(Taube & Poetsch, 2001; see also Table 3). In contrast, organic farming considerably reduces N surpluses in regions of more intensive agriculture such as Denmark (Danish country report; see also Table 3). As milk production per cow and stocking rates are usually lower in organic farming systems, a comparison should refer to a similar stocking rate or a similar milk quota.

2.4 Challenges

From a European perspective, major challenges in order to develop and implement sustainable dairy farming systems are:

- integrated research projects at the farm scale (like 'De Marke' and 'Karkendamm') to document the site-specific and management-specific input-output relationships and internal nutrient fluxes between farm subsystems
- efficient extension and transfer of knowledge from science into practice
- nutrient policy regulations that efficiently reduce nutrient losses to the environment while accounting for site-specific conditions, the regional context, different farming systems and economic aspects
- the development of a holistic indicator-based system, especially for livestock and mixed farming systems

Whole-farm simulation models such as DAFOSYM (ROTZ *et al.*, 1999), FASSET (Jacobsen *et al.*, 1998) or REPRO (Hülsbergen, 2003) provide efficient tools for evaluating both environmental and economic performance of farming systems. The further development and use of such models, together with the aspects mentioned above, will contribute to improved dairy farming systems in Europe and elsewhere.

References

Aarts, H.F.M., Biewinga, E.E. & Van Keulen, H. (1992)
Dairy farming based on efficient nutrient management. Netherlands Journal of Agricultural Science, 40, 285-299.

Aarts, H.F.M., Habekotté, B., Hilhorst, G.J., Koskamp, G.J., van der Schans, F.C. & De Vries, C.K. (1999)
Efficient resource management in dairy farming on sandy soils. Netherlands Journal of Agricultural Science, 47, 153-167.

Bartley, P., Johnston, P. & Culleton, N. (2002)
Nutrient loss to groundwater from a conventional dairy farm and an organic dairy farm. End of Project Report, Teagasc, Dublin, Ireland.

Büchter, M., Wachendorf, M. & Taube, F. (2002)
Nitrate leaching from permanent grassland on sandy soils – Results from an integrated research project. In: Durand J.-L., Emile J.-C., Huyghe C. and Lemaire G. (eds.) Multi-function grasslands. Proc. 19th Gen. Meeting Europ. Grassl. Fed., La Rochelle (France), pp. 668-669.

CEC (Commission of the European Communities) (2002a)
Mid-term review of the Common Agricultural Policy. COM(2002)394, Brussels, 2002.

CEC (Commission of the European Communities) (2002b)
Implementation of Council Directive 91/676 EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Synthesis from year 2000 member states reports. COM(2002)407, Brussels, 2002.

Crosse, S., Kearney, S., Markey, A. & Phelan, J. (1999)
Winter housing and feeding system for small to medium sized dairy farms. End of Project Report – Project 4247, Teagasc, Dublin, Ireland.

EEA (European Environment Agency) (1999)
Environment in the European Union at the turn of the century. Environmental assessment report No. 2. European Environment Agency, Copenhagen.

Eriksen, J. & Vinther, F.P. (2002)
Nitrate leaching in grazed grasslands of different composition and age. In: Durand J.-L., Emile J.-C., Huyghe C. and Lemaire G. (eds.) Multi-function grasslands. Proc. 19th Gen. Meeting Europ. Grassl. Fed., La Rochelle (France), pp. 682-683.

Eriksen, J., Askegaard, M. & Kristensen, K. (1999)
Nitrate leaching in an organic dairy/crop rotation as affected by organic manure type, livestock density and crop. Soil Use and Management, 15, 176-182.

Fødevareministeriet (2003)
Økologisk jordbrug i Danmark. Ministeriet for Fødevarer, Landbrug og fiskeri (Fødevareministeriet), www.fvm.dk

Fraters, D., Boumans, L.M.J., van Drecht, G., De Haan, T. & De Hoop, D.W. (1998)
Nitrogen monitoring in groundwater in the sandy regions of The Netherlands. Environmental Pollution, 102, 479-485.

Halberg, N. (1999)
Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. Agriculture, Ecosystems and Environment, 76, 17-30.

Halberg, N. & Kristensen, I.S. (1997)
Expected crop yield loss when converting to organic dairy farming in Denmark. Biological Agriculture and Horticulture, 14, 25-41.

Høgh-Jensen, H., Loges, R., Jensen, E.S., Jørgensen, F.V. & Vinther, P.F. (1998)
Empirisk model for symbiotisk kvælstoffiksering i bælgplanter (in Danish). In: Kristensen E. and Olesen J. (Eds.) Kvælstofudvaskning og –balancer i konventionelle og økologiske produktionssystemer. FØJO-rapport nr. 2, pp. 69-89.

Hülsbergen, K.J. (2003)
Entwicklung und Anwendung eines Bilanzierungsmodells zur Bewertung der Nachhaltigkeit landwirtschaftlicher Systeme (in German). Institute for Agronomy and Crop Science, Martin-Luther-University Halle (Germany).

Humphreys, J., Lawless, A., O'Connell, K. & Casey, I.A. (2002)
Reducing nitrogen inputs to grass-based dairy production systems. In: Profitable grass and forage: meeting the needs of the farmer and society. Proceedings of the British Grassland Society.

Jacobsen, B.H., Petersen, B.M., Berntsen, J., Boye, C., Sørensen, C.G., Søgaard, H.T. & Hansen, J.P. (1998)
An integrated economic and environmental farm simulation model (FASSET). Statens Jordbrugs- og Fiskeriøkonomiske Institut, Kopenhagen, Rapport nr. 102

Jarvis S.C. & Aarts H.F.M. (2000)
Nutrient management from a farming systems perspective. In: K. Søegaard, C. Ohlsson, J. Sehested, N.J. Hutchings and T. Kristensen (eds.). Grassland Farming. Balancing environmental and economic demands. Proc. 18th Gen. Meeting Europ. Grassl. Fed., Ålborg, 22-25 May 2000, pp. 363-373.

Johnston, A.E. (1986)
Soil organic matter, effects on soils and crops. Soil Use and Management, 2, 97-105.

Kristensen, I.S. (2002)
Principles and methods used for calculating and evaluating nitrogen balances on dairy farms, exemplified with data from 3 Lithuanian mixed dairy farms in 2000-2001. Danish Institute of Agricultural Sciences, Foulum, Denmark.

Kühbauch, W. & Anger, M. (1999)
Modellberechnung des Nährstoffspielraums von Grünlandbetrieben mit Milchproduktion (in German). Agribiological Research, 52, 77-84.

Ledgard, S.F. & Steele, K.W. (1992)
Biological nitrogen fixation in mixed legume/grass pastures. Plant and Soil, 141, 137-153

Mounsey, J., Sheehy, J., Carton, O.T. & O'Toole, P. (1998)
Nutrient management planning on Irish dairy farms. End of Project Report – Project 4347, Teagasc, Dublin, Ireland.

Poetsch, E.M. (1998)
Fertilizing intensity and its effects on the N-cycle in alpine grassland. In: G. Nagy and K. Petö (eds.) Ecological Aspects of Grassland Management. Proc. 17th Gen. Meeting Europ. Grassl. Fed., Debrecen (Hungary), 18-21 May 1998, pp. 581-585.

Poetsch, E.M. (2000)
Auswirkung der biologischen Wirtschaftsweise auf pflanzenbauliche Kennwerte im Dauergrünland (in German). Bericht zur 27. Viehwirtschaftlichen Fachtagung, BAL Gumpenstein (Austria), pp. 147-153.

Rotz, C.A., Mertens, D.R., Buckmaster, D.R., Allen, M.S. & Harrison, J.H. (1999)
A dairy herd model for use in whole farm simulations. Journal of Dairy Science, 82, 2826-2840.

Ryan, M., Fanning, A. & Noonan, D. (2001)
Monitoring of potential N losses from dairy and organic farming systems. End of Project Report – Project 4482, Rural Environment Series No. 28, Teagasc, Dublin, Ireland.

Scheringer, J. (2002)
Nitrogen on dairy farms: balances and efficiency. PhD thesis, University of Göttingen (Germany). Göttinger Agrarwissenschaftliche Beiträge, Band 10.

Taube, F. & Poetsch, E. (2001)
On-farm nutrient balance assessment to improve nutrient management on organic dairy farms. In: J. Isselstein, G. Spatz, M. Hoffmann (eds). Organic grassland farming. Proceedings of the International Occasional Conference of the European Grassland Federation, Witzenhausen, Germany, 144-147.

Taube, F., Wachendorf, M., Greef, J.M. & Wulfes, R. (1997)
Perspektiven semi-intensiver Produktionssysteme in Milchvieh-/Futterbauregionen Norddeutschlands (in German, with English summary). Berichte über Landwirtschaft, 75, 586-603.

Thomet, P. & Koller, P. (1996)
Gute N-Effizienz auf Luzerner Milchwirtschaftsbetrieben (in German). Agrarforschung, 3 (2), 77-80.

Van der Werf, H.M.G. & Petit, J. (2002)
Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. Agriculture, Ecosystems and Environment, 93, 131-145.

Vellinga, T.V., Van der Putten, A.H.J. & Mooij, M. (2001)
Grassland management and nitrate leaching, a model approach. Netherlands Journal of Agricultural Science, 49, 299-253.

Wachendorf, M., Büchter, M., Trott, H. & Taube, F. (2003)
Performance and environmental effects of forage production on sandy soils – Results from an integrated research project. II. Impact of defoliation system and nitrogen input on nitrate leaching losses. Submitted to Grass and Forage Science.

Wetterich, F. & Haas, G. (1999)
Ökobilanz Allgäuer Grünlandbetriebe (in German). Schriftenreihe Institut für Organischen Landbau, University of Bonn (Germany). Verlag Dr. Köster, Berlin.

Part II. Country reports

1. Italy

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1.1 Introduction

The environmental problems that can result from a too intensive management of animal husbandry in agriculture are well known. However, the quantification of the external effects produced by farm management is often very difficult and it is even more difficult to establish effective measures to prevent such problems. For these reasons several regulations have been established in the European Union and in all European countries to control the environmental impact of agriculture.
Due to its internal political organization, Italy controls the agricultural and environmental problems at different administrative levels. Therefore, some regulations are national, others are regional. Local authorities (like municipalities) sometimes play an important role in the application of the regulations.
Although Italy is not one of the largest milk producers in Europe, dairy farming is an important part of agricultural activity in several regions. This study presents some of the results on the monitoring of the environmental impact of dairy farming in two representative Italian regions (Piedmont and Emilia Romagna), it briefly describes the most relevant Italian regulations and policy objectives and discusses the future evolution and impact of these regulations.

1.2 Dairy farming in Italy

1.2.1 General characterisation

Animal husbandry in Italy is described synthetically in Table 1. The most recent national census shows that with over 6 million cattle units (LU) and a total live weight (LV) of cattle of more than 2 300 kt, the production of beef meat and cow milk is by far the most important husbandry activity in Italy. Pig production comes second. There are 1.7 million dairy cows (45% of the total of cattle LU in Italy) and nearly 80 000 dairy farms. Dairy production is therefore very important in Italy, especially in the North.
The evolution of the number of animals in Italy is also given in the Table 1. In the last ten years, the number of stocked animals has strongly decreased in the cattle sector (-21%). This is the result of a sharp decrease in the number of farms (-46% over 10 years) and the concentration of animal husbandry in larger farms. The total number of pigs and poultry has been rather stable over the last ten years, even though they are also concentrating in larger farm units. The number of dairy cows is also progressively decreasing, because only larger farms are economically sustainable and the milk quota for dairy farming are concentrating to fewer farms. A higher individual cow performance also contributes to this reduction.
It should be noted that the milk quota regime limits dairy production. Italy imports a significant proportion (33%) of its internal milk consumption. This limiting regime, which has been greatly criticised by Italian dairy farmers, has contributed to the reduction of the environmental problems potentially associated to intensive dairy production, transferring them to other European regions.
In Italy, cattle, pig and poultry livestock production is traditionally concentrated in the northern regions (particularly in the Po plain) where soil, climatic and infrastructural conditions are the most favourable. More than 68% of cattle,

77% of dairy cows, 83% of pigs and 74% of poultry are concentrated in these regions. Sheep and goat production occurs mainly in central and southern regions. However, local concentrations of all types of animal husbandry can also be found in areas outside the northern Po plain. Information acquired from research and monitoring in the northern regions are therefore also of interest to small areas scattered over Italy.

Table 1. Number and weight of stocked animals and number of animal husbandry farms in Italy. The variation indicates the difference over the 1990-2000 ten-year period (source Istat).

	LU (number)	% Variation	Farms	% Variation	LV (t)	LU in North Italy %
Cattle	6 046 506	-21	171 853	-46	2 373 254	68.3
of which:						
Dairy cows	1 771 006	-33	79 807	-62	1 062 604	77.2
Pigs	8 614 016	3	195 325	-45	663 279	83.4
Sheep	6 808 900	-22	96 939	-41	383 341	4.6
Goats	923 402	-27	48 561	-47	51 988	14.9
Poultry	171 343 324	-1	521 539	-37	239 881	74.2

If the northern regions of Italy are considered, it can be shown that cattle breeding farms, and more particularly dairy production, are more uniformly distributed over the whole territory of the Po plain than the pig and poultry farms, which are more concentrated.
All aquifers of the northern regions, with the exception of Liguria, flow towards the Adriatic Sea. So far, no clear relation has been proven between agricultural management and the occurrence of algal blooms in the Adriatic Sea. However, animal husbandry is one of the potential contributors to the apparent degradation of marine water due to eutrophication. The Po river (the longest river in Italy) collects water from the Aosta Valley, Piedmont, Lombardy and Emilia Romagna. The interest in high quality superficial and deep flowing water is increasing because of the need of conservation and restoration of natural habitats and because it is increasingly used for human consumption.
Table 2 reports an estimate of the relative importance of animal husbandry and arable farm agriculture on the production of N and P loads which are potentially harmful for the environment. These estimates are far from perfect and not universally accepted; nevertheless they suggest that both types of agriculture contribute to pollution to a great extent.

Table 2. Quantity of nutrient losses from different sources in the Po plain, northern Italy (source Autorità di Bacino Fiume Po).

	N (t year^{-1})	P (t year^{-1})
Municipal wastes	78 000	10 000
Industries	25 000	1 000
Animal husbandry	260 000	50 000
Arable farms	310 000	90 000
Total	673 000	151 000

The environmental authority (Autorità di Bacino Fiume Po) has published a study that shows that non-point pollution contributes, respectively, 60 and 38% of the total nitrogen and phosphorus quantity that flows with the Po river to the Adriatic sea.

1.2.2 Characterisation of dairy farming in Piedmont and Emilia Romagna: two northern Italian regions

A description of some important characteristics of dairy farms in Italy and a comparison of these characteristics with other types of animal husbandry or stockless farms are reported in Table 3. These data refer to a large sample of efficient farms in the northwestern Po plain. In dairy farming, the average farm area (30.4 ha farm^{-1}) is slightly larger than in other farming types, but farm units are often smaller than in other European regions. The average stocking density is just above 1.7 t LV ha^{-1}, while it is much higher for pig and poultry production. However, animal density in dairy farming is very variable and a great number of farms might significantly exceed the reported value. The distribution of crops shows that maize is traditionally the reference crop for dairy farming. This cereal is both grown for the production of grain (26% of the farm surface) and for silage (20%). Maize silage is directly used on the farm. Maize grain (dried and stocked inside or outside the farm) contributes also directly to the feeding of farm animals.

Table 3. Comparison of the main characteristics of dairy farms and other farm types. All farms are located in the intensive Po plain area (hills and mountains excluded).

	Dairy cows	Beef	Pig	Poultry	Stockless
Farm size (ha)	30.4	21.0	24.0	20.5	20.4
Animal density (t LV ha^{-1})	1.7	1.0	4.0	3.1	0.0
Milk (kg cow^{-1} y^{-1})	5 572.7				
Crop distribution (%)					
wheat	6.6	12.3	11.3	9.5	11.7
other winter cereals	3.8	4.5	5.6	2.1	2.1
maize grain	26.3	29.9	53.5	35.4	24.0
maize for silage	20.1	5.8	2.6	1.1	0.4
other annual forage crops	2.1	2.1	0.2	0.1	0.3
rotational meadows	12.3	10.9	0.9	0.5	1.6
permanent meadows	16.5	19.0	2.0	7.0	3.8
other cash crops	7.8	9.2	11.5	31.3	39.5
poplar and fruit trees	0.8	3.7	6.4	7.3	11.6
set aside	3.7	2.7	6.0	5.7	3.5

More traditional forages are represented by rotational and permanent meadows (appr. 19% of the farm area). Meadows normally produce hay, however the first and the last cuts are less frequently used for silage production. Grazing is very rare. White clover is the dominant legume during summer in most permanent and in some rotational meadows. Lucerne is frequently cultivated in pure stands in rotational meadows. Other, less frequently cultivated forage crops are winter Italian ryegrass (often in combination with maize) and winter barley or triticale harvested for silage making. Winter wheat and a few other arable crops complete the list of cultivated crops.
If Italian dairy production is compared with that of other European countries it should be noted that the main difference is the lack of grazing, as animals are normally housed indoors year-round. Nevertheless, most building types allow the animals to move freely outside the building to paddocks where the manure is collected.
Another important aspect that should be considered to characterise dairy farming in the two regions is its contribution to the production of N and P in animal manure (Table 4). Dairy cows contribute 28 and 20% of the total amount of excreted N and P, respectively, by stocked animals in Piedmont. They contribute 31 and 33% of N and P excreted in Emilia Romagna. The amount of N available for land spreading is also shown for the two regions in the same table.

Table 4. Contribution of different types of animal husbandry to the total production of nitrogen and phosphorus and estimation of the amount of nitrogen available for land spreading in the two Italian regions.

		Nitrogen				Phosphorus	
		total		available for land spreading			
		t y^{-1}	%	t y^{-1}	%	t y^{-1}	%
Piedmont	Cows	17 514	28	9 082	25	3 637	20
	Beef	26 598	42	16 562	45	8 524	46
	Pigs	13 519	21	7 969	22	3 884	21
	Poultry	5 782	9	3 205	9	2 424	13
	Total	63 413	100	36 818	100	18 469	100
Emilia Romagna	Cows	22 107	31	14 634	34	7 723	33
	Beef	11 904	17	7 880	18	4 159	18
	Pigs	24 283	34	13 391	31	6 110	26
	Poultry	13 521	19	7 617	18	5 408	23
	Total	71 816	100	43 522	100	23 400	100

The amount of N that is available for land spreading is the quantity that farmers must account for when balancing nitrogen fertilization in their field or farm balance sheets.

1.3 Nutrient policies

1.3.1 Policy objectives

The previously described concerns about environmental problems have led to the formulation of a large number of regulations that have been implemented in different ways by the different regions. After the first legislative framework of 1975, and the following different local rules and regulations, an important input towards a more common behaviour has been produced by the Nitrate Directive (EEC 676/91). Despite all debates about this famous Directive, the only official effect in Italy was the publication of the Code of Good Agricultural Practice (Decree of Agriculture Ministry nr. 86/99). However, the Nitrate Directive influenced the application of pre-existing legislation. The maximum animal density was progressively lowered and set to 4 t LV ha^{-1}. Several regions in northern Italy published the first stringent rules for a sustainable use of manure in agriculture (Bonazzi, 2001). These rules considered aspects such as requirements to manure spreading, maximum application rates of manure, fertiliser plans and minimum manure storage capacity.

It should be noted that the prevailing opinion was that most environmental problems were linked to the use of liquid manure. Dairy farming produces farmyard manure and was, therefore, often less subject to restrictions, compared to beef and, above all, pig and poultry husbandry.

Another effect induced by the Nitrate Directive was the first designation of vulnerable zones. Emilia Romagna was the first region to reach this point. Designation criteria between regions were very different (Bonazzi, 2001).

Emilia Romagna, for instance, identified vulnerable zones based on hydrogeological criteria (type of aquifer, percentage of sand and gravel in the surface or deep soil and subsoil layers). Lombardy based its designation on the whole territory of single municipality according to the actual quality of drinking water.

The Nitrate Directive also created the need to revise the monitoring programs for water quality, rationalising the sampling and analysis criteria and adding new sampling points.

An important aid towards a more sustainable use of fertiliser (and manure) was produced by agri-environmental programmes, based on EU Council Directive 2078/92 which then evolved into the new EC Regulation 1257/1999. These Directives established a premium regime for farmers who freely undertook, for a minimum fixed period,

new forms of agricultural management that could help protect the environment. Within this framework, major steps were taken towards the reduction of chemical fertiliser (N and P) and manure inputs into the soil. In the Piedmont region the effect on manure management was probably not as strong as had been expected, but farmers definitely gained knowledge about more efficient ways of managing chemical fertilization and cutting back fertilization if manure was given to the soil.
More recently, rules concerning the quality of surface and deep water tables were revised by new national legislation, called DLgs 152/99. This is the Italian reference law that defines several legislation objectives in Italy, among which a key point is the official transfer of the European Nitrate Directive to the jurisdiction of the Italian law.
The main objectives of DLgs 152/99 are:

- To establish a correct management of all public water resources, protecting their ecological quality.
- To establish public standards so as to respect the quality and the quantity of surface water and water tables in the Italian environment.
- To establish criteria to harmonize the Regional legislation on the use and protection of water.

The Regions still have the responsibility for the application of this decree. Following this new law and because of the risk of being convicted for infringement of the Nitrate Directive, more Regions in Italy have designated nitrate vulnerable zones (Figure 1). The criteria for these more recent designations, such as those in the Piedmont Region, take a larger set of parameters into consideration. Other Italian regions are now processing the same new information with the aim of redefining and updating their own vulnerable zones.

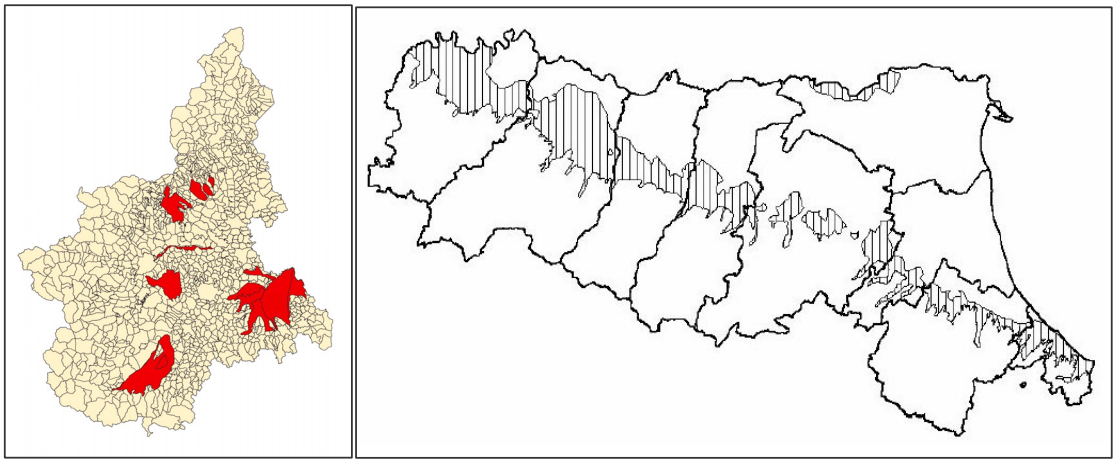

Figure 1. Vulnerable zones designated in the Piedmont Regions (left) and Emilia Romagna region (right).

Some Regions have already published the action programmes and some others will soon do so.
Concerning gaseous emissions, the Executive Body of the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) adopted the so-called Gothenburg Protocol, signed by 31 European Countries on 30 November 1999. The Protocol sets emission ceilings for 2010 for four pollutants: sulphur, NOx, VOCs and ammonia. Once the Protocol is fully implemented, Europe's sulphur emissions should be reduced by at least 63%, its NOx emissions by 41%, its VOC emissions by 40% and its ammonia emissions by 17%, compared to 1990.
Within the EU, a parallel National Emission Ceilings (NEC) Directive was adopted in September 2001. The NEC Directive sets national ceilings for four pollutants (SO_2, NOx, NH_3, VOCs), to be achieved in 2010. These ceilings are defined to ensure that the emission reductions already anticipated over the next decade are fully accomplished and that still further progress is made towards the achievement of the Community's long-term environmental objectives. The anticipated effects of the NEC Directive are: 78% reduction of SO_2 emissions, 55% reduction of NOx emissions, 60% reduction of VOC emissions and a 21% reduction of NH_3 emissions.
Both the Goteborg Protocol and the NEC directive define the policy objectives for gaseous emission for Italy. For Italy the following figures have been assessed as base line emission level in 1990 (in kt per year): 1679 for SO_2, 2037 for NOx, 2055 for VOCs, and 462 for NH_3. For ammonia a reduction of 6% should be reached by Italy.

1.3.2 Policy instruments

One of the main instruments proposed by Dlgs 152/99 is a rational system to look at the results of water quality monitoring and to judge the effects of the action programmes on this basis.
A few examples are provided in Table 5 for some chemical parameters. Each water body (surface or groundwater) is classified on the basis of the sum of the 'scores' given by each parameter. Once defined, the final score must be improved if it is under a 'sufficient' level. All water bodies must reach the 'sufficient' level before the end of 2008. After that year, the next goal is for 2016, when all water bodies must reach the classification 'good'. It is obvious that the quality of all water bodies should not become worse.

Table 5. Selected chemical parameters used to classify water quality in relation to nutrient content (from Italian DLgs 152/99).

Groundwater table

	Class 1	Class 2	Class 3	Class 4	Class 5
Nitrates (mg NO_3 L^{-1})	<5	<25	<50	>50	
Ammonium (mg NH_4 L^{-1})	<0.05	<0.5	<0.5	>0.5	
Sulfates (mg SO_4 L^{-1})	<25	<250	<250	>250	

Surface water (in rivers)

Nitrates (mg NO_3 L^{-1})	<0.13	<6.65	<22.15	<44.3	>44.3
Ammonium (mg NH_4 L^{-1})	<0.04	<0.12	<0.60	<1.82	>1.82
Total P (mg P L^{-1})	<0.07	<0.15	<0.30	<0.6	>0.6

The list of the actions that the Regions or the Po River Authority will undertake to fulfil the requirements of Dlgs 152/99 is the so-called 'Plan for the Protection of Water'. Several of these plans will be produced for all large watersheds throughout the whole Italian territory. Each plan interacts with agriculture and therefore with animal husbandry.
A large national debate on the minimum rules that all Regions must respect to limit the risk of pollution from animal husbandry among politicians, farmers, regional technical staff and scientists is finally coming to an end. The most stringent rules will be those concerning nitrate-vulnerable zones, but more generally all farms will have to show that they can prevent any further pollution.
A key point in this debate concerned the standard information on the amount of N and P excreted by animals (Table 6). The example that is given refers to data used in Piedmont regions, but very similar data are also used in other regions. All calculations concerning the allowable stocking density and fertilization plans can be carried out on this basis.
Another important instrument for reaching the objectives mentioned in the previous section is the manure and fertilization plan (often called PUA in Italy). This document is necessary for larger farms or farmers in vulnerable zones. Farmers must demonstrate a given ratio between N (and eventually P) in the livestock manure and the crop needs. They must also show that all the best agricultural practices have been adopted. Most Northern Regions are now producing software programs available from Internet, or in Internet, that will help guide farmers in formulating the PUA.

Table 6. Examples of data used for quantifying N and P excreted by dairy and beef stocking (from Piedmont legislation for the application of the Nitrate Directive).

	kg P/head	kg N/head	kg N in manure/head
Dairy			
dairy cows (milk > 5000 kg)	22	107	61
dairy cows (milk < 5000 kg)	20	98	48
replacement stock			
0 to 1 year old	6	19	12
1 to 2 years old	14	43	29
bulls for breeding	34	105	71
Beef			
beef cows	22	68	32
replacement stock			
0 to 1 year old	7	22	15
1 to 2 years old	13	41	27
bulls for breeding	34	105	71
slaughter stock			
0 to 1 year old	5	16	11
1 to 2 years old	16	51	34

1.4 Environmental indicators: monitoring programmes and trends

1.4.1 Nutrient surpluses at farm scale

Over the last 10 years, a great deal of information has been acquired concerning nutrient cycling in dairy farming. The so-called 'farm gate balance' has been used to describe the fluxes of nutrients at the farm scale, disregarding internal fluxes (Table 7).

1.4.1.1 Nitrogen surplus

The N surplus in intensive dairy farming systems is more than 300 kg $ha^{-1}yr^{-1}$. This surplus is lost into the air and to groundwater and surface waters, as only a small proportion can be accumulated in the soil. N surplus is due to excessive N inputs, mainly in the form of purchased feeds or roughage, but also fertilisers. The reduction in the amount of purchased fertilisers is often the first and easiest suggestion that can be made to farmers willing to reduce N surplus.

Table 7. Short description and farm gate nitrogen balance for some groups of dairy farms.

	Intensive dairy farms		Parmigiano Reggiano	Organic dairy farms
	Piedmont	Emilia Rom.	Emilia Rom.	Piedmont
Size of farm (ha)	33.6	36.1	23.7	26.6
Forage and feed crops (%)	91.6	82.3	85.7	70.8
Stocking rate (LU ha^{-1})	3.1	2.4	2.2	2.9
Milk production (kg cow^{-1})	6 700	6 200	6 130	6 435
Nitrogen inputs (kg ha^{-1})				
Fertilisers	120	96	65	5
Purchased feeds and roughage	303	274	218	81
Purchased animals	1	1	1	1
Leguminous N fixation	10	15	22	70
Atmospheric deposition	30	18	18	30
Total N inputs	464	404	324	186
Nitrogen outputs (kg ha^{-1})				
Sold manure	7	0	9	0
Sold animals	10	19	17	7
Milk	93	62	54	74
Crops	16	22	13	34
Total N outputs	126	104	93	116
Nitrogen surplus	338	300	231	71
Apparent N efficiency (%)	27.1	25.7	28.6	62.0
Number of farms	66	9	55	3
Source	Grignani, 1996	De Roest, 2000	De Roest, 2000	Grignani, unpubl.

The group of dairy farms that produces milk for the long-maturing Parmigiano Reggiano cheese constitutes an interesting example of a dairy farming system that relies more on leguminous meadows (mainly lucerne). These farms have to follow strict production regulations and any type of silage is forbidden. The whole farm system is somehow different from classical intensive dairy farming, but it is interesting to note that with a small reduction of the stocking rate and milk production per cow, a large reduction in N surplus is achieved. Data describing a small group of organic dairy farms are also shown in Table 7. With organic production, a sharp reduction in N surplus is achieved. However, organic farming is a very new system for dairy production in all Italian situations. Therefore, some of these farms might still look for an internal balance in nutrient management and data on animal husbandry organic farming must be considered only as preliminary indications.

When multivariate analysis or multiple regression analysis is used to find the factors that most influence the N surplus (Simon *et al.*, 2000; Grignani, 1996; De Roest, 2000), it can be noted that a positive correlation exists between the size of N surplus and both the average cow productivity and stocking density. On the other hand, a negative correlation exists between the size of N surplus and the percentage of farm area used for meadows. In all cases, few examples of very efficient farms show that it is possible to both correctly manage N, as well as keeping milk production per cow at very high standards.

1.4.1.2 Phosphorus surplus

Table 8 shows data on P surplus in dairy farming in Italy. In intensive farming, the P surplus is 76 kg P ha^{-1}, while in extensive dairy farming, excess P is reduced to 34 kg ha^{-1}. The risk of progressive accumulation of P in soil is clear. This is one of the reasons for the high Olsen P content in soils where farmyard manure is systematically added. Once again, purchased feeds are the main source of P inputs in intensive dairy farming, but farmers also buy chemical fertilisers. Purchased fertilisers are the main inputs in extensive farming. The average apparent efficiency of P is similar to the N efficiency. If farmers were to avoid buying fertilisers, the P surplus would be cut to 50% in intensive farming (and the apparent efficiency would increase from 24 to 36%), and extensive dairy farming would show an input-output balance. Some environmental regulations oblige farmers in Piedmont receiving a premium for 'sustainable farming' to avoid any fertiliser input in soil where P Olsen is high. In Emilia Romagna no further manure can be applied to soils characterised by P Olsen content over 200 ppm.

Table 8. Farm gate phosphorus balance for some groups of intensive and extensive dairy farms (source: Grignani, 1996).

	Intensive dairy farms	Extensive dairy farms	Organic dairy farms
Phosphorus inputs (kg ha^{-1})			
Fertilisers	34	31	6
Purchased feeds and roughage	66	18	44
Purchased animals	0	0	1
Total P inputs	100	49	51
Phosphorus outputs (kg ha^{-1})			
Sold manure	1	1	0
Sold animals	3	4	6
Milk	17	3	74
Crops	3	7	14
Total P outputs	24	15	94
Phosphorus surplus (kg ha^{-1})	76	34	-43
Apparent P efficiency (%)	24.3	30.7	

1.4.2 Nutrient concentrations in groundwater and surface water

1.4.2.1 Factors influencing nitrate leaching to groundwater

The amount of nutrients that is lost has not been specifically quantified taking into consideration any experimental dairy farm. However, a great deal of information is available from single plot experiments or through the application of theoretical models.

Nitrate leaching has been quite intensively investigated. Table 9 shows a synthesis of some of the data from different sources in the Po plain (Grignani & Laidlow, 2002; Grignani & Zavattaro, 2000; Sacco *et al.* 2001). Leaching is here defined as the quantity of N that permanently leaves the root zone. Table 9 shows that the soil draining condition is a dominant variable that controls leaching. If drainage is scarce, even high nitrate contents in soil may result in low leaching losses. The drainage conditions in Northern Italy can be classified as 'slow' where the soil texture is fine or where the capillary rise is as high as drainage on a yearly basis (strong evapotranspiration and efficient soil hydraulic conductivity). The drainage conditions are 'fast' in other situations. The effect of the amount of N supplied to the crop is larger when drainage is the dominating water movement ('fast' draining conditions). Maize harvested for silage results in the highest leaching losses as only a small amount of C stays in the soil. When maize is harvested for grain production, it leaves the straw in the soil and straw C helps block part of the excessive mineral N in the soil.

The double cropping of maize and Italian ryegrass (winter intercropping) reduces leaching, as do all types of meadows, which are the most effective soil cover in reducing N leaching. Unfortunately, rotational and permanent meadows have been less studied than annual forage crops, hence their potential environmental impact when exposed to very high N fertilization is not known. Experiments on meadows tend to reproduce the traditional farm management approach, where fertilization inputs are low. All experimental data and models would seem to suggest that they could help reduce leaching.
These data can be used to formulate hypotheses for more efficient forage systems. They show that when drainage is 'fast', leaching can be very high if the fertilization inputs are as in farm practice. In these conditions, it is important to limit the area cropped with maize for silage. If maize has to be cultivated, it should not be the only crop during the year, but the soil should be covered during winter. The covering in winter with maize straw from maize grain production is an efficient way to reduce leaching. In this case, straw should be incorporated in the very first soil layer by superficial harrowing. Meadows show beneficial effects in preventing high N leaching. Despite the very high N fixation (about 270 kg N ha^{-1}, Borreani *et al.*, 2002) lucerne shows low N leaching. All meadows are only cut, therefore leaching in the first year of the subsequent crop in the rotation is not high. Farm meadow area should be increased. Finally, data in Table 9 suggest that solid manure is preferable to liquid slurry.

Table 9. Examples of recorded N leaching from different crops, with different N inputs from cattle manure and soil conditions. The data are given in kg $N\text{-}NO_3$ ha^{1} $year^{1}$. The draining conditions take into account both soil type and water balance. A low N input corresponds to an input that varies between 170 and 210 kg N (manure and chemical fertiliser) ha^{1}; a high N input corresponds to 300 to 340 kg N ha^{1}.

	Draining conditions		
	Fast		Slow
	low N input	high N input	
Maize silage (liquid manure)	88-100	126-136	0-40
Maize silage (solid manure)	56-58	-	0-40
Maize grain	56-64	84-92	0-40
Maize and Italian ryegrass	20-28	30-32	0-10
Lucerne or other rotational meadows	10-11	12-13	-
Permanent meadow	0-5	-	-

In Italy, few monitoring programmes exist to verify consequences of reduced levels of nitrogen input on plant yields and nitrate leaching. An example is given by the monitoring of nitrate leaching through the unsaturated zone in the Emilia-Romagna region (Mantovi *et al.*, 2003). In representative fields, plots were equipped with tensiometers, ceramic cup samplers and piezometers. Monitoring results have given a more consolidated scientific basis to previous empirical estimates. For example, high N input from slurry landspreadings (about 340 kg N ha^{-1}) have shown to cause nitrate accumulation in the surface layer of the soil and this process was only partially attenuated by plant uptake. As a consequence of rainy seasons, nitrates were transported through the first meters of the unsaturated zone (below the root depth). Nitrate leaching depth was associated with water flow in the soil. Nitrates were leached by water infiltration rather than being washed away by the upward movements of the groundwater table. Rainy conditions in autumn, associated with bare soil, have been the most critical ones with respect to nitrate leaching towards the unsaturated zone, especially after summer landspreadings of manure on wheat stubble. It must be said that this is common practice in northern Italy.
Despite the limited timescale and the characteristics of contamination (diffuse pollution), there seems to be an increase of nitrate concentration in shallow groundwater due to the surplus nitrogen in the soil.

1.4.2.2 Monitoring of groundwater

The data used as references for monitoring the quality of groundwater come from a large set of piezometric measurements that each Italian region has been setting up in the last few years. Previously, only data from wells used for the extraction of drinking water were available. The new monitoring system covers the territory more uniformly and helps the interpretation of results on a stricter, hydro-geological basis.
Table 10 provides an example of data from the Piedmont region, synthesising information from the years 2000 and 2001. Table 10 shows that 17.8% of the upper water table is over the limit of 50 mg NO_3, but only 1.7% of the samples coming from deeper water table.

Table 10. Quality of water table at two different depths as assessed by the monitoring campaign in 2000 and 2001 in Piedmont (source: Ass. Ambiente Agricoltura e Qualità, Regione Piemonte).

Classes	Upper water table		Deeper water table	
mg NO_3 L^{-1}	n. samples y^{-1}	%	n. samples y^{-1}	%
0 – 25	467	53.4	320	89.4
25 – 40	188	21.5	23	6.4
40 – 50	64	7.3	9	2.5
>50	156	17.8	6	1.7
Total	874	100.0	358	100.0

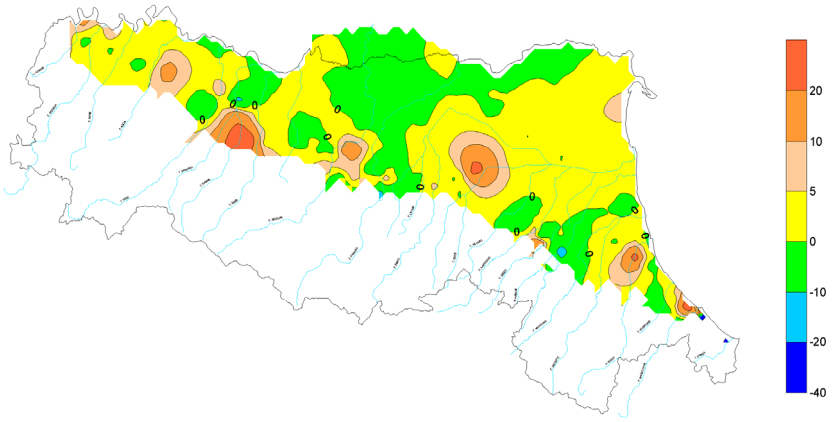

Figure 2. Variation in nitrate concentration in upper water table in Emilia Romagna in the period 1988-1990 (data expressed as variation in mg NO_3 L^{-1}).

Figure 2 shows the variation in nitrate concentration of upper groundwater in the period 1988-1999 in Emilia Romagna. There is not always a clear link between the areas where the 50 mg NO_3 L^{-1} limit is exceeded and the area with the most intensive animal husbandry. The amount and the direction of water flowing in the water tables is obviously very important in determining nitrate concentrations. However, the analysis of data available in Emilia Romagna highlights the most risky aquifers.

1.4.2.3 Monitoring of surface water

Some examples of data acquired through the monitoring of surface water are given in Table 11. The parameter that creates most problems is total P (in Piedmont in the last three years 16% of samples exceeded the 0.14 mg L^{-1} limit). Total P is influenced by municipal sewage plant waste water, but even in the flat plain conditions of the Po river, runoff losses of 3-5 kg P ha^{-1} due to intensive rains are not infrequent. For environmental purposes, the importance of reducing the P content of the upper soil layers is clear.

Table 11. Quality of surface water in rivers as assessed by monitoring campaigns in 2000, 2001 and 2002 in Piedmont (source: Ass. Ambiente Agricoltura e Qualità, Regione Piemonte).

$N\text{-}NH_3$			$N\text{-}NO_3$			Total P		
classes	n. samples y^{-1}	%	classes	n. samples y^{-1}	%	classes	n. samples y^{-1}	%
< 0.03 mg L^{-1}	1 151	57	<0.3 mg L^{-1}	68	3	<0.07 mg L^{-1}	1 444	64
0.04-0.1 mg L^{-1}	446	22	0.4-1.5 mg L^{-1}	1 161	52	0.08-0.10 mg L^{-1}	294	13
0.2-0.5 mg L^{-1}	235	12	1.6-5.0 mg L^{-1}	922	41	0.11-0.14 mg L^{-1}	147	7
> 0.5 mg L^{-1}	187	9	>5.0 mg L^{-1}	77	3	>0.14 mg L^{-1}	361	16
total samples	2 019	100		2 228	100		2 246	100
average (mg L^{-1})	0.330			1.826			0.116	
st. dev. (mg L^{-1})	1.740			1.791			0.211	

1.4.3 Gaseous losses

The most recent national emission inventory for the most significant greenhouse gases (CH_4 and N_2O) and ammonia from agriculture and animal husbandry was published by CRPA-ANPA, the Italian National Environmental Protection Agency (Valli *et al.*, 2000). These inventories mainly focused on animal husbandry. Unfortunately, a more recent evaluation on a regional scale is lacking.

In the national emission inventory, a number of animal categories and sub-categories were considered, according to statistical agriculture census data, the main ones being dairy cows, other cattle, sows, other pigs, laying hens, broilers, other poultry, ovine and equine animals. The emissions were calculated as the product of specific emission factors and the number of animals, for each category and for each stage of the waste management process.

In the ammonia emission inventory, the following main sources were taken into account: housing, storage, manure application, grazing animals and fertiliser application. The calculations were made on the basis of a step-by-step procedure, starting from excreted N (indoor or outdoor) for each animal class. As Italian data based on field experiment results are very limited, emission factors derived from literature were used, with the calibration being based on national conditions. The main local factors taken into account were: local climatic conditions (ambient temperature, detailed on a provincial basis), animal productivity (especially for dairy cows as regards milk yield, which depends on feed ingestion and which in time affects nitrogen excretion), and manure management systems (for instance, housing types for cattle and pigs).

The main differences between the NH_3 emission factors assessed by CRPA and the CORINAIR (1996) default values for cattle are the following: a) a longer grazing period considered by CORINAIR for this category (emissions from grazing are much lower than those resulting from the 'housing + storage + spreading' sequence); b) in the corrections on the temperature introduced in the calculation of emissions from the housing systems; c) a higher percentage of emissions from storage and land application of manure assessed by CRPA, due to the higher temperature in Italy than in central-northern European countries, where the emission factors were calculated.

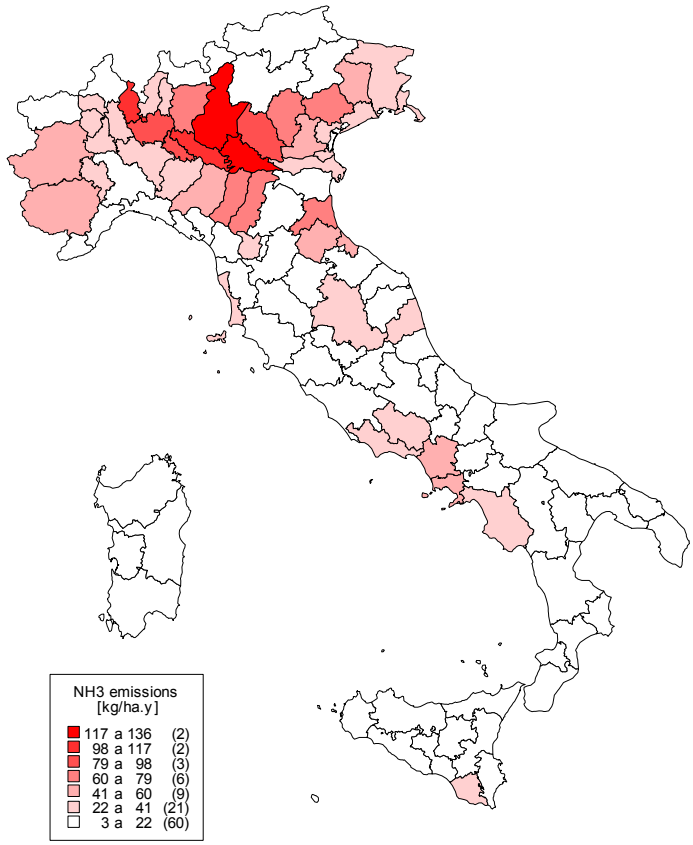

Figure 3. NH_3 emission density (kg ha^{-1} yr^{-1}) assessed on a provincial grid (year 1995).

The nitrous oxide inventory estimates emissions on the basis of the IPCC/OECD/IEA (1997) methodology. The inventory considered not only emissions from animal waste management systems, but also N_2O formation in soils, induced by animal waste, mineral fertiliser application and crop residues (direct emissions), as well as indirect production of N_2O.

The total ammonia emission was 403 kton NH_3 yr^{-1}, 76% of which are emissions from livestock, 20% from fertiliser application and 4% from grazing animals. The largest share is due to cattle, accounting for over 63% of the total emission from the livestock sector, with 89 kton yr^{-1} coming from dairy cows (of which 22% from housing, 30% from storage and 48% from land spreading) and 108 kton yr^{-1} from other cattle. Pigs and poultry have an equal share (16% of the total), while the ovine contribution is only 2% of the total emission. The contribution by other species is insignificant. A comparison of emissions between years would suggest that ammonia emissions have not changed significantly. It is interesting to note that in all cases the predominant contribution comes from manure spreading on the land (about 30%), followed by emissions from housing (25%), and finally from slurry storage (22%). On a national basis (Figure 3), the largest share of the ammonia emission (65% of the total) can be attributed to northern Italy, due to both the intensive livestock husbandry and the high level of agricultural production. The share of the two regions considered in this report is 24% of the total. Emilia-Romagna and Piedmont produce 54.3 and 41.8 kton NH_3 yr^{-1}, respectively.

The amount of lost ammonia shows that this N loss pathway can be as important or even more important than leaching. Any change in management for a more sustainable use of N must be aimed at reducing simultaneously all sources of N losses. The application of the Nitrate Directive, instead, has often made the agricultural extension service and the environment protection service concentrate only on the N leaching problem.

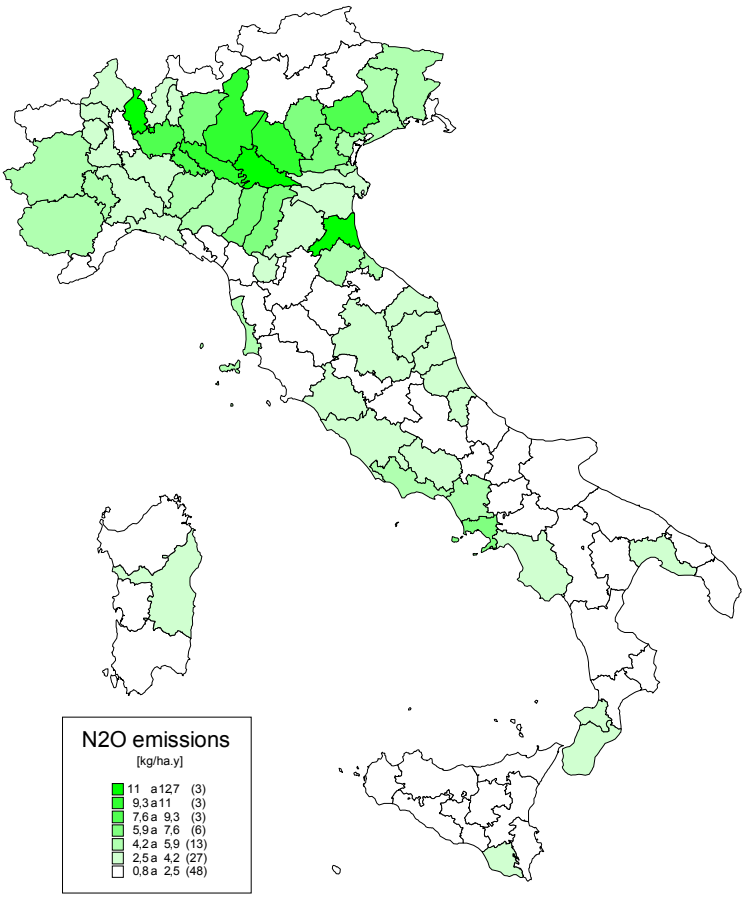

Figure 4. N_2O emission density (kg ha^{-1} y^{-1}) assessed on a provincial grid.

The estimated total nitrous oxide emission is 47.6 kton N-N_2O yr^{-1}. According to the IPCC categories, the greatest responsibility can be attributed to direct emission from the soil (42% of the total), followed by indirect emissions due to leaching and run-off (27%), emissions from slurry management (16%), emissions from grazing animals (10%), and emissions due to atmospheric deposition of nitrogen (5%). Of the soil emission percentage, the mineral fertiliser effect is estimated to be 46%. The direct contribution of the dairy sector is only 2.3 kton N-N_2O yr^{-1} from slurry management and 0.9 from grazing animals.
As for NH_3, emissions of N_2O were basically constant over the years and the highest national contribution to N_2O losses was agriculture in northern Italy: 55% of the total (Figure 4).
In the Italian situation, losses through denitrification do not seem very important as quantitative flux. It is important, however, to reduce these losses for environmental reasons, as these gases are harmful for the environment.

1.5 The search for 'sustainable' dairy farming systems

Table 12 shows the main criteria that are now adopted or will soon be adopted for reaching the objectives of managing Italian animal husbandry systems towards a better environmental sustainability. Currently, not all measures are respected and some of them will definitely affect farm economics. The extent is unknown.

Table 12. Measures to reduce environmental hazards from dairy farming in Italy. Synthesis of measures that have already been implemented or which will be adopted in the near future.

	Measures for all zones	Stricter measures in the nitrate-vulnerable zones
Nitrogen load	340 kg N ha^{-1} max. N manure input in the field	170 kg N ha^{-1} max. N manure input in the field
Control of N surplus	reduction of mineral input	agronomic balance sheet (PUA) only for larger farms[1]; PUA considers animal density, crop rotation, soil and manure management
		50 kg N ha^{-1} max surplus allowed
Control of P surplus	reduction or exclusion of mineral input	agronomic balance sheet (PUA)
Timing of nitrogen distribution	no distribution on snow, very shallow water table, water logged soil, or frozen soil	
		no winter distribution (1/XII - 28/II)
Storage capacity	minimum storage capacity time for liquid manure: 180 d for pig, beef and poultry, 120 d for dairy farms; 90 d for small farms (< 2000 kg N $farm^{-1}$ $year^{-1}$)	
	minimum storage capacity for solid manure: 90 d (uncovered piles in the field allowed for another 120 d)	
Land spreading	direct injection or incorporation of liquid manure within 12 hours only if required by local municipalities	
Slope	max slope of 10% (in Piedmont) or 15% (in Emilia Romagna) for liquid manure spreading	
Cover crops	if erosion is a risk or when manure spreading is far from crop growth (Piedmont)	
		mandatory in Nitrate-Vulnerable Zones in Emilia Romagna if appropriate rotation is not practiced
Distance from rivers and lakes	solid manure minimum 5 m, liquid manure 10 m	
NH_3 emissions in stable and storage	from 2004 an authorisation will be necessary for intensive livestock farms (larger than 2000 LU $farm^{-1}$ pig 750 sows or 40 000 places for poultry farms) according to IPPC directive	

[1] *Large farms are all farms that exceed 6 000 kg N in Piedmont, or pig breeding farms over 80 t LV $farm^{-1}$ yr^{-1} in Emilia Romagna; here PUA is only recommended for dairy farms.*

Dairy farms often show less environmental problems than other types of animal husbandry farms.
When farms in vulnerable zones exceed the 170 kg N ha^{-1} limit, they do not reduce stocking rates, but rather transport part of their manure to fields of neighbouring farms. In areas not saturated with an overall excess of manure this is positive as manure is a valuable fertiliser. However, in Italy it has become necessary to control the land spreading of manure also on the receiving farms. Unfortunately farmers often tend not to reduce mineral fertilisation when extra manure is distributed in their fields. In areas where average stocking density is very high (for example because there are several pig breeding farms) there is the need to control that out-farm spreading is done efficiently, avoiding that fields closer to the farm barn receive more manure than those that are more distant. In such areas farmers accepting the manure are paid by farmers exporting manure.
Nutrient surplus at farm level (the farm gate balance) is an indicator for environmental sustainability. At the moment, this indicator is not required by environmental legislation, because it is considered too difficult to calculate for the

large number of farms that must be controlled. However farmers should be encouraged to use it, because it can show clearly the strategy for reducing excessive inputs of N and P and optimising uptake by crops.
In Italian dairy farming, a reduction of fertiliser input is still possible and should be proposed, also because it is a direct way to reduce costs.
New farm machines for a more appropriate management of manure are now available but they are expensive. It is possible, for example, to directly inject liquid manure in June when maize is already actively growing. A development of contractors selling the use of these machineries to farmers as external services should be encouraged.
In the near future, positive results are expected from the large set of information that will be become available from the fertilization plans that all large stocking farms and farms in vulnerable areas will be forced to calculate and apply. The data will also enable economic analyses.
Monitoring of gaseous losses seems very important and should be intensified.

1.6 Conclusions

According to what has been presented in the preceding sections, the main objectives of the Italian (and regional) policy on the environmental impact of animal husbandry are:

- To increase the knowledge on where vulnerable nitrate zones are in order to correctly identify the areas in which to concentrate stricter environmental rules;
- To reduce the nitrate content in the water table in areas where the problem exists (vulnerable zones) and to prevent any further increase of this problem in other areas;
- To reduce the P content of surface waters to values below 0.1 mg P L^{-1};
- To reduce the emission of ammonia and NO_X gasses according to BAT.

References

Bonazzi, G., 2001.
Environmental pressures and national environmental legislation with respect to nutrient management. In: Nutrient Management Legislation in European Countries. Ed. P. De Clerq *et al.*, Wageningen Pers, pp. 207-218.

Corinair, 1996.
Emission Inventory Guidebook.

De Roest, K., 2000.
Interrelationships between nitrogen balances and technical and structural characteristics of dairy farms in Northern Italy. In Agricultural data for Life Cycle Assessments, Ed. B.P. Weidema and M.J.C. Meeusen, The Hague, Agricultural Economics Research Institute (LEI), pp. 161-175.

Grignani, C., 1996.
Influenza della tipologia di allevamento e dell'ordinamento colturale sul bilancio di elementi nutritivi di aziende padane. Rivista di Agronomia, 3 suppl., pp. 414-422.

Grignani, C. & Laidlow, A.S., 2002.
Nitrogen economy in grasslands and annual forage crops: control of environmental impact. In Multi-function grasslands. Quality Forages, Animal Products and Landscapes. Edited by J.L. Durand, J.C. Emile, C. Huyghe, G. Lemaire. Vol. 7 EGF 2002, La Rochelle (F), pp. 625-633.

Grignani, C., & Zavattaro, L., 2000.
A survey on actual agricultural practices and their effects on the mineral nitrogen concentration of the soil solution. Europ. J. Agron. 12, 251-268.

Mantovi, P., Beretta, G.P., Cortellini, L., Fumagalli, L., Guermandi, M. & Preti, D., 2003.
Monitoraggio e modellazione della migrazione dei nitrati nel mezzo insaturo in un'area vulnerabile della provincia di Reggio Emilia. Ingegneria Ambientale, Vol. XXXII, n. 6.

IPCC/OECD/IEA, 1997.
Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Reference Manual.

Sacco, D., Grignani, C. & Monaco, S., 2001.
Confronto tra sistemi colturali a diversa intensità. . Atti del convegno SIA: 'Strategie agronomiche al servizio della moderna agricoltura', Pisa, 17-21 settembre 2001, pp. 57-58.

Simon, J.C., Grignani, C., Jacquet, A., Le Corre, L. & Pages, J., 2000.
Typologie des bilans d'azote de divers types d'exploitation agricole: recherche d'indicateurs de fonctionnement. Agronomie 20, 175-195.

Valli, L., Fabbri, C. & Bonazzi, G., 2000.
A national inventory of ammonia and greenhouse gas emissions from agriculture in Italy. Proceedings of the 9th International Conference of the FAO ESCORENA Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture (RAMIRAN 2000). Edited by F. Sangiorgi, University of Milan, pp. 153-159.

Regione Emilia-Romagna.
Nuova Carta regionale della Vulnerabilita: aspetti metodologici. Luglio 2002. (in relazione a figure vulnerabilita e figure nitrati nelle acque sotterranee).

Regione Emilia-Romagna, Servizio Meteorologico ARPA RER.
Studio inserito nei supporti tecnici per l'elaborazione del Piano regionale di tutela delle acque. Maggio 2003. (in relazione a stima carichi N e P).

2. United Kingdom

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2.1 Introduction

Agriculture in the UK, as elsewhere, is undergoing substantial change brought about by shifts in international markets, CAP reforms, international and national legislation relating to environmental and other issues, national adjustment of policies relating to food production and the overall functioning of the rural environment. Importantly, there is also increasing public awareness of broad scale issues related to food production, the environment and health and safety all resulting in increasing public pressure to make change. Livestock production has been particularly affected by these issues, and dairying, as well as being influenced by these current and on-going pressures, has been undergoing a period of long-term and substantial change over decades.
Livestock production has a low rate of 'capture' of imported nutrients into the final products exported from the farm. This relatively 'open' nutrient cycle provides opportunity for the release of materials which may be potential pollutants into the wider environment. Of all the farming sectors intensive dairying has one of the greatest potentials to be a major source for diffuse nutrient dispersion. On the other hand, and because of this, it also offers a great opportunity to identify and implement practical farming options to remedy or reduce this large potential. In order to be able to make change and adjustment, it is necessary in the first instance to know and understand the current status and trends in UK dairy herds.

2.2 Background

Agriculture is practised on 75% of the total UK land area of 24 million ha (Scholefield, 2001) and contributes 1.4% of GDP. Table 1 provides a broad-scale picture for UK agriculture and provides the latest set of information for land use and livestock numbers as provided by census data for 2002 (Defra, 2003a). Most livestock production occurs in the wetter western half of the country and most of the arable sector is based in the east. As far as England is concerned (and this accounts for the largest proportion of the total British dairy herd), the densest areas of dairy cow distribution are in the SW peninsular, and the counties in the NW of the country (Figure 1). This distribution is a reflection of a combination of climatic and geographical factors which are conducive to the large amounts of dry matter production required to sustain intensive production from high yielding cows. This distribution is important not only from the production standpoint but also with respect to the potential local, national and international impact of emissions to waters and the atmosphere.

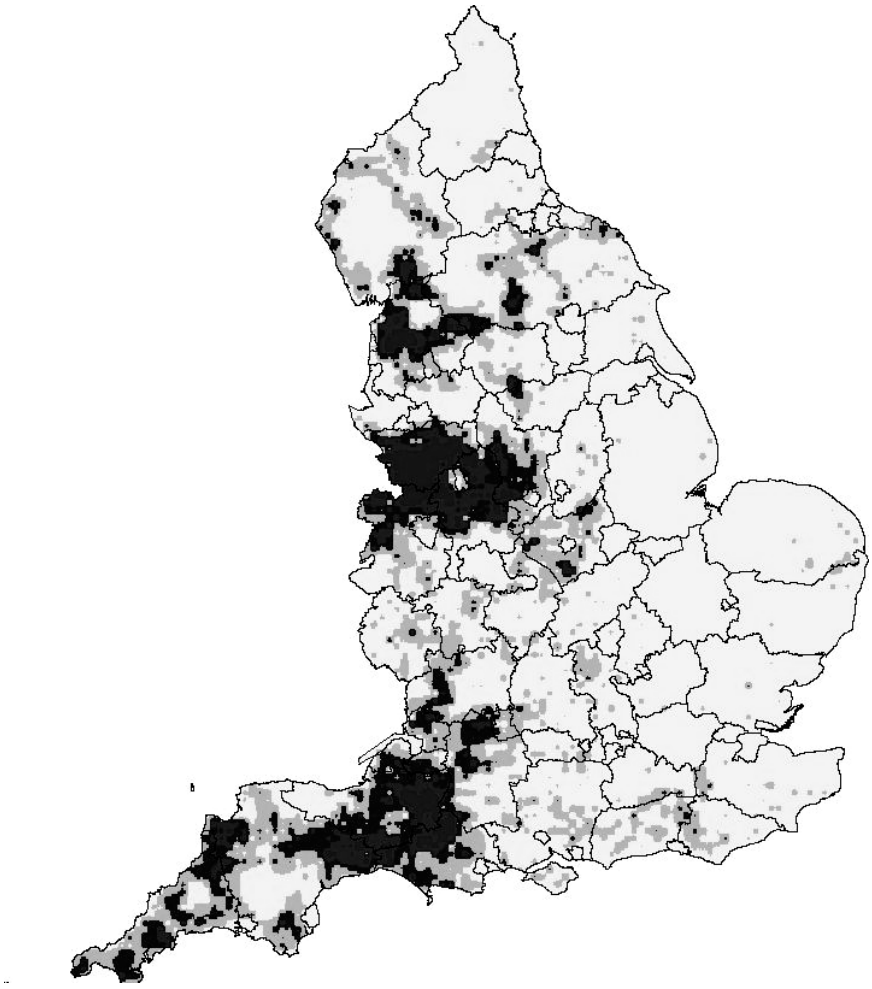

Figure 1. Distribution of dairy cattle in England: darker colours represent highest density) (from Defra, 2003).

Table 1. Crop areas and livestock numbers in the UK in 2002 (Defra 2003a).

Land use area ('000ha)		Livestock numbers ('000)	
Cereals (total)	3 245	*Total cattle & calves*	10 345
wheat	1 996	(dairy cows)	(2 227)
barley	1 101		
oats	126		
others	23	*Total sheep & lambs*	35 834
Other arable crops			
oil seed rape	357		
sugar beet	169	*Total pigs*	5 588
peas & field beans	249		
potatoes	158		
others	218	*Total fowl*	155 005
Horticultural crops	176		
Grassland (total)	12 370		
grass under 5 years	1 230		
grass 5 years & over	5 442		
rough grazing	4 484		
common land rough grazing	1 234		

Table 2. Changes in dairy herd numbers and size between 1995 and 2000 (Defra 2003a).

	Numbers of holdings ('000)		Numbers of livestock ('000)	
	1995	2000	1995	2000
Herd size 1 - 49	17.4	12.8	468	316
50 - 99	13.7	11.0	673	793
> 100	7.8	8.0	1159	1226
Average herd size	66.8	73.3		
% of herd > 100	44.6	52.5		

The statistics relating to the national (English) dairy herd demonstrate substantial change over recent decades. Even over the relatively short period of 5 years (Table 2) there has been a substantial decrease in the numbers of smaller herds with a consequent change in the numbers of cows that are associated with these smaller enterprises. Thus, while total cow numbers have remained more or less constant, those in herds of < 100 have decreased by 23% and those in herds of >100 cows have increased by 6%. This illustrates a continued polarisation (i.e. bigger intensive units on the one hand and smaller specialist units on the other) in the dairy sector which has implications for production and the associated pollution potential.

Milk yields have continued to rise over a considerable period as illustrated by the data in Figure 2. This indicates that yields, expressed both on a per autumn and (during the latter phase) on an annual basis, have increased steeply over the last 3 decades with a relatively constant rate of increase in milk yield per cow over that time. It is also worth noting the changes in milk prices over the last decade with a peak achieved in 1995/96. Current prices for conventionally produced milk in the UK are less than 18p (currently *c.* 0.25 Euros) per litre. The changes illustrated are the result of many interacting factors which cannot easily be disentangled, but which have contributed to the changes in herd structure already noted with consequences for the socio-economic structure of those areas

(Figure 1) with a dense population of dairy herds. These changes have, and will continue to have, major impact on the dispersion of pollutants (nutrients, greenhouse gases and other materials) which affect the environment from both local and national/international perspectives.

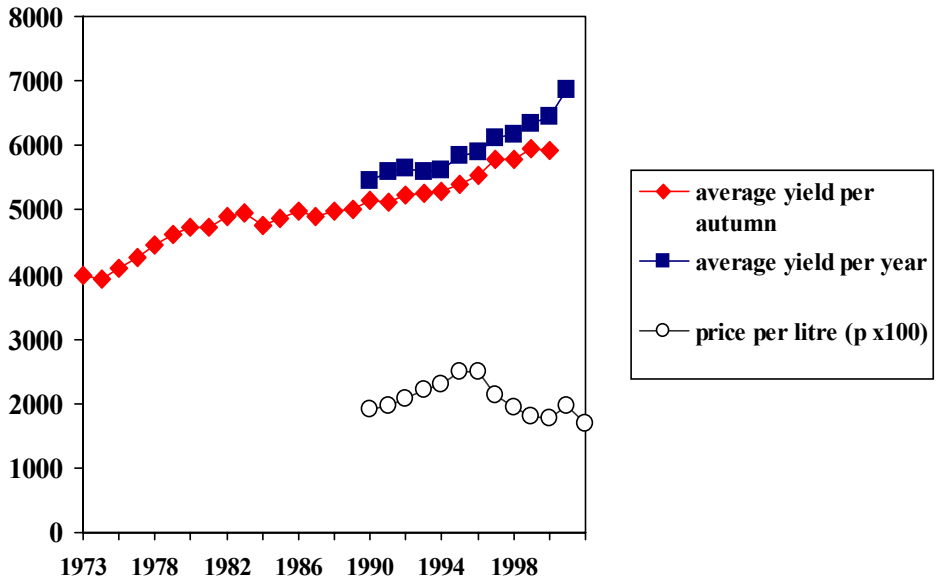

Figure 2. *Changes in average milk yield (L) per dairy cow from 1973 to 2001. Also shown are milk prices 1990- 2001 (pence per litre x 100: nb 1 euro = ca. 145p)*

Table 3. *Changes in dairy farm characteristics in England between 1996/7 and 2001/2 (Defra 2003a).*

	1996/7	2001/2
Sample size (numbers of farms)	423	364
Average farm size (ha)	78	71
Livestock numbers:		
dairy cows	83	76
total LUs	133	122
Annual labour units	2.7	2.3
Inputs (£'000)		
Total	130.4	100.1
of which – feed	34.7	25.1
fertilisers	7.6	4.2
labour	18.0	13.6
others	34.9	29.9
Total outputs (£'000)	160.5	110.9
Net farm income (£'000)	30.4	10.8

Table 3 also shows changes in the nature of dairy farming - in this case over the relatively short period of 5 years. It is clear from these data for a representative sample of dairy farms, that some substantial changes in farm structure and operation have occurred over this short time span that have influenced operational aspects of farm management and labour inputs, nutrient use and farm income. Spending on feed and fertiliser decreased by 28% and 45%, respectively, over this period, while net farm incomes dropped by 64%. The use of milk has also changed over the

last four decades (Table 4) with declines in liquid consumption and the production of butter but increases in the production of cheese. Although it fell in 2002, production of milk powder remains an important component of milk use.

Table 4. Milk product use in the UK (Defra 2003a): million litres.

	1973	1980	1990	2000
Production	13 998	15 513	14 825	14 078
Exports	-	-	75	105
Liquid consumption	7 557	7 218	6 727	6 768
Butter	206	355	309	270
Cheese	1 817	2 448	3 289	3 032
Others	1 310	1 398	1 385	1 428
Milk powder	1 698	2 941	2 482	1 821

Table 5. Farm gate nutrient balances (N and P) within a typical English dairy farm system calculated from best available data (Scholefield, 2001).

	kg N/ha	kg P/ha
Input		
Mineral fertiliser	244	16.0
Concentrates/bedding	51	27.2
Atmospheric deposition	40	0.2
Biological fixation	10	0.0
Total input	*345*	*43.4*
Total output (milk and meat)	*65*	*16.5*
Surplus	280	26.9
Utilisation %	19	38

Sources: Jarvis, 1993, Haygarth et al., 1998.

2.3 Nutrient balances on dairy farms

There are only limited published data on nutrient use and utilisation for UK dairy farms. Table 5 provides estimates for farm gate nutrient (N & P) balances calculated for typical modelled farm systems which were developed in 1993 and 1998. In experimental whole-farm dairy system comparisons involving detailed and continuous measurements of nutrient inputs and outputs over a 3-year period, N and P surpluses for a conventional system were 389 and 23 kg ha, respectively, with corresponding utilisation rates of 15 and 34% (Peel *et al.*, 1997; Withers *et al.*, 1999). A very simple survey of N use amongst some 110 dairy farms in the UK illustrated some very wide ranges in the use of N fertiliser and the consequences for the on farm surpluses of this nutrient (Table 6). Surplus N is a key indicator for this nutrient because it is directly related to fertiliser input (Jarvis, 1999) and is directly related to measured or modelled losses (Jarvis & Aarts, 2000). It is very clear from this that there is a very wide range in the use of N and, if this is expressed in relation to per capita of production (milk), i.e. litres produced per unit of N applied, there is a very wide range in the effectiveness with which this nutrient is being used (a 13-fold difference). There is an urgent need for a wider suite of observations incorporating greater detail to be obtained, so that the reasons for such wide

differences in the effective use of nutrients, including those other than N, can be examined. Once this is done, then positive actions can be taken for make improvements. The consequence of the broad range in inputs and in effectiveness of utilisation, is that there is a very wide range in N surplus (10-fold, Table 6). As already noted, this has impact on the potential for emissions of N to the wider environment.

Table 6. Nitrogen inputs, surplus and efficiency in 110 UK dairy farms (Jarvis, 1999).

	Range	Mean
N fertiliser applied kg ha	100 - 689	281
N removed in milk kg ha	15 - 82	36
N surplus kg ha	63 - 667	257
Litre milk per kg N applied	6.5 - 84.6	29.4
Surplus N (kg) per 1000 litres milk	7.0 - 150.0	31.1

Another recent and more detailed analysis/modelling exercise has been undertaken on N utilisation and losses in dairy farms. This centred on information from six typical dairy farms in SW England. The farms were between 59 and 110 ha in area, with stocking rates of between 1.7 and 2.3 LU/ha and milk outputs of between 5 790-6 200 l/cow. All six farms had more than 75% of the farm area under grass. Data were collected so that inputs, outputs and N flows into, within and from the farm could be calculated (Cuttle, 2002). Losses were estimated using appropriate models.

When averaged over the whole farm area, total N inputs ranged from 290 - 416 kg N/ha, and only 12-19% of this was recovered in milk and livestock sales, leaving N surpluses of between 234 - 367 kg ha (Table 7). Again one of the surprising features is the wide range in N use and efficiency of use that occurs in what, at first sight, are relatively similar farms. In each case, however, there is a substantial surplus of N in the farming system. When this surplus is expressed on a per unit of production basis, there is a 1.5-fold difference between upper and lower rates. Once again, this has demonstrated substantial differences in the potential to pollute per unit of production on apparently similar dairy farming units.

Table 7. Characteristics and N statistics for 6 dairy farms in SW England (Cuttle, 2002).

	Range	Mean
Farm size (ha)	59 - 95	84
Number cows	88 - 155	124
Milk yield per cow (l)	5 790 - 6 420	6 071
Overall stocking rate (lso/ha)	2.04 - 2.30	2.15
Fertiliser N (kg N/ha)	182 - 302	256
Recoveries in milk and livestock %	12 - 19	16
Surplus kg N/ha	234 - 367	316
Surplus N (kg) per 1 000 litres milk	29 - 44	36

Table 8. Typical nutrient content of dairy manures and effluent (on a fresh weight basis). Source, HMSO (2000).

	Dry Matter (%)	Total N (kg/t FYM or kg/m^3 slurry)	Total P (kg/t FYM or kg/m^3 slurry)	Total K (kg/t FYM or kg/m^3 slurry)
Dirty water	<1	0.3	trace	0.2
Cattle slurry	6	3.0	0.5	2.8
Cattle FYM	25	6.0	1.5	6.4

2.4 Manure/slurry production and utilisation

One of the key components of the management of improved nutrient efficiency within a dairy farm is understanding the contribution and effectiveness of use of nutrients within manures and slurries. Manures are variable materials, with variable nutrient supply rate patterns, but there is still only a limited appreciation and knowledge of their nutrient contents and effectiveness of supply. Typically, each adult dairy cow generates *c.* 60 kg of dung and urine per day; therefore during the housing period large quantities of slurry and solid farmyard manure (FYM) are produced. Dairy cow manure arising from UK dairy farms totals 30 million tonnes, with the dairy farms operating on straw-bedded and slurry-based systems estimated contributing 34% and 66%, respectively, of this (Smith *et al.*, 2001). In addition, large volumes of dirty water (6-167 litres/cow/day) (Cumby *et al.*, 1999) are generated in the wash-water from milking parlours, collection yards and other yard areas receiving rainfall.

The chemical and physical composition of manure varies with animal type and age, diet, manure collection design (e.g. amount of clean water allowed into the collection system) and storage time. Typical nutrient contents of dairy cow slurry, FYM and dirty water are shown in Table 8. Manures also contain trace elements and organic matter which are essential to plant growth and maintenance of soil structure. Assuming average N, P and K contents (HMSO, 2000: Table 8), quantities of manure generated during housing and present fertiliser prices (Chambers *et al.*, 2001), the total nutrient value (N, P and K) of this manure is ~ £90M.

Increased farmer confidence and knowledge of manure nutrient content is essential in moving from an attitude of manure management to one of nutrient management. At worst, farmers are encouraged to use the average values of N, P and K contents published in national handbooks and literature (e.g. HMSO, 2000). A better alternative is to persuade farmers to submit representative slurry and manure samples for nutrient analysis. If feeding and manure management regimes remain similar, then manure nutrient composition should remain constant and a limited number of samples would require analysis. However, there can be considerable variation in typical nutrient contents and farmers risk under-application and poor crop response or over-application and risk of transfer to air and water courses.

A further option is for farmers to analyse manures on their farm with portable test kits. There are several N meters available for estimating the plant available N content of manures. Nitrogen meters are used on sub-samples of slurry prior to application to the field (Kjellerup, 1996). These tests take approximately 10 minutes to complete and are accurate and reliable at estimating the NH_4^+-N content of pig and dairy slurries (Williams *et al.*, 1999). Hydrometers can be used to indicate total N, P and K content of slurries as there is a good relationship between dry matter and nutrient contents (Piccini & Bortone, 1991). Significant progress has also been made in quantifying nutrient contents in-line on slurry tankers (Lenehan *et al.*, 1999). Knowledge of the total nutrient content is only part of the requirement to match nutrient application to crop demand, as only a percentage of the total nutrient content of manure is in a form that is readily available to plants. So, the form of nutrient and its rate of supply to the crop are also important. For example, up to 90% of the total N in cattle FYM may be in the organic form and will need to be mineralised before it is available to plants (Chadwick *et al.*, 2000). Mineralisation and release of organically bound nutrients at times of low crop demand can result in increased risk of transfer to air and watercourses, depending on the season of application and soil type (HMSO, 2000).

In a comparative study using 17 different manure types, Chadwick *et al.* (2000) found that only 2% of the organic N in one dairy slurry was mineralised within 199 days of application, whereas in the same study 19% was mineralised from another. The availability of the N was related to the C:organic N ratios, which were 10 and 15, respectively.

Generally, organic materials with a ratio > 15 will immobilise N, and those with ratios < 15 will mineralise organic N. Knowledge of the relationship between the C:organic N ratio and mineralisation rates, coupled with that between mineralisation rates and soil thermal units (Honeycutt and Potaro, 1990), offers a promising route forwards in predicting N supply from manure applications throughout the growing season (Figure 3). Some information on N supply from manures is made available to farmers in 'look-up' tables (HMSO, 2000). The same publication also advises farmers that the P availability of manures is 60%, and potassium 90% of the total applied, irrespective of soil type. Increasingly, PC based decision support systems (DSS) will be required to assimilate all the information and provide advice to farmers on the best time of year to apply manures to gain maximum utilization of manure nutrients. An example of such a DSS is MANNER (Chambers *et al.*, 1999).

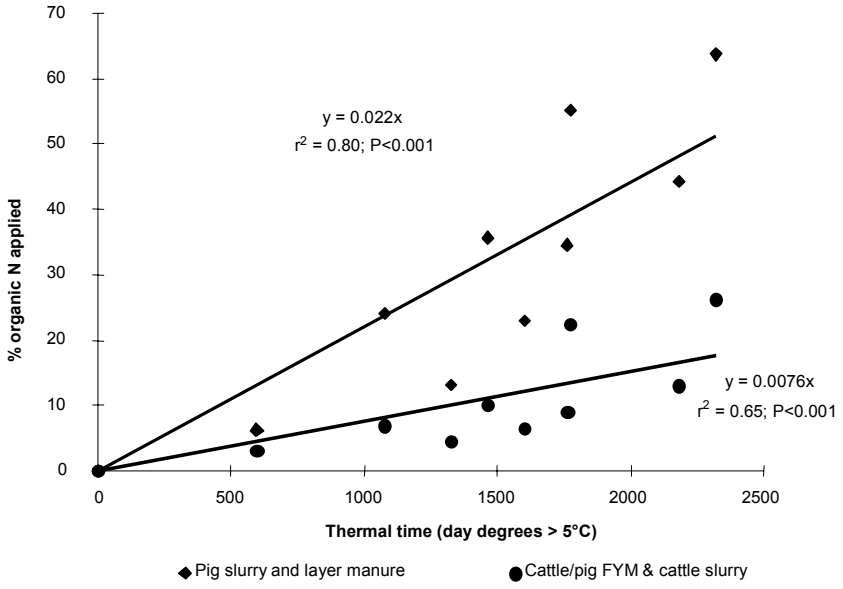

Figure 3. Relationship between % organic N release and thermal time for two manure groups (IGER/ADAS, unpublished data).

2.5 Nutrient flows and losses within and from dairy systems

There have been few full scale analyses of UK farming systems in terms of the internal recycling and flows of nutrients from farms. Table 5 has data for a hypothetical farming system and losses have also been calculated for the 6 SW farms noted in Table 7 using various modelled estimates, and shown in Table 9. Losses range from 131 to 187 kg N/ha on a whole farm basis and these represent the equivalent of between 55 and 75 (mean 66) % of the N fertiliser input in line with other previous data both for the UK and elsewhere.

Table 9. Components of farm N budgets for the alternative managements (averaged for 6 SW England dairy farms) kg N/ha over whole farm (Cuttle, 2002).

	A	B	C	D
Total inputs (fertiliser)	288 (182)	329 (224)	182 (4)	271 (166)
Total outputs	59	58	53	58
N surplus	228	271	129	213
Efficiency %	21	18	29	22
Total estimated loss	102	160	64	105

A: improved slurry/fertiliser utilisation
B: incorporation of forage maize
C: clover based swards with forage maize
D: combining A and B

This exercise also considered the possibility of changing features of management to reduce losses, this was again as part of a desk exercise. A number of options were considered in line with those proposed by Jarvis *et al.* (1996) and were as follows: A) improved slurry/fertiliser utilisation, B) incorporation of forage maize, C) incorporating clover based swards in combination with forage maize and D) combining (A) and (B). This analysis quite clearly suggests that there are immediate practical opportunities to reduce N losses (nb.: the values shown are averages for the 6 farms, individual effects on each farm may be substantially different). However, on average, it is possible to reduce overall losses from 170 to between 64 and 160 kg N/ha depending upon the strategy taken. Surplus N is decreased from, on average, 316 to between 129-271 kg N/ha and overall efficiency, i.e. capture into product, can be increased from, on average, 16 to between 18 and 29%. The switch to a clover based system is the most effective one in terms of conversion of N into product but has some implications for productivity.
The study also examined the effect of attentive management strategies on financial performances of the 6 study farms and these are shown in Table 10. This again indicates that there is a wide range of possible effects which, so far as the financial impact on the farm is concerned, depend upon current management and for each option ranged from a reduction (-) to an increase (+) in financial margin. Utilising maize as part of the system resulted generally in modest improvements in margin but was the least effective at reducing loss. Improving slurry and fertiliser use was the most effective of the options shown but the additional costs of the alternative, improved application techniques were greater than the savings in fertiliser cost depending on current status of the farming system. This desk study approach using real farm information does a number of things: 1) raises awareness of real circumstances and issues, 2) contributes to a low level base of knowledge of operational activities on farms and 3) demonstrates real opportunities to make improvement with an assessment of economic impact. There is little comparable information for other nutrients in the UK which can be used for similar modelling purposes.

Table 10. Effect of alternative management on total N loss and financial performance of six study farms in SW England expressed as the % change from the existing management (based on 2002 costs and prices) (Cuttle and Turner, 2003).

Management	Total N loss (% change)		Financial margin* (% change)	
	range	mean	range	mean
A: improved slurry/fert	-29 to -48	-39	-3 to -8	-6
B: maize forage	-3 to -8	-6	+2 to +11	+5
C: clover & maize	-28 to -54	-42	-4 to +26	+6
D: A and B	-29 to -45	-38	-4 to +11	+2

* *Excludes capital costs.*

Table 11. A comparison of the inputs, surplus and efficiency of N use in selected systems of the MIDaS whole farm study at ADAS Bridgets 1994-2001.

	System 1 All grass 19 ha	System A Grass/Maize 19 ha	System C Grass/Maize 21 ha
N inputs			
Feed	106	90	85
Fertiliser	321	195	154
Atmosphere	30	30	30
Total input	427	315	269
Total outputs (milk and meat)	68	64	63
Surplus	359	251	206
Utilisation %	15.9	20.3	23.4
Litre of milk per kg N applied	20.5	32.7	42.6
Surplus N (kg) per 1000 litres milk	54.6	39.3	31.4
N losses			
Nitrate leaching	45	16	10
Ammonia loss	NA*	19	13

Source: Adapted from Peel et al., 1999; Withers et al., 2003.

* *Data not available.*

Research work on whole farm dairy systems at ADAS Bridget's incorporated combinations of management strategies and techniques to reduce emissions of nutrients over a number of years (Peel *et al.*, 1999). Although not in a main dairying area, the site overlies a chalk aquifer and under average winter drainage, N leaching losses must be <30 kg ha in order to meet the 50 mg NO_3 l limit set in the EC Nitrates Directive. This is a stringent and challenging target and the 'improved' systems adopted combinations of reduced stocking rates, progressive reductions in fertiliser N and P use, cover cropping, refined dietary formulation, extended slurry storage and advanced slurry application

techniques. System performance and nutrient flows within each system were carefully monitored, nutrient balances constructed and N and P losses measured or modelled.
The combinations of measures adopted in the improved grass/maize systems (Table 11: A and C) reduced surpluses of N compared with the conventional all-grass system, with corresponding improvements in all indicators of efficiency. Losses of N through ammonia volatilisation, and by nitrate leaching, were reduced to within EC limits at this high risk site without detriment to either forage or milk production (Table 11). Large reductions in fertiliser N use were made possible by taking account of the N in manure, soil mineral N supply and sward age. In ancillary replicated experiments, slurry provided all the nutrients required for optimum yield of maize. Ammonia losses during slurry application were dependent on total N applied and weather and site conditions during spreading. A combination of rapid incorporation of slurry before maize was grown in spring, and the use of a trailing shoe applicator for slurry applications to grassland, resulted in a 60% reduction in ammonia losses compared with broadcast applications. However, the improved systems A and C required a higher level of technical awareness and management skill than the conventional system (1). Furthermore, system C was 10% less profitable than System A. The majority of the extra costs were in slurry storage: however, a number of management techniques could be employed on commercial farms at nil or low relative cost.

2.6 Nutrient outputs by dairy cattle

Key areas to achieve success are an improved understanding and utilisation of manures and slurries and an accurate knowledge of nutrients voided at pasture. Accurate, quantitative data on N and P excretion by dairy cattle are needed to assist in the management and utilisation of manures. Published figures for the production and composition of farm livestock excreta vary widely. Current figures (HMSO, 2000) are usually based on analyses of stored manures which contain variable amounts of feed and bedding materials and wastewater, and from which losses (e.g. through ammonia volatilisation) are likely to have already occurred. Relatively less information on the relative contributions of faeces and urine is available.
Estimates in the literature of N excretion by dairy cattle based on manure analyses are 9-40% lower than those based on N balance calculations. A recent project, conducted jointly by ADAS and IGER, measured directly the output and N and P content of faeces and urine from dairy cattle in 10 representative commercial herds in the UK. Five cows were chosen at random from each herd and urine and faeces collected separately over an 8-hour period. Eighty percent of the cows in the core groups were Holstein x Friesian and 20% pure Friesian. The values for the lactating and dry cows (Table 12) are similar to those in previous studies (Smith & Frost, 2000), except for the frequency of urination which is lower than the reported value (7.0 compared with 10.2) and may account for the overall reduction in excretal output. The mean daily excretal output (42.6 kg for lactating cows of 644 kg live weight) was lower than other estimates for cows of comparable live weight (42, 53 and 64 kg for dairy cows of 450, 550 and 650 kg live weight, respectively). Thus, annual N excretion for lactating cows (89.4/kg cow) was also lower than the reported value of 116 kg/cow for cows of comparable live weight obtained by nutrient balance calculation (Smith & Frost, 2000).

Table 12. N and P output in faeces and urine from lactating and dry dairy cows (Laws, unpublished data).

	Lactation	Dry
Mean excretal output (kg)cow/day	42.6	42.9
Mean no. of defaecation events per cow/day	11.9	-
Mean weight of faeces (kg)passed per event	2.3	2.6
Mean no. of urination events per cow/day	6.9	-
Mean weight of urine (kg)passed per event	2.0	1.8
Mean excretal N output (kg) per cow/day	0.245	0.153
Mean excretal P output (kg) cow/day	0.045	0.018
Faeces:urine ratio in slurry	1.8	2.4
Mean N content of slurry (kg/t)	5.75	3.57
Mean P content of slurry (kg/t)	1.06	0.42
Mean slurry DM (%)	11.0	11.0
Mean excretal N output per cow[1] per year	89.4	56.3
Mean excretal P output per cow[1] per year	16.4	7.8

[1] *Assuming 100% occupancy and a silage-based diet.*

2.7 Utilisation of manures/slurries

Key to efficient use of animal manures and slurries is matching nutrient supply with crop demand. This requires knowledge of nutrient content and availability (see earlier), adequate manure storage facilities to facilitate timely applications of manures; sufficient land area to ensure sensible loading rates; application techniques that reduce losses of N as ammonia.

2.7.1 Manure storage facilities

Slurry

Slurry store type and storage capacity influence both the magnitude of ammonia emissions and the flexibility to spread slurry onto land. In the UK, above ground tin tanks account for *c.* 30% of slurry stored, earth banked lagoons account for *c.* 30%), and weeping wall stores for *c.* 15% of slurry storage in England and Wales (Smith *et al.*, 2001). Surprisingly, over 15% of the population surveyed had little or no storage. On many of these units, there is only a small below ground tank which is emptied and spread to land on a daily basis. This type of unit will have an increased risk of overflowing stores or application of slurry at times when soil and weather conditions are conducive to nutrient utilisation, resulting in a greater risk of land run-off. Slurry storage capacity in dairy units is commonly between 3-4 months; the UK Code of Good Agricultural Practice for the Protection of Water (MAFF 1998a) recommends 4 months storage capacity. Some units have >6 months capacity allowing greater flexibility in the timing of applications to land. However, there is <1 month's storage capacity for up to 16% of dairy slurry (Smith *et al.*, 2001). The requirements for farms on certain soils in NVZ's are also different (see later). Over the past 20 years, advice on slurry store management has recommended preventing crust formation by frequent mixing. However, it seems from limited research (Sommer *et al.*, 1993) that encouraging crust formation will reduce ammonia emissions from cattle slurry stores. This would be a significantly lower cost abatement practice than purchasing a fixed cover for tanks.

Dirty water

Dirty water is produced in large quantities on dairy farms, especially in high rainfall areas, where containment within the slurry store adds to the storage capacity required. Therefore, farmers are encouraged to fit gutters to all roofs and divert this 'clean' water away from dirty water and slurry stores. Dirty water is usually collected in a separate store to dairy slurry and disposed of by application to land without prior treatment. The survey by Smith *et al.* (2001)

showed that over 70% of dairy farmers have separate storage and disposal systems to slurry. This effluent is commonly pumped from the store to low rate irrigators. The volume produced and its chemical composition can vary greatly from farm to farm because of differences in rainfall, drainage and collection systems, and whether silage effluent or contents of slurry tanks enter the store (Cumby *et al.*, 1999). The volume of dirty water produced per cow can range from 7 l/d to 167 l/d (mean 60 l/d) (Brewer *et al.*, 1999).

Solid manure heaps

According to the 2001 Farm Practices Survey Report, 50% of cattle FYM is stored in the open in field heaps and 31% stored on a concrete or impermeable base, with a further 17% being spread or exported from the farm within one week after removal from the building. Only 2% of cattle FYM is stored under cover. There is an obligation to collect all effluent from heaps on an impermeable base, but this is not the case for field heaps. In the latter case, the UK Code of Good agricultural Practice for Protection of Water (MAFF 1998a) recommends that field heaps are not sited within 10 m of a watercourse, ditch or drain or within 50 m of a bore hole for potable water. The typical storage period for cattle FYM on impermeable bases is 4 months but is for longer periods in field heaps.

There is increasing evidence that the nutrient composition of FYM changes considerably during storage. Up to 40-50% of the dry matter can be lost during 6 months storage, reducing the volume of FYM to spread, offering cost savings in transport. Typically, *c.* 30% of the total N content is lost. Although undesirable, some of this loss is as ammonia, nitrous oxide and nitrate, resulting in a more stable N source which is less prone to immediate losses once applied to land. During storage the C:N ratio also decreases, typically from *c.* 17 to *c.* 12. This will result in mineralisation of organic N rather than immobilisation of soil N when manure is applied to land (Chadwick *et al.*, 2000). Storage has little effect on total P, S and Mg content, although small mass losses of these elements, particularly P, can still result in concentrations that can have detrimental effects on the environment. Significant losses of K can occur (30-40%) if the FYM heaps are not covered or stacked in buildings.

2.7.2 Land area

At the farm-scale, not all the land receives equal application rates of manure. There are several reasons why this is the case, e.g. proximity to stores (transport costs), and land used for growing silage and hay is often avoided to reduce the possibility of poor silage or hay quality. The result is that some fields, particularly maize stubbles in autumn, receive large quantities of manure each year. Repeated applications increase the nutrient status of the soil (Leinweber *et al.*, 1997) and the risk of transport of potential pollutants to watercourses.

At the field-scale, manures are inherently more difficult to spread evenly than inorganic fertilisers. Not only can this result in an uneven yield of crop, but excess nutrients can remain in the soil after harvest. Recent advances in spreading efficiency have decreased the coefficient of variation in spread pattern. There are a limited number of occasions during the winter when soil conditions are suitable for machinery to travel onto fields without risk of compaction. Because of this, application rates tend to be greater than those recommended. Inadequate storage capacity often results in manure applications at times when there is a low crop demand, e.g. to frozen soil. Winter application is not recommended because of the risk of transfer to water in early spring (MAFF, 1998a). If manure was spread onto all available grass and arable land, application rates would be much lower than surveys suggest (Smith *et al.*, 1998). For example, in the UK manure is only applied to 18% of the arable land and 48% of the grassland (Burnhill *et al.*, 1994). This results in average manure-P loadings of 80 and 16 kg ha^{-1} to arable and grassland, respectively, instead of 14 and 8 kg ha^{-1} if manure were spread on all the arable and grassland available in the UK (Smith *et al.*, 1998).

In the UK, manure applications are based on N loading (MAFF, 1998a) and can result in a significant enrichment of the soil P content because of the N:P ratio (Smith *et al.*, 1998). Thus P loadings with manure applications targeting a N application of 250 kg N/ha (the maximum rate recommended (MAFF, 1998a) represent 42 and 62 kg P/ha, respectively, for dairy slurry and cattle FYM, and could result in significant accumulation of P in the soil. Manures should only be applied to growing crops, i.e. when there is crop demand for nutrients and at rates that crops can use. This prevents accumulation of nutrients at risk of transfer to water and air. The application of FYM is generally reduced in the summer months to avoid contamination of grazing and silage grassland and a higher proportion of dairy FYM is applied in the August-October period (Smith *et al.*, 2001), when there is access to suitable fields with soil and weather conditions that are suitable. In contrast, a high proportion of dairy slurry is applied to grazing land

(60%) and silage fields (26%) during August-October, which would enhance nitrate leaching over winter (Chambers *et al.*, 2000). High proportions of dairy slurry and FYM are applied to maize land in February-April, since this is available and high application rates do not appear to result in adverse yields. The use of forage maize stubbles as a disposal area is of environmental concern because there should be opportunity to reduce the fertiliser input accordingly, but this potential is not reflected by statistics on fertiliser use (Smith and Chambers, 1995). Manure incorporation can significantly reduce ammonia loss and odour nuisance (Pain *et al.*, 1991). Therefore, it is advised that incorporation is carried out as soon as possible after application, preferably within the same day, or for slurries, the application should be by injection or surface placement, rather than broadcast. Survey data (Smith *et al.*, 2001) show that there is very little same day incorporation of either slurry or FYM (<10%). However, over 60% of dairy slurry and 90% of dairy FYM is incorporated within a week after application.

2.7.3 Application techniques - use of slurries on grazing and silage land

IGER and ADAS research has demonstrated that alternative slurry spreading techniques can be used on grazing land without causing aversion to grazing (Laws & Pain, 2002). When slurry was applied immediately after a first silage cut, shallow injection or trailing shoe methods had little impact on grazing whilst the cattle showed significant aversion to treated swards when slurry was applied by conventional surface broadcasting. On tall swards in spring, aversion to swards treated with slurry by trailing shoes was less and lasted for a shorter period than with the other application methods. Laws *et al.* (2002) have shown that the novel application methods can be used without affecting silage quality. This is because slurry is placed at a level below the height of cutting and consequently does not contaminate the grass crop whereas silage made after surface broadcasting at the same time was badly contaminated with slurry and fermentation was poor. This improvement in sward hygiene has permitted the use of slurry rather than mineral fertiliser in grazing rotations in some instances without affecting herbage intake or milk yield and thus provides farmers with greater flexibility in spreading slurry in grassland systems.

2.7.4 Controlling losses - implications of manure management on air quality

Agricultural livestock and their excreta and urine are important sources of ammonia, methane and nitrous oxide, as well as nuisance gases, e.g. odours. There is increasing European pressure for UK agriculture to reduce emissions of ammonia and changes in manure management could make a large contribution to the overall reduction required. Agriculture accounts for nearly 80% of the UK's national emissions of ammonia (currently estimated at 320 000 tonnes), most of the remainder originating from wild animals and combustion processes (DEFRA, 2002). Emissions occur from grazing, housing, the storage and treatment of manures and application of all types of animal manures to land (Fig. 4). Inorganic N fertilisers are also a small source, especially from urea. Because the potential for ammonia loss is greater from slurry than from FYM and because more cattle are housed on slurry systems than on straw-based FYM systems, slurry from cattle is the major source.

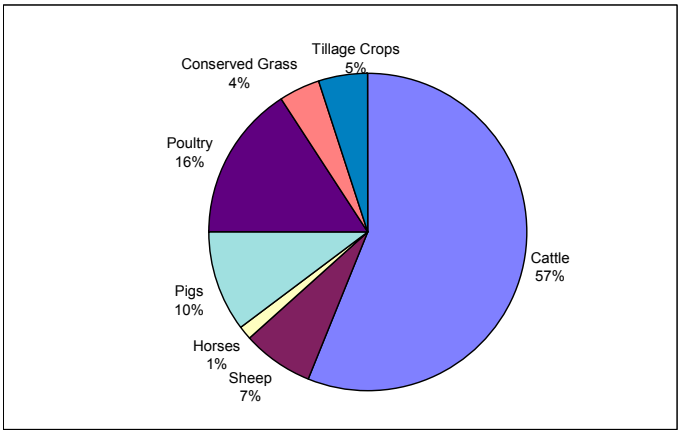

Figure 4. UK ammonia inventory for the year 2000. Breakdown by livestock type (Misselbrook, pers. comm.).

Not only is ammonia volatilisation and emission important from environmental perspectives, it also represents inefficient use of a valuable resource, plant available N. Recent estimates suggest that the average loss of ammonia per dairy cow represents ~25 kg N per year, which, at present fertiliser prices, represents ~£6 (8.5 euros) per animal. Total nutrients in manure produced by 100 dairy cows over winter is worth ~£2 200 (>3 100 euros) based on current fertiliser (N, P, K) costs. Controlling ammonia emissions from storage and manure spreading is the most practical and cost-effective way of reducing pollution risk and saving nutrients.

Slurry store covers

Purpose made covers are available for above-ground circular steel and concrete slurry stores and earth-banked slurry lagoons. There are two types of cover: lightweight rigid covers made of roofing material (fibreglass or lightweight metal) supported on a central metal pole, or flexible, tent type covers made from heavy gauge, PVC-coated polyester, supported by a central pole and tensioned to the rim of the tank. This type of cover is most suited to retro-fitting to existing tanks. Covers significantly reduce odours and ammonia emission is reduced by up to 90%. A major practical benefit is the exclusion of rain which increases storage capacity for slurry and reduces volume. The saving in store size can be up to 15-20% depending on local rainfall and the volume of slurry to be stored. Slurry lagoons are generally shallower and have a greater surface area than circular, above-ground stores; it is therefore more cost-effective to cover the former (Nicholson, pers. comm.)

Novel slurry application methods

Ammonia emissions are greater from slurry than from FYM, and spreading on land is the major management factor contributing to emissions (33% of the total from agriculture). In recent years, slurry distribution systems have been developed primarily to reduce ammonia emissions following land spreading. Slurry is placed in narrow bands either in open 'V' shaped slots (5 cm deep and 20 cm apart) cut in the soil (shallow injection) or on the soil/crop surface (3-5 cm wide and 20 cm apart) via trailing hoses. Emissions are decreased because the surface area of the slurry exposed to air is decreased. Trailing hose applicators are particularly suited to arable crops and can be used effectively to apply slurry to growing crops. Trailing hose applicators have been further adapted for use on grassland by fitting a metal 'shoe' to the end of each hose which parts the grass and allows the slurry to be placed on the soil surface below the canopy. Each of these methods reduces ammonia emissions compared with conventional broadcasting, with reductions of up to 90% with shallow injection and up to 70% when placed under a growing crop with trailing hose and trailing shoe (Smith *et al.*, 2000). Misselbrook *et al.* (2002) demonstrated that emission reductions are smaller with these methods on arable land. On grassland, shallow injection, trailing shoe and band spreading reduced NH_3 emissions by 73, 57 and 26%, respectively, compared with surface spreading. On arable land, these reductions were only 23, 38 and 27%, respectively. Rapid incorporation of manure into soil reduces ammonia loss and is the only practical method of reducing emissions from FYM; ploughing is the most effective method which should be carried out as soon as possible after spreading.

2.7.5 The practicalities of adopting ammonia abatement techniques on farms

As part of a 5-year study, data are being gathered on the practical use of ammonia abatement methods (slurry placement in narrow bands, covering slurry stores, rapid incorporation of FYM after application to arable land) on livestock farms (dairy, pig and beef) throughout England. Shallow disc injectors and trailing-hose band spreaders are being used in place of broadcasting on eleven farms and by four contracting companies. In addition, four slurry stores and one earth-banked slurry lagoon have been covered. FYM is ploughed-in as soon as possible after spreading. Feedback after the first three years is favourable and a number of important additional benefits of the new technologies have been identified (Table 13). Particularly important is the potential to reduce herbage contamination with slurry solids, which may allow spreading closer to silage cutting and, thereby, an opportunity for spreading without the risk of adversely affecting silage quality. In circumstances where the normal buffer period between slurry spreading and grass cutting is compromised, e.g. as a result of a high workload in spring or adverse weather conditions, slurry application in narrow bands or below the grass canopy may be advantageous. Reduced contamination of pasture for grazing was also reported as a major benefit with narrow band slurry placement techniques making it possible to replace N fertiliser with slurry in the grazing rotation.

Table 13. Benefits and disadvantages of on-farm ammonia abatement practices.

Narrow-band slurry applicators	**Store covers**
Benefits:	*Benefits*:
Conserved nutrients	Conserved nutrients
Reduced fertiliser inputs	Exclusion of rain
Reduced odour and public nuisance	Reduced volume of slurry
Reduced contamination of grass	Reduced spreading costs
Uniformity of application	More flexible manure management
Perceived increased overall farm fertility	
Disadvantages:	*Disadvantage*:
Purchase price	Purchase cost
Higher maintenance and repair costs	
Greater expertise required	

2.7.6 Pollution swapping

There is increasing evidence that measures taken to reduce one form of pollution, e.g. NH_3 volatilisation by shallow injection, may result in greater losses of other forms, e.g. N_2O. In recent work (Chadwick, unpublished), shallow injection decreased NH_3 emissions from 72% (surface spreading) of the ammonium-N applied in the slurry to 11%. However, shallow injection increased N_2O emissions from 2.8% (surface spreading) of the ammonium-N applied to 10.2%. Research is being conducted in the UK to assess the extent to which pollution swapping occurs and optimise applications of manures to grassland and arable land.

2.8 Environmental regulations

2.8.1 Nitrate vulnerable zones

Agricultural management is informed by Codes of Good Agricultural Practice (Defra, 2003b; MAFF, 1998a, b, c) for air, soil and water. A recent change has been the implementation of NVZ (nitrate vulnerable zone) rules to meet the requirements of the Nitrates Directive. In the main, most of the area involved is dominated by tilled crops but significant components of the dairy industry are affected (Figure 5). The Action Programme implemented for English NVZs came into force on December 19th 2002, and separate Action Programmes have also been implemented in Wales and Scotland. The English Action Programme promotes best practice in the use and storage of fertilisers and manures and builds on the guidelines set out in the Codes for Good Agricultural Practice, especially that for waters. The four key aspects of the actions needed to be taken within NVZs are those indicated by the Nitrates Directive, i.e. 1) limitation in using inorganic N fertilisers to meet that of crop requirements, 2) limitation in the application of organic manures, 3) provision of adequate storage capacity for farms on sandy or shallow soils for annual closed periods for the application of some types of manures (slurries in the case of dairying) and 4) keeping adequate records (cropping, livestock numbers and the use of fertilisers and manures). The English Environment Agency is responsible for assessing farmers' compliance with the Action Programme in England and enforcing this where necessary. Help has been provided in the form of booklets and decision support systems (e.g. 'your farm and NVZ's – do you comply?', and a 'manure nitrogen evaluation routine - MANNER'). Farm advisory visits, farmers and consultation meetings are also available as is other guidance on managing manures and fertilisers. The current booklet supplying advice for fertiliser use (RB209) (HMSO, 2000) can be used to estimate soil N supplies in relation to requirements and the potential for nitrate loss. Although the various actions required within NVZ's relate to N, there will be 'knock-on' effects for other nutrients, particularly the effects of changing organic manure use on P supplies and potential for its loss into waters. The time of year when manures are applied to land is of great importance in terms of nitrate leaching. Recent NVZ rules (MAFF, 1998d) include restrictions on timing for some manures including cattle slurries. There are closed periods for grassland between 1st September and 1st November, and 1st August and 1st November for arable land with manures of high available N on sandy and shallow soils. Similar to the recommendation in the Code for Protection of Water, there is an upper field limit to N applications in manures in NVZs of 250 kg N/ ha. In addition to the need for sufficient storage capacity to meet the autumn closed period for slurry spreading, adequate farm records must be kept to cover cropping, livestock numbers and the use of N fertilisers (which also have closed spreading periods) and organic manures (see MAFF, 1998b).

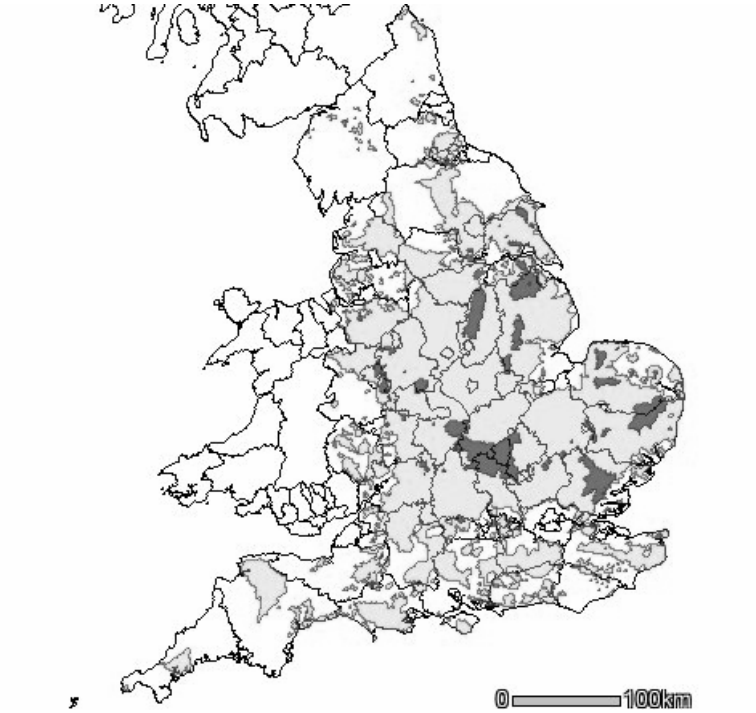

Figure 5. Distribution of Nitrate Vulnerable Zones in England. Areas designated in 2002 in light shading, those designated in 1996 in dark shading (from Defra, 2002b).

2.8.2 Greenhouse gases

There is global pressure for the UK to reduce emissions of the greenhouse gases (GHGs, nitrous oxide and methane). Under the 1992 UNCED Framework Convention on Climate Change (UNFCCC), the UK committed itself to reducing GHGs to 1990 levels by the year 2000. The Kyoto Protocol, signed by the UK, negotiated legally binding targets to reduce GHG emissions after 2000. The agreed targets represent an 8% decrease by the end of 2012 for the EU. The UK accepted a target of 12.5% reduction for the same period. Additionally, the UK Government is committed to reducing our carbon dioxide emissions to 20% below 1990 levels by 2010. Although agriculture does not have a specific target for reducing GHG emissions, all sectors are expected to contribute to the UK's need to meet national and international targets. While the contribution of agriculture to the total GHG budget is small, its relative contribution to methane and nitrous oxide emissions is important, and becoming relatively more significant as other sources decline more rapidly. The agricultural sector is estimated to be responsible for 70 and 40% of national nitrous oxide and methane emissions, respectively. In contrast, net carbon dioxide emissions from soils (i.e. emissions resulting from liming and drainage and peat extraction, and removals from set aside of arable land and increases in crop biomass) comprise only 3% of the national total; agriculture is estimated to be responsible for about 1% of total carbon dioxide from fossil fuel. However, taking into account the relative global warming potential of each of the GHGs, agriculture (including fossil fuel use) with net carbon dioxide emissions from soils contributed 30, 21 and 21 Mt CO_2 equivalents as nitrous oxide, methane and carbon dioxide in 1999. This was 11% of the emission of the total 'basket' of six greenhouse gases for UK of 654 Mt.
The major sources of nitrous oxide are inorganic fertilisers, animal manures and dung and urine returns during grazing. Over 90% of methane emissions from the livestock sector originate from the rumens of cattle and sheep, but some originates from manures and slurries. Some changes in manure management could result in reductions in GHG emissions, e.g. enhanced manure-spreader maintenance, manure-free zones for spreading, optimising N application by allowing for manure N and residual N, and anaerobic digestion of manures.

2.8.3 IPPC and other regulations

The European Directive on Integrated Pollution Prevention Control (IPPC, 1997) has now been implemented. It applies to units for intensive rearing of pigs (>2000 sows or 750 sow places), and poultry (>40 000 birds). Farmers managing such units must submit plans to demonstrate adequate storage facilities and sufficient land for spreading manures safely before licenses are agreed and production commences. The possibility exists that the IPPC regulations with respect to ammonia emissions already being applied to large new pig and poultry units may also be applied to large dairy units in the future.
A new protocol has been proposed under the UNECE Convention on the Long-Range Transport of Air Pollutants. It is likely that the protocol will seek to reduce emissions of several gaseous N compounds including ammonia. The European Commission is also in the process of developing a strategy on acidification which is likely to include proposals to reduce ammonia emissions. Several other European countries have already adopted changes in manure management to reduce ammonia emissions and much research has been conducted in the UK to determine cost-effective abatement practices.

2.8.4 Water Framework Directive

In December 2003, the government regulators will acquire new discretionary powers to control diffuse pollution as part of the implementation of the Water Framework Directive (WFD). The WFD was introduced to protect, enhance and restore 'good' ecological status in aquatic ecosystems (including wetlands) as a result of the increasing concerns over the deterioration of watercourses arising from enrichment with sediment and nutrients, and contamination from a range of harmful substances. The directive applies to all surface and ground waters and came into force on 22nd December 2000. Once 'good' ecological status has been defined for different types of waterbody, a series of basic and supplementary measures will be introduced as part of river basin management planning to achieve the required goals and environmental objectives by 2015. The WFD therefore provides the legislative driver required to enforce adoption of these measures where they cannot be adopted voluntarily during the period up to 2010. The degree to which the measures will influence farming practices will depend on how far waterbodies have deteriorated from their desired state in different areas of the country. It is anticipated that much of lowland England will need to implement improved farming practices under this directive.

2.9 Conclusions

The Common Agricultural Policy has been the biggest influence on agricultural land use in the last 30 years with some discrete and spatially distinctive forms of change leading to intensification and higher stocking rates, reduced diversity (both in overall biodiversity terms and in the use of local and specialised breeds). For dairy farmers this has meant the use of high inputs (energy and fertilisers) with consequent effects on losses, often poor manure management and the problems of dealing with specialised forage crops such as maize. Current discussions on agricultural policy and support mechanisms and other issues within Europe will demand new approaches to agricultural land and livestock management. Key amongst these will be improved management of the balances between inputs, offtakes and losses: not just of nutrients *per se*, but also, because of their connectivities, of energy (C) and water. Scientists and livestock farmers alike will need to take different approaches to develop sustainable managements for the future which will have to include a better knowledge of current practice, consideration of full life cycles and an appreciation of effects over a range of scales (field, farm, river basin/catchment etc).

References

Brewer, A. J., Cumby, T. R. & Dimmock, S.J. (1999)
Dirty water from dairy farms, II: Treatment and disposal options. Bioresource Technology 67, 161-169.

Burnhill, P., Chalmers, A.G. & Fairgreave, J. (1994)
Fertiliser use on Farm Crops 1993.

Chadwick, D.R., John, F., Pain, B.F., Chambers, B.J. & Williams, J. (2000)
Plant uptake of nitrogen from the organic nitrogen fraction of animals manures: a laboratory experiment. Journal of Agricultural Science, Cambridge, 134, 159-168.

Chambers, B.J., Lord, E.I., Nicholson, F.A. & Smith, K.A. (1999)
Predicting nitrogen availability and losses following application of organic manures to arable land: MANNER. Soil Use and Management 15, 137-143.

Chambers, B.J., Smith, K.A. & Pain, B.F. (2000)
Strategies to encourage better use of nitrogen in animal manures. Soil Use and Management 16, 157-161.

Cumby, T.R., Brewer, A.J. & Dimmock, S.J. (1999)
Dirty Water from Dairy Farms, I: biochemical characteristics. Bioresource Technology 67, 155-160.

Cuttle, S.P. (2002)
Desk studies which use models to predict nitrogen losses from farming systems. Final report to Defra.

Cuttle, S.P. & Turner, M.M. (2003)
The effectiveness of alternative managements to reduce N losses from dairy farms. Abstracts of 12th N Cycle Workshop. Exeter September 2003.

DEFRA (2002a)
Ammonia in the UK. DEFRA Publications, 89pp.

Defra (2002b)
Nitrate vulnerable zones. http://www.defra.gov.uk/ environment/water/quality /nitrate/maps.htm

Defra (2003a)
Defra, Economics and statistics. http://statistics.defra.gov.uk/esg/

Defra (2003b)
Codes of good agricultural practice: summary. 10pp. Defra, London.

Haygarth, P.M., Jarvis, S.C., Chapman, P., and Smith, R.F. (1998)
Phosphorus budgets for two contrasting grassland farming systems in the UK. Soil Use and Management 14, 160-167.

HMSO (2000)
Fertiliser recommendations for agricultural and horticultural crops. (RB209). 7th edition, 177pp. HMSO, London.

Honeycutt, C.W. & Potaro, L.J. (1990)
Field evaluation of heat units for predicting crop residue carbon and nitrogen mineralisation. Plant and Soil 125, 213-220.

IPPC (1997)
EC Directive 96/61 concerning integrated pollution prevention and control (IPPC) implementation in the pig and poultry sectors. Consultation paper, MAFF.

Jarvis, S.C. (1993)
Nitrogen cycling and losses from dairy farms. Soil Use and Management 9, 99-105.

Jarvis, S.C. (1999)
Accounting for nutrients in grassland: challenges and needs. In: Accounting for Nutrients: A Challenge for Grassland Farmers in the 21st Century, British Grassland Society Occasional Symposium No 33, BGS Conference, Great Malvern, UK, 22-23 November 1999. Ed. Corrall, A. J. pp 3-12 British Grassland Society, Reading, UK.

Jarvis, S. C. & Aarts, H. F. M. (2000)
Nutrient management from a farming systems perspective Grassland Farming: Balancing Environmental and Economic Demands. Proceedings of the 18th General Meeting of the European Grassland Federation, Aalborg, Denmark, 22-25 May 2000 (Grassland Science in Europe, Vol 5). Eds Soegaard, K., Ohlsson, C., Hutchings, N.J., Kristensen, T., Sehested, J. pp 363-373.

Jarvis, S. C., Wilkins, R. J. & Pain, B. F. (1996)
Opportunities for reducing the environmental impact of dairy farm managements: a systems approach. Grass and Forage Science 51 21-31.

Kjellerup, V. (1996)
Agros nitrogen meter for estimation of ammonium nitrogen in slurry and liquid manure. In: Dam Kofoed, A., Williams, J.H. and L'Hermite, P. (eds.) Land Use of Sludge and Manure. Elsevier Applied Science, London, pp. 216-223.

Laws, J. A. & Pain, B. F. (2002)
Effects of method, rate and timing of slurry application to grassland on the preference by cattle for treated and untreated areas of pasture. Grass and Forage Science 57, 93-104.

Laws, J. A., Smith, K. A., Jackson, R. & Pain, B. F. (2002)
Effects of slurry application method and timing on grass silage quality. Journal of Agricultural Science 139, 371-384.

Leinweber, P., Lunsmann, F. & Eckhardt, U. (1997)
Phosphorus sorption capacities and saturation in soil in two regions with different livestock densities in north-west Germany. Soil Use and Management 13, 82-89.

Lenehan, J.J., Cumby, T., Huijsmans, J., Lorenz, F., Provolo, G., Perros, J. & McGechan, M. (1999)
SWAMP: optimising the use of slurry. In: Martinez, J. and Maudet, M.M. (eds.). Proceedings of the Eighth International Conference on Management Strategies for Organic Waste Use in Agriculture. CEMAGREF, France, pp. 37-48.

MAFF (1998a)
Code of good agricultural practice for the protection of water (The water code). 97pp. MAFF, London.

MAFF (1998b)
Code of good agricultural practice for the protection of soil (The soil code). 60pp. MAFF, London.

MAFF (1998c)
Code of good agricultural practice for the protection of air (The air code). 80pp. MAFF, London.

MAFF (1998d)
Guidelines for Farmers in Nitrate Vulnerable Zones. MAFF Booklet PB 2377. London.

Misselbrook T.H., Smith K.A., Johnson R.A. & Pain B.F. (2002)
Slurry application techniques to reduce ammonia emissions: results of some UK field-scale experiments. Biosystems Engineering 81, 313-321.

Pain, B.F., Phillips, V.R., Huijsmans, J.F.M. & Klarenbeek, J.V. (1991)
Anglo-Dutch experiments on odour and ammonia emissions following the spreading of piggery wastes on arable land. Wageningen: Institute of Agricultural Engineering. IMAG-DLO rapport 91-9, pp. 28.

Peel S., Lane, S.J., Withers, P.J.A, Chalmers, A.G., Chambers, B.J., Mansbridge, R.M., Metcalf, J.A, Jarvis, S.C, Harrison, R., Ellis, S. & Moore, N. (1997)
Profitable but sustainable dairy systems. Proc Brit Grass Soc Winter Meeting 1997 Grass is Greener? British Grassland Society, Reading.

Piccini, S. & Bortone, T. (1991)
The fertiliser value of agricultural manure: simple rapid methods of assessment. Journal of Agricultural and Engineering Research 49, 197-208

Scholefield, D. (2001)
United Kingdom. In: Nutrient Management Legislation in European Countries. Eds De Clercq, P., Gertsis, A.C., Hofman, G., Jarvis, S.C., Neeteson, J.J. & Sinabell, F. pp. 295-306 Wageningen Pers.

Smith, K.A., Chalmers, A.G., Chambers, B.J. & Christie, P. (1998)
Organic manure phosphorus accumulation, mobility and management. Soil Use and Management 14, 1-7.

Smith, K. A., Jackson, D. R., Misselbrook, T. H., Pain, B. F. & Johnson, R. A. (2000)
Reduction of ammonia emission by slurry application techniques. Journal of Agricultural Engineering Research 77, 277-287.

Smith, K. A. & Chambers, B.J. (1995)
Muck: from waste to resource. Utilisation: the inputs and implications. Agricultural Engineer 50, 33-38.

Smith, K.A., Brewer, A.J., Crabb, J. & Dauven, A. (2001)
A survey of the production and use of animal manures in England and Wales. III. Cattle manures. Soil Use and Management, 17, 77-87.

Smith K.A. & Frost J.P. (2000)
Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters. Part 1: cattle and sheep. Bioresource Technology 71, 173-181.

Sommer S.G., Christensen B.T., Nielsen N.E. & Schjorring J.K. (1993)
Ammonia volatilisation during storage of cattle and pig slurry: Effect of surface cover. Journal of Agricultural Science (Cambridge) 121:63-71.

Williams, J.R., Hurst, C.L., Chambers, B.J., Brookman, S. & Chadwick, D. (1999)
Rapid methods for the analysis of readily available nitrogen in manures. In: Corrall, A.J. (ed.) Accounting for Nutrients – A Challenge for Grassland Farmers in the 21st Century BGS Occasional Symposium No. 33, 171-172.

Withers, P.J.A., Peel, S., Mansbridge, R.J., Chalmers, A.G. & Lane, S.P. (1999)
Transfers of phosphorus within three dairy farming systems receiving varying inputs in feeds and fertilizers. Nutrient Cycling in Agroecosystems 55, 63-75.

Withers, P.J.A., Lane, S.J., Bowles, E., Chalmers, A.G., Allison, R., Blake, J., Williams, J & Jarvis, S.C. (2003)
Development of profitable and robust dairy systems with an acceptable level of emissions. Final Report to DEFRA.

3. Denmark
Part I: Regulations and environment

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3.1 Status of agriculture and nutrient losses

3.1.1 General characterisation

Denmark has a land area of about 43 100 km^2 and the landscape varies from flat to gently rolling. The climate is temperate, typically humid and overcast with mild, windy winters and cool summers. Agriculture occupies a large part of the land area of Denmark. As a result of the cultivation of heathland and wetland drainage, the percentage rose in the later part of the 1800s and early 1900s, reaching a peak of about 70% in the 1930s. Since this time, the percentage has been gradually declining, reaching 65% in 1990 and 62% in 2001. According to the Danish soil classification, sandy, clay and peat soils cover about 61, 32 and 7% of the land area, respectively (Madsen *et al.*, 1992). However, a soil is classified as clay if the clay content exceeds 10%. If only soils with a clay content >30% are considered, the area falls to about 1%. The sandy soils are mainly in the western half of Jutland, with the more clayey soils in eastern Jutland and on the main islands of Funen and Zealand. Valley bottoms will often contain soils with a high organic matter content, having once been wetlands.

About 55% of the agricultural area is in cereal production, mainly winter wheat, spring barley and winter barley. About 16% is used for roughage production in rotation, with grassland accounting for about half of this amount. Permanent grassland accounts for 14%, root crops and seed production about 4% each and the remaining area is in vegetable crops and orchards. Agriculture accounts for about 1.7% of the gross national income.

The number of farms declines by 3-5% annually, with the remaining farms expanding in size. Danish law gives neighbouring farms priority in bidding when a farm comes onto the market but there is still a tendency for land holdings to fragment. This is expected to be an increasing problem, especially for dairy farms, where transport or walking time for animals will restrict land use. The total number of farms in 2000 was 52 200, of which 21 500 were classed as fulltime farms, the remainder being part-time. Of the fulltime farms, 10 300 were cattle farms and 6 700 pig farms, the remainder being exclusively arable.

The cattle farms are predominantly in the central and western part of Jutland, corresponding with the lighter, sandy soils. Many of the pig farms are also in this area, so competition for land to utilise manure can be intense. Dairy farms accounted for about 90% of the cattle farms. The average area of dairy farms in 2001 was 73 ha and the average herd size was 60. Herd size has increased considerably with time, with small enterprises disappearing or expanding (Table 1).

Table 1. Number of enterprises, partitioned according to herd size.

Herd size	1990	2000	2010
1-29	10 571	2 045	400
30-49	6 813	2 441	500
50-74	3 352	2 710	500
75-99	780	1 587	600
100-199	400	1 432	2 300
>200	19	112	500
Total	21 935	10 327	4 800

Source: Danish Agricultural Society, 2002.

Milk quotas mean that milk production has remained fairly constant over the last 10 years (Table 2). Milk yield per cow has risen, so the national herd has decreased.

Table 2. Milk production and the national herd.

	1990	2000	2010
Milk production, kg x 10^6	4 742	4 720	4 721
Mean milk yield per cow, kg	6 297	7 426	9 046
National herd x 10^3	753	636	522

Source: Danish Agricultural Society, 2002.

Dairy farms vary in the extent to which they rely on roughage for feeding and this is reflected in a variation in crop rotation. A typical crop rotation in the fields nearest to the farm buildings would be whole crop barley/pea with undersown grass/clover (1 year), grass/clover for grazing and conservation (2 years) and then winter wheat (1 year). Further from the farm buildings, a typical crop rotation might be spring barley (2 years), whole crop barley/pea with undersown grass or grass/clover (1 year) and grass or grass/clover for conservation.

The future changes in dairy farming in Denmark are, as everywhere else, dependent on the commercial and regulatory climate. Assuming the current trends in the structure of agriculture and genetic milk yield potential continue and milk quotas still exist, dairy farms will become larger but there will be fewer of them (Table 1). Milk yield per cow will increase but total production will remain static, so the national herd will shrink. Paid employment on dairy farms could fall by as much as 40% between 2000 and 2010 (Danish Farmer's Union, 2002).

3.1.2 Environmental impact

Nitrate leaching, as estimated by modelling, has been declining over the years (Figure 1).

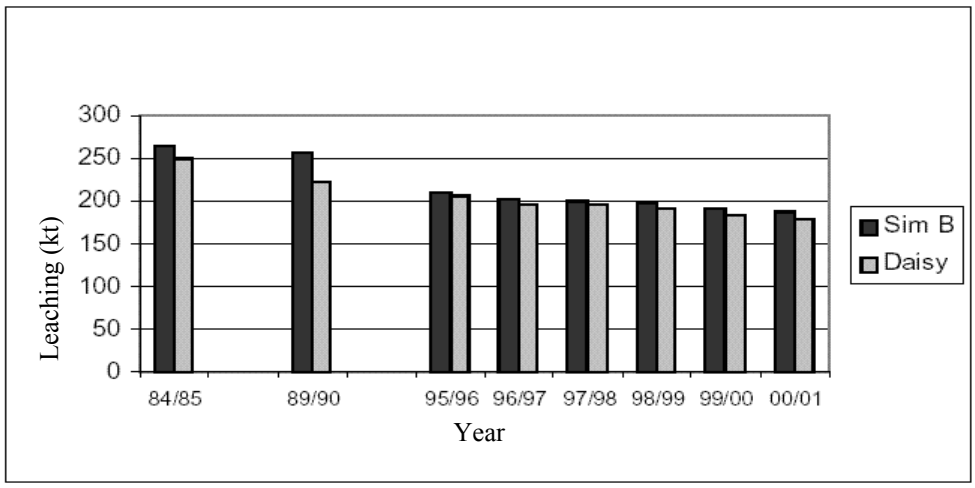

Figure 1. *Nitrate leaching as modelled by the empirical SIM B model and the mechanistic DAISY model (Kyllingsbæk et al., 2000).*

Recent estimates suggest that nitrate leaching is equivalent to an average of about 80 kg N ha^{-1} yr^{-1} but a partitioning between different farm types is not available. At a national level the average estimated leaching of nitrogen has been between 40 and 44% of the total amount of N applied to the fields in artificial fertiliser and livestock manure (excl. N from N-fixing plants and atmospheric N deposition) from 1990 to 2000, despite an decreased N input.

Ammonia emissions have also been falling (Figure 2).

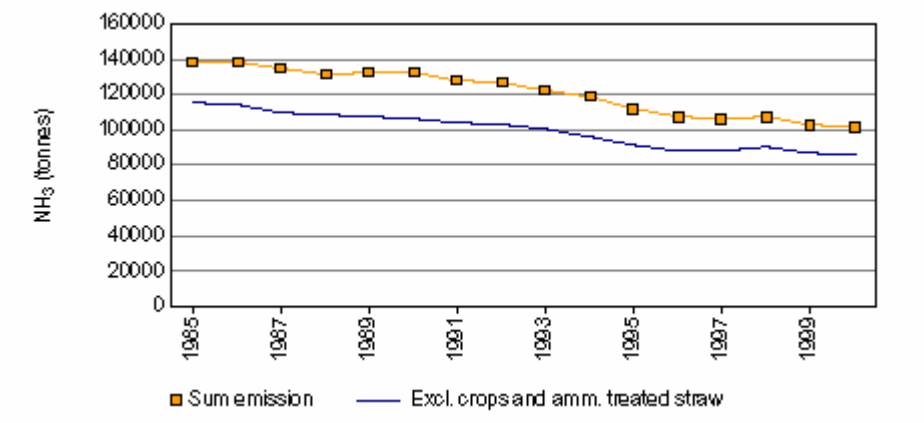

Figure 2. *Ammonia emission from agriculture in Denmark (Illerup et al., 2002). Blue line represents emission as defined by NECD.*

At a national scale, cattle farming is estimated to account for about 34% of the ammonia emission (Hutchings *et al.*, 2001). In contrast, pig farming accounts for about 40%.

Losses of N to the sea have decreased somewhat over the last 10 years (Figure 3), although there is considerable annual variation due to differences in rainfall between years. Losses of P have fallen more dramatically but this has mainly resulted from the control of point sources, such as sewage works.

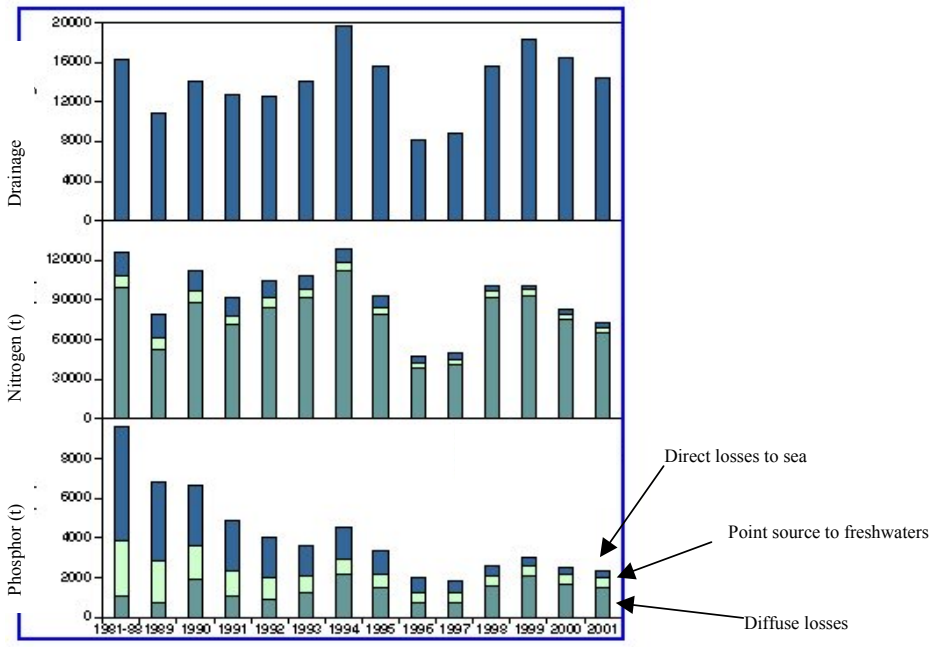

Figure 3. Annual flow, N and P in freshwater entering the sea around Denmark (www.dmu.dk).

The concentration of nitrate + nitrite in freshwater streams and rivers is generally below the limit set in the Nitrate Directive. However, the situation for nitrate levels in groundwater remains of concern, with a significant proportion of the surface groundwater exceeding the permitted limit (Figure 4).

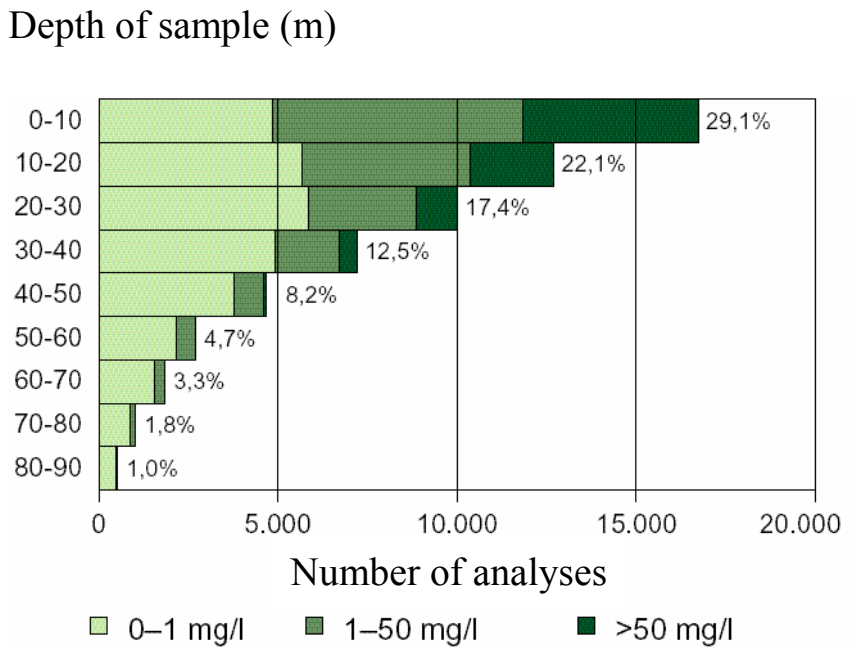

Figure 4. Nitrate concentrations in groundwater with increasing depth.

It is unclear to what extent this distribution with depth reflects denitrification as water drains downwards, as opposed to a continued problem with water quality near the surface. However, since drinking water boreholes continue to be closed due to excessive nitrate concentrations, the issue will continue to have a high political focus.

Regarding greenhouse gas emissions, the reduced number of dairy cattle has reduced the enteric emission of CH_4. However, there has been an increase in the straw-based animal housing systems at the expense of liquid manure handling, so CH_4 from manure management has increased a little. The decreased used of N fertiliser and the reduced ammonia emission has furthermore reduced the emission of N_20.

3.1.3 Nutrient cycling in dairy farming systems

The main inputs to dairy farming occur via the purchase of animal feed and fertiliser, plus the fixation of N in leguminous crops (Figure 5). The main controlled outputs are in animal products (milk, animals sold) and plant products (grain etc.). The remainder (the nutrient surplus) either accumulates on the farm or is lost to the environment.

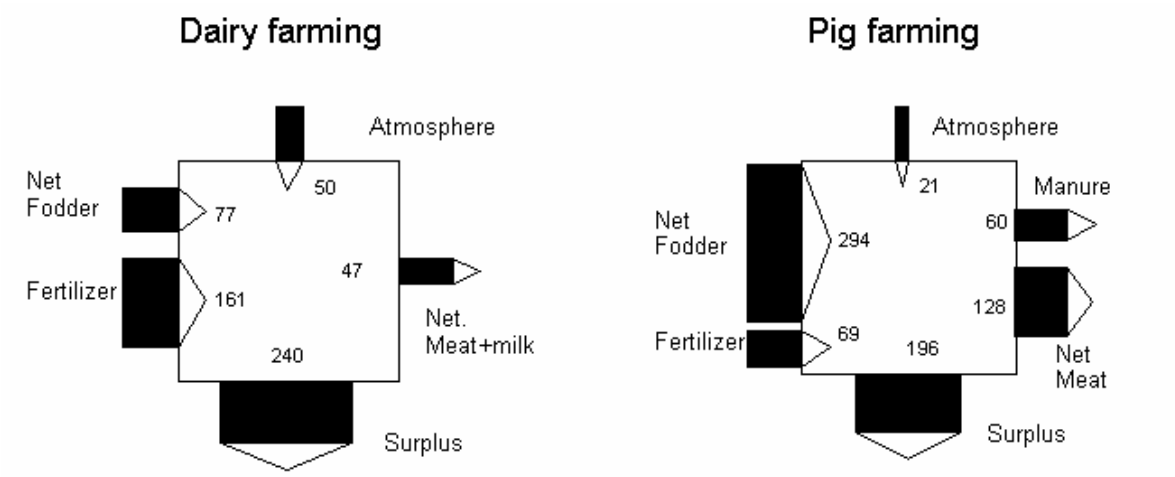

Figure 5. Typical N surpluses for dairy and pig farms.

The farm P surplus tends to increase with stock density (Figure 6). Although it may appear that the increase is greater for cattle than for pig farms, it should be noted that when the stock density exceeds 1.4 livestock units (LU) per ha for pigs and 1.7-2.3 LU per ha for cattle, the 'Harmony rules' are enforced. These mean that the manure produced in excess of these levels must be exported from the farm. One LU represents 100 kg manure N yr^{-1} ex storage, so a dairy cow with a mature weight of around 600 kg equates to 0.85 LU. This enforced export of manure makes the relationship between P surplus and stock density markedly non-linear. The corresponding relationship for N is shown in Figure 7. This non-linearity can be largely excluded by relating the farm surplus to the amount of manure N applied in the field (Figure 8).

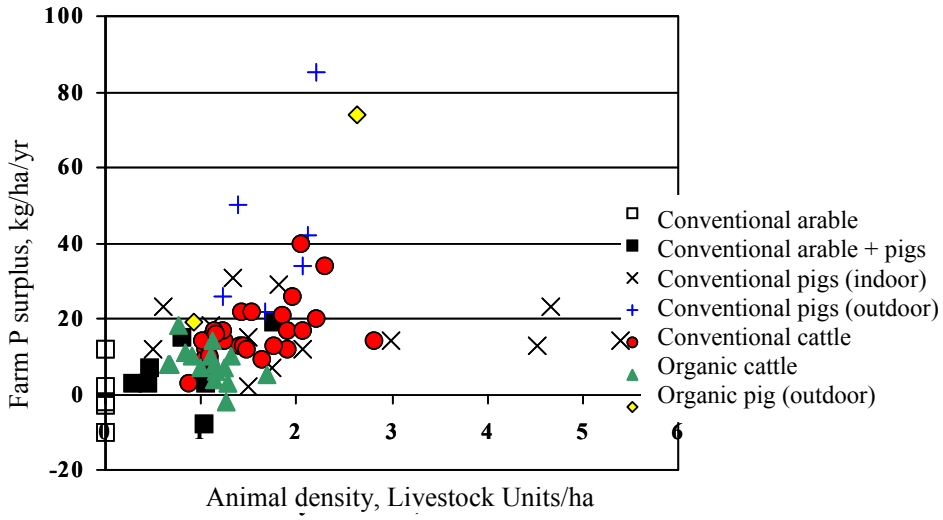

Figure 6. *Farm P surplus.*

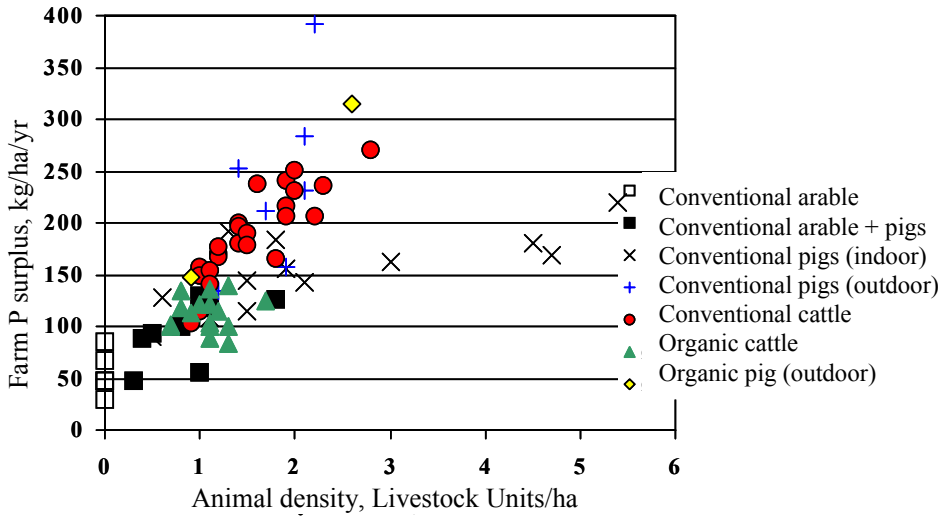

Figure 7. *Farm N surplus.*

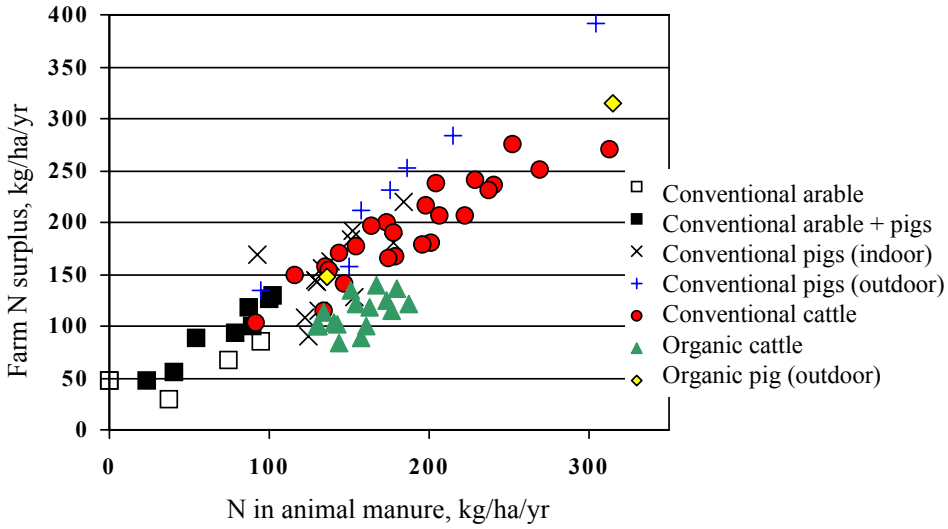

Figure 8. Farm N surplus related to manure N applied to fields.

At a particular stock density, the variation in the nutrient surplus results from differences between farms in farming styles, animal housing and manure storage system, the soil/environment interaction and in the diligence of the farmer in managing nutrients. The internal flows of N within dairy farms are described in detail in Part II of the Danish country report.

3.2 Legislation and policy relating to nutrient management

3.2.1 Background

In the 1970s and start of the 1980s, there was increasing concern about the effect of nutrient losses from agriculture. However, the event that finally kick-started the regulation of nutrient management in agriculture is attributed to a television report. This showed dead lobsters in the sea area between Denmark and Norway and was attributed to hypoxia resulting from an algal bloom stimulated by agricultural nutrient runoff. The first legislation ('NPO') was passed in 1985 and was mainly targeted at nitrate leaching or direct pollution of waterways. The main elements were:

- 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 large dairy cows per ha.
- Various measures to reduce runoff from silage clamps and manure heaps.

The second major legislation was the Aquatic Action Plan (VMP I). This was adopted in 1987 and followed substantial hypoxia in the Danish inshore waters in 1986. Although the main target was nitrate leaching, measures to reduce ammonia volatilisation were also included. The main elements of VMPI included:

- Minimum 9 months slurry storage capacity.
- Ban on slurry spreading from harvest to 1 November on soil destined for spring crops.
- Mandatory fertiliser and crop rotation plans.
- Minimum proportion of area to be planted with winter crops.
- A floating barrier (natural crust or artificial cover) mandatory on slurry tanks.
- Mandatory incorporation of manure within 12 hours of spreading.

The third major legislation, the Action plan for sustainable agriculture, was adopted in 1991 and included the following elements:

- Ban on slurry spreading from harvest until 1 February, 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.
- Statutory norms for the proportion of manure N assumed to be plant-available.

The fourth major legislation, the second Aquatic Action Plan (VMP II) was adopted in 1998, partly in response to the Nitrates Directive. It contained a mixture of regulation and incentives:

- 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.
- Maximum limits on the plant-available N applied to different crops reduced to be the economic optimum minus 10%. The economic optimum is calculated annually, taking into account the mineral N in the soil (from a comprehensive soil sampling system).
- Mandatory 6% of area to be planted with catch crops.
- Subsidies to plant 20 000 ha with trees.

VMPII was designed to run for 6 years and included a mid-term assessment of progress. This resulted in a further action:

- 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 fertilisation norms and assumed plant-available N in slurry.

The latest regulations are the Ammonia action plan. This was adopted in 2001 as a result of concern over the deposition of N to sensitive ecosystems. It had the following elements:

- Subsidies to encourage good manure handling in animal housing and improved housing design.
- Mandatory covering of all slurry tanks and 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.
- Guidance to planning authorities regarding agricultural developments near sensitive ecosystems.

The trend that can be seen in the development of these regulations is that the regulations initially concentrated on enforcing good agricultural practice but that when this was perceived to be insufficient, there was an increasing focus on reducing nutrient inputs, particularly of N.

3.2.2 The current situation

3.2.2.1 Nitrates

When implementing the Nitrate Directive, Denmark decided to designate the whole country as a nitrate sensitive area (NSA). This decision reflects the dependence of Denmark on groundwaters for virtually all its drinking water, combined with the problems that would arise if a large number of relatively small areas were designated. Such areas would often divide individual farms into NSA and 'non-NSA', making effective control extremely difficult.

A major element of the Nitrate Directive is the limit of 170 kg N ha^{-1} yr^{-1} in organic manures that applies in NSAs. However, in 2002, Denmark succeeded in negotiating a derogation from the Directive, to allow up to 230 kg N ha^{-1} yr^{-1} for cattle farms where more than 70% of the land area are planted with fodder crops (pasture, fodder beet, grass catch crop) (EC, 2002). The arguments used were:

a. that the longer growing period of such crops allowed them to capture more plant-available N than crops with a shorter growing season, so could tolerate a higher N application without causing excessive nitrate leaching and
b. that the general regulation of agricultural nutrients in Denmark is sufficient to ensure compliance with the target for nitrate concentrations in water. The derogation is valid for about 5% of the agricultural area and expires on 1 August 2004.

The Harmony Rules, setting a limit for each farm for the maximum amount of manure N that can be applied in a year, are based on standard values that are published each year for the different livestock types and manure handling systems. These standards are based on an average value for the average amount of N excreted per livestock type, obtained from statistical data relating to feeding practice and N removed in the relevant animal products (e.g. milk). For each of the main animal housing and manure storage types, the loss of N as ammonia is calculated and subtracted from the N excreted to obtain the ex storage value. The calculation of ammonia emission is based on emission factors for each livestock, housing and storage type (Hutchings *et al.*, 2001). To ensure compliance with the Harmony Rules, the farmer must report the number of livestock of each type on an annual basis. These data are stored in the national Central Livestock Database (CHR). The land area used in the calculation of the maximum stock density relates to the areas to which manure can legally be applied i.e. arable and grassland but not areas such as woodland or heathland. The data are reported annually and are stored in the General Agricultural Database (GLR). If farmers have more livestock than permitted by the Harmony Rules, they are obliged to negotiate a legally-binding agreement with a neighbouring farm to accept the excess manure.

The VMP I and II established maximum levels for the amount of plant-available N that could be applied to crops of different types, with limits specified for different soil types. These maximum levels are calculated on the basis of the yield response of each crop to mineral fertiliser N, using data obtained from national fertiliser trials. The level is currently set at 10% below the economic optimum. The proportion of plant-available N assumed in manure is 75% for pig slurry, 70% for cattle slurry, 45% for FYM and 65% for all other manure types. To ensure compliance, farmers must calculate and submit an annual manure budget. This shows how the manure N (as calculated from the published norms) is distributed over the crops on the farm and how much supplementary fertiliser N was applied. The administrative authorities receive an annual account of fertiliser N purchases for each farmer from the fertiliser wholesaler, allowing them to cross-check fertiliser consumption and the amounts stated in the manure plan.

VMPII also included a plan for up to 16 000 ha of riverine meadows to be converted to wetlands, with the assistance of a subsidy to the farmer. The intention of this measure was to protect aquatic environments by increasing the denitrification of nitrate from surrounding farmland, as it drained towards the river or lake. However, the total area of meadow so far converted to wetland is very small. In those situations where large-scale denitrification is achieved, it is also uncertain what proportion of the nitrate N is converted to harmless dinitrogen gas, as opposed to nitrous oxide, which is a greenhouse gas.

3.2.2.2 Other compounds

The Gothenburg Protocol of the Convention on Long Range Transboundary Pollution, as enforced in the EU National Emission Ceilings Directive (NECD), limits the Danish emission of ammonia to a total of 79 kt yr^{-1} in 2010. The EU Habitat Directive also requires protection of natural and semi-natural ecosystems, including heathland and woodland areas that receive quantities of N via atmospheric deposition that exceed the relevant critical load for such areas. Agriculture, and particularly livestock farming, is responsible for about 99% of the Danish ammonia emissions. To reduce these emissions, the government adopted the Ammonia Control Programme (see above).

There is currently no explicit regulation for phosphate. However, farmers are obliged to leave a 2 m uncultivated strip adjacent to all watercourses. This strip is intended to work as a buffer area, to filter P from surface water flowing from the cultivated area.

3.2.2.3 Environmental Impact Assessment

Farmers wishing to expand their production above certain limits must undergo an Environmental Impact Assessment (EIA), conducted by the county authorities. This assessment covers a wide range of impacts, including the consequences of losses of nitrates and phosphate to water resources, ammonia deposition to nearby semi-natural ecosystems and the impact on biodiversity on the farm.

3.3 Future legislation and policy relating to nutrient management

Legislation relating to the control of agricultural nutrients in Denmark has grown stepwise, as politicians perceive new threats to the environment or the failure to achieve previous goals. Figure 1 and Figure 2 show that the losses of both nitrate and ammonia are coming down, so the measures adopted so far can be said to have had an effect. Denmark is one of the few countries where the measures to implement the Nitrates Directive have been accepted as adequate by the Commission of the EU. On the other hand, the current regulations are complex, expensive to administrate and drinking water boreholes continue to be closed, due to excess nitrate concentrations. However, rather than ask whether or not the current regulations are the most effective way to control agricultural nutrients, it is more relevant to ask whether it is likely that they can meet the challenge of future demands. To address this question, it is necessary to consider how the regulatory and financial climate is likely to develop over the next few years.

Until recently, projections of the Danish national ammonia emissions in 2010 suggested that they might be below the limit of 69 kt set by the NECD. However, the most recent projection (Illerup *et al.*, 2002) suggest that the emissions may exceed the limit by about 10 kt. This newer projection makes assumptions concerning both the production environment over the next few years and the manure management in Denmark, so must be treated with caution. If true, further measures will be required, in addition to those in the Ammonia Action Plan (see above).

Arguably the most important change to agricultural nutrient management is likely to be the adoption of the Water Framework Directive (CEC, 2000) (WFD). The WFD operates on the basis of ecological goals that are determined independently for each catchment. This geographically variable, goal-oriented legislation contrasts with the Nitrates Directive, which is national, behaviour-oriented, and the NECD, which is goal-oriented, but at a national scale. As the goals have yet to be set in detail, its impact in Denmark is unclear. However, what is clear is that there will be a need for a regulative system that can manage the geographic variations. It is also very likely that regulation of P, which has not explicitly been regulated hitherto, will be necessary. This is because it is often P rather than N that is responsible for the disturbance to inland surface water ecosystems.

The Danish regulations have hitherto been at the national scale and aimed exclusively at controlling behaviour. Given that the EU regulation is increasingly goal-oriented and at regional or local scales, it is worthwhile considering whether regulation should also be goal-oriented and how scale may impact on regulation.

3.3.1 Behaviour-oriented versus goal-oriented regulation

The suitability of the current (largely behaviour-oriented) regulations to manage nutrients in the future can be challenged on several grounds. The first is that the regulations are already complex and are likely to become increasingly so, if P must also be controlled as well as N and if environmental goals vary geographically. Although there is little evidence of fraud, the complexity of the regulation leaves scope for one-sided interpretations and avoidance. The second is that by imposing behaviour rather than setting targets, the farmer is unable to choose the most cost-effective management option to reduce nutrient losses. Thirdly, it is important to remember that the current system of managing N is based on national average values of excretion and ammonia emissions for each of the livestock type x manure handling combinations. As the scale at which the regulations are targeted decreases from national to catchment to individual farm, these averages become increasingly invalid. At the scale of the

individual farm, the use of these norms can lead to either an underestimate of the nutrients in manure, leading to increased environmental impact, or an overestimation, leading to unwarranted loss of income by the farmer. This is particularly true for cattle farms, where there is a greater scope for variations in feeding than on pig farms.

Using a goal-orientated approach, such as annual farm-scale nutrient balances, overcomes some of these disadvantages but creates new ones. For both farmer and regulator, it remains to be shown that a system based on farm balances will really be less complex than the present one. For the farmer, there would be a degree of uncertainty each year whether a target balance will be achieved (due to annual variations in the weather). For the regulator, there are several problems. How should one account for the import and export of manure and (for N) fixation in leguminous crops? How are surpluses related to losses to the environment, as opposed to changes in the soil storage? How can losses be partitioned between the different loss routes (e.g. for N, leaching, denitrification, ammonia volatilisation), so that Denmark can ensure that it obeys the relevant national laws and EU directives? The cost implications of reducing a target balance becomes difficult for regulators to assess, as farmers can choose a variety of options to achieve a given target balance. Finally, Denmark has an established system that both farmers, national regulators and the Commission of the EU have learnt to accept, so there has to be a good case made if this system is to be replaced. These matters are still being debated in the run-up to a third Aquatic Action Plan.

3.3.2 Regulation and scale

Regulation at the regional scale or below places a high demand on both the models used to assess the economic and environmental consequences of different policy measures and the data needed to drive them. The models must be capable of linking production and the losses to the environment and be adaptable to the particular circumstances within the target region or locality. If behaviour-oriented regulation is under consideration, not only must the direct consequences be simulated (e.g. on crop growth and nitrate leaching) but the indirect consequences (e.g. on changes in the choice of crop rotation or fertilisation regime). This is particularly the case for cattle farming, where crop production, animal nutrition, milk yields and manure production are closely connected. Data concerning both the physical environment (e.g. soils, climate), farm structure (land ownership, animal numbers, manure handling systems) and current agricultural practices must be present at the regional or local scale. If goal-oriented regulation is under consideration, the situation is more complicated. A range of maximum surpluses and financial penalty options must be tested. At each surplus level, the likely response of the farmers in the area must be simulated, in terms of the extent to which they are prepared to pay for excess surplus and the methods they choose to achieve a given surplus. The environmental consequences of these behavioural responses to goal-oriented regulations need then to be modelled, so an appropriate surplus can be selected. Whether using goal-oriented or behaviour-oriented regulation, limitations imposed by data quality and the models currently available constrain the accuracy of predictions. Stepwise changes in regulations, similar to those seen over the last 15-20 years, will also be necessary in the future.

Irrespective of the method of regulation that is chosen, there will be difficulties in gaining effective control if environmental targets are set at a scale below the farm level. For example, the current annual manure budgets calculate manure use on a field-by-field basis but there is no guarantee that those fields actually receive the calculated amounts of manure. With the expansion of farm sizes, it is not unusual for farms to have fields lying some distance from the animal housing and manure storage. This will increase in the future, as average farm size continues to grow. Manure application is an expensive and time-consuming process and it is logical for farmers to wish to apply manure preferentially to those fields nearest the manure storage, year after year. For dairy farms, there is the added demand that grazing by lactating cattle must occur sufficiently close to the animal housing that walking times are not excessive. The combined effect may be a localised over-fertilisation with animal manure. This will be a problem, particularly if these fields are close to ecosystems sensitive to ammonia deposition (as much ammonia is deposited close to the source), within the catchment areas of drinking water boreholes or are adjacent to aquatic ecosystems with stringent ecological goals.

3.4 Research; concepts and tools

Research related to the losses of nutrients from agriculture to the environment, both past and present, can be broadly divided into two directions. The first is designed to examine, explain and predict the effect of agricultural activity on losses of nutrients. This research is mainly driven by the desire of regulators to measure and control the losses from agriculture, i.e. the key word is 'constraint'.
The second is designed to develop indicators of environmental pollution and to develop systems that enable farmers to manage their farms so that the production and environmental goals are balanced. This research is more farmer-orientated and the key word is 'enablement'.

An example of the first type of research is the agricultural catchment monitoring programme, which is managed by the National Environmental Research Institute. The objectives of the agricultural catchment monitoring programme are to determine:

- the developmental trend in the agricultural sector's contribution to pollution of the aquatic environment,
- the relationship between agricultural practice and the loss of substances to the surroundings,
- the reduction in the nutrient content of the water from the time it leaves the root zone to the time it reaches the watercourses,
- the developmental trend in the concentration of nutrients, pesticides and degradation products in subsurface groundwater,
- the developmental trend in agricultural consumption of nutrients and hazardous substances, and
- the magnitude of and developmental trend in the nutrient load from fields.

The programme started in 1988 as part of the first Aquatic Action Plan but has been modified and extended during the intervening period. The programme has been recently revised, to account for the demands for new knowledge that arises through the need to implement the WFD. Full details can be found at http://ovs.dmu.dk/0english/index_html

One example of the second type of research was the collection by the Advisory Service of P and K from 60 farms over 3 years. Cattle, pig and arable farms were represented in approximately equal numbers. These data were used to generate farm nutrient surpluses and the results enabled farmers to compare their performance with a relevant 'reference' surplus. The reference surplus was calculated using the standard animal excretion and animal/plant production values used by the Danish authorities for regulatory purposes. This approach was taken further in a recently completed project that developed a 'multi-objective decision support' tool (MODS) based on ethical accounting. The ethical accounting consists of a number of discussions with the farming family (to help them clarify their own values and goals in the light of interests existing in society) and a yearly accounting with indicators of resource use, environmental impact and animal welfare etc. Included in the indicators of resource use is a calculation of a farm nutrient surplus. The goal is to enable farmers to voluntarily contribute to the development of the agricultural production in a more environmentally friendly direction. The MODS was developed in co-operation with the organic and conventional farmers' unions in Denmark and with 20 animal husbandry farms (9 of which organic).

Lying somewhere between the two approaches is the development of the FASSET farm model (www.fasset.dk), developed by the Danish Institute of Agricultural Sciences and the Danish Institute of Food Economics. This was mainly prompted by the need to simultaneously predict the environmental and economic consequences of imposing or adopting various management practices. However, it also reflected the recognition that with the increasing number of compounds to regulate, there was a risk of pollution-swapping, i.e. a measure introduced to reduce the loss of one compound leading to the increase loss of another. An example of this is the increase in nitrate leaching that would occur if ammonia emissions from field-applied manure were reduced, without a change in fertilisation to take account of the higher amounts of plant-available N remaining in the manure. The FASSET model is dynamic and process-oriented, and includes both animals, the manure handling system and the fields (Figure 9).

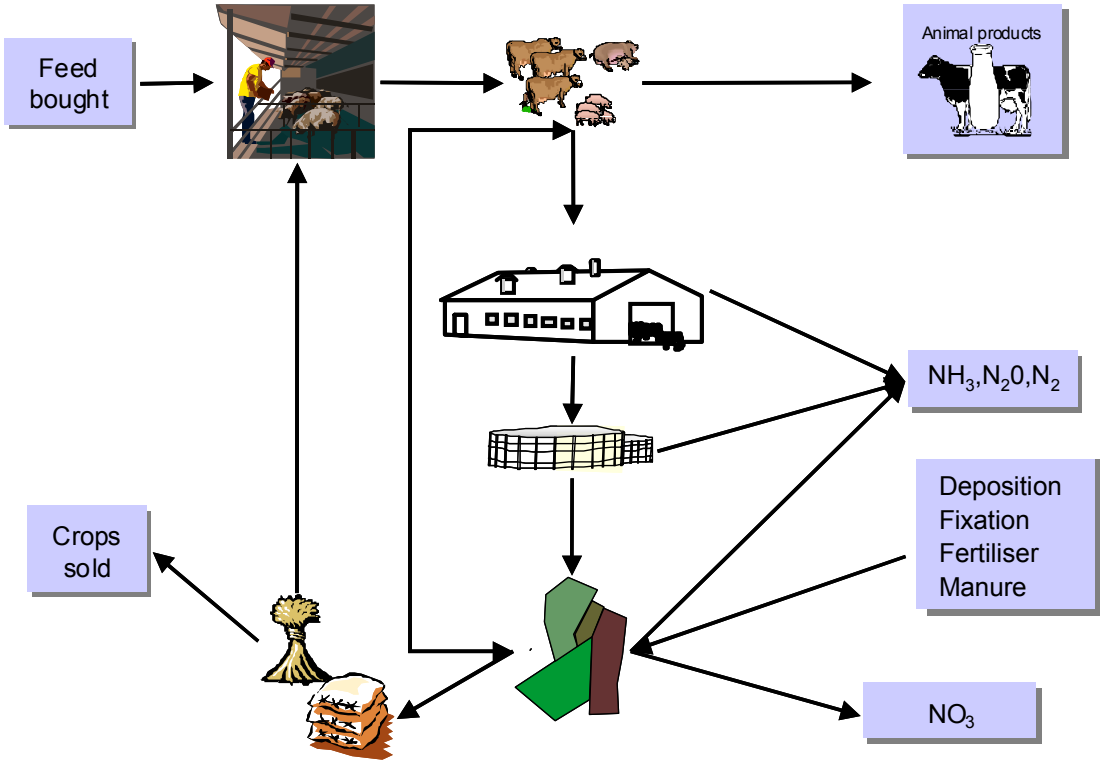

Figure 9. N flow in FASSET.

This makes it a useful testbed for asking 'what if' type questions of the type asked in environmental impact assessments. It is currently being parameterised and tested in a new research project (FARM-N). In addition to drawing upon field-scale data from the research and advisory systems, the project will also use data from the Study Farm programme, which intensively monitors production on 55 commercial farms. The project will also lead to the development of a prototype Internet-based interface that will allow farmers and regulators to estimate the losses of N as nitrate leaching, ammonia volatilisation or via denitrification. However, FASSET requires information on farm structure and farm management (including fertilisation and cultivation), so cannot alone answer questions concerning scales above the farm level, such as the catchment or nation. A system developed in a recently completed project (ARLAS) took a step towards these higher scales by constructing a GIS-based system to predict responses to economic and regulatory measures (assuming economic rationality) and then generating appropriate crop rotations and fertilisation schemes, for input to FASSET. The results from FASSET are then passed to a hydrogeological model, where the consequences for drinking water and surface water can be predicted.

3.5 Conclusions

Over the past 20 years, an increasingly strict set of regulations relating to the use of N in agriculture has evolved in Denmark. Measurements show that these regulations have reduced losses of N to the environment.

The focus of regulation in Denmark has hitherto been almost exclusively on nitrate leaching but the number of compounds to be regulated is increasing and will continue to do so. These compounds include ammonia, nitrous oxide, methane, carbon dioxide and atmospheric particulates. If regulators are not careful, policies related to one pollutant compound may increase emissions of another (pollution swapping). It is uncertain whether such a situation can be avoided by making an already complex system of regulation even more complex. For nutrients, a system based partly on managing farmer behaviour and partly on farm surpluses may be appropriate. However, we still lack good tools to predict the environmental impact of agriculture at the farm scale and, in particular, to distribute farm N surpluses between losses or retention on the farm.

References

CEC, 1992.
Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities L 206, 7-50.

CEC, 2000.
Council Directive 2000/60/EC of the European parliament and of the council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities L 327, 72 pp.

CEC, 2001.
Council Directive 2001/81/EC of the European parliament and of the council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants. Official Journal of the European Communities L 309, 22-30.

CEC, 2002.
Commission decision of 18 November, 2002 concerning a request for derogation under paragraph 2(b) of Annex III and paragraph 9 of Council Directive 91/676/EEC concerning protection of waters against pollution caused by nitrates from agricultural sources.

Danish Farmers' Union, 2002.
Danish agriculture 2010 – development scenarios. Danish Farmers' Union, Copenhagen, 60 pp (in Danish).

Hutchings, N.J., Sommer, S.G., Andersen, J.M., Asman, W.A.H., 2001.
A detailed ammonia emission inventory for Denmark. Atmospheric Environment 35, 1959-1968.

Illerup, J.B. Birr-Pedersen, K., Mikkelsen, M.H., Winther, M., Gyldenkærne, S., Bruun, H.G & Fenhann, J., 2002.
Projection Models 2010. Danish emissions of SO_2, NOx, NMVOC and NH_3 NERI Technical Report No. 414.

Kyllingsbæk, A., Børgesen, C.D., Andersen, J.M., Poulsen, H.D., Børsting, C.F., Vinther, F., Heidmann, T., Jørgensen, V., Simmelsgaard, S.E., Nielsen, J., Christensen, B.T., Grant, R. & Blicher-Mathiesen, G., 2000.
Nitrogen balances in Danish agriculture. Field and housing balances. National Environmental Research Institute and Danish Institute of Agricultural Sciences, 74 pp.

Madsen, H.B., Nørr, A.H. & Holst, K.A., 1992.
The Danish Soil Classification. Atlas of Denmark Series I, Volume 3. Rosendahl Press, Copenhagen.

4. Denmark
Part II: N turnover on Danish mixed dairy farms

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Summary

Nitrogen balances from three sets of pilot farms from 1989 to 2001 are presented, and a set of representative farms based on Danish farm accounts from 1999. The data represent typical management and the range between farms is well documented. The results from all independent analyses show the same tendencies. The conventional dairy farms have reduced their farm gate N surplus with around 30% during the 1990s. Since 1994 the surplus has been 173-177 kg N ha^{-1} with a stocking rate of about 1.5-1.7 LSU ha^{-1} (1 LSU = 0.85 Holstein dairy cow). In the same period, the N surplus on organic dairy farms was between 112-128 kg N ha^{-1} with a stocking rate of 1.1-1.3 LSU ha^{-1}. On the conventional farms the N surplus significantly increased with stocking rate, with the ratio of 78 kg N LSU^{-1}. The difference between farm N balance of conventional and organic dairy production systems was 57-61 kg N ha^{-1} corrected for stocking rate. An average field level balance was estimated using simple models of ammonia losses and denitrification to subtract gaseous emission from the farm gate balance. It is discussed how assumptions regarding soil-N changes can give estimates of N leaching.

4.1 Background

Dairy production is characterized by major internal flows between field and herd, both with fodder and recycling of animal manure. Grazing grass/clover sward is important on many farms. This paper gives a description of the internal and external N flow and N loss on Danish dairy farms from 1990 to 2003. After entering into the EU in 1972, a specialization from mixed dairy and pig farms has been going on towards bigger and more specialized dairy farms. Already in the 1970s, regulations were introduced limiting maximum stocking rate of animals per area, and in 1999 only 5% of the specialized dairy farms had more than 2.3 LSU ha^{-1}. During the last 10-15 years detailed, public regulations have been introduced and continuously tightened. In the early 1990s mandatory slurry storage capacity was extended to a minimum of 6-9 months, and later restrictions for imported mineral fertilizer have been introduced. For a more detailed description of these regulations, see Part I of the Danish country report.

Since 1950, pilot farm studies have been part of applied agricultural research in Denmark. The Danish Institute of Agricultural Sciences monitors 30-40 mixed dairy farms per year and prepares technical-economic reports on livestock and field production, animal welfare and environmental impact. Farms with pig production, organic dairy, organic egg, organic pig and organic arable production have been included, and the environmental aspects, especially concerning N flows between field and herd have become primary focus areas. On the pilot farms the flow

of feed and nutrient from field to herd has been measured, and internal N balances of fields and groups of animals have been measured and published; see Table 6. From 1996 onwards, the central advisory organization has been involved in data recording and reporting.

The private pilot farmers were selected to be progressive and interested in cooperation with experts. The farms have been larger than average, partly because 'future' farms were chosen to ensure that the data could be used for the development of the total dairy sector in Denmark. Advisors, farmers and other stakeholders have regarded the results as representing typical and relevant farms. Lately, the demand for comprehensive descriptions of resource use and environmental impacts from major farm types in question (dairy, pig and arable) has generated a need for statistically representative farm models based on an average management level. Technical-economic data based on Danish farm accounts are available from a group of farms representing the major agricultural sectors in Denmark with the actual production and management level. This publication describes the Danish method of nutrient accounting using data from dairy pilot farms and representative technical-economic data for the total dairy sector in Denmark.

The objectives of this paper are:

- to characterize Danish dairy farms in terms of production, size and crop-livestock interactions,
- to compare N surplus from different dairy systems especially organic vs. conventional production,
- to present data on nutrient cycles and farm N surplus for Danish dairy farms in comparison with other Danish farm types,
- to demonstrate the use of pilot farms in combination with models of typical farms based on representative technical-economic accounts as a method for the quantification of nutrient losses and the potential for improvements.

We intend to present analyses of N flows and surpluses from four independent data sets, three of which are based on different groups of pilot farms and one based on a large, representative sample of farm accounts. On the basis of these data, it is demonstrated how relatively simple assumptions allow modelling of farm N flows and breakdown into herd and crop sub-systems. From this it is possible to estimate emissions and losses that allow for comparisons between different systems and projections of developments of typical dairy systems in the near future.

4.2 Methods

All Danish farms are obliged to keep detailed records of purchases and sales for tax purposes and the yearly accounts are made with professional help. A representative set of these accounts, 2239, are reported by the advisors to the Danish Research Institute of Food Economics (DRIFE) and constitute the basic empirical input into the representative farm types presented here. Besides the economic data, information on land use, livestock numbers and amounts of produce are included in the data set compiled by the advisors. The modelled representative farm types were based on 1999 farm accounts, sampled as to represent the total Danish agricultural sector for main livestock and crop production. The data will be described in detail on the homepage www.lcafood.dk. The same overall method was used in the years 1995-1996 (Halberg *et al.*, 1999). Table 1 shows the number of accounts used for the models and which farm parameters were found directly from the accounts. The modelled representative farm types were compared with data from 83 pilot farms. Pilot farms were monitored during the years 1987-2002 by longitudinal survey techniques as described at http://www.agrsci.dk/jbs/bepro/concept%20pdf%20format.pdf. Pilot farm results were used for comparisons with model farms and for demonstrating the variation around the average N surplus.

Table 1. Characteristics of representative specialized Danish dairy farms in 1999.

			Sandy (< 5% clay)			Loamy (5-15% clay)			Average				
			Conventional		Organic	Conventional		Organic	Dairy		Pig	Arable	DK
	Farm type[3]		LSU < 1.4	1.4-2.3		LSU < 1.4	1.4-2.3		Conv.	Org.			
	Unit	Measured (M) Calculated (C) Estimated (E)											
Farms in population	Number of farms	C	1912	4004	695	432	849	115	7794	810	7310	7706	43570
Farms in dataset	Number of farms	M	83	182	125	23	32	24	350	149	476	318	2073
Agricultural area	1000 ha in DK	M	156	261	69	43	43	10	530	81	587	732	2523
Herd													
Number of cows	Cows/farm	M	48	67	84	56	55	62	61	82	0	3	13
Number of LSU[3)]	LSU/farm	M	81	109	131	87	84	100	99	128	111	17	48
Area													
Farm area	Ha/farm	M	81	65	99	100	50	88	68	100	70	82	51
Permanent grass	Ha/farm	M	7	6	8	8	3	9	6	9	1	1	3
Set aside	Ha/farm	M	6	4	5	6	2	5	4	5	5	7	4
Cereal for harvest	Ha/farm (%)[1)]	M	33(49)	12(23)	14(16)	45(56)	16(38)	21(29)	20(34)	15(17)	50(79)	49(66)	27(61)
Maize & whole crop	Ha/farm (%)[1)]	M	13(20)	22(41)	29(34)	15(19)	13(31)	20(28)	18(32)	28(31)	0(0)	1(1)	4(9)
Grass/clover in rotation	Ha/farm (%)[1)]	M	13(20)	16(30)	39(47)	12(15)	12(27)	28(39)	14(26)	40(44)	1(1)	1(2)	5(10)
Stocking rate	LSU/ha farm area	M	0.99	1.67	1.32	0.88	1.66	1.13	1.46	1.28	1.59	0.21	0.93
	LSU/ha cultivated[2)]	M	1.21	2.05	1.48	1.06	1.91	1.31	1.76	1.41	1.76	0.23	1.07
Field production													
Cereal	100 SFU/ha	M	52	49	41	56	54	44	52	42	59	64	57
Tot 100 SFU ha^{-1}cultivated	100 SFU/ha	C	55	57	44	55	58	44	57	45	52	55	54
Avr. protein in total fodder	% protein of SFU	E	13.6	14.9	17.4	13.3	14.8	16.2	14.3	17.0	11.2	10.6	11.8
Animal production													
Milk yield	Kg ECM cow^{-1} year^{-1}	M	7431	7429	6866	7227	7288	6811	7373	6860	-	7354	7305
Fodder requirement													
SFU/LSU, in total	SFU/LSU	E	4768	4768	4468	4844	4781	4406	4774	4461	4622	4807	4555
-in roughage	SFU/LSU	E	2802	2721	2841	2620	2250	2676	2568	2823	42	767	1306
-in grain	SFU/LSU	M	1217	1210	1227	1446	1646	1330	1347	1272	3252	2938	2262
Avr. protein in total fodder	% protein of SFU	E	18.4	18.3	18.2	18.3	18.1	18.3	18.3	18.2	16.2	-	-

1) *% of area in rotation.*

2) *On organic farms set aside is included in the cultivated area, on conventional farms set aside is assumed not cultivated.*

3) *Livestock units per ha; 1 LSU = 0.85 Holstein dairy cow.*

In the Danish dairy sector, biological fixation is an important N input, especially on organic farms. On pilot farms, fixation in grass/clover was calculated by the method presented by Kristensen et al (1995). For the representative farms, the fixation and mineral fertilizer for grass/clover was assumed to be at the same level as on the pilot farms. Details of the level of fixation in grass/clover and information regarding fodder, N demand, crop yield estimates and fertilizer use are given in the Appendix. The ammonia and denitrification losses shown in Tables 3-5 were calculated using the method of Poulsen and Kristensen (1998), Andersen *et al.* (1999), Illerup *et al.* (2002) and Vinther and Hansen (2004) respectively.
Farm balances were calculated following the principles described in Halberg et al (1995) and further developed by Sveinsson et al (1998) and Kristensen (2002). Coherent N balances at farm level were calculated, incorporating imports of fodder (cereal and concentrates) and mineral fertilizers and exports of milk, meat, cash crops and surplus manure. Summarizing and up scaling key inputs and outputs across representative farm types showed good agreement with national statistics of land use, livestock numbers, average yield per crop, input of fodder concentrate and fertilizer per crop. The fertilizer was adjusted 8% in the farm models to account for the national consumption level.
The sample represents 4% of the conventional farms and 18% of the organic farms in Denmark (Table 1). Seventy-five percent of the dairy cows are on sandy soil, mostly in western Jutland. The dairy farm types cover 23% of the agricultural land and include 75% of all dairy cows (data not shown). The average herd size on conventional farms is 61 cows and 82 cows on organic farms. The average stocking rate on conventional farms is 1.46 LSU ha^{-1} and 1.28 on organic farms. Eighty-five percent of the farm area is part of a crop rotation. Twenty-six percent of the farm area of conventional farms is grass/clover. This percentage on organic farms is twice as large. The remainder of the rotating area is mainly under cereals, partly for grain and partly for whole crop silage harvested 2-3 weeks before being full ripe. Maize for silage has become important, mainly on conventional farms. Cereal grain yield is 5.2 t ha^{-1} on conventional farms and 20% lower on organic farms. Roughage yields are assumed to be on the average level of pilot farms, and the average yield of rotating crops is 5 700 SFU ha^{-1} = 6 300 kg DM ha^{-1} on conventional farms and 21% lower on organic farms.
The milk yield level in 1999 was 7 373 kg milk cow^{-1} $year^{-1}$ on conventional farms and 7% lower on organic farms. Of the total SFU intake by cows, 54% is home-grown roughage on conventional farms and 63% on organic farms. An average level of protein was 18.3% of SFU = 20% of DM.

Summation within the following tables may not always give the exact sum due to rounding errors.

4.3 Results

4.3.1 Dairy farm N balances

Table 2 shows the farm N balances. On organic farms, fixation constitutes app. 50% of the total N input. On conventional farms, imported fertilizer and fodder together account for app. 75% of the total N input. On farms with stocking density below 1.4 LSU ha^{-1}, fertiliser input alone accounted for 50% of the total N input and feed 25%, while it was vice versa on the high stocking density farms. On conventional farms, the weighted average N surplus is 184 kg N ha^{-1}, which is 63 kg higher than the average for organic farms. The conventional farm types with high stocking density have higher N surplus than the two low-density farm types. This is in accordance with an analysis of the effect of stocking rate on N surplus on the 38 pilot farms (Nielsen and Kristensen, 2005). The data from pilot farms show that the farm gate N surplus strongly correlates with stocking rate (Figure 1). Using the stocking rate corrected for import and export of manure, it can be shown that N surplus at the dairy farms increased significantly with increasing stocking rate, but not in a way that differed significantly between conventional and organic dairy farms. The average effect of stocking rate on farm N surplus was 78 kg N ha^{-1} per LSU. At the same stocking rate, the N surplus of organic pilot farms was 48 kg lower than that of conventional farms. In Figure 1, the average (1997-2003) farm gate N surplus for each farm is shown for comparison with the modelled farm types. The modelled farm types closely fit the average of the pilot farms.

Table 2. Farm gate N balances of representative specialized Danish dairy farms in 1999. All data in kg N ha^{-1} year^{-1}.

Farm type	Sandy (< 5% clay)			Sandy loamy (5-15 % clay)			Average				
	Conventional		Organic	Conventional		Organic	Dairy		Pig	Arable	DK
	LU < 1.4	LU 1.4-2.3		LU < 1.4	LU 1.4-2.3		Conv.[1)]	Org.			
Avr. LSU ha^{-1}	1.0	1.7	1.3	0.9	1.7	1.1	1.5	1.3	1.6	0.2	0.9
Inputs											
Mineral fertilizer	104	95	0	103	83	0	95	0	83	118	98
Fixation	23	34	78	21	35	68	29	76	4	5	15
Manure import	9	10	16	6	9	7	4	15	0	9	3
Supplement feed	46	105	51	42	109	42	91	50	194	14	84
Precipitation	16	16	16	16	16	16	16	16	16	16	16
Total input	198	260	160	189	252	132	236	156	296	162	216
Outputs											
Milk	-23	-40	-28	-21	-41	-24	35	-28	0	-1	-10
Meat	-8	-10	-6	-8	-10	-6	-10	-6	-99	-10	-36
Cash crops	-18	-4	-2	-27	-8	-7	-11	-2	-39	-71	-41
Manure export	0	0	0	0	0	0	-3	0	-20	0	0
Total output	-49	-55	-36	-55	-59	-36	-53	-36	-158	-83	-86
Farm gate N balance	**149**	**206**	**124**	**134**	**193**	**96**	**184**	**121**	**138**	**79**	**130**
Sensitivity on N balance											
- by 25% higher N fixation	+6	+9	+20	+5	+9	+18	+7	+20	+1	+1	+4
- by 10% lower N efficiency	+7	+14	+8	+7	+13	+10	+11	+10	0	0	+3
- by 10% higher N in roughage	-6	-10	-9	-7	-11	-11	-9	-11	-4	-1	-4
- by 10% higher yield from field	-5	-3	-10	-4	-2	-12	-3	-11	-8	-8	-6

[1)] *Average includes farms with more than 2.3 LSU ha^{-1}. Data presented of www.LCAFood.dk>processes>agriculture.*

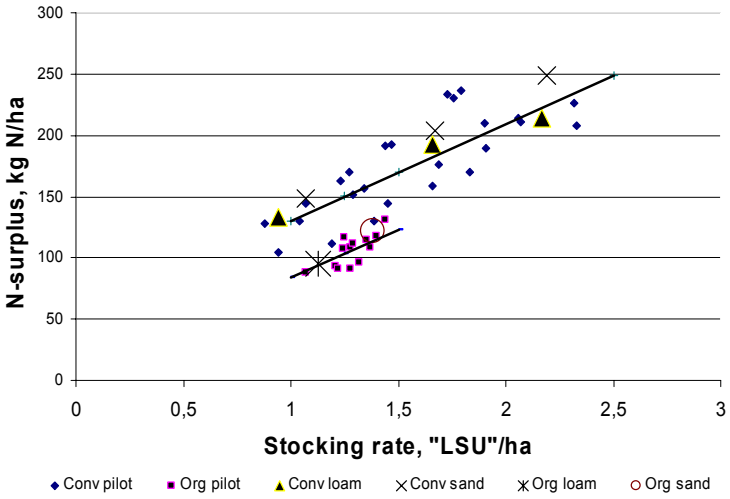

Figure 1. *Farm N surplus on specialized Danish dairy farm types in 1999, see Table 2, and on pilot farms (one point is average per farm for the years 1997-2001) as a function of stocking rate, corrected for import/export of animal manure (100 kg N = 1 LSU). Lines are average pilot farms, see Nielsen and Kristensen (2004).*

A sensitivity analysis was conducted to check the effect of assumptions on the results, see Table 2. Farm balances were calculated with 25% higher fixation, 10% lower N efficiency in feeding (= higher N content in imported feed), 10% higher protein content in roughage, and 10% higher net yield in roughage, respectively, and all other parameters unchanged. The analysis changed the farm gate N balance 2-20 kg N ha^{-1}, with the largest changes on organic farms as a result of the higher percentage of homegrown roughage. Increasing fixation by 25% decreases the difference between conventional and organic dairy production by 13 kg N ha^{-1} (the difference between 7 and 20 kg increased N surplus on average conventional farms and organic farms). Also higher yield from fields decreased the demand for imported feed more on the organic farms and 10% higher yield decreased the import by 8 kg N ha^{-1} more on the organic farms compared with the conventional farms with higher overall import. The other sensitivities only change the difference between conventional and organic types by 2-4 kg N ha^{-1}.

4.3.2 Dairy N balances at the herd and field level

Tables 3 and 4 show the coherent herd and field N balances, which together represent the within farm N flow, summing up to the overall farm gate N balance. Table 3 shows the herd balance both from the representative data and as the average result from dairy pilot farms on sandy soils. The representative farm types all have a herd input around 150 kg N LSU and a milk yield of 23-25 kg N LSU^{-1}, resulting in almost identical surplus of 118 kg N LSU^{-1}. The reason for this is that the cows protein intake was modelled using a standard 20% N – use herd efficiency. However, the modelled herd balances fit well with the average of pilot farms (122 kg N surplus). On the pilot farms, the N input with roughage is lower than for the representative farm types, especially during grazing. This is due to a lower N uptake in grazed grass/clover. N output in manure is higher on the pilot farms. This makes the animal manure input into the fields and the field N surplus higher on the pilot farms. The between-farm variation on the pilot farms is also presented in Tables 3 and 4. This gives an indication of the scope for improvements in N use efficiency. The CV (Coefficient of Variance) of the herd balance on conventional pilot farms was 8% (10 divided by 122) and 14% on the organic farms. This is mainly a consequence of lower N intake during grazing on the conventional farms, which means that N intake is more easily adjusted with imported feed. On organic farms, Danish-produced conventional rapeseed cake is the dominating concentrate fodder import, which gives a high herd N surplus, especially during the grazing season. The herd N efficiency varies between 19-22%, with no systematic difference between conventional and organic.

Table 3. Herd N balance on representative specialized Danish farms in 1999 and pilot farms in 1997-2001. All data in kg N LSU[1] year[-1].

Farm type	Dairy on sandy (< 5% clay)					Dairy on loamy (5-15% clay)			Dairy		Pig	Arable	DK
	Conventional, repr.			Organic		Conventional, repr.		Organic, repr.	Conv.	Org.			
	LSU<1.4	1.4-2.3	pilot[3)]	repr.	pilot[3)]	LSU < 1.4	1.4-2.3						
Av. LSU ha^{-1}	1.0	1.7	1.6	1.3	1.1	0.9	1.7	1.1	1.5	1.3	1.6	0.2	0.9
Input													
Conserved roughage	44	44	50	55	65	42	37	51	42	54	1	12	20
Grazing	30	26	37	31	58	28	23	30	25	31	1	11	14
Concentrates	46	50	52	25	21	48	52	26	50	23	79	67	75
Imported cereals	0	13	16	14	16	0	14	12	11	14	43	0	23
Home-grown cereals	20	7		6		24	13	10	11	6	27	56	21
Straw & imported animals	11	9	-[4)]	8	-[4)]	10	9	9	10	8	9	14	10
Total input	151	149	155	138	160	151	149	138	149	138	161	159	164
Output													
Milk	-23	-24	-27	-22	-26	-24	-25	-21	-24	-22	0	-6	-10
Meat	-8	-6	-6	-4	-6	-9	-6	-5	-7	-4	-62	-48	-42
Total output	-31	-30	-33	-26	-32	-33	-31	-26	-31	-26	-62	-54	-52
Herd N balance	**120**	**118**	**122**	**112**	**128**	**118**	**118**	**111**	**119**	**111**	**98**	**105**	**112**
Standard deviation on N bal.			10		18								
Anim. manure excr. during grazing	-23	-19		-23		-20	-17	-23	-19	-23	-1	-8	-11
Amm. loss, stable & storage	-12	-13		-11[1)] – -17[2)]		-9	-10	-8[1)] – -14[2)]	-13	-11	-20	-17	-18
Denitrification, solid manure	-2	-2		-3		-2	-2	-3	-2	-3	-1	-2	-2
Animal manure from storage	-82	-84		-63 – -74		-83	-86	-74	-86	-74	-77	-78	-79
N efficiency, herd, %	**20**	**20**	**21**	**19**	**20**	**22**	**21**	**19**	**21**	**19**	**39**	**34**	**32**
Standard deviation on N eff.			1.4% units			1.8% units							

1) *Same losses as conventional dairy systems (23% deep litter, 77% slurry and 10% solid and liquid manure).*

2) *50% deep litter, 40% slurry and 10% solid and liquid manure.*

3) *Pilot farms, average of 1997-2001.*

4) *Included in meat output.*

Table 4. Field N balance on representative specialized Danish farms in 1999 and pilot farms in 1997-2001. All data in kg N ha^{-1} year^{-1}.

Farm type	Dairy on sand (< 5% clay)					Dairy on loam (5-15% clay)			Dairy		Pig	Arable	DK
	Conventional, repr.			Organic		Conventional, repr.		Organic	Conv.	Org.			
	LSU <1.4	1.4-2.3	pilot[5]	repr.	pilot[5]	< 1.4	1.4-2.3						
Av. LSU[7]ha^{-1}	1.0	1.7	1.7	1.4	1.3	1.0	1.7	1.2	1.5	1.4	1.3	0.4	1.0
Input													
Animal manure from storage	89	140	195[8]	105[1]-114[2]	160[8]	79	142	83[1]-93[2]	124	102	94	28	75
Animal manure during grazing	23	32		30		18	28	26	27	30	1	2	10
Mineral fertilizer	104	95	92	0	0	104	83	0	95	0	83	118	99
Fixation	23	34	37	78	76	21	35	68	29	76	4	5	14
Precipitation	16	16	16	16	17	16	16	16	16	16	16	16	16
Total input	255	317	343	228[1]-236[2]	253	238	303	193[1]-203[2]	291	224	198	169	215
Output													
Conserved roughage	-44	-74	-81	-72	-69	-37	-62	-58	-61	-70	-1	-2	-19
Grazed	-30	-43	-61	-40	-61	-25	-38	-34	-36	-39	-1	-2	-14
Home-grown cereals	-29	-15	-15	-9	-10	-29	-29	-14	-23	-10	-70	-65	-52
Cash crops	-18	-4		-2		-26	-8	-7	-11	-2	-21	-25	-16
Total output	-121	-137	-157	-123	-140	-117	-137	-114	-130	-122	-93	-94	-101
Field N balance	**134**	**180**	**186**	**106[1] to 114[2]**	**113**	**121**	**166**	**79[1] to 89[2]**	**161**	**102**	**105**	**75**	**114**
Standard deviation, field N bal.			42		16								
Amm. loss spreading	-10	-15		-9[1] to -5[2]		-10	-14	-7[1] to -4[2]	-13	-9	-11	-6	-9
Amm. loss during grazing	-2	-2		-2		-1	-2	-2	-2	-2	0	0	-1
Amm. loss crops	-4	-4		-2		-4	-4	-2	-4	-2	-5	-5	-4
Denitrification in field	-12	-15		-12 to -11		-34	-34	-32 to -31	-17	-14	-13	-11	-13
Soil-N changes[9]	25	39		36[3] to -41[4]		7	24	15[3] to -22[4]	31	34	1	0	8
Nitrate leaching estimated by diff.[6]	-81	-105		-45 to -64 .		-65	-88	-21 to -42	-94	-41	-75	-53	-79
N efficiency, field, %	**47**	**43**	**46**	**54 to 56**	**55**	**49**	**45**	**59 to 61**	**45**	**54**	**47**	**56**	**47**
Standard deviation, field N eff.			5% units				5% units						

1) *Same losses as conventional dairy systems (23% deep litter, 77% slurry and 10% solid and liquid manure).*

2) *50% deep litter, 40% slurry and 10% solid and liquid manure.*

3) *Same soil-N changes as conventional dairy systems.*

4) *25% lower crop residues in grass/clover and 25% higher C input from deep litter.*

5) *Data from pilot farms 1997-2001.*

6) *Leaching = field N balance – amm. loss – denitrification +/– soil N changes. For example organic dairy on sand: 106 –9 –2 –2 –12 +36 = 45 kg N ha^{-1}.*

7) *Including correction for manure import, 100 kg N import = 1 LSU.*

8) *Including manure deposited directly on grazed fields.*

9) *Calculated with c-tool, see www.agrsci.dk/c-tool.*

Table 5. Estimated environmental losses on representative specialized Danish farms in 1999.

Farm type	Sandy (< 5% clay)			Loamy (5-15% clay)							
	Conventional dairy		Organic	Conventional dairy		Organic	Average, dairy		Arable	Pig	DK
LSU	< 1.4	1.4-2.3	dairy	<1.4	1.4-2.3	dairy	Conv.	Org.			
	kg N ha^{-1} $year^{-1}$										
Farm gate N balance	149	206	124	134	193	96	184	121	79	138	133
Gaseous loss stable & storage	-15	-24	-18	-13	-25	-15	-22	-18	-4	-33	-19
Field N balance	134	180	106	120	165	79	161	102	75	105	114
Amm. loss animal manure & min. fert	-12	-17	-11	-11	-16	-9	-15	-11	-6	-9	-10
Amm. loss, crops	-4	-4	-2	-4	-4	-2	-4	-2	-5	-5	-4
Denitrification in field	-12	-15	-12	-34	-34	-32	-17	-14	-11	-13	-13
Soil-N changes[1)]	25	39	36	7	24	15	31	34	0	1	8
N leaching estimated by difference[1)]	-81	-105	-45	-65	-88	-21	-94	-41	-53	-75	-79
	Different units										
Emissions[2)]											
Methane, kg CH_4 ha^{-1}	113	189	141	101	181	121	164	139	12	39	62
N_2O, kg N_2O ha^{-1}	11	14	9	9	13	7	13	8	6	8	8
Ammonia, kg NH_3 ha^{-1}	35	51	28	32	51	28	46	33	18	57	38
CO_2, kg CO_2 ha^{-1}	458	526	392	471	530	397	508	393	427	447	437
Global Warming Potential, ton CO_2 equivalent ha^{-1}	6.1	8.9	6.0	5.5	8.5	5.0	7.9	5.9	2.5	3.7	4.3

1) *Soil-N changes calculated with C-tool, see www.agrsci.dk/c-tool/.*

2) *Leaching = field balance – amm. loss – denitrification +/- soil-N changes. For example organic dairy on sand: 106-11-2-12-36 = 45 kg N ha^{-1}.*

3) *See www.LCAFood.dk.*

Table 4 shows that while the N production in manure per LSU is almost identical for the dairy farm types, the manure N supplied per ha is not surprisingly – higher in the farm type with 1.7 LSU^{-1} than farm type 1.0 LSU^{-1}, the 84 kg N LSU^{-1} in animal manure from storage (Table 3) equals an average input of 140 kg N ha^{-1} on the fields on farm type 1.4-2.3 LSU ha^{-1}. This corresponds to app. 50% of total N supplied to the crops. The field level N surplus of 134 kg N per ha on the low stocking rate type plus the ammonia loss in stables and storage (and denitrification – (12+2) * 1.1 LSU ha^{-1} – corresponds to the farm gate balance of 149 kg N ha^{-1} in Table 2.
The CV of the field balance on conventional pilot farms is 23%, and for organic this is 15%. There is a large variation between the lowest and highest N surpluses and possibilities for lowering the N surplus are numerous. The organic dairy farms realize 54-60% field N efficiency and the conventional dairy farms 43-49%. On farms with a low efficiency, there should be good possibilities to improve the N utilization.

The field N balance in Table 5 was calculated by subtracting the ammonia loss and denitrification in animal housing and manure storage from the farm surplus and corresponds to the detailed balance in Table 4. Organic farms more often than conventional farms tend to have deep litter systems, so losses of ammonia during storage will be higher. However, extra conventional straw is imported and ammonia losses during spreading are smaller than for slurry-based systems, so the total losses are calculated to be a similar proportion of the manure N flow. The average field N balance on conventional farms was 161 kg N ha^{-1}. The ammonia losses during spreading were assumed to be 8% of the manure N applied, see appendix for details of gaseous N losses. The remaining surplus (e.g. 126 kg N on conventional average) includes the soil-N changes and leaching.
Partitioning the remaining field surplus between changes in soil-N and leaching is difficult. There is no reason to believe that there should be any systematic difference between conventional and organic dairy farms in changes of the soil-N pool. Conventional has a lower proportion of grass/clover in the crop rotation but a higher stocking rate, compared to organic, probably resulting in about the same organic matter input on the two farm types. Therefore, the difference in field balance of around 60 kg (102 in organic vs. 161 in conventional) probably corresponds with an identical difference in leaching. The calculated leaching was 50 kg N ha^{-1} lower from organic dairy farms compared to conventional milk production.

A preliminary attempt at partitioning the remaining field N-surplus between changes in soil-N and leaching is shown in Tables 4 and 5. The method used will be described at www.agrsci.dk/c-tool. There is a tendency towards higher leaching losses on sandy farms, as expected. However, although there is an increase in the farm surplus with increasing stocking rate, this is accounted for partly by higher gaseous losses (ammonia volatilisation and denitrification) and partly by higher N leaching.
Estimating leaching as the difference between farm gate surplus and gaseous emissions implies that any errors in the surplus and gaseous emissions will assemble in that estimate. An alternative method is needed, but so far, no simulation model can reliably predict leaching for dairy farms with grazed grass/clover pasture. Leaching measurements made in Denmark under organic cattle trials with continuous grazing for 8 years of grass/clover and with nutrient removal from the grazed area only via milk and meat, resulted in a maximum leaching of 5-60 kg N ha^{-1}, measured in the winter in year 7-8. Leaching values of <10 kg N ha^{-1} were recorded in unfertilised grass/clover, while leaching from pure grass fertilised with 300 kg N ha^{-1} was around 65 kg N ha^{-1} $year^{-1}$ in year 7 and 8 (Eriksen *et al.* 2004). Results from other organic crop rotation trials also show an average leaching of around 40 kg N ha^{-1}, although higher losses have been measured after green mulching at sandy soils (www.agrsci.dk/pvj/plant/croprot/resultuk.shtml).
The lower leaching from organic farms compared to conventional farms could be explained by the crop rotation on organic farms, with around 50% of the area under grassland and with organic grass/clover being more N efficient than conventional, N-fertilized grass/clover. The latter is the consequence of the substitution rate between N fertilizer and fixation, where 1-2 kg extra N-fertilizer lowers fixation by 1 kg N ha^{-1} (Kristensen and Kristensen, 2002). Also a better utilization of nitrogen in urinated grass/clover patches gives higher N-utilization (Hutchings and Kristensen, 1995).

4.3.3 Emissions of greenhouse gases from representative farm types

Table 5 shows N balances and greenhouse gas emissions of the main farm types in Denmark and the Danish average. Relative to dairy farms, pig farms have a larger external N exchange of both fodder and meat production and a higher ammonia loss from stables and manure storage. Emissions of CO_2 only include emissions from combustion of fossil fuel on farms. Organic dairy farms have a lower CO_2 emission than the conventional equivalents, due to less use of fossil fuel per hectare, because of a greater grassland area. Emissions of greenhouse gases (calculated in CO_2 equivalents) are higher for farms with livestock than for those without. Emissions are higher for dairy farms than for pig farms, because of the contribution of enteric fermentation to methane emissions.
The emission per kg of milk has been calculated using the LCA methodology, showing only small differences between farms with different stocking rates (www.lcafood.dk).

4.3.4 Changes in dairy N balances over time

Changes in N balances over time, based on additional datasets from the pilot farms, are given in Table 6. It appears that the farm N surplus on conventional farms has been reduced by 30% over the last 10 years, whereas the surplus on organic farms has fallen only slightly (but not identical farms in the three pilot farm samples). The reduction in cow dairy farm surplus appears to have happened during the first half of the 1990s, coinciding with the implementation of manure use regulations. Note that conventional and organic farms cannot be compared directly here, as they have different stocking rates. In the bottom line the LSMEANS estimates for difference at the same stocking rate is shown. The results from pilot farm investigations fit very well with the modelled data from representative farms.
The progressive implementation of the Water Protection Plan VMPII is expected to result in a further decrease in N losses (Hutchings *et al.*, 2003). A model forecast incorporating VMPII is shown in Table 7. The conventional representative farm has improved 26 kg N ha^{-1}, from 184 to 158 kg N ha^{-1}, and the organic farm has the same level, i.e. 122 kg N ha^{-1}. On the relatively few pilot farms, the conventional farms showed the same decrease as the representative farm, but the organic farms in year 2003 only had a farm gate N surplus of 98 kg N ha^{-1} (LSMeans estimate, see Nielsen and Kristensen (2005)). The reason for the lower farm gate N surplus was mainly reduced import of artificial fertilizer on the conventional farms and reduced fodder import on the organic farms in order to fill in a new regulation of 100% organic feed from the year 2001 onwards. A typical response of organic dairy farms has been the substitution of rape cakes by concentrates with a higher proportion of cereals.

4.3.5 Comparison of environmental impact between farm types

While the arable farm types on both sandy and loamy soil have N surpluses below 100 kg N ha^{-1}, the pig types show a farm N balance of around 140 kg N ha^{-1} with 1.5 - 1.6 LSU ha^{-1}. The field surplus was 161 kg N ha^{-1} on dairy, compared with 75 and 105 on average arable and pig farms (Table 5). However, it cannot be assumed that soil N changes are the same in these systems. To illustrate the possible combined effect of field N surplus and soil N change in these different systems, a preliminary model was used to predict net mineralization. Because of the high input of organic material and grass/clover on dairy farms, the model predicted an accumulation of 7-39 kg N ha^{-1} $year^{-1}$ on dairy farms compared with steady state on pig and arable farms (Table 5). Thus, due to low input of organic matter, the modelled leaching from pig farm models was 20 kg N ha^{-1} lower than on dairy farms, and arable farms with only 53 kg N ha^{-1} in N leaching. The overall average change in soil-N across soil types and farm models was an increase of 8 kg N ha^{-1}. This may be a bit too high, since Heidmann *et al.* (2001) found no overall change during a ten-year period in 300 samples representing Danish farming systems. But the national balances used for assessing the effects of Water Project schemes estimated 62 kg N ha^{-1} leaching and residual and soil build up corresponding to 11 kg N ha^{-1} (VMPII). The combined result of our representative farm types scaled to national level using the weights behind each farm type is in accordance with the VMPII report. However, changing the mineralization parameters in the model will probably not change the relative soil-N change between pig and dairy. Nitrate leaching was measured in 1996-2000 in about 40 fields and amounted to 94-98 kg N ha^{-1} (Grant *et al.*, 2000). The measurements were extrapolated to the whole Danish territory with standard precipitation. The overall modelled N-leaching in Denmark in 1999 was around 75 kg N ha^{-1} (Grant *et al.*, 2000). Thus, if no overall change in soil-N is assumed, then the model based on the representative sample gives the same level of N-leaching (100 – 23 = 77 kg N ha^{-1}).

Table 6. Farm gate N turnover on representative specialized Danish dairy farms. All data in kg N ha^{-1} year^{-1}.

	Conventional					Organic				
Year	1989-90[3]	1994-97[4]	1997-2003[6]	1999-2002[7]	1999[5]	1989-90[3]	1994-97[4]	1997-2003[6]	1999-2002[7]	1999[5]
Number of farms	16	5	25	87	350	14	10	13	42	149
Avr. LSU ha^{-1}	1.76	1.70	1.54	1.52	1.46	1.24	1.26	1.14	1.21	1.3
Inputs										
Fertilizer	161	100	86	80	95	0	0	0	0	0
Fixation	29	45	27[1]	33[1]	29	87	89	78[1]	95[1]	76
Manure import	0	0	34	17	4	9	14	25	17	15
Supplement feed	77	129	115	114	91	39[2]	47	38	50	50
Precipitation	16	16	16	19	16	16	16	16	17	16
Total input	283	290	278	264	236	151	166	157	179	156
Output										
Milk	-47	-39	-42	-41	-35	-32	-28	-28	-31	-28
Meat		-18	-9	-9	-10		-6	-6	-6	-6
Cash crops	0[2]	-22	-19	-22	-11	0[2]	-4	-1	-3	-2
Manure export	0[2]	-21	-29	-16	-3	0[2]	0	-6	-11	0
Total output	-47	-101	-99	-88	-53	-32	-38	-41	-51	-36
Balance	240	173	177	176	184	124	112	116	128	121
Standard deviation	52	50	43	51		19	35	23	35	
Difference from conv						-116	-61	-61	-48	-63
Difference on same stocking rate						-85	-61	-57		-44

1) *Calculated after Kristensen et al. (2003).*
2) *Crops for sale and manure is deducted import.*
3) *Halberg et al. (1995).*
4) *Halberg (1999).*
5) *Table 2.*
6) *See Nielsen and Kristensen (2004).*
7) *See Hvid et al. (2004), only in Danish.*

Table 7. Farm gate N turnover on representative specialized Danish dairy farms in 1999 and 2002 after full implementation of environmental regulations (VMP-II). All data in kg N ha^{-1} year^{-1}.

	Conventional			Organic		
Year	1999[1)]	2002	(pilot farms)	1999[1)]	2002	(pilot farms)
Number of farms	350	379	(25)	149	147	(13)
Avr. LSU ha^{-1}	1.46	1.45	(1.54)	1.30	1.20	(1.14)
Inputs						
Fertilizer	95	66		0	0	
Fixation	29	29		76	78	
Manure etc., import	4	3		15	8	
Supplement feed	91	96		50	53	
Precipitation	16	16		16	16	
Total input	236	211		156	155	
Outputs						
Milk	-35	-37		-28	-26	
Meat	-10	-9		-6	-5	
Cash crops	-11	-8		-2	-2	
Manure export	-3	0		0	0	
Total output	-53	-54		-36	-33	
Farm gate N-balance	184 (177)[2)]	157	(155)[3)]	121 (116)[2)]	122	(98)[3)]
Difference from conv. 2002				-37 (39)	-36	(57)
Gaseous loss stable & storage	-22	-22		-18	-17	
Field N-balance	161	135		102	105	
Amm. loss animal manure and crops	-19	-19		-13	-12	
Denitrification, field	-17	-16		-14	-13	
Soil-N change	+31	+31		+34	+35	
Leaching estimated by difference[4)]	-94	-69		-39	-45	

1) *Average dairy farms from Tables 5 and 6.*

2) *See Table 6.*

3) *Lsmeans estimate in year 2003, see Nielsen and Kristensen (2005).*

4) *Leaching and soil-N changes= field balance – amm. loss – denitrification +/- soil-N changes. For example organic dairy in 1999: 102 –13 -14 -34= 39 kg N ha^{-1}.*

4.4 Conclusion

A large group of representative dairy farms in 1999 has been used to calculate farm N surpluses. Both investigations on pilot farms and representative farms have shown the same overall result. The conventional dairy farms have an increase in farm surplus of 78 kg N LSU^{-1} in the interval of 0.8–2.5 LSU ha^{-1}. Organic dairy farms have consistently 44–63 kg lower N surplus than conventional farms since 1994. The strength of this conclusion is that the underlying data represent realistic management situations. This is especially relevant for cattle farms, because the large internal flows on these farms are difficult to quantify, so that it is difficult to accurately calculate field level balances directly from field input and outputs. It is very important that each farm is analysed as an entity, where interaction between management, agricultural production (herd and crops) and N losses can be analysed at the farm level.
Farm N surplus is an expression of the long-term potential losses. If changes in soil-N are assumed to be similar on both organic and conventional dairy farms, then nitrate leaching at equal stocking rate is about 50 kg N ha^{-1} less on organic farms than on conventional dairy farms in year 1999. In 2002 the difference has decreased to around 25 kg N ha^{-1}.

The data from organic mixed dairy farms production have been used as an extreme case, to demonstrate the capacity of unfertilised grass/clover to reduce farm N surplus. Using this knowledge in models of conventional farms shows there is also scope to reduce the farm N surplus in these systems. It is likely that the lower farm N surpluses for organic systems are due to the inclusion of unfertilised grass/clover, combined with the use of cereals on about 50% of the land area, to utilise the carry-over of N from the grass/clover pasture.

Losses of nitrate, ammonia and nitrous oxide from livestock farming appear to be higher than for arable farming. Increases of nitrate leaching with increasing livestock density in Denmark are lower than increases of farm N surpluses. This is because a relatively higher proportion of the extra surplus is lost in gaseous form.

Our analysis shows that the combination of pilot farms and representative farms is a relevant tool for predicting agronomic, economic and environmental effects on farm and regional scale of different farm types and interventions. As demonstrated in Figure1, the pilot farms show differences between farms with comparable soil types and stocking rates (variation around average line). To the extent that these differences can be explained by differences in management, including the farmer's choice of crop rotation and feeding systems, the farm variation may be used to generate ideas and benchmarks for improvement of farms with high surpluses. The farm models generated from the representative sample allow for the generalisation of average farms within the selected groups, for calculation of other emissions in a standard Life Cycle Assessment framework and for scaling up to national emission and N surplus levels. Thus, these methods combined could be powerful tools in the search for improvements and for the evaluation of proposed regulations and interventions in dairy farm nutrient management.

References

Andersen, J. M., S.G. Sommer, N.J. Hutchings, V.F. Kristensen & H.D. Poulsen, 1999.
Emission af ammoniak fra landbruget - status og kilder. Ammoniakfordampning - redegørelse nr. 1, Danmarks JordbrugsForskning. 1-63.

Anon., 2000.
Gødningsregnskaber. Fysisk kontrol. Statistik 1998/99., 1-49. Plantedirektoratet.

Anon., 2001.
Vejledning og skemaer 2001/02., 1-99. Ministeriet for Fødevarer, Landbrug og Fiskeri. Plantedirektoratet.

Anon., 2002.
Vejledning og skemaer 2002/03., 1-99. Ministeriet for Fødevarer, Landbrug og Fiskeri. Plantedirektoratet.

Eriksen, J., F.P. Vinther & K. Søegaard, 2004.
Nitrate leaching and N_2-fixation in grasslands of different composition, age and management. Journal of Agricultural Science 142: 141-151.

Grant, R., G. Blicher-Mathiesen, J.O. Jørgensen, B. Kloppenborg-Skumsager, B. Kronvang, P.G. Jensen, M. Pedersen & P. Rasmussen, 2000.
Landovervågningsoplande 1999. NOVA 2003. Faglig rapport fra DMU nr.334 334, 1-147.

Halberg, N., 1999.
Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. Agric Ecosyst Environ 76, 17-30.

Halberg, N., E.S. Kristensen & I.S. Kristensen, 1995.
Nitrogen turnover on organic and conventional mixed farms. Journal of Agricultural and Environmental Ethics 8, 30-51.

Halberg, N. & I.S. Kristensen, 1997.
Expected crop yield loss when converting to organic dairy farming in Denmark. Biological Agriculture and Horticulture 14[1], 25-41.

Halberg, N., I.S. Kristensen, T. Dalgaard, B.P. Weidema & M.J.G. Meeusen, 1999.
Linking data sources and models at the level of processes, farm types, and regions. Proceedings of the 2nd Invited Expert Seminar on LCA of food Products: 'Agricultural daa for life Cycle Assessments'. Eds. Weidema, B.P. and Meeusen, M.J.G. Concerted action PL-97-3079 of the EU Food and Agricultural Programme. Den Haag, 25-26 Jan. 1999. Agricultural data for Life Cycle Assesments 1, 16-30. Den Haag. 25-1-0099.

Heidmann, T., J. Nielsen, S.E. Olesen, B.T. Christensen & H.S. Østergaard, 2001.
Ændring in indhold af kulstof og kvælstof in dyrket jord: Resultater fra Kvadratnettet 1987-1998. DJF rapport. Markbrug 54, 1-73.

Hutchings, N.J. & I.S. Kristensen, 1995.
Modelling mineral nitrogen accumulation in grazed pasture: will more nitrogen leach from fertilized grass than unfertilized grass/clover? Grass and Forage Science 50, 300-313.

Hutchings N., A.H. Nielsen, R. Grant, S. Gyldenkærne & L Knudsen, 2003.
Agricultural nutrient management in Denmark Part I. With special reference to intensive dairy farming – Regulation and Environment. This report.

Hvid, S.K., B. Weidema, I.S. Kristensen, R. Dalggard, A.H. Nielsen & T. Bech-Larsen, 2004.
Miljøvurdering af landbrugsprodukter. http://www.mst.dk/udgiv/publikationer/2004/87-7614-395-3/html. Miljørapport [954], 1-90.

Illerup, J.B., K. Birr-Pedersen, M.H. Mikkelsen, M. Winther, S. Gyldenkærne, H.G. Bruun & J. Fenhann, 2002.
Projektion Models 2010. Danish emissions of SO_2, NOx, NMVOC and NH_3. NERI Technical Report 414, 1-195.

Kristensen, E.S., H. Høgh-Jensen & I.S. Kristensen, 1995.
A simple model for estimation of atmospherically-derived nitrogen in grass-clover systems. Biological Agriculture and Horticulture 12[3], 263-276.

Kristensen, I.S., 2002.
Principles and methods for collecting and evaluation nutrient balances, 29-40. http://www.agrsci.dk/jbs/demolit/Principles%20and%20methods.pdf, Danish Institute of Agricultural Science. Lithuanian Dairy Farms Demonstration Project.

Kristensen, I.S. & T. Kristensen, 2002.
Indirekte beregning af N-fiksering. Intern Rapport, Danmarks JordbrugsForskning 157, 31-40. Kvælstofbalancer på landbrugsbedriften -status og perspektiv. Temadag arrangeret af Afdl. for Jordbrugssystemer. 24-4-2002.

Nielsen, A.H. & I.S. Kristensen, 2005.
Level of nitrogen and phosphorus surplus at Danish livestock farms in relation to farm characteristics, (submitted to) Livestock Production Science, Special Issue, 2005.

Poulsen, H.D. & V.F. Kristensen, 1998.
Standard values for farm manure. A revaluation of the Danish standard values concerning the nitrogen, phosphorus and potassium content of manure. Danish Institute of Agricultural Science report Animal Husbandry. 7, 1-160.

Sveinsson, T., N. Halberg & I.S. Kristensen, 1998.
Problems associated with nutrient accounting and budgets in mixed farming systems. In: Keulen, H. v., Lantinga, E. A. and Laar, H. H. v. (Eds), Mixed Farming Systems in Europe, APMinderhoudhoeve-reeks 2, p. 135-140.

Vinther, F.P. & S. Hansen, 2004.
SimDen – a simple model for quantifying N_2O-emmission and denitrification. DJF rapport, markbrug, no. 104, see www. Agrsci.dk/simden.

Østergaard, V. & A. Neimann-Sørensen, 1989.
Grundlag for valg af avlsmål og tilhørende produktionssystem i mælkeproduktionen. Statens Husdyrbrugsforsøg, Beretning 660, 1-157.

Appendix.

Fixation in grass/clover and information regarding fodder, N demand, crop yield estimates and fertilizer use

In the Danish dairy sector, N fixation in grass/clover swards constitutes a significant N input. On pilot farms, clover content is evaluated visually and fixation is calculated directly from visual clover content (Table A1).

Table A1. Total input of atmospherically derived nitrogen (totally fixed – kg N ha^{-1}) at varying clover content and different cropping year, Kristensen et al (1995).

Visual clover content (soil cover) (dry matter clover content)	10-29 (13-16)	30-49 (17-29)	above 49 above 30
1st and 2nd year sward	78	156	248
3rd and older sward	47	84	128

Fixation in pure legume crops with measured yield is calculated after Høgh-Jensen *et al.* (2003). Mixed crops of peas and cereals are calculated with a combination of the two methods (Kristensen and Kristensen, 2002).

In order to calculate the fodder N import from economic figures, roughage yield must be known. The average roughage yield over 10 years of 15-30 pilot farm studies per year has been chosen. The yield is presented as Scandinavian Feed Units (SFU), where 1 SFU is equal to the feeding value of 1 kg barley grain (see Table A2). On conventional dairy farms, permanent grass is set to 2 230 SFU/ha (= 2 768 kg DM/ha) and on organic dairy farms to 2 000 SFU/ha (= 2 386 kg DM/ha).

The yield has been described in detail by Halberg og Kristensen (1997). The herd feed requirement is calculated in relation to milk and meat production measured. From milk production the yearly demand for fodder (Y) is calculated from Østergaard & Neimann-Sørensen (1989):

$$Y = 1000 * (-400+\sqrt{((400^2 - 4 * 16.7 * (1860 - X)))}) / (2*16,7)$$

Y = SFU demand per dairy cow per year

X = Kg milk production per dairy cow per year

The total demand for N in feed is calculated so that a total of 24.3% N efficiency is achieved in conventional dairy cows (Poulsen and Kristensen 1998) and 23.0% on organic dairy cows. The N efficiency of young stock is set to the standard from Poulsen and Kristensen (1998). The need for N and energy import is achieved by a combination of the 'know' produced home-grown feed and also the needed combination of grain and concentrate feed import. The N efficiency is equal to the average level of around 30 pilot farms in 1997-2001.

To calculate fertilizer import, a fertilization of permanent grass was set to 80 kg N ha^{-1}. All other crops have been given the maximum allowed level of mineral fertilizer, including around 50% fertilization value of the nitrogen in animal manures. In order to achieve the national level of fertilizer use, 8% extra N fertilizer was given to all crops.

Table A3 shows N standards of the most important grassland crops, as applicable in 1999. After the establishing year, the N standards are not influenced by the age of the grassland. The N standards are the maximum amounts of N from mineral fertilizer plus animal manure. N in cattle manure is expected to have an efficiency of 60%, and therefore only 60% of total-N in cattle manure is included in the calculations.

As mentioned earlier, one of the advantages of short-lasting grassland is the residual effect on the following crop. In the N standards, the residual effect of grass/clover is estimated at approximately 60 kg N ha^{-1} for the first year, when compared to the residual effects after a grain crop (Table A3).

Table A4 shows the percentage losses in gaseous forms from the main farm types. The stable and storage ammonia and denitrification N losses is mainly updated from Andersen *et al.* (1999) and Poulsen and Kristensen (1998). The denitrification in the field is from Vinther and Hansen (2004).

Table A2. Net yields and crude protein content for field production on conventional and organic farms selected for modelling technical turnover on representative farms in 1999.

System	Conventional				Organic			
	SFU ha^{-1}	~Kg DM ha^{-1}	~GJ dig. energy ha^{-1}	% crude protein of DM	SFU ha^{-1}	~Kg DM ha^{-1}	~GJ dig. energy ha^{-1}	% crude protein of DM
Crops:								
Grass/clover silage	6666	7400	91	16.8	5525	6133	76	16.8
Grass/clover grazed	6666	7200	95	22.0	5525	5967	78	22.0
Whole crop[1)]	4470	6035	54	10.4	3522	4754	42	10.4
Maize	8957	10456	117	8.7	6587	7706	86	8.7
Fodder beets	10800	10989	152	7.4	9248	9340	129	
Grain	measured			10.1	measured			10.1

[1)] *Excluding grass harvested during the autumn.*

Table A3. Standards for maximum N application at a certain annual net yield (yield-standard) are shown for some crops on two soil types in 2002. In total there are 99 N standards for different agricultural crops on three different soil types and for sandy soil there are standards for both irrigated and unirrigated.

	Sandy soil – unirrigated		Clay soil	
	N-standard kg N ha^{-1}	Yield-standard t DM ha^{-1}	N-standard kg N ha^{-1}	Yield-standard t DM ha^{-1}
Grass crops:				
Permanent pure grass	27-140[1)]	0-4	27-140[1)]	0-4
Grass/clover, < 50% clover	233	6.0	233	6.5
Establishing year after harvest of cover grain-crop:				
Grass/clover	54	1.0	54	1.0
Spring barley:				
Cereal as previous crop	116	4.1[2)]	108	5.9[2)]
Grass/clover as pervious crop	85	4.1[2)]	78	5.9[2)]

[1)] *Depending on yield level (Anon., 2001).*
[2)] *Grain yield.*

Table A4. Danish standard gaseous N-losses in 1999. [% of input].

		Mixed dairy			
		Conv.	Org.	Pig	Arable
Ammonia loss					
-from stall	% of excreta	4.6	4.1	15.3	10.8
-from storage	% of produced	4.7	4.3	4.6	4.5
-from spread manure	% of spread	8.4	8.4	8.9	8.8
-from grazing animals	% of excreta	7.0	7.0	7.0	7.0
-from applied artificial fertilizer	% of spread	3.0	-	3.0	3.0
-from crops	% of N yield	2.9	1.4	5.2	5.2
Denitrification, total	% of field input	7.0	8.0	7.5	6.9
Denit. from solid manure storage	% of storage inputs	2.4	3.7	1.4	2.0
Denitrification, field	% of field input	5.9	6.5	6.7	6.7
-from N_2O	% of field input	1.7	1.8	1.8	1.6
-from N_2	% of field input	4.3	4.6	4.9	5.1

5. France

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5.1 Introduction

The continued intensification of agricultural production over the last decades has affected the environment. Among the main problems, nitrogen and phosphorus emissions to water and air are partly due to intensive livestock farming, particularly in areas where monitoring networks show (1) excessive nitrate concentrations, with continuously increasing trends in surface waters and groundwaters and (2) strong enrichment of soil phosphorus content proportional to accumulated slurry spreading (Coppenet *et al.*, 1993). These deteriorations may induce eutrophication effects, affecting human health, human activities (fishing, aquaculture, tourism) and aquatic/terrestrial ecosystems (Barroin, 2003).
After the first regulation to control milk production – quotas in 1984 – the CAP (1982) modified subsidy rules and introduced environmental care. During the last decade, multifunctionality of agriculture and particularly animal husbandry was better taken into account (*cf.* EGF meeting in Hervieu, 2002): contracts were signed between farmers and administration (Sustainable Development Plans, Territorial Contracts for Exploitation) at farm level, then collective (at watershed level) in order to improve the efficiency of application of the Directive on water quality. Depending on local characteristics, the regulations may to a stronger or lesser extent modify farmers' habits and may be more or less easy to apply. With all European countries being subject to similar constrains for parts of their territory, research efforts were intensified: at watershed scale to understand the relationship between agricultural practices and water quality (Durand, this workshop) and at farm scale to find the key-points allowing better functioning and best compromises for sustainable production (Chambres d'Agriculture, Institut de l'Elevage, INRA, ITCF-Arvalis).

This paper will focus on three main points, mainly concerning the farm scale:
- characterisation of intensive dairy production in France (particularly Western France), and associated nitrogen and phosphorus excess, placed in its natural and agricultural environment;
- implementation of the EU Nitrates Directive in France: 'nitrate-vulnerable zones', action programmes and monitoring programmes, establishment of codes of good agricultural practices at field and farm level;
- ways proposed to achieve sustainable dairy production and their consequences as propositions to national (EU) policies.

The main focus will be on nitrogen fluxes, as these are better known, the main subject of the Nitrate Directive and in some way indicators of practices and fluxes at farm scale.

5.2 Dairy farming in France

5.2.1 Agricultural France [1]

France has about 60 million inhabitants and covers 55 million hectares. Farming uses 33 million hectares, forest occupies 15 million hectares, whilst the remaining 7 million hectares correspond to urban areas and natural ecosystems. Over the past fifty years, the area used by agriculture has steadily diminished. In 1950, farming covered 63% of the total area, but by 1998 it represented no more than 55% of the surface area. This decline occurred to the benefit of forest, but above all of urban areas, which have increased on average by about 50,000 hectares per year.

On the whole, the climate of France is oceanic and temperate, with relatively moderate seasonal differences in temperature. There are, however, regional differences, from a Mediterranean climate in the South East to a mild damp climate in the North West of France. Climate, combined with deep soils in the basins (such as the Paris Basin) or with lighter soils in the older massifs (like the West of France) is generally favourable to most farming production. The major agricultural regions are the following:

- the fertile plains of the Paris Basin (Centre, Champagne-Ardennes and Picardie regions), Poitou-Charente and the South West, mainly with crop production (corn, maize);
- the West of France, directed towards animal productions (milk, pigs and poultry), in particular in Brittany;
- the mountains of the Centre of France (Limousin, Auvergne, Charolais) mainly concentrating on beef production with permanent grassland;
- the dry mountains (South of France) with sheep production and the wet mountain areas (Franche-Comté, Auvergne, Alps and Pyrenees) mainly with cow milk production, including the production of AOC cheeses.

5.2.2 Dairy farming in France

About 60% of the surface area of France is devoted to farming. Herbivores occupy about 60% of the Useable Agricultural Area (AA) whilst about 30% of the AA is valorised for dairy production.

Cereal crops cover about 45% of the total AA of the country and forage areas therefore represent 55% of AA. Within this forage area, the area always under grass, consisting of both permanent grassland and summer pastures, covers 10 million hectares or about 70% of the forage area (FA). However, this area has declined by 30% in 30 years. Temporary grassland covers 2.6 million hectares and is to be found essentially on dairy farms. Grass/legume mixtures now represent more than two thirds of sown grassland. Finally, maize silage, intended mainly for dairy production, covers 1.4 million hectares. This forage crop has developed alongside the intensification of dairy farming in France, as its area has multiplied fourfold in 30 years.

The number of dairy farms was 128,000 in 2000 and has diminished by 70% since 1984, when quotas were introduced at EU level. Remaining farms have 4.2 million cows, i.e. an average of 33 cows per farm. The dairy herd outnumbered the suckling herd in France for a very long time (7 cows out of 10 were dairy cows in the early 1980s), but there are now more suckling cows than dairy cows. This reduction in the dairy cow population can be explained by the increase in production per cow. The average yield was 5 600 kg milk per cow in 2000, whilst it was about 4 000 kg in 1984.

National milk production is about 24 million tons, representing about 20% of the total production of the EU-15. Milk production has been reduced by 9% since 1983. 145 000 people are employed in the dairy industries, corresponding with 20% of the employment in the food-processing industries.

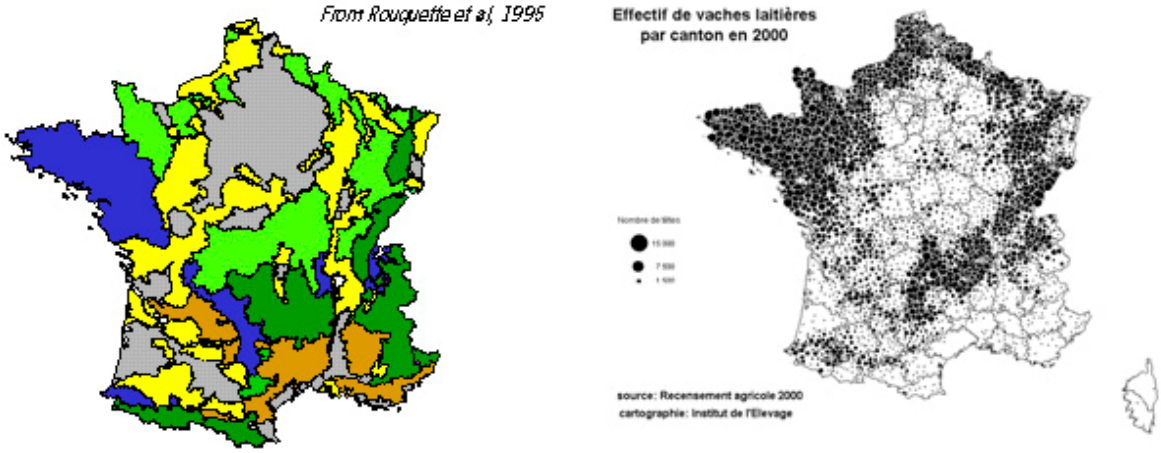
1 Adapted from Rapion *et al.*, 2001.

Dairy farms are predominantly located in the North West, the East and the Massif Central, with some smaller areas in the South West. Given the diversity of soil and climate in the country, four major regions of dairy production can be identified (Table 1 and Maps 1 and 2).

Table 1. Characterisation of the major dairy production regions in France.

Area	Rainfall (mm)	Drainage (mm)	Number of farms (000)	% FA /AA	% maize /FA	LSU.ha^{-1} FA	LSU.ha^{-1} FA	Milk/cow (000 l)	Milk.ha^{-1} FA (000 l)
Areas of forage crops in the West and the foothills	800-1200	200-500	40	70-90	20-50	1,6-1,8	1,1-1,6	6-7.5	6.5-9.5
Areas of mixed crops and livestock	600-800	150-250	30	30-50	40-60	1,6-2,0	0,5-1	6-7.5	6.5-10
Grassland areas of the North and East	800-1000	200-300	30	80-90	0-20	1,2-1,4	1-1,3	5.5-6.5	4.5-6.5
Wet mountains of the Massif Central, Franche Comté, Alps and Pyrénées	1000-1400	400-500	15	90-100	0-5	1-1,2	0,9-1,2	5-6.5	3.5-5.5

Maps 1 and 2. Dairy areas in France and population of dairy cows per canton.



The areas of forage crops of the West of France and the foothills. About a third of French dairy production comes from these regions, characterised by plains and low hills. The soil and climate conditions, with a marked oceanic influence, are by and large favourable to dairy production and explain its development over the past 40 years. The soils, on schist or granite, enable both temporary grassland and maize to be cultivated. Taking the rural density into account, dairy farms are relatively average, which has led to specialisation, intensification and sometimes to an association with pigs and poultry (in the West of France: 25% of dairy farms in Brittany). The dairy farming systems are rather intensive (1.6 to 1.8 LSU.ha^{-1} FA) and include forage maize, which accounts for between 30 and 50% of the forage area. Temporary grassland (from 3 to 6 years) is included in the rotations with maize and cereals (from which the straw provides manure). About half of this sown grassland is an association of grass and white clover. Under these conditions, milk production is between 6,000 and 7,500 kg per cow and 6,500 and 9,500 kg.ha^{-1} FA.

Mixed areas of crops and livestock. These are transition regions between the major livestock regions and the cash crop regions. They represent 25% of French production. The farms concerned, situated on land with good potential, combine dairy production and cereal production. The forage systems are therefore often based on cultivated grassland, unless livestock uses permanent pasture that cannot be ploughed. Taking the level of mechanisation into account, maize silage often figures largely (between 40 and 60% of the FA). In these conditions, the level of dairy intensification is considerable, between 7,000 and 10,000 kg milk.ha^{-1} FA.

The grassland areas of the Northwest and the East. These regions represent about a quarter of French milk production. Their dairy farms are relatively large, with a considerable proportion of permanent grassland. Forage maize represents 10 to 30% of the forage area. Under these conditions, the stocking rate is moderate, i.e. between 1.2 and 1.6 LSU.ha^{-1} FA.

The wet mountains of the Massif Central, Franche Comté and the Alps. This area covers all the mountainous areas in the country. It represents 12% of national milk collection of which a good part is used by AOC (Appellation d'Origine Contrôlée) products. The climate in these regions is characterised by cold winters and summers with relatively high rainfall. The forage systems are for the most part based on permanent pasture and hay, as the use of silage is forbidden for cheese-making. The stocking rates are moderate, between 1 and 1.4 LSU.ha^{-1} FA.

5.2.3 Share of dairy production in total N and P excess and key figures on environmental quality

Soil nitrogen balance at national scale

French livestock produces about 1.4 million tons of organic nitrogen per year, of which 75% comes from cattle (around 1/3 dairy cows; 1/3 suckling cows and 1/3 young breeding and fattening animals), 8% from pigs, 6% from poultry and sheep, 3% from horses and 1% from goats. Thus, cattle by far account for the largest proportion of organic nitrogen production. In Brittany, the shares of cattle, pigs and poultry are 54, 28 and18%, respectively.

These figures as such are of little interest since it is the nitrogen load brought down to the hectare that enables it to be used as a fertiliser or contribute to excess. This organic nitrogen load is on average 96 kg N.ha^{-1} AA for specialised dairy farms and 89 to 94 kg N.ha^{-1} for other herbivores, whilst it is 330 kg N.ha^{-1} for pig and poultry farms (OTEX Granivores, see Appendix II). However, in some regions, notably Brittany, these organic loads can be considerably higher; thus specialised pig and poultry enterprises produce 420 kg N.ha^{-1} AA in Finistère and 390 kg N.ha^{-1} AA in the Côtes-d'Armor and a good number of them are envisaging solutions for the treatment of the excess amounts.

The SCEES (2003) show that the excess N balance of farms in 2001 mainly concerns areas of intensive livestock farming (milk, pigs and poultry) and areas of cash crops. This excess calculated at departmental level makes a count of the inputs by mineral and organic fertilisers (on the basis of animal manure) and the outputs by plants (grassland and other crops). According to this balance, the theoretical excess would seem to be about 20% of the requirements, if it is assumed that all the organic N produced in the farm can be effective fertiliser (Table 2).

Table 2. Nitrogen balance in 2001 in France in thousands of tons of nitrogen (SCEES Agreste, 2003).

Inputs		Outputs	
Mineral fertilisers	2 369	Use of plants	3 064
Organic fertilisers	1 410	Grassland	1 370
Cattle	1 074	Wheat	629
Pigs	114	Maize	226
Sheep	88	Other plants	839
Poultry	87		
Other herbivores	47		
Total	3 779	Total	3 064
		Excess nitrogen	715

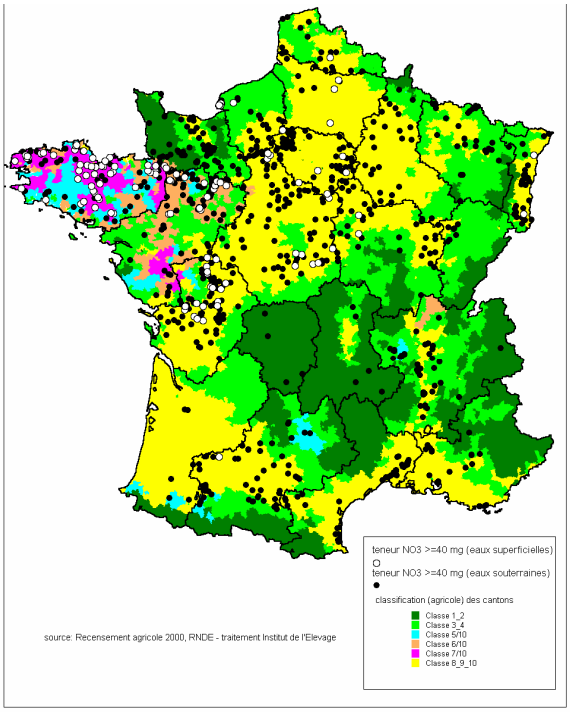
Nitrate concentrations in waters according to agricultural areas

However, this average balance hides considerable disparities between regions. Moreover, calculated excesses do not always correspond very well to the nitrate content of the water. In a recent study (Perrot *et al.*, unpublished; Map 3), cantons were classified according to a certain number of variables to characterise the farming activity: proportion of forage area and area always under grass in the AA, total, mineral and organic nitrogen fertilisation, proportion of landless livestock (pig and poultry), nitrogen balance surplus (inputs: inorganic and organic nitrogen, outputs: crop yields x N%), percentage of forest and population density.
This analysis has enabled us to identify six areas (Table 3) with different characteristics on which we have superimposed the points where nitrate concentrations exceeded 40 mg during the last measurement period (Map 3). Three of these areas are relatively specific to the Armorican Massif and have quite significant differences as to the level of pollution by nitrates, in spite of a forage area that is not very different and a stocking rate of the order of 1 $LU.ha^{-1}$ AA:

Table 3. Main characteristics of the agronomic areas (Perrot et al., unpublished).

Area	% FA/AA	% Permanent grassland/AA	Total N loading (kg/ha AA)	Inorganic N (%)	Ruminants organic N (%)	Pigs and poultry organic N (%)	N surplus (kg/ha AA)	Part of national AA (%)
Mountains and grassland areas	90	70	98	31	67	2	9	18
Mixed areas and grassland	60	40	135	56	41	2	28	28
Brittany intensive milk	66	21	179	43	44	13	54	4
Mayenne west	60	20	161	45	45	10	37	5
Brittany milk + pigs	60	11	221	33	36	31	84	3
Cash crop areas	16	9	123	85	13	2	25	42

Map 3. Nitrate concentrations according to agricultural areas (Perrot et al., unpublished).



- The area « Brittany milk + pigs » covers the North of Brittany with a large organic load per ha, about half of which comes from pig and poultry farming. This area has the highest level of total fertilisation, the highest level of nitrogen excess and the highest nitrate concentrations, particularly in surface waters (see also Appendix II).

- The area « Brittany intensive milk », covering a large part of South and Central Brittany, with few landless systems, has a lower nitrogen excess and considerably lower nitrate concentrations in surface waters. The map shows that the number of measurements higher than 40 mg nitrate is markedly lower in this area compared with the previous one.

- The area called « Mayenne West » has several points in common with the previous area, with few landless systems, a cattle stocking rate that is a little lower and a lower nitrogen excess, but with higher nitrate concentrations in surface water and groundwater, quite similar to those in the area with many landless systems. Higher concentrations would seem to be due to a lower dilution rate (lower rainfall and winter drainage) and doubtless to other parameters too (type of subsoil, type of crops, higher or deeper water tables, etc).

Finally, the major crop-growing area with little livestock farming also has a low nitrogen excess but relatively high nitrate contents, mainly in groundwater. The number of measurements above 40 mg is particularly high on the Angoulême-Châlons en Champagne diagonal. The low calculated nitrogen excess may be linked to the method and the calculation references. Conversely, the high nitrate concentrations may be associated with the type of fertilisation (mineral), combined with a lower dilution rate, again linked to lower rainfall. This type of analysis should make it possible to better define the real risks for water and better prioritise practical recommendations for livestock farmers.

Water quality monitoring

Drinking water supply varies from one region to another. On the primary soils, drinking water is taken mainly from surface waters (more than 80% in Brittany). Conversely, in regions with secondary soils (or sedimentary origin), the water is taken from deep waters. Nitrate pollution problems exist in both cases.
Since 1971, the quality of surface waters has been regularly monitored in the framework of a national network, consisting of 1,100 measurement points. The analyses focus on more than 40 parameters, including the different forms of nitrogen and phosphorus. Results of this network show that nitrate concentrations in surface waters increase on average by 0.22 to 0.56 mg NO_3-N/litre/year. In recent years, this tendency has become slightly less marked, only increasing by 0.11 to 0.22 mg NO_3-N/litre/year (IFEN, 1999). All the same, nitrate concentrations in surface waters vary widely from season to season, with peaks during winter. These results, observed in all basins, are directly linked to nitrogen pollution of agricultural origin (see Appendix II). The levels and trends of nitrate concentrations vary significantly, and depend on the basin under consideration and the size of the water course. Thus, water quality in small streams is more variable than in rivers. The water quality network also shows that phosphorus concentrations are higher than natural levels (0 to 0.01 mg PO_4-P/litre), indicating that there is a certain level of contamination in all the basins.
The deep water monitoring network is less complete and has functioned systematically since 1993. Nitrate concentrations in deep waters are lower than 11.3 mg NO_3-N/litre, with higher values being observed in the surface, permeable or alluvial aquifers. The critical areas concern regions with significant agricultural activity, but with little or

no livestock (Poitou Charentes, Paris Basin). The nitrate concentrations in underground waters are on average higher than those observed in surface waters, and they are also more constant.

5.2.4 Nutrient cycling in dairy farming systems

Farm gate balance method

As in the dairy countries of Northern Europe faced with pollution problems, the farm gate nutrient balance (nitrogen, phosphorus and potassium) is used in France (Simon *et al.*, 1994) to assess the main flows and surpluses of nutrients at farm level. This balance has the following inputs: fertilisers, concentrates, symbiotic fixation, animals and imported manure. Outputs are milk, meat, cash crops and exported animal manure. Nitrogen deposition is neglected (less than 15 kg/ha in West France). Internal nitrogen flows are not taken in account. All data come from account books, except legume fixation which is based on field estimations.

Nitrogen

Several studies have assessed the nitrogen surplus in dairy farming systems in France (Simon *et al.*, 1994; Simon *et al.*, 2000; Farruggia *et al.*, 1994; Le Gall, 2000; Vertès *et al.*, 2002a). The first characterisation of balances of specialised intensive dairy farms (Simon *et al.*, 1992; 2000) revealed high surpluses (200-220 kg N/ha), corresponding with forage systems based on highly fertilised maize and temporary grassland, and with high imports of concentrates. The results observed in mixed farms, i.e. with dairy and pig production, showed notably higher nitrogen surpluses (about 300 kg $N.ha^{-1}$), associated with the absence of a direct link between land and pig production. The nitrogen balance surpluses observed in dairy systems are greater than those observed in crop systems (less than 50 kg $N.ha^{-1}$ AA), but significantly lower than those obtained in monogastric farms (between 300 and 400 kg $N.ha^{-1}$ AA). Nevertheless, the balances of these farms should improve significantly, because they are obliged to respect the organic nitrogen threshold of the Nitrates Directive (170 kg organic $N.ha^{-1}$, i.e. about 40-50 pigs produced.$ha^{-1}.yr^{-1}$), in other words, by reabsorbing the structural surpluses by treatment or spreading slurry on external spreading areas, under contract.
Rapid progress was brought about by changes of fertilisation practices on grassland and maize, the partial replacement of pure grass by mixed grass-clover stands with a moderate clover content and a reduction in concentrate imports. A study carried out recently at national level on a sample of representative dairy farms (Le Gall, unpublished) shows that the nitrogen surplus on the average French dairy farm is 85 kg $N.ha^{-1}$ (60 kg $N.ha^{-1}$ without symbiotic nitrogen fixation). Variability is large, with the nitrogen surplus varying from 30 to 150 $kg.ha^{-1}$, depending on the level of dairy intensification and the proportion of cereals (Tables 4 and 5). On pilot intensive dairy farms in Brittany (1.8 $LU.ha^{-1}$ FA, 5650 kg $milk.ha^{-1}$ AA) (Table 4), the N surplus is appr. 140 $kg.ha^{-1}$ AA. The same study shows that good management of nitrogen inputs at farm level can reduce surplus nitrogen by 40% (about 80 kg per hectare for the best 'third'), usually with lower dairy production per hectare. But large variability is still observed, as the 'worst third' average is still around 220 kg $N.ha^{-1}$. Another study carried out on low-input grass-based dairy systems in Brittany (Vertès *et al.*, 2002a) shows a nitrogen surplus of 120 $kg.ha^{-1}$, notably with high nitrogen inputs by symbiotic fixation due to a high proportion of white clover in grassland (Table 5). The results observed in networks of pilot farms are better than the average observed in specialised dairy farms, where the surplus nitrogen is between 150 and 250 $kg.ha^{-1}$ AA.

Table 4. Characteristics of the dairy farms studied.

	France	Brittany Pays de Loire	Brittany	Brittany	Brittany
Type of farm	Milk	Specialised milk	Specialised milk	Milk +pigs	Milk from grass
Source	Le Gall, 2003	Simon *et al.,* 2000	Le Gall, 2000		Vertès *et al.*, 2002a
Years of observations	2000	1989-1994	1995-1996		1998
N° of farms	316	48	128	11	9
% crop/AA	36	12	19	15	19
% maize/FA	20	46	33	28	14
Stocking rate (LSU.ha^{-1} FA)	1,5	1,8	1,8	1,8	1,4
Production (l.dairy cow^{-1})	6 600	6 900	6 600	5 800	6 000
Concentrate (kg.dairy cow^{-1})	1 240	1300	1 080	1 070	860
Milk.ha^{-1} AA (l)	3 300	6 400	5 650	5 800	4 200

Table 5. Nitrogen flows and balances in different studies carried out on dairy farms.

	France	Brittany Pays de Loire	Brittany	Brittany	Brittany
Type of farm	Conventional dairy	Specialised conventional dairy	Specialised dairy	Milk +pigs	Milk from grass
Inputs:					
Fertilisers	85	200	100	101	30
Concentrates	38	72	49	327	23
Fixation	15	0	27	29	91
Animal waste	1	0	14	6	12
Others[1]	4	4	6	8	0
Total inputs (kg N.ha^{-1} AA)	**143**	**276**	**196**	**471**	**156**
Outputs:					
Milk	17	44	30	32	23
Meat	7	8	9	83	5
Crops	35	7	14	10	9
Other	0	0	1	55	0
Total outputs (kg N.ha^{-1} AA)	**59**	**59**	**54**	**180**	**37**
Balance without fixation	69	217	115	262	28
Balance with fixation (kg N.ha^{-1} AA)	**84**	**217**	**142**	**291**	**119**
Conversion rate (N input/N output)	41	21	30	32	24
Phosphorus balance (kg P.ha^{-1} AA)	10		15		

[1] *Including animals and straw.*

These different studies also show that the nitrogen provided by fertilisation (mineral fertilisers, imported animal manures, symbiotic fixation) represents 60 to 80% of the total input, whilst nitrogen inputs with concentrates constitute between 20 and 40%. Finally, nitrogen balances appear well linked to the intensity of dairy production, combining the level of both plant and animal intensification as well as the proportion of crops (Figure 1).

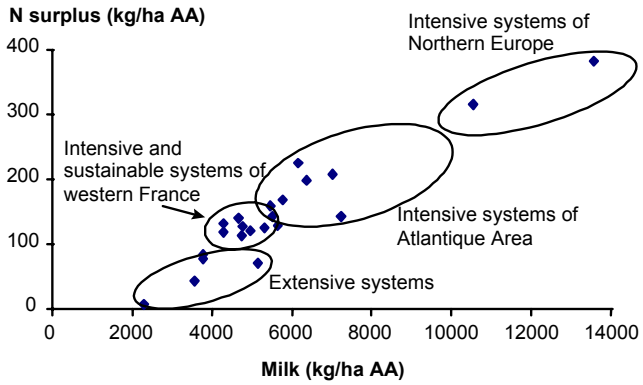


Figure 1. Relation between surplus balance and milk production/ha AA (from Le Gall, 2000).

Figure 1 shows the close relationship between the level of intensification (expressed by the indicator milk production.ha^{-1} AA) and the nitrogen surplus. The results presented correspond to the average of farms observed or surveyed in the study. Within each study, one can however observe a great variability, also at the same level of intensification. This is linked to the large variety in practices (i.e. adjustment of fertiliser inputs to demand of crops) and of contexts of soil and climate conditions. Indeed, for a given level of intensification, the surplus can have a threefold variation!

Phosphorus

Balance studies carried out for phosphorus show that the surplus is between 10 and 15 kg.ha^{-1}. Phosphorus inputs with concentrates cover the outputs by milk and meat, the surplus essentially being associated with excess fertilisation (Coppenet *et al.*, 1993, Vertès *et al.*, 2002d). The surplus is then accumulated in the top centimetres of the soil, for leaching losses are minute in our conditions and runoff losses very low. Nevertheless, the increase in soil phosphorus content can increase runoff risks if the soils are bare. As it requires sixteen times less phosphorus than nitrogen to develop algae in water, the risks of algae proliferation can be conditioned by low quantities of phosphorus in the water.

5.2.5 Strong and weak points of French dairy farming systems

The different elements raised earlier make it possible to establish the strengths and weaknesses of French dairy systems in relation to water and air pollution risks (Table 6). In fact, two major types of situations can be observed (Farruggia, 2000; Farruggia, 2002):

Dairy systems in regions of forage crops and mixed crop and livestock areas record nitrogen surpluses of between 100 and 200 kg N.ha^{-1}. These dairy systems, sometimes complemented by a housed rearing unit, are therefore fragile as far as the environment is concerned, in particular regarding water contamination by nitrates. Risks of nitric pollution are all the higher because there is a significant proportion of bare soils in autumn and winter, flows of organic materials are abundant, and the pastureland is managed intensively.

What is more, the presence of bare soils and the size of the land area under maize cause relatively high risks of water pollution through runoff of phosphorus, plant health products and even pathogenic germs following the spreading of farm manure. Furthermore, the intensity of these systems generates relatively high risks of ammonia emission. In fact, about half of total French milk production is produced in regions of intensive forage cultivation which present fragility in relation to the environment.

Table 6. Evaluation of risks of water pollution in the major French dairy regions.

					Risks of water pollution				Risks of air pollution
	% FA AA^{-1}	% maize in FA	LU ha^{-1} FA	Surplus nitrogen ($kg.ha^{-1}$ AA)	Nitrates	Phosphorus	Pathogenic germs	Pesticides	Ammonia
Areas of forage crops of the West and the foothills	70-90	20-50	1,6-1,8	150-200	+ + +	+ +	+ +	+ +	+++
Areas of mixed crops and livestock	30-50	40-60	1,6-2,0	100-200	+ +	+	-	+ + +	++
Grassland areas of the North and East	80-90	10-30	1,2-1,6	50-100	+	+ / -	+	-	+
Wet mountains of the Massif Central and Franche Comté	90-100	10-20	1,2-1,4	50-80	+	+	+ +	-	+

+: Size of pollution risk.

The mountain or semi-mountain dairy regions of Auvergne and Franche-Comté and the grassland areas of the East of France characterised by a high proportion of permanent pasture and a low proportion of maizeland, moderate stocking rates and low nitrogen surplus. In these conditions, problems of water quality are most often limited to microbial contamination (direct pollution), related to spreading practices.

Finally, it is important to underline that most French dairy systems have positive externalities in relation to the environment, notably by actively contributing to the 'production' of landscape (grasslands, maintenance of a network of banks and hedges) and to biodiversity. This contribution is larger as the proportion of permanent grassland is higher. This multifunctionality was largely discussed in the last EGF congress (La Rochelle, 2002) through grasslands which are the base of cattle farms (Béranger, 2002; Boiffin, 2002). There is lots of research in evaluation of those positives externalities (see for example the IDEA method; Vilain, 2000, Appendix IV), to assess global quality of farm production systems. Besides, a small part of manure surpluses from landless pig and poultry farms can be valorised by moderate intensive dairy farms, constituting a positive externality from a local agricultural point of view.

5.3 Legislation and policies

5.3.1 Background and objectives

In France, regulations on pollution of agricultural origin focus mainly on nitrogen with as main objective to reduce nitrate concentrations and as secondary objective to reduce microbial pollution. There are no specific regulations concerning phosphorus, nor on emissions of ammonia or nitrous oxide, although France has ratified the Gothenburg and Kyoto protocols on these pollutants. The current policy of pollution control of agricultural origin combines regulations and the raising of a levy, based on potential pollution and the means of control implemented.

Until now, French regulations for the control of agricultural pollution has been based on three main texts: the law on classified installations, the law on water and the European Nitrates Directive. Regulations comprise obligations of means and not obligations of results.

The 2000/60/EC Directive establishes a new framework for a community policy concerning water. It will be based on major hydrographic districts at the scale of the European Union and aims at a 'good ecological state' of surface waters, including marine waters for 2015. On 7 June 2001, the European Commission adopted a list of thirty-three priority substances, for which discharges, emissions and leaks need to be stopped or progressively eliminated within 20 years. Thus, we are going from an obligation of means, as laid down in previous regulations, to an obligation of results, which should further increase the pressure on agriculture and intensive livestock rearing.

5.3.2 European and national policies

The obligations of the regulations relating to water pollution by nitrates and incentive measures are recapitulated in Table 7.

The French Departmental Health Regulation (RSD) was established in 1978 and applies to all livestock farms. It includes an obligation to store livestock effluents for 45 days, and, depending on the department, some instructions in terms of spreading distances.

Table 7. Recapitulative of regulations relating to the pollution of waters by nitrates.

	Regulator	Farms concerned	Distances & bans on spreading	Nitrogen ceilings	Fertilization programme, fertilisation log	Catch crop	Nitrogen balance
RSD - Classified installations	*Limitation of pollutions of farming origin in particular in relation to nitrogen pollution*						
	Department	< 40 cows 40 to 80 cows > 80 cows	X X X	 170 kg N_{org}/ha spreadable 170 kg N_{org}/ha spreadable	 X X		CORPEN balance
Nitrate Directive	*Reduction of nitrogen pollution of farm origin in affected regions*						
	EU & Dep.	ZV ZES ZAC	X X X	170 kg N_{org}/ha spreadable Idem 210 kg N_{total}/ha spreadable	X X X	 (X) X	Rational fertilisation
PMPOA	*Bringing the dairy farm into conformity (buildings, fertilisation) in relation to nitrogen pollution*						
	State	Geo priority areas	Respect of Nitrates Directive imperative				Global Nitrogen Balance
CAD	*Financial incentives in favour of the environment*						
	State & Dep.	Voluntary		140 kg N_{org}/ha spreadable 210 kg N_{total}/ha AA	X	X	Apparent balance

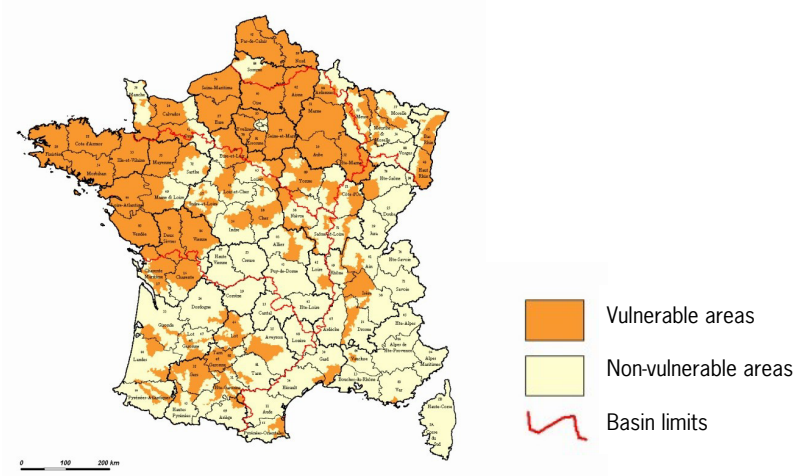
The law on classified installations, very old, concerns all activities whether industrial or agricultural. In dairy production, it concerns farms with more than 40 cows, which are subject to declaration, and those of more than 80 cows, which are subject to authorisation. This law comprises obligations in terms of storage of effluents (4 or 6 months of storage, according to department), quality of effluent recuperation in the livestock housing, spreading distances (spreading limits in relation to third parties, water courses, etc; see Appendix I), spreading dates, rational fertilisation (spreading programme, fertilisation programme), and ceiling of organic nitrogen per hectare. Progressively, these last two regulations are being brought in line with the Nitrates Directive.

The Law on Water of 1992 defined six major hydrographic basins, managed by agencies and coordinated by the Ministry of the Environment. Each agency has defined a Directing Scheme for Water Management and Development

(SDAGE), which determines the water protection objectives and the evaluation of the resource, and arbitrates conflicts of use. The Law on Water does not include specific obligations for the agricultural sector, which must obey, like other sectors, the polluter pays principle. A levy is thus collected according to the potential pollution of the farm and of the means of control implemented at animal housing and spreading level.

The Nitrates Directive was established at EU level in 1991 and was implemented in France by a first action programme in 1996 and a second in 2000. It applies in areas with problems caused by nitrate pollution, representing 43% of the French agricultural area. This zoning affects about 60% of French dairy farms (Map 4)

Map 4. Vulnerable areas in France as at July 2003 (from the Ecology Ministry).



Within these vulnerable areas, there is an additional zoning with Areas of Structural Surplus (ZES, i.e. where the organic nitrogen pressure is higher than 170 kg organic nitrogen per ha of spreading) and Areas of Complementary Actions (ZAC, i.e. where pollution problems necessitate stronger actions). The regulatory obligations also concern spreading distances, the spreading programme for farm-produced fertilisers, organic nitrogen ceilings, and rational fertilisation (spreading programme, annual fertilising programme, keeping a spreading record). In the ZAC, there are complementary instructions, notably the obligation to cultivate 'nitrogen trap' catch crops during the winter and a ban on spreading farm-produced fertiliser after a return to grassland. In the ZES (about 60% of the surface in Brittany), obligations for organic nitrogen treatment over 15,000 kg of nitrogen per farm (i.e. over 170 LU or sows plus piglets) have been set up and it is no longer possible to enlarge livestock farms.

In the vulnerable areas, the organic nitrogen ceiling is 170 kg per hectare, as required in the official text of the European Union, without any particular distinction for crops or grassland areas. However, the French transcription deserves to be specified. The production of organic nitrogen corresponds to animal populations multiplied by their nitrogen excretions, established by the CORPEN. These excretions have been assessed from a balance at animal level (nitrogen from feed minus nitrogen exported with milk or retained in the body) minus the losses of nitrogen by volatilisation in the cattle shed or in storage. For dairy cows, technical references have been established according to the feeding system and the production level of the cows (CORPEN, 1999). But, in the end, a single standard of discharge has been retained (85 kg per cow).

The spreadable area is without doubt more restrictive than in other European countries because it corresponds to the area spreadable with livestock effluents (thus incorporating the constraints of spreading distances) to which is added the grazed area outside this area. Taking into account the spreadable distances imposed in France, the spreadable area in a dairy farm is between 80 and 85% of the useable farm area, which appears more restrictive than in other European countries. Nevertheless, the two effects are cancelled out and the pressure of organic nitrogen finally obtained in a given situation is quite close to that which would have been obtained in the countries of Northern Europe.

The assessments carried out by the Institut de l'Elevage in 2002 show that about 10% of dairy farms would seem to be situated above the threshold of 170 kg of organic N per spreadable hectare. In other words about 20% of farms are situated in vulnerable areas (Le Gall, 2003). The farms concerned are either mixed farms in the West of France combining dairy production with pig or poultry production, or highly intensive farms with a stocking rate higher than 2 $LU.ha^{-1}$ and a low proportion of crops.

In this regulatory context, the French State, the Water Agencies (charged with managing water resources) and the farming community negotiated in 1993 a **Programme for Controlling Pollution of Agricultural Origin (PMPOA)**, helping farmers financially to comply with existing regulations (storage of animal effluents and rational fertilisation). In a first phase (1993-2000), the choice was to integrate into this system the largest farms with more than 70 LU (cattle or equivalent). Thirty thousand farms joined the system. This was reviewed in 2002 and refocused on vulnerable areas. On 31/12/2002, more than 100, 000 livestock farmers, half of them dairy farmers, declared their intention to commit themselves to this programme which insists on compliance with the Nitrates Directive and agronomic rules.

In 2000, the French public authorities set up a new policy of financial support for farms based on the so-called Farm Land Contracts (CTE), renamed Sustainable Agriculture Contract (CAD) in 2002. This policy aims at redirecting direct aid to farms, according to considerations of environment, employment or land occupation, with a desire to emphasise the multifunctionality and sustainability of agriculture. The farmer must therefore respect a certain number of rules relating to the environment and in particular to the management of nitrogen and plant health products on their farm. These rules differ from one region to another, but it is often necessary to rationalise nitrogen fertilisation and respect organic nitrogen and/or mineral ceilings, sometimes more restrictive than those imposed by the Nitrates Directive.

In fact, today there are several regulatory programmes that oblige dairy enterprises to have greater respect for the environment. These programmes are the expression of regulations of good agronomic recommendations and are globally consistent with each other.

5.3.3 Implementation of policies

Setting up the Nitrates Directive

The Nitrates Directive was added to existing regulations for water protection, not harmonious from one department to another, complex and not very well inspected for classified installations. The schedule and content of the Nitrates Directive brought about a start to harmonisation and plans for simplification in 2002-2003. In spite of much criticism, the Nitrates Directive has been a driving force to justify the PMPOA, the first programme of aid and technical support for the control of pollution caused by livestock farming, and with an important if not exclusive focus on nitrates.

The first two stages, the definition of a code of good agricultural practices and the designation of vulnerable areas did not give rise to particular problems for livestock farming areas in spite of a restrictive definition of spreading surfaces and areas of structural excess by the authorities.

The first programmes of action favoured incentive measures, aids to increasing slurry and manure storage capacities and information and training, much more than inspections and sanctions, notably for lack of any precise regulations before 2003.

In fact, two farming regions are particularly concerned: the regions of intensive livestock farming of the West, in particular Brittany and to a lesser extent the Pays de Loire, as well as the regions of cash crops where the nitrate concentrations in groundwater continues to increase.

For regions of intensive livestock farming and in particular for Brittany, there is a growing sense of awareness and pressure at three levels:

- *Local*: pressure from consumers and environmentalist associations who have taken the water board and the State to court;
- *Regional:* to preserve tourism potential (green tide, algae and risk of toxicity for shellfish farmers);
- *European*: the Commission has given notice to France for failure to respect several clauses of the Nitrates Directive.

It is doubtless for these different reasons that France has not asked for a dispensation to put back the schedule or increase the ceiling of organic nitrogen per hectare for grasslands, for example. It is doubtless also because the great majority of livestock farmers must be able to respect the ceiling of the 170 kg organic N per hectare, without having to reduce herd numbers.

However, two types of livestock farmers are particularly concerned: farmers who specialise in pigs, the biggest units being obliged to treat waste above 15,000 kg of nitrogen per year, and mixed dairy and pig farmers who combine two intensive units on a small area. These are the ones for whom technical solutions are the most difficult to find.

So, nearly 10 years after the first action programme started, the whole of the programme of regulations and technical and financial support is in place, with the ambition to enable 100,000 livestock farmers to be perfectly in order with the Nitrates Directive between now and the end of 2006.

Other environmental sectors have taken second place

Phosphorus, although also responsible for eutrophication problems, has not been subject to the same vigilance as nitrate, neither from the Authorities, nor from the water agencies, nor from the media. In fact, there has been no public debate about the relevance of phosphorus as a major indicator of risk for aquatic environments, perhaps because the threshold value limiting the development of algae is so low that it may appear impossible to attain. Moreover, the contribution of livestock farming to discharges of phosphorus into water is only 10 to 20% depending on the region, in parallel with domestic and industrial discharges!
However, as the debate on nitrate toxicity is out of date (i.e. considered as overrated), it would be more worthwhile to consider phosphorus as the main element for checking eutrophication and reviewing the action programmes, with the dual concern to limit N and P discharges, by playing on synergies, and promote specific measures to avoid surface run-off. It would also limit problems of bacteriological pollution associated with the run-off of slurry or manure diluted by rain, as well as the run-off of some pesticides. If the same good practices could limit several risks at the same time, it would be more attractive to farmers.

Ammonia emissions

Ammonia emissions from agriculture in France amount to 20 $kg.ha^{-1}$ AA and are mainly concentrated in West France, according to pigs and poultry population, where emissions amount to about 100 $kg.ha^{-1}$ AA (CORPEN, 2001). Dairy production accounts for about 25% of the emissions. France has not undertaken any programme for reducing ammonia losses from livestock farms, but the set of reduction objectives agreed in Göteborg in 1999 could be attained simply by continuing to reduce the population of ruminants.

5.4 Actual and intended research for sustainable dairy farming systems

It was shown in the preceding part that intensive dairy production systems have positive as well as negative impacts on water, air and soil quality. In the last 15 years, different working methods have been mobilised in France by INRA, the Institut de l'Elevage, Arvalis, CEMAGREF and the Chambers of Agriculture for the study of more sustainable and environmentally friendly dairy systems. Working methods combine sectional trials, modelling at farm level,

experimentation on complete systems (crops and herds), balances in livestock farms and studies carried out at catchment basin scale (Figure 2).

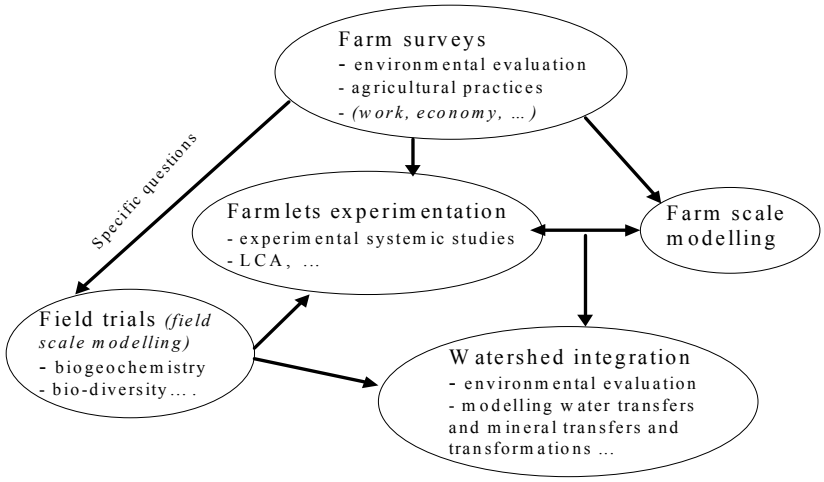


Figure 2. Working methods and means used to study the impact of dairy systems on the environment.

In this paper, we will elaborate studies carried out at farm level. First, we present the indicators used at different levels, in particular the different nutrient balances that made it possible to describe the main flows and surpluses according to the types of dairy farm, and to analyse farmers' practices. The experimentation on complete systems, combining herds and forage crops associated with return of farm-produced fertilisers, made it possible to specify nitrogen flows and in particular losses of nitric nitrogen. Modelling at the farm enabled previous work to be pursued, notably to extrapolate the results obtained and/or to study other systems.

5.4.1 Indicators used for evaluation of dairy farm sustainability

The indicators used at farm level enable a diagnosis to be made and developments over time to be measured. To be really useful, they have to be robust, i.e. established from easily accessible farm data, and relevant, i.e. showing a direct relationship with the impact on the environment. The most frequently used indicators of nitrogen and phosphorus management in France focus essentially on diffuse pollution and can also be qualified as agronomic. All the indicators presented below are based on simple calculations.

A structural indicator: the pressure of organic nitrogen by spreadable hectare

This is the indicator of the Nitrates Directive, established from the production of organic nitrogen (animal numbers x nitrogen discharge standards) and the spreadable surface, as defined in France (cf. Section 5.3.2). This indicator makes it possible to situate the farm in relation to the ceiling of 170 kg organic N per hectare. Naturally, it is directly linked to the animal stocking rate and/or to the dairy production per hectare of AA.

Two balances at farm level

We use two nutrient balance types at farm level. As presented in Section 5.2.4, **the farm gate nitrogen balance** indicates the amount of apparent N excess (inputs – outputs)/ha, corresponding to potential pollution risks for air and water. As it does not take into account the accumulation or depletion of nitrogen in the soil, very dependent on the crop/grass ratio and management, and as it is an average per ha, it cannot be used directly to calculate specific N losses. However, for a large sample of usual dairy production systems, it allows good comparison between similarly structured farms, and research progresses with modelling the fate of the N surplus. It can be extended to phosphorus and potassium. This type of balance is more or less identical to the one used in many European countries.

Other, complementary indicators can be calculated from this global nitrogen balance:
- the nitrogen conversion rate, i.e. the ratio of nitrogen output and nitrogen input (Aarts, 1992), indicating the nitrogen efficiency within the farm;
- the nitrogen wastage index, i.e. the ratio of surplus and nitrogen output (Simon *et al.*, 2000; Vertès *et al.*, 2002a);
- the nitrogen surplus per ton of milk or 1000 litres of milk.

The soil nitrogen balance (adapted from CORPEN) is used in the framework of the DEXEL (Environmental Diagnosis of the Livestock Farm). Inputs are total nitrogen production by the animals, purchased fertilisers and imports of farm manure. Outputs are exports with crop products (grass, maize and cereals), equal to production x N% standards. This soil balance is qualified as agronomic, because it is made at the level of plots and therefore incorporates the needs of the cultivated crops.
These indicators are useful for systems diagnosis and optimisation within system types.

Indicators of farmers' practices

Other indicators are used to characterise farmers' practices, notably in the framework of the DEXEL:
- **Quantity of mineral N per hectare of AA** or for each component of the crop system (meadows, maize and cereals).
- **Surface Amended by Organic Manure (SAMO)**: this is the farm area that receives the farm manure and it can be expressed as percentage of the AA. Expressed per ha, it indicates the organic N pressure and it is recommended not to exceed the threshold of 200 kg per hectare.
- **Percentage of bare soils in relation to the AA**: the objective is to reduce as much as possible the area of bare soils during the drainage period (winter), either by increasing the proportion of grassland and/or cultivation of catch crops.

These indicators are useful for practices diagnosis and improvement.

5.4.2 Synthesis of sustainable results: objectives, methods and results

Experimentation on complete systems

Experimentations on complete systems were carried out in France in intensive dairy farming systems (Table 8), presenting risk for water and air pollution. Studies were carried out at the Ognoas station in the South West (Legarto & Le Gall, 1999), at Crécom (Le Gall *et al.*, 2000; Le Gall & Cabaret, 2002) and Trévarez (Le Gall & Le Meur, not published) in Brittany, each case representative of the prevailing dairy farming system in each region (Table 8). These programmes were very similar to those carried out by Aarts *et al.* (1999) at the De Marke farm in the Netherlands, Peel *et al.* (1997) at Bridgets in England, Ledgard *et al.* (1999) at Hamilton in New Zealand, and Humphreys *et al.* (2002) in Ireland.
The systems were optimised from an environmental viewpoint, incorporating the different techniques to reduce nitrogen and phosphorus inputs and limit nitrogen losses: control of the quantity of concentrate and reduction of their nitrogen content, sufficient storage capacity for farm manure, postponing the spreading of farm manure to the end of winter, rational fertilisation and timely planting of catch crops under maize at the 6-8 leaves stage.
N leaching losses were estimated from successive measurements of mineral N in soil profiles in the plots of the system, sampled three (Trévarez) to five (Crécom) times during the winter, used with Burns model for drainage.

Table 8. Characteristics of experimental systems.

System	Crécom[1]		Trévarez
	'40% maize'	'80% grass'	
Years of study	1996 to 1998		1999 to 2001
% SFP/SAU	76	78	88
% maize silage/FA	38	18	30
Stocking rate (LU/ha FA)	1,75	1,78	1,66
Production (kg/cow)	7800	7340	6420
Concentrate (kg/cow)	1170	1250	580
Milk/ha AA (l)	7030	6910	6000
Pressure of organic nitrogen/ha spread.	134	132	171
% of grassland destroyed by year/AA	10	13	7
Nitrogen inputs (kg/ha/ year)	140	159	183
- fertilisation	90	121	120
- symbiotic fixation	0	0	25
- concentrates	40	34	43
Nitrogen outputs (kg/ha/ year)	55	53	56
Farm gate nitrogen surplus (kg/ha/year)	85 (7%)	106 (8%)	127 (8%)
Conversion rate (%)	39	33	29
Soil nitrogen balance (kg/ha/year)	11	31	69
% of bare soils	0	0	15
Drainage (mm/year)	400	388	531
Estimation nitrogen leaching (kg/ha/year) whole system	40 (13%)	43 (12%)	42 (20%)
Concentration in nitrates (mg/l)	44 (31%)	49 (33%)	35 (13%)

[1] *Results complemented by modelling for areas devoted to heifers and cereals.*
Figures in brackets are variation coefficients.

The results observed, respectively over 4 and 3 years, show that excess nitrogen was reduced by 50% compared to that observed in commercial farms (Table 8). The conversion rate that measures the effectiveness of the nitrogen within the system is between 30 and 40% (vs. 20 to 25% presently in commercial farms). In these conditions, N leaching is estimated at 40-45 $kg.ha^{-1}.yr^{-1}$, corresponding to a mean nitrate concentration varying with observed drainage between 30 and 50 $mg.l^{-1}$, i.e. close to but lower than the threshold for drinking water as defined by the European Union. In most grassland system, nitrate leaching is lower under meadows (45 $kg.ha^{-1}$ versus 49 $kg.ha^{-1}$ in the system with more maize), because there is more mowing and fewer days grazing. This is compensated by the effect of grassland cultivation to maize crops in the most grassland system (53 $kg.ha^{-1}$ versus 48 $kg.ha^{-1}$ in the system with more maize).

The results of the experimentation and complementary modelling work show that the proportions of grassland and maize have little influence on nitrate leaching losses, for the same stocking rates and perfectly optimised management of maize, i.e. suitable management of farm manure, rational fertilisation, systematic and successful establishment of catch crops. On the other hand, if the management of maize is imperfect, as usually observed on commercial farms, with excessive organic fertilisation associated with surplus effluents (up to 170 kg organic N per ha), and/or followed by bare soil, the grassland systems appear more robust. A large margin for progress thus exists in Brittany, which encourages to study the reasons for the hold-ups: uncertainties about quantities and the agronomic value of farm manure and costs in work and money. Finally, when an increased proportion of grassland

allows a reduction in stocking rate, the nitrogen excess drops and nitrate leaching is reduced, even with longer grazing periods, as shown by Vertès *et al.*(2002b) and Journet (2003).

Strategies of rotations of grassland and crops

As shown for commercial dairy farms by Alard *et al.* (2002), the main ways to optimise sustainable production concern vegetal products and animal management. In particular, several questions remain unanswered in forage crop systems on rotation strategies between grassland and crops, and the present trend of specialisation, alongside the enlargement of farms by the addition of isolated islands of land, has to be questioned. A recent European-wide synthesis on grassland cultivation and ley-arable systems (Conijn *et al.*, 2002) shows the interest of long rotations with grassland for agronomic and environmental issues. A systemic approach is necessary to integrate the interest for animal production, varying with the rearing methods between countries.

Recent studies have quantified nitrogen mineralisation (amounts and kinetics) after grassland cultivation (Vertès *et al.*, 2002c). N mineralisation rates were very high during the year following grass destruction, then decreased rapidly to 'basal' mineralisation rates, more linked to soil and climate characteristics. Morvan *et al.* (2002) enhanced the primordial role of the crops post destruction and their ability to use mineralised nitrogen. The recent results will largely modify the references used until now in France (Laurent *et al.*, unpublished), and work in progress investigates the role of organic matter compartments and evaluates indicators to predict mineralisation.

Impact of dairy production level per cow

The increase in genetic potential of dairy cows reduces organic N excretion per ton of milk, since a given amount of milk quota can be produced with less cows (Table 9). It thus reduces the nitrogen pressure per hectare of AA, and also potential spreading and spreadable area. In France, the increase of milk production per cow was associated with an increase of protein concentrate consumption and of the proportion of maize silage in the diet, and therefore with a reduction of the necessary forage area. Thus the nitrogen discharge per ton of milk decreases, as does the nitrogen pressure per spreadable hectare. Conversely, the lowest levels of dairy production are often associated with more grassland systems and larger farming structures. The nitrogen discharges per ton of milk are higher but the pressure per spreadable hectare is reduced. Work in progress tends to show that nitrogen losses by leaching are not connected with the production level, but much more with the use of the land and agronomic practices. In this context, the nitrogen excretion per animal or ton of milk is not a suitable indicator to evaluate the risks of nitrogen pollution in dairy systems.

Table 9. Effect of milk production level and forage system on nitrogen returns and their valorisation.

AA (ha) [1]	30	30	30	30	30
N° of dairy cows	42	42	34	28	28
Milk/cow (kg)	6000	6000	7500	9000	9000
Grazing (months)	7½	5	5	5	3½
Grass silage (months)	4½	1	1	1	0
Maize silage (months)	0	6	6	6	8½
Grass (ha)	30.0	15.0	12.1	10.0	5.8
Maize (ha)	0.0	10.0	8.1	6.7	9.4
Other crops (ha)	0.0	5.0	9.8	13.3	14.7
FA (ha)	30.0	25.0	20.2	16.7	15.3
PSA (ha)	30.0	25.5	24.6	24.0	22.8
Stocking rate (/ha FA)	1.40	1.68	1.68	1.68	1.83
N waste/cow (kg)	125	105	113	121	116
N return to grassland (kg) [2]	71	47	50	54	34
N waste/t milk (kg)	20.8	17.5	15.1	13.4	12.9
N spreadable/cow (kg)	109	88	94	101	91
N spreadable/ha FA (kg)	152	147	158	169	167
N spreadable/ha PSA (kg)	152	144	130	118	112
N export/ha FA (kg)	202	187	187	187	175

FA: Forage Area (Grass + Maize + crops used in animal diet); PSA: Potentially spreadable area.

(1) Farm with a quota of 250000 litres. The actual production of a hectare of grass and maize is fixed respectively at 8000 and 12000 kg MS. The spreadable area represents 70% of the crops area and 100% of the grass area.

(2) Direct return to the grassland and 70% of the nitrogen from the animal waste collected in the buildings.

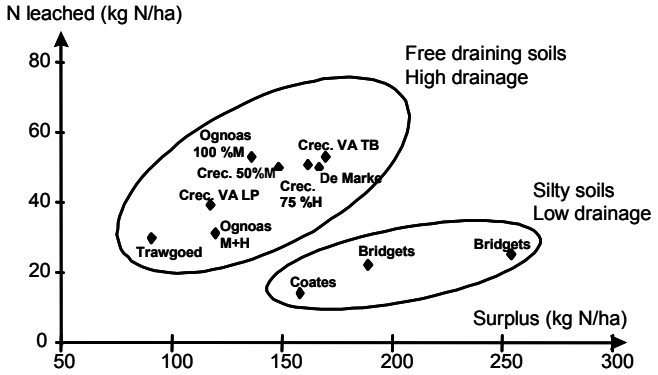


Figure 3. Relation between the farm gate apparent balance surplus and the amount of leached nitrogen.

Relevance of the nitrogen balance as a risk indicator

A previous synthesis of European experimental results (Le Gall and Cabaret, 2002) shows that N leaching is better linked to farm gate N balance surplus when the soil and climate condition contexts are distinguished. Amounts of N leaching represent 30 to 40% of the N surplus in filtering soils associated with high drainage, and only 10 to 20% in more loamy soils combined with low drainage (Figure 3), the latter situation being more favourable to gaseous losses, mainly by denitrification (Scholefield, 1991). With larger nitrogen surpluses or a larger proportion of crops, the proportion of leached nitrogen is probably greater.

As this global balance integrates both nitrogen and phosphorus inputs with fertilisers and concentrates, it is very instructive for farmers as it represents simply the main flows of N and P pollution risks, and thus is relevant in terms of advice. All the same it requires a regional interpretation grid. Simon *et al.* (2000) showed a positive linear relation between production level (l milk.ha^{-1}AA.year^{-1}) and balance surplus. They noted a considerable variability, associated essentially with the potentialities of soil and climate conditions and the technical skills of the farmers. Much progress has been made in the last ten years, but a significant margin of improvement remains. A simulation study for Brittany (Chambaut *et al.*, 2000) quantified the minimum level of nitrogen surplus for dairy farms which would respect all the recommendations in feed and fertilisation. On average in the farm network, levels of farm surpluses are 20 to 25 kg N per 1000 l milk and would seem to approach 10 to 15 kg N per 1000 l in the best simulations, very close to performances obtained by the best farms. However, vagaries of climate, farm structures (field pattern, insufficient storage installations) and farmers' practices may not enable all farms to attain these thresholds.

Encouraging results for French intensive dairy systems

The different studies carried out for intensive dairy farming systems (stocking rate < 2 LSU.ha^{-1} FA, 6,000 to 9,000 litres milk produced per hectare of AA), based on forage crops in rotation with cereals, show that the optimisation of nitrogen flows reduces nitric nitrogen losses and reaches a nitrate content in water of between 30 and 50 mg per litre. Taking into account the expected reductions in nitrogen between the farm and the catchment basin outlet, these results appear encouraging. On the other hand, the de-intensification of the dairy system associated with the increase in the proportion of grassland and the reduction in the proportion of cereals also appears promising. As evidenced by Jarvis & Aarts (2000) system scale studies are one of the necessary approaches to optimise N (and other minerals) management.

5.4.3 Economic impact of the optimisation of dairy systems

The environmental impact of the optimisation of dairy systems can be assessed in two situations. In the first case, the existing system is optimised, often by creating the necessary manure storage installations, by cultivating catch crops and by adjustment of fertilisation and concentrate supplementation to the animals. In the second case, it can involve de-intensification of the system, with greater recourse to grassland and grazed grass. Simulation studies and observations in farms have made it possible to evaluate the economic impact of this optimisation.
In the most common scenario, optimisation of the existing system involves creating additional storage installations for slurry and manure, in order to bring them as close as possible to the needs of the crops. The investment costs after financial aid, translated into annuity of loans per liter of milk is often between 1 and 2 euro centimes per liter of milk, but can be much higher if the creation of storage areas involves considerable modernisation of buildings. Better management of farm fertilisers combined with rational fertilisation halves the cost of mineral fertilisation. Cultivating a catch crop between two annual crops involves additional expenditure. Depending on cases and the level of waste of concentrates, the adjustment of the quantity of cattle feed enables an economy on this item to be made. In this scenario, the environmental optimisation of the system does not modify the volumes produced (milk, meat and cereals), and the margin obtained in the optimised situation is either higher or slightly lower (Table 10). Usually the economies made on fertilisers more or less compensate for the additional costs associated with the creation of storage installations, and the profit for a dairy farm will depend very much on investments in housing and economic savings in fertilisers. A complementary approach, carried out in a catchment basin with 800 intensive dairy farms in the Loire Atlantique (catchment basin of the Don), confirms these results (Bontemps *et al.*, 2003).

Table 10. Economic impact of the environmental optimisation of dairy systems (simulations).

			Fertilisers €/ha AA	Annual cost of storage installations		Catch crop €/ha AA	Concentrates €/LSU	Margin [1]	
				€/LSU	Cts €/l			€/LSU	€/ha AA
Simulation on a classic system	Le Gall & Cabaret, 2002	Present	122	-	-	0	1580	1298	1573
		Optimized	51	607	1,1	12	1580	1253	1519
Case study on five dairy farms	Chambaut, 2003	Present	110	-	-	26		1042	1250
		Optimized [2]							
		Level 1	44	304	0,06	72		1207	1404
		Level 2	34	417	0,09	80		1205	1398

[1] *Concerns the farm product minus the operating costs, the costs of mechanisation and the investments for storage installations.*

[2] *Level 1: Rational fertilisation without involving the management of farm produced fertilisers, adjustment of concentrate quantities.*
Level 2: Optimisation of farm fertiliser management and strict adjustment of mineral fertilisation, cultivating catch crops.

The de-intensification of the system with more recourse to meadow and pasture land is the other possible way. The work carried out shows that these de-intensified systems present the same effectiveness and economic results as more conventional systems, in spite of the reduction in the amount of the maize premium (Le Lan *et al.*, 2000; Alard *et al.*, 2002). The complementarity between the different livestock systems must be studied at all levels, integrating regional micro-economy, all production channels, consideration given to capital, work and product quality, etc. The complexity of this analysis requires better co-operation between 'agronomists' and economists and needs the development of multi-criteria evaluation methods.

On the catchment basin, presented earlier, different policies regulating nitrogen pollution have been studied (Bontemps *et al.*, 2003). These policies centred on the taxation of mineral nitrogen (0,23 euro per kg N), limitation of chemical N fertilisers, taxation on excess nitrogen and imposed extensification of dairy production (reduction in milk production per ha of FA, to the detriment of cereal production). The results show that the taxation of bought mineral nitrogen is more effective than the arbitrary limitation of the use of nitrogen fertiliser, both in terms of reduction in nitrogen emissions at the outlet and of costs of control (Appendix III).
Finally, it is obvious that these economic results have to be put in perspective with the environmental gains, the possible taxations and the costs of de-polluting water.

5.4.4 Tools available for predicting at field, farm or regional (watershed) level the agricultural and environmental results

The approaches presented above can give a good estimate of the amount of nitrogen leached from the individual fields at farm scale, but a lot of processes come into play when this nitrogen is transferred to the hydrosystems, i.e. groundwater and surface water. The relationship between the agricultural nitrogen budgets and the nitrate concentrations at the catchment scale is complex (Ruiz *et al.*, 2002).
In regions with permeable substratum, where the water table depth is much greater than the soil depth, nitrogen is transferred to the groundwater at variable rates, but is usually conservative. The concentration in the groundwater will be directly related to the sum of the contributions from each field, after accounting for the non-cultivated areas

(e.g. Gaury and Benoit, 1992). The time span between changes in agricultural practices and changes in groundwater concentrations will depend on the transfer rate and on the mean residence time in the vadose zone and in the groundwater (i.e., the ratio of storage volume and water flux through the system).

In regions with less permeable substratum, the groundwater is relatively shallow and the interactions between soil, groundwater and surface water are more complex. Usually, in the upper parts of the landscape, the groundwater table is several meters deep and the same reasoning as above applies. However, in the bottom slopes, in areas varying dynamically with rainfall, the groundwater table is within the soil or can reach the surface. This implies, first, that the transfer time to the groundwater is much quicker and can affect not only soluble pollutants but also particles or colloids, and second, that nitrogen in groundwater can be involved again in bio-transformations in the soil, especially plant uptake and denitrification. On the whole, in such systems, the transfer time from soil to surface waters ranges from several years or decades in the upper slopes to several days or months in the valley bottoms. This transfer is generally non-conservative, due to the bio-transformations affecting nitrogen in the lower parts of the landscape.

In this context, a quantitative description of the transfer of nitrogen from fields to surface waters is difficult. At the regional scale, Aurousseau *et al.* (1996) have estimated that up to 40% of the excess nitrogen could be retained and/or denitrified during transfer to surface water. At the catchment level, the estimations are much more variable, from nearly zero to more than 60% retention. Local studies of nitrogen retention in riparian zones (Pinay *et al.* in Fustec and Lefeuvre, 2000) or by hedges (Caubel, 2000) suggest very high retention rates, although the effective impact on downstream water quality may well be much lower due to the heterogeneity, in time and space, of the fluxes from the hill slopes to the streams (Beaujouan *et al.*, 2002).

A modelling approach is currently developed at UMR SAS INRA, Rennes, specifically to address this problem in different catchments (Beaujouan *et al.*, 2001, 2002). Preliminary results show that the loss of nitrogen during the transfer to the stream is in the order of magnitude of 100-300 kg per hectare of 'interaction zone', i.e. the zone where the groundwater reaches the soil during several weeks of the year. The area of this zone depends of course of the topography of the catchment, of the bedrock and of the man-made modifications of the system (namely, artificial drainage and watercourse network straightening). This tool may be used to evaluate the effect of crops location in watershed, including field exchange between farms of different types, as suggested by Lemaire *et al.* (2003).

5.4.5 Prospects for multi-criteria environmental assessment

Until now, environmental impact assessments of dairy farming systems have focused on nitrogen losses, with as prime concern the leaching of nitrates. Phosphorus emissions have also been taken into account, but in a less detailed way. Nitrogen and phosphorus emissions contribute to the problem of eutrophication or, more generally, to the problem of water quality. However, the environmental impacts of dairy production are not limited to this problem. In particular, pesticide residues may affect water and soil quality. Like all economic activities, dairy production contributes more or less seriously to the emission of greenhouse gases, acidifying gases and toxic substances and to the use of resources such as non-renewable energy and water. What is more, dairy farming systems have a significant effect on the quality of the landscape and bio-diversity. These problems are already serious now and they could well become more important in the near future. Thus, it appears obvious that environmental impact assessment studies, aiming at improving dairy production systems for the future, cannot be limited to one single problem (water quality), but will have to be multi-criteria and take the major environmental problems into account. Such an approach would avoid the choice of solutions that solve one problem only to create two others.
One of the most appropriate tools for implementing such a multi-criteria assessment is Life Cycle Analysis or Ecological Balance (van der Werf and Petit, 2002; de Boer, 2003), which is a method based on the quantification and evaluation of the use of resources and of the principal emissions likely to adversely affect the environment. It has the advantage of being based on a precise methodology and of being able to cover all pollutants of agricultural origin. This method has been applied by the INRA of Rennes to pig production and fish farming for two years now.

A collaboration project with the Chamber of Agriculture of Brittany « Ecological balance of production systems » will soon begin. The evaluation of dairy systems will be at the heart of this project.

Conclusions

1. The mobilisation against water pollution by nitrates dates from the early 1990s. It was given concrete expression by a programme of technical support and aids to investment after 1994, but tailed off after 1998 in the face of strong criticism. Focusing on the largest farms, in the whole of France, from 1994 to 2000, rather than on the problem regions did not help in passing a clear message.
2. The French translation of the Nitrates Directive regulations was perceived as complex and more restrictive than in other countries and, relatively speaking, not completely operational before 2003. It concerned mainly nitrate losses: no regulation on NH_3 emissions neither on phosphorus surplus, but voluntary actions on equilibrium inputs/outputs of crops. It must be quoted that the legislation has very recently limited some pesticides and antibiotics, which induces more systemic approaches to improve sustainability of animal productions.
3. Even in the region with the highest animal population density, Brittany, the average organic load is lower than 170 N per AA. However, as the French calculation method only retains 70% of the AA for the spreadable surface at canton level, and as animal densities vary a lot, more than half of the region is considered as structural excess area, with constraints aimed at all livestock farmers in the canton.
4. The special features of French regulations, the prospects for technical and agronomic solutions at a reasonable cost, and the lower pressure on land compared to other countries with intensive livestock farming, may explain why there was no request for special dispensation in relation to the 170 kg N ceiling.
   However, as long as water, air and soil quality still decrease, it is also local pressure from consumers and ecologists demanding respect for regulations and more inspections and sanctions, by bringing an action against the French State. The debate around the relevance of the 170 kg N indicator has therefore not taken place for fear of opening the floodgates to a new growth in landless livestock farming.
5. The system studies on experimental farms show that the nitrate level in groundwater can be kept below 50 $mg.l^{-1}$ on dairy farms with good management practices, including grazing, even with stocking rates close to 2 $LSU.ha^{-1}$. Nevertheless, there are large differences in nitrate leaching sensibility between soil types, and research on water quality as well as coherent action programmes with farmers must concern the catchment scale.
6. The relevance of focusing on nitrate leaching without any formal guarantee of consistency with a reduction of other pollution sources (gaseous N, phosphorus, pesticides, heavy metals) remains the main weakness of French procedures in the last ten years. Today, in spite of very real awareness, this more integrated approach is still more a subject for applied research, rather than a real programme of coherent action to protect water and air at the level of dairy farms and livestock farming regions.
7. Multi-criteria approaches (LCA) and systemic and territorial modelling are essential methods and tools for actual and future research to evaluate and conceive sustainable agricultural productions among which dairy systems have a very important role through grassland use.

References

Aarts, H.F.M. & Biewinga, E.E., 1992.
Dairy farming systems based on efficient management. Netherlands Journal of Agricultural Science, 40, 285-299.

Aarts, H.F.M., Habekotte, B. & van Keulen, H., 1999.
Nitrogen (N) management in the 'De Marke' dairy farming system. Nutrient Cycling in Agro-ecosystems 56, 231-240.

Alard, V.; Rousset, D.; Leterme, P. & Journet, M., 2002.
Comparaison de trois types de systèmes de production par simulation. In: 'A la recherche d'une agriculture durable. Etude de systèmes Herbagers économes en Bretagne', Alard V., Béranger C., Journet M. (Eds), INRA Editions, 217-230

Aurousseau, P., Baque, M.C. & Squividant, H., 1996.
Les bassins versants de Bretagne et leur charge polluante. Rapport de convention DRAF de Bretagne, Rennes, 30 p.

Barroin, G., 2003.
Phophore, Azote et prolifération des végétaux aquatiques. Courrier de l'Environnement, INRA, 48, 13-26.

Beaujouan, V., Durand, P., Ruiz L. & Aurousseau, P., 2001.
Modelling the effect of spatial distribution of agricultural practices on nitrogen fluxes in rural catchments. Ecol. Model., 137, 1 93-105.

Beaujouan V.; Durand P.; Ruiz L.; Aurousseau P.; Cotteret G., 2002.
A hydrological model dedicated to Topography-based simulation of nitrogen transfer and transformation. Rationale and application to the geomorphology-denitrification relationship. Hydrological Processes,16, 493-507.

Beranger C., 2002.
La multifonctionnalité des prairies: les acquis et les interrogations du 19ème Congrès Européen des Herbages. Fourrages, 171, 227-237

Boifffin J., 2002.
La multifonctionnalité des prairies: incantation ou moteur de renouveau ? Fourrages, 171, 327-329.

Bontems P., Rotillon G. &Turpin N, 2003.
Acceptability constraints and self-selecting agri-environmental policies, in '12th annual conference of the European Association of Environmental and Resource Economists', Bilbao, 28-30 June 2003, 43 p.

Caubel V., 2001.
Influence de la haie de ceinture de fond de vallée sur les transferts d'eau et de nitrate. Doctorat de l'ENSAR, Mention Science de l'Environnement, INRA UMR Sol-Agronomie-Spatialisation Rennes: 151 p.

Chambaut, H., 2003.
Optimisation de la gestion de l'azote dans cinq exploitations intégrées dans un bassin versant. CR Institut de l'Elevage.

Chambaut H., Cabaret M.M., Le Lan B., Bras A., Grasset M., Guionie C., 2000.
Optimisation du bilan des minéraux des exploitations laitières. Méthode de simulation des flux N-P-K paramètrée pour la région Bretagne. Institut de l'Elevage, EDE Bretagne, 76 pages.

Conijn J.G., Velthof G.L., Taube F. ,(eds), 2002.
Grassland resowing and grass-arable crop rotations. International workshop on agricultural and environmental issues, Wageningen 18-19 april 2002, PRI report n°47, 127 p.

Coppenet M., Golven J., Simon J.C., Le Corre L., Le Roy M., 1993.
Evolution chimique des sols en exploitation d'élevage intensif: exemple du Finistère. Agronomie. 13, 77-83.

Corpen, 1999.
Estimation des flux d'azote, de phosphore et de potassium associés aux vaches laitières et à leur système fourrager. 18 p.

Corpen, 2001.
Les émissions d'ammoniac d'origine agricole dans l'atmosphére. Etat des connaissances et perspectives de réduction des émissions. Document du CORPEN.

De Boer, I.J.M., 2003.
Environmental impact assessment of conventional and organic milk production. Livestock Production Science 80, 69-77.

Farruggia, A., 2000.
L'eau et les herbivores, les chemins de la qualité. Ouvrage Institut de l'Elevage. 170 pages.

Farruggia, A., 2002.
Bilan environnemental dans les exploitations laitières. CR final, IE Editions, 156 p.

Farruggia A., Pichot L., Perrot C., 1995.
Bilan apparent des minéraux et systèmes de production. Essai de hiérarchisation des systèmes à partir des réseaux d'élevage. Renc. Rech. Ruminants, 2, 355-360.

Fustec E., Lefeuvre J.C. eds., 2000.
Fonctions et valeurs des zones humides, Dunod, 426 p.

Gaury F., Benoît, M., 1992.
Modélisation de la qualité des eaux souterraines; influence de l'occupation des sols en situation karstique de Lorraine. Les dossiers de la Cellule environnement. INRA, 4, 77-81.

Hervieu B., 2002.
La multifonctionnalité: un cadre conceptuel pour une nouvelle organisation de la recherche. Fourrages 171, 219-226.

Humphreys J., Lawless A., O'connell K., Casey, I.A; 2002.
Reducing nitrogen inputs to grassland based dairy production. In BGS winter meeting 2002.

Ifen, 1999.
L'environnement en France. Editions La Découverte, 500 p.

Jarvis S.C., Aarts H.F.M., 2000.
Nutrient management from a farming systems perspective. In EGF, Volume 5, Grassland science in Europe, 363-373.

Journet M., 2003.
Des systèmes herbagers économes: une alternative aux systèmes intensifs bretons. Fourrages, 173, 63-88.

Le Gall A., 2000.
Bilans des minéraux dans les exploitations laitières bretonnes. Compte rendu EDE-CA de Bretagne - Institut de l'Elevage.

Le Gall A., 2003.
Impact des réglementations environnementales sur les systèmes laitiers. CR Institut de l'Elevage.

Le Gall A., Cabaret M.M., 2002.
Mise au point de systèmes laitiers productifs et respectueux de l'environnement. Compte rendu de l'expérimentation conduite à Crécom. CR n°2023301.

Le Gall A., Legarto J., Cabaret M.M., Pflimlin A., 2000.
Impact of intensive dairy systems on nitrogen flows at the farm scale. In EGF, Volume 5, Grassland science in Europe, 409-411.

Le Lan B., Brocard V., Cadoret P., Follet D., Grasset M., Lavedrine F., Queffelec A., 2000.
Systèmes laitiers demain en Bretagne: 11 fiches témoignages. Dossier EDE-CA de Bretagne-Institut de l'Elevage.

Ledgard S.F., Pennoj W., Sprosen M.S., 1999.
Nitrogen imputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. Journal of Agriculture Science, Cambridge, 132, 215-225.

Legarto J., Le Gall A., 1999.
Les incidences de la part de maïs et de la prairie sur la qualité en nitrate de l'eau . Etude de deux systèmes de production laitière au Domaine d'Ognoas. Recueil des communications de la journée technique 'Systèmes laitiers productifs et qualité de l'eau'.17-31.

Lemaire G., M. Benoit, Vertes F., 2003.
Rechercher de nouvelles organisations à l'échelle du territoire pour concilier autonomie protéique et préservation de l'environnement.

Morvan T., Alard V., Ruiz L., 2002.
Les risques de pollution azotée en rotations herbagères. In A la recherche d'une agriculture durable: étude de systèmes herbagers économes en Bretagne. INRA éditions. 163-176.

Peel S., Lane S. J., Whiters P.J.A., Chalmers A.G., Chambers B.J., Mansbridge R.J., Metcalf. J.A., Jarvis S.C., Harrison R., Ellis S., Moore N., 1997,
Profitable but sustainable dairy systems. In BGS winter meeting 1997: Grass is greener ?

Rapion P., Martinez J., Le Bozec G., 2001.
Environmental pressure and national environmental legislations with respect to nutrient management, France, in 'Nutrient management legislation in European countries', de Clerq P. *et al.*, eds, Wageningen pers, 152-168

Ruiz, L., Abiven, S., Durand, P., Martin, C., Vertes, F. Beaujouan, V., 2002.
How nitrate concentration in stream water is affected by agricultural practices in small agricultural catchments? I-Annual nitrogen budgets for six small catchments in western Brittany (France). Hydrol. Earth Syst. Sci., 497-505.

Savin A., 2002.
Projet de mise en place de 3 systèmes de production laitière complets optimisés. DAA ENSA Montpellier, 103 p + annexes.
Scees, 2003.
Agreste n°123
Scholefield D., Lockyer D.R., Whitehead D.C., Tyson K.C., 1991.
A model to predict transformations and losses of nitrogen in UK pastures grazed by beef cattle, Plant and soil, 132, 164-177.
Simon J.C., Grignani C., Jacquet A., Le Corre L., Pages J., 2000.
Typologie des bilans d'azote de divers types d'exploitation agricole: recherche d'indicateurs de fonctionnement. Agronomie, 20, 175-195.
Simon J.C., Le Corre L., 1992.
Le bilan apparent à l'échelle de l'exploitation agricole, Fourrages, 129, 79-94.
Simon J.C., Le Corre L., Vertes F., 1994.
Nitrogen balances on a farm scale: results from dairy farms in north west France, in Proceedings of the 15th General meeting of the European Grassland Federation, 429-433.
Turpin N., Rotillon G., Bontems P., Bioteau T., Laplana R., 2004.
Mitigating non point source polluation from dairy farms :Economic evaluation on the Don watershed. In 'Controlling nitrogen fluxs and losses', D. Hatch, DR Chadwick, SC Jarvis and JA Roker (eds), 12th N Workshop, Exeter; UK, 21-24 sept 2003, 54 - 62
Van der Werf H M G, Petit J., 2002.
Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. Agriculture, Ecosystems and Environment, 93, 131-145.
Vertes F.; Alard V.; Le Corre L., 2002a.
Les exploitations étudiées.Résultats environnementaux. In: A la recherche d'une agriculture durable. Etude de systèmes Herbagers économes en Bretagne, Alard V., Béranger C., Journet M. (Eds), INRA Editions, 80-89
Vertes F.; Journet M.; Alard V.; Etesse A., 2002b.
Les systèmes de production. Le pâturage et les pertes d'azote. In: A la recherche d'une agriculture durable. Etude de systèmes Herbagers économes en Bretagne, Alard V., Béranger C., Journet M. (Eds), INRA Editions, 115-144
Vertes F; Loiseau F.; Laurent S.; Recous S.; Leterme P.; Mary B., 2002c.
Grassland resowing and grass-arable crop rotation in France: agricultural and environmental issues. In: Grassland resowing and grass-arable crop rotation, International Workshop, Wageningen, NL, 18-19 avril 2002, Conijn J.G, Velthof G.L., Taube F.(eds), report 47, 47-64
Vertes F.; Walter C.; Lemercier B.; Cluzeau D.; Chaussod R., 2002d.
Variabilite regionale et observatoire de la qualite des sols.,in Fontionnement environnemental des sols, Rapport final Gessol, Walter C., Chaussod R., Cluzeau D., Curmi P., Hallaire V. (Eds), Inra-Ensar UMR SAS, INRA Dijon-CMSE, CNRS Universite Rennes 1 UMR Ecobio, 113-127
Vilain L., 2000.
La méthode IDEA, Indicateurs de la Durabilité des exploitations agricoles. Educagri Editions, 100 p

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Appendix I.
Additional remarks on regulations implemented in France

Spreading distances of farm fertiliser (in metres)

	Water course	Habitation
Manure	35	50
Compost		0
Slurry	35	100
Buried slurry (within 12 hours)	35	50

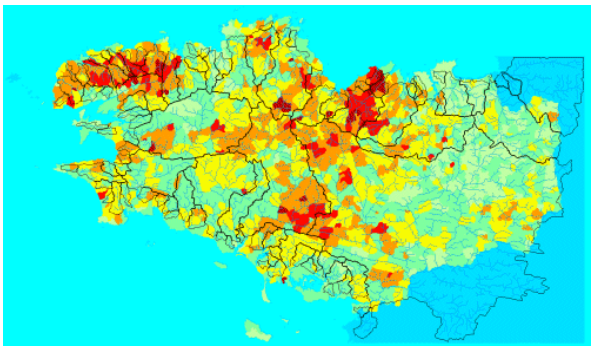
Cattle nitrogen discharge standards

	1993	2002	Variation (%)
Dairy cow*	73	85	+16
Suckler cow without the calf	51	67	+31
Animal in growth (0 to 1 year)	25	22	-12
Animal in growth (1 to 2 years)	44	42	-5
Animal in growth (2 to 3 years)	58	53	- 9

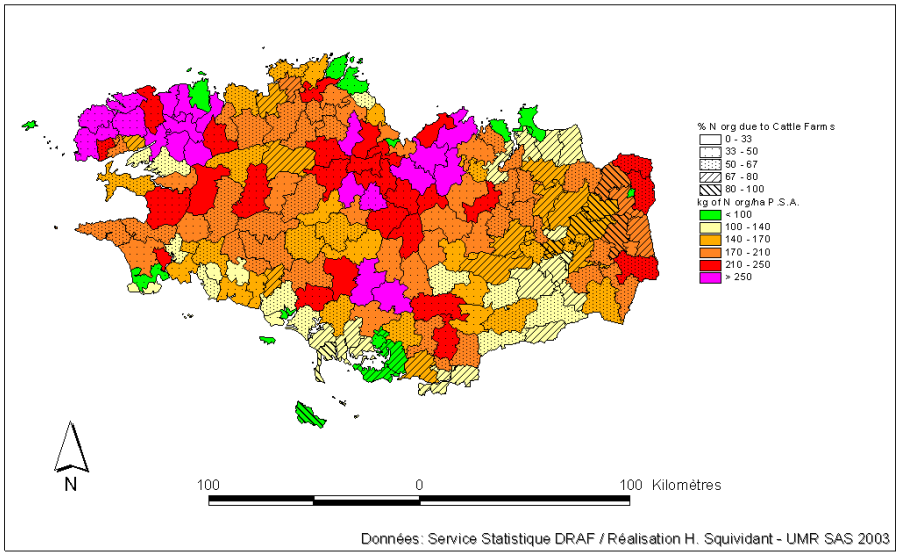
* *Independent of the level of dairy production.*

Appendix II.

Organic nitrogen load and nitrogen content of surface waters in Brittany (www.inra.fr)



Cantonal distribution of total organic N loads in Britanny and part of cattle farms



Distribution charge org/ha Herbivores
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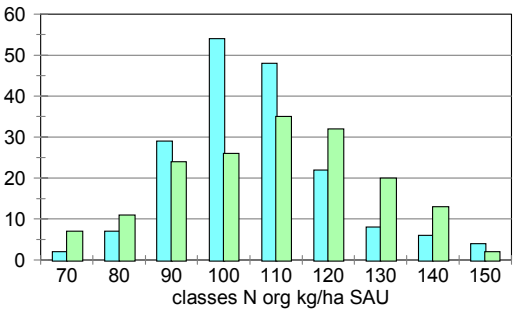
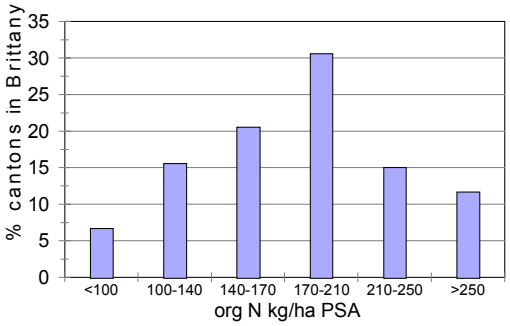


Distribution of total organic N load
Brittany, DDRAF 2003



Appendix III.

Evaluation of different policies for regulating nitrogen pollutions (from Turpin, 2003)

A study was carried out in a catchment basin with 800 farms in the Loire Atlantique (catchment basin of the Don). The farms were mainly operating towards dairy production with quite intensive forage systems based on maize. For this basin, different policies regulating nitrogen pollution have been studied. These policies centred on the taxation of mineral nitrogen (0.23 € per kg N), limitation of use of mineral nitrogen in fertilisers, taxation on excess nitrogen and imposed extensification of dairy production (reduction in milk production per ha of FA, to the detriment of cereal production). The results show that the taxation of mineral nitrogen bought is more effective than the arbitrary limitation of the use of nitrogen fertiliser, both in terms of reduction in nitrogen emissions at the outlet and of cost of control (table below). The extensification of dairy production is a way that seems interesting, notably in the framework of incentive programmes.

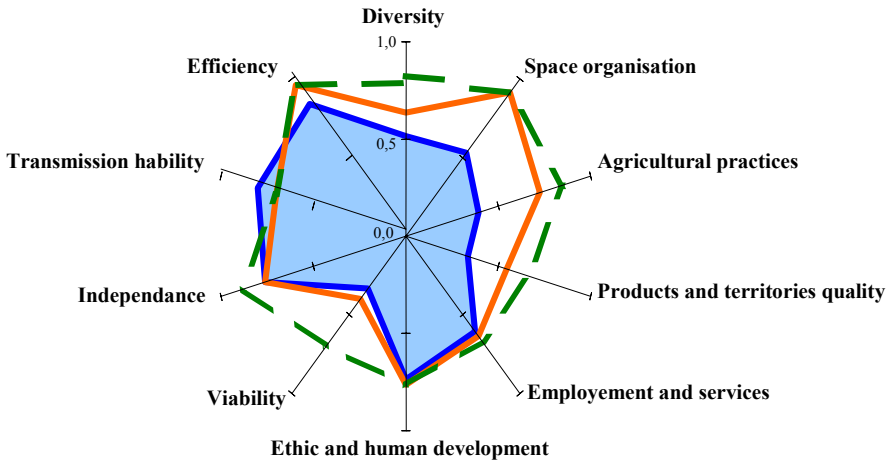
Effect of different policies regulating nitrogen pollution.

Measurement	Level	Estimation of the reduction in emissions at the outlet[1]	Estimation of the evolution of farmer profits	Estimation of the cost of control
Tax on nitrogen mineral fertilisers	0.23 €/kg N	7.5%	-1%	Nil
Limitation of use of mineral N fertiliser	Limit at 90 kg N mineral /ha (present average input: 125 kg N/ha)	1.2%	Neutral because increase of areas under grass-white clover	+++
Tax on nitrogen surplus				+
Extensification of dairy production	Reduction of 5% of milk production per ha of FA	16%	Neutral because drop in operational costs	+

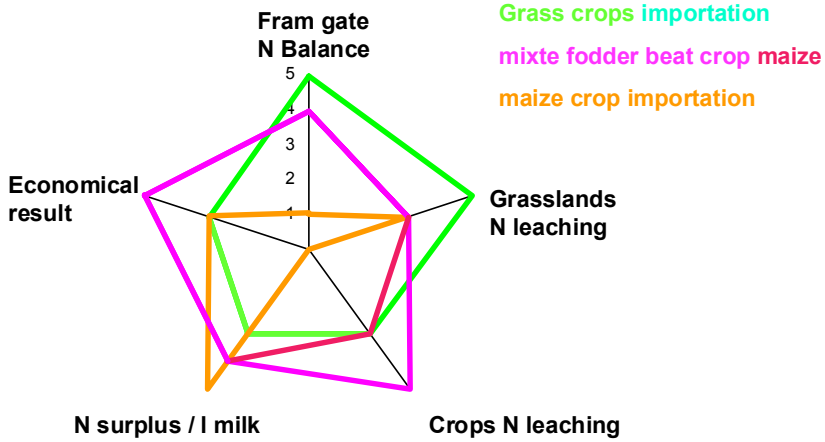
[1] *Estimation from the SWAT model.*

Appendix IV.

Systems evaluation by simulation (from Savin, 2002) illustrating the IDEA evaluation method



Environnmental and economical compromise (from Alard et al., 2002)



6. Ireland

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6.1 Introduction

Land-use, soils and climate

Ireland has a total land area of just over 7 million ha. Agriculture utilises approximately 4.4 million ha. The climate in Ireland is cool, humid and maritime, characterised by an evenly distributed annual rainfall and relatively narrow annual temperature range, averaging 4.5°C in winter and 15.5°C in summer. Annual rainfall varies between over 1500 mm along the Atlantic coast (higher in hilly areas) to around 750 mm along the east coast. Annual, potential evapo-transpiration is around 500 mm in coastal areas, being as high as 550 mm along the south coast, and 450 mm in inland-areas of the North-West. In the far North-West of Ireland the average accumulated soil moisture deficit between May and August is 0 mm and does not exceed 25 mm in the north-western half of the country, and is around 50 mm in the South-East (Collins & Cummins, 1996).

These climatic features promote a long grass-growing season, ranging between 330 days/year in the South-West to around 250 days/year in the North-East (Collins & Cummins, 1996). Relatively low summer temperatures facilitate the maintenance of highly digestible grass swards throughout the grazing season. While a long grazing season of over 300 days is possible in the South-West, the length of the grazing season is closer to around 180 days on soils with poor drainage, particularly under unfavourable climatic conditions in the North and West. Dry lowland mineral soils account for around 62% of the agricultural area, while moderately wet mineral soils account for 20% and wet impermeable mineral soils for around 17% (Coulter *et al.*, 1996). Climate and soils largely dictate agricultural practices, with grassland and rough grazing accounting for approximately 4 million ha or 91% of agricultural land use. Annual fertilizer input to grassland, excluding rough grazing, is around 90 kg N/ha and 9 kg P/ha (Coulter *et al.*, 2002).

Livestock numbers and organic N & P loads

An inventory of total livestock numbers in Ireland, their associated organic N and P excretion and organic N and P loads/ha for the country are presented in Table 1. Organic N is 117 kg ha and organic P is 19 kg ha. The organic N load/ha has declined in recent years from around 140 kg ha in 1998. Dairy production accounts for around 25% of organic N and P load in Ireland.

Dairy farming

The predominant approaches to milk production in Ireland aim to maximise grazed grass in the diet of the dairy cows. This involves compact spring calving to grass over a 90-day period (February to April). Lactation length is around 280 to 300 days. In this system, nearly 90% of the annual diet is grassland-based, either as grazed grass or grass-silage. It has been estimated that up to 85% of milk produced comes from grazed grass (Dillon & Stakelum, 1999). A substantial proportion of the silage component of the diet is fed during the non-lactating period of between 65 to 85 days during the winter. Data from the National Farm Survey 2000 (NFS-2000) (Connolly *et al.*, 2001) indicate that average stocking rates on dairy farms in Ireland is a little under 2.0 Livestock Units (LSU)/ha. Average annual fertilizer N use on such dairy farms was 176 kg N/ha (Coulter *et al.*, 2002). Average annual fertilizer P use

was 12 kg ha. An estimated 270 kg/cow/year of milk produced on farms is fed directly to calves. Annual average milk yield per cow in Ireland is estimated at approximately 4 650 kg. A little under 700 kg concentrate is fed on average to each cow each year (CSO, 2003).

In comparison with other European countries (EDF, 2002) dairy production in Ireland is characterised by relatively low milk production per cow and low costs of production. However, it is also comparatively inefficient due to the lack of scale of milk production on most farms, which is in part a consequence of relatively high costs associated with milk quota and land. Milk production is highly seasonal, with most milk produced between March and November. Only around 8.5% of annual milk is supplied between December and February. This seasonal production of milk is an important constraint on the development of consumer orientated products. In 2002, Ireland used around one third of the intervention support for butter and skim milk powder, while supplying only around 4.7% of the EU milk pool.

Table 1. Livestock numbers in Ireland, organic N and P production by livestock (DAFF, 1996), estimated organic N and P loads for each enterprise and nationally (Central Statistics Office, Cork, 2003).

	Number *Thousands*	N *(kg/head)*	P *(kg/head)*	N *(tonnes)*	P *(tonnes)*	*Proportion* N	P
Dairy Cows	1 176	85	13	99 960.0	15 288.0		
Replacement stock							
0 to 1 year old	210.5	24	3	5 052.0	631.5		
1 to 2 year old	208.5	57	8	11 884.5	1 668.0		
Bulls for breeding	25.9	65	10	1 683.5	259.0		
Dairy						*0.25*	*0.24*
Beef Cows	1 177	65	10	76 505.0	11 770.0		
Replacement stock							
0 to 1 year old	129.6	24	3	3 110.4	388.8		
1 to 2 year old	125.2	57	8	7 136.4	1 001.6		
Bulls for breeding	25.9	65	10	1 683.5	259.0		
Slaughter stock							
0 to 1 year old	1 530.4	24	3	36 729.6	4 591.2		
1 to 2 year old	1 481.8	57	8	84 462.6	11 854.4		
Over 2 years old	877.5	65	10	57 037.5	8 775.0		
Beef						*0.57*	*0.51*
Sows	181.65	67*	22*	12 170.6	3 996.3		
Boars	4.1	8.8	3	36.1	12.3		
Pigs						*0.03*	*0.05*
Breeding ewes	4 104.4	12	2.4	49 252.8	9 850.6		
Rams	112.2	10	2	1 122.0	224.4		
Other Sheep	1 888.6	4	0.75	7 554.4	1 416.5		
Sheep						*0.12*	*0.15*
Ordinary Fowl	12 180.6	0.64	0.22	7 795.6	2 679.7		
Other Fowl	1 618.7	1.0	0.38	1 618.7	615.1		
Poultry						*0.007*	*0.043*
Horses & Ponies	69.9	50	10	3 495.0	699.0		
Other Equines	5.0	30	6	150.0	30.0		
Equines						*0.008*	*0.010*
Goats	8.1	15	3	121.5	24.3	*0.000*	*0.000*
Farmed Deer	12.1	20	3.5	242.0	42.4	*0.001*	*0.001*
Total				468 803.6	76 077.0		
Average Loading (kg ha); *assuming 4 million ha*				**117**	**19**		

* *Includes nutrient loads of progeny through to slaughter.*

6.2 Dairy farmers

Out of a total population of 140 thousand farmers, there are 27 thousand dairy farmers in Ireland. These farmers currently supply the national quota of 5.15 million t of milk. The number of dairy farms has declined from around 42 thousand in 1993. This decline is expected to continue, if not accelerate, during the coming decade and Hennessy (2002) has projected that the number of dairy farms will be halved by 2012. National Farm Survey (2000) data indicates that around 10% of dairy farms exceed 210 kg organic N/ha, while around 45% exceed 170 kg organic N/ha. These are the most commercial, economically viable farming enterprises and are primarily located in Munster in the south-west of Ireland. Approximately 55% of dairy farms and 60% of dairy cows are situated in Munster, which represents 37% of the agricultural area of Ireland.

6.3 Environmental quality in Ireland

Water quality

The Environmental Protection Agency (EPA) is responsible for national monitoring programmes for waters. In a recent report, the EPA (2002) concluded that water quality in Ireland is generally good in comparison with that in most European countries.

Groundwater quality is assessed at 200 locations that comprise the national monitoring network. There is no wide-spread pollution. Nitrate concentrations in groundwater samples exceeded the maximum allowable concentration (MAC, a mean nitrate concentration of 50 mg/l) at a total of three sampling stations in two areas, both of which are located in the east of Ireland. However nitrate levels, exceeded the guide concentration of 25 mg/l nitrate at approximately 20% of well sampling stations (EPA, 2002).

Lake water quality is monitored on 304 lakes that amount to 957 km^2 of surface area or approximately 64% of the lake surface area in Ireland. A large majority (260 or 86%) of these lakes have been categorised as unenriched oligotrophic or mesotrophic, indicating satisfactory water quality. Of the remaining 44 lakes, 34 were categorised as eutrophic and the remaining 10 were categorised as hypertrophic. The principal source of the nutrients causing the enrichment of these eutrophic and hypertrophic lakes is attributed to non-point discharges of agricultural origin. However, discharges from municipal and industrial waste treatment are considered to be partly or wholly responsible for the unsatisfactory water quality condition of the lakes in the hypertrophic category. In recent years, trends in lake water quality indicate that there is a tendency towards an increase in the percentage of lakes in the oligotrophic and mesotrophic categories and a corresponding reduction in the number in the higher trophic states (EPA, 2002).

A 'main rivers' baseline was established in 1971 and a more extensive and more representative baseline established in 1987. This involves ecological assessments at 3 200 sites and over 350 thousand physico-chemical measurements are carried out on 1 080 rivers and streams that comprise the established baseline channel length of 13 200 km. Since the baselines have been established, there has been a trend towards increasing slight and moderate pollution. However, in recent years there are indications that this trend may be halted and perhaps reversed to a certain extent (Table 2).

The EPA currently undertakes basic water quality monitoring of estuarine and coastal waters at 25 sites. However, a recent assessment of the trophic status of estuarine and coastal water at 47 locations around the country indicates that the quality of these waters has remained generally high. However, 13 estuaries and bays exhibit serious pollution. This pollution is mainly attributed to excessive local enrichment by sewage (EPA, 2001).

The EPA (2002) reported that there was no evidence of pollution from any of a range of targeted pesticides, heavy metals and volatile organic compounds; the concentrations of which appear to be very low in Irish waters.

Table 2. Trends in river water quality in Ireland (EPA, 2002).

Period	1987 to 1990	1991 to 1994	1995 to 1997	1998 to 2000
	Percentage of channel length			
Unpolluted	77%	71%	67%	70%
Slightly polluted	12%	17%	18%	17%
Moderately polluted	10%	11%	14%	12%
Seriously polluted	1%	1%	1%	1%

The EPA (2002) has identified eutrophication of inland freshwaters as 'probably Ireland's most serious environmental pollution problem'. Enrichment by P is recognised as the main cause of this eutrophication. In general, nitrate concentrations are moderate and well within EU limits for abstraction and drinking. Overall the compliance rate with prescribed standards for nitrates (50 mg/l nitrate) in both private and public water supplies in Ireland exceeds 99%. Nevertheless, concern was expressed about rising nitrate levels in groundwater and surface waters in some areas. Excessive inputs of nitrates may contribute to eutrophication, especially in saline waters i.e. estuaries, coastal and marine waters (Duggan, 2002).

Agriculture and water quality

Overall, the EPA (2002) estimates that agriculture is the source of 73% of all inputs of P and 82% of all inputs of nitrates to water in Ireland. Regional analysis indicates that levels of water pollution, in general, tend to be highest in the North-East and East. The North-West, West and South are the least polluted.

Oxidised-N levels in the main rivers of the South-East are between 5 and 7 times higher than the main rivers in the West, where maximum values are typically 1 to 3 mg N/l (around 4 to 12 mg/l nitrate). Lower rainfall and generally drier and lighter soils favour arable cropping and 63% of all crops are grown in the East (30% of agricultural area), compared to 29% in the South-West (Munster; 37% of agricultural area) and 7% in the North and West (33% of agricultural area). In a regional-scale study, Neill (1989) concluded that arable cropping was the principle factor affecting the concentrations of nitrate in rivers in the south-east of Ireland.

While land-use is important, soil type and rainfall levels probably have a major bearing on the differences in the extent to which waters are enriched by nutrients in the east and west of Ireland. Typical rainfall levels in the South-West are around 1 200 mm/year (Figure 1) and evapo-transpiration is approximately 500 mm/year, hence run-off and drainage amount to around 700 mm/year. However, in the East, rainfall levels are closer to 800 mm/year (Fig. 1), evapo-transpiration is around 500 mm/year, and drainage and runoff amount to 300 mm/year. Higher rainfall is likely to promote nitrate leaching and P runoff, but it is also likely to cause denitrification on heavier soils. However, doubling of the volumes of water leaving agricultural and surrounding areas (forests, scrubland etc.), greatly increases the dilution of any nutrients that might be present.

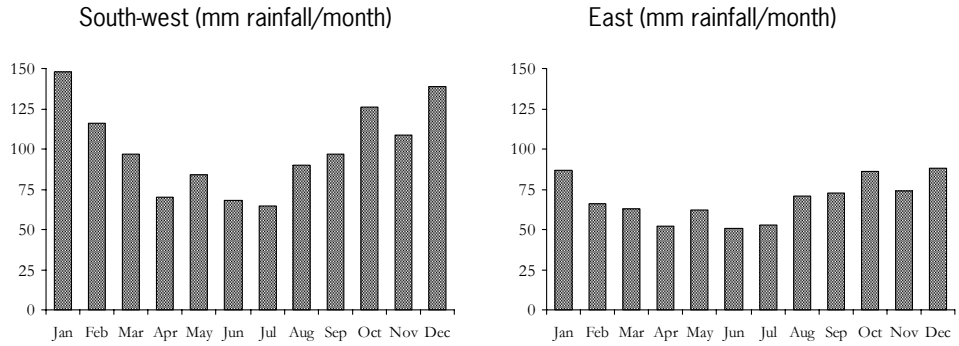

Figure 1. Average monthly rainfall levels (mm/month 1981 to 1990) in the South-West and East of Ireland.

Soil type is also an important factor. High nitrate concentrations in groundwater in localised areas of the South (> 25 mg/l nitrate) and East (> MAC) are associated with shallow sandy free-draining soils in areas of intensive agricultural production; generally dairy, pigs and arable cropping in the South and arable cropping and dairy production in the East. However, less than 10% of Irish soils are classified as such. A number of studies of intensive grassland-based dairy production systems on heavier soils in Ireland has shown that large farm-gate surpluses of N (> 300 kg N/ha) are not associated with excessively elevated nitrate levels in drainage and ground water (Humphreys *et al.*, 2002; Bartley *et al.*, 2002). The implication of this is that where large surpluses of N exist on farms on heavier soils in Ireland, it is likely that much of this N is being lost in gaseous form, either as dinitrogen or as undesirable gasses such as ammonia, nitrous oxide *etc*. In the north midlands on the border with Northern Ireland, high P concentrations in surface waters are associated with areas of intensive pig and poultry production on heavy clay soils with low permeability and prone to run-off.

Emission of undesirable gasses and agriculture in Ireland

Ireland's commitment under the United Nations Framework Convention for Climate Change, Kyoto Protocol, adopted in December 1997, is to limit the increase in greenhouse gas emissions to a maximum of 13% above 1990 levels in the period 2008 to 2012. Target emissions of greenhouse gasses from Ireland is 60 740 thousand tonnes of CO_2 equivalents (kt CO_2 eq.). Inventories prepared by the EPA show that Ireland emitted approximately 63 239 kt CO_2 eq. in 1998 (DELG, 2000). Ireland differs from other EU countries in that agriculture accounted for 32% of total national emissions in 1998, being the source of 86.8% of methane and 78.1% of nitrous oxide emissions (Table 3). Agriculture has the highest emissions of any sector of the economy but accounts for less than 5% of Gross Domestic Product. Targeting the abatement of emissions from agriculture is considered to be a relatively low cost option for Ireland to adopt in order to meet greenhouse gas reduction targets (Behan & McQuinn, 2002).

Table 3. Greenhouse gas emissions arising from agriculture in Ireland in 1998 (All data is presented in thousand tonnes of CO_2 equivalents (kt CO_2 eq.)) (DELG, 2000 & DAFRD, 2002)

Source	All Gasses	Comprised of:		Targeted Reduction
		Methane	Nitrous Oxide	
		(kt CO_2 eq.)		
Fossil Fuel Combustion (CO_2)	807			
Enteric Fermentation	10 365	10 365		1 200
Manure Management	2 208	1 477	731	60
Agricultural soils	7 125		7 125	900
On-Farm Forestry (Sink)				(250)
Total	20 505			2 410

To implement Ireland's commitments under the Kyoto Protocol, the Irish government has put in place the National Climate Change Strategy. The Strategy targets a reduction of 2 410 kt CO_2 eq. from agriculture, bringing emissions down to 18 095 kt CO_2 eq. per annum, by 2010 (DAFRD, 2002).

Ammonia

Agriculture is the principal source of ammonia emissions in Ireland, accounting for over 90% of national emissions or the emission of 130 kt in 1998. Under the objectives of the Gothenburg Protocol and the National Emissions Ceilings Directive (2001/81/EC), target emission of ammonia from Irish agriculture is 116 kt by 2010 (DAFRD, 2002). Hyde *et al.* (2003) constructed an ammonia inventory for Ireland and indicated that with the projected downsizing of the national herd by 2010 and the adoption of low emission spreading techniques Ireland will meet its obligations with respect to reducing ammonia emissions.

6.4 Policy

Common Agricultural Policy

The Common Agricultural Policy (CAP) has had a major impact on livestock numbers in Ireland over the last decade. Projections indicate that it will continue to do so over the next few years. The impact has been mostly on the number of beef cattle. The size of the national dairy cow herd has remained relatively static, being over 1.3 million in 1990 declining to the current level of a bit less than 1.2 million. This decline is the result of increased output per cow and of the quota limiting national milk output. Kelly *et al.* (2003) project that dairy cow numbers will continue to decline during the present decade to around 1.13 million in 2010.

The impact of the CAP on beef livestock numbers is of relevance to dairy farming because on most dairy farms (estimated at > 90%) in Ireland beef production is an important second enterprise. Beef production is much less profitable than dairy production (Teagasc, 2002). Therefore, following the imposition of limits on organic N loads on farms, reduction or elimination of the number of beef livestock on farms is an issue that will have to be considered on farms. The second aspect is that beef cattle numbers have increased substantially in Ireland during the 1990s. This has had a major bearing on organic N loads on farms, on national methane emissions, and on national fertilizer N use, which is likely to have had knock-on effects on nitrous oxide and ammonia emissions.

In 1990 there were 655 thousand beef cows in Ireland, which along with the dairy cow population supported a total cattle population of around 6.65 million. Beef cow numbers increased steadily to around 1.2 million in 1998, leading to an increase in total cattle numbers, peaking at approximately 7.3 million in 1998. However, total cattle numbers

have declined by around half a million since then (Table 1). Changes to extensification payments under Agenda 2000, coupled with the facility to claim beef cow premia on heifers, has been the main cause for the decline in cattle numbers (Binfield *et al.*, 2002).

Kelly *et al.* (2003) examined possible implications of the EU Commission proposals (July 2002) for the Mid-Term Review (MTR) of the CAP for livestock numbers in Ireland until 2010. An important component of these MTR proposals is the possibility of decoupling direct payments from production. Projections were made on the basis of (1) unchanged and (2) full decoupling, policy scenarios. Projections for both policy scenarios indicate a continued decline in beef cow numbers and in the total cattle population during the present decade: to 1.05 million beef cows and 6.15 million cattle under unchanged policy scenario, and to 0.74 million beef cows and 5.31 million cattle consequent to decoupling. These projections indicate that the future impact of CAP will be conducive to the Irish agricultural sector meeting greenhouse gas emission targets outlined within the National Climate Change Strategy.

6.5 Legislation

Existing legislation

Statutory responsibility for water management and protection rests primarily with the 27 local authorities in Ireland. The Water Pollution Acts 1977 and 1990 and regulations made thereunder, including regulations giving effect to EU Directives, constitute the main national legislation governing water management and protection. The Phosphorus Regulations (S.I. No. 258) introduced in 1998 are targeted at lessening eutrophication of inland waters. These regulations prescribe water quality standards which must be met by 2007 (DELG, 1998). These standards were defined by reference to the baseline quality data established by the EPA in the 1995 to 1997 review period. Under the Regulations local authorities were required to take measures in order to comply with the standards.

A number of local authorities have implemented or are currently implementing bye-laws to regulate farming practices in specified catchment areas. However, at present there are differences in the various bye-laws that are being imposed by different local authorities. This reflects the variation in soils, climate and farming conditions as well as the range of environmental issues being addressed. However, in general, bye-laws governing agricultural practice include a requirement for slurry (organic liquid manure) storage on the farm for periods ranging between 90 and 180 days; the length of this period being inversely proportional to the length of the grass growing season. Twenty-five local authorities have initiated surveys of farms to pinpoint pollution sources and determine high-risk farms and/or activities. In some instances of non-compliance, farmers have been compelled to cease existing agricultural activity. In selected catchments, soil tests are required on farmland every 5 years. In general, soil P concentrations (Morgans P extracted with sodium acetate and acetic acid at pH 4.8) must not exceed between 10 and 15 mg/l soil on mineral soils, the higher concentration being the concentration used for spread-lands under IPPC licensing of large-scale pig units. On peat soils, soil P concentrations should not exceed around 30 mg/l. No fertilizer or manure P can be applied to soils that exceed these concentrations

Another instrument of the regulating authorities is control over direct payments to farmers under various schemes such as suckler cow premium, special beef premium etc. (and presumably decoupled payments in the future). Under the Agenda 2000 agreement, all farmers receiving payments under the various EU supported schemes must practice farming in accordance with certain environmental requirements (EC) No. 1 259/99 and 1 259/99. The Department of Agriculture, Food and Rural Development (DAFRD, which recently replaced the DAFF) have drawn up rules governing Good Farming Practice (GFP) outlining the farm practices required to comply with environmental standards to be applied in Ireland to schemes other than the Rural Environment Protection Scheme (which involves more stringent requirements; see hereafter). These rules are similar to the local authority bye-laws outlined above and include measures governing other issues such as animal welfare, hygiene, etc. They include requirements for allowing buffer zones of varying widths around drains and streams (10 m), main river channels and lakes (20 m), domestic wells (50 m) and other sources of public water supply (300 m) within which no organic manure can be applied.

More than 100 thousand Irish farmers are in receipt of these direct payments in one form or another. Failure to comply with GFP can include prosecution by enforcing authorities and a reduction or forfeiture of direct payments. These penalties are additional to any penalties accruing under the Water Pollution Acts. An estimated 25 thousand farmers have to improve their waste management facilities or management systems to comply with requirements (Regan, 2001).

Incentives

Tax allowances are available to farmers who have nutrient management plans in place and incur necessary capital expenditure for pollution control facilities such as storage facilities (usually for liquid organic manures and dirty wash water). This relief allows the write-off of 50% of the capital expenditure, subject to a maximum of 31 743 Euro in any one year. Furthermore the DAFRD provides grant support for improvements in farm waste storage and handling facilities on farms. In recent years substantial investment has been made by farmers in waste storage facilities and other infrastructure to prevent pollution (Duggan, 2002). Expansion of this scheme is currently under review and it is expected that dairy farmers supplying under 468 100 kg milk will qualify for grant aid to the extent of 40% of expenditure up to 75 000 Euro.

The Irish manifestation of the Agri-Environmental Regulation, (EEC 2 078/92) is the Rural Environment Protection Scheme (REPS). During the period 1994 to 1999 there were up to 46 thousand farms involving 1.5 million ha (or around 36%) of farmland being farmed under this scheme. Farmers in REPS receive annual payments of around 151 Euro/ha for a maximum of 40 ha for complying with regulations that include (among others) limiting total N (organic and inorganic combined) inputs to a maximum of 260 kg ha/year. Between 1994 and 1999 average fertilizer application rates on REPS-farms were 69 kg N/ha and 8 kg P/ha. This is compared to non-REPS extensive farmers who applied fertilizer at rates of 98 kg N/ha and 13 kg P/ha during the same period. Investment in farm-buildings and maintenance was around 14% higher on REPS farms compared with non-REPS extensive counterparts. This is considered to be an indicator of measures taken to control farmyard pollution, which is a requirement of the scheme (Regan, 2001).

Government Departments, the DAFRD and the Department of Environment and Local Government (DELG) hold the opinion that maximum participation by farmers in REPS contributes to an improvement in water quality (Duggan, 2002). In recent years, since 1999, the number of farmers involved in the scheme has tended to decline to around 40 thousand at present. The DAFRD aims to reverse this decline and targets 55 thousand farmers participating in the scheme by the end of 2005. This will be achieved by increasing payments. It is envisioned that these higher payments will be made on a sliding scale of 200 Euro/ha for the first 20 ha, 175 Euro/ha for the next 20 ha and 70 Euro/ha for another 15 ha, or a maximum of 8 550 Euro for 55 ha. (This is compared to maximum payments of around 6 040 Euro/farm at present).

Action Programme and Good Agricultural Practice (GAP)

The Nitrates Directive has generally been implemented in Ireland in terms of monitoring of waters, the establishment of a Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates and the implementation of a range of measures to protect water from pollution from agriculture outlined above. However, over the last number of years, government departments, DELG and DAFRD, have been involved in formulating an action programme to deal with the many aspects of environmental impacts of agriculture. The motivation for this action programme is primarily aimed at meeting the requirements of EU legislation such as the Framework Waste Directive (91/156/EEC), Nitrates Directive and Water Framework Directive. However, commitments under the Kyoto and Gothenburg Protocols are also an important consideration. It is hoped that this action programme will lead to measures that are multifaceted, comprehensive and complementary (Duggan, 2002).

This action programme will provide statutory support for adherence to standards of GFP on all farms, including those not presently in receipt of direct payments. These standards will be applicable across all regions of the Irish Republic. Duggan (2002) points out that agricultural activities can affect water and atmospheric quality in all areas, whether it is eutrophication of inland waters due to P, eutrophication of estuaries due to nitrate or biological contamination of drinking water sources. The implementation of the National Climate Change Strategy and the National Emissions Ceilings Directive also requires that action is taken on farms across the country. This approach will facilitate the simplification of regulatory regimes, enabling several aspects of environmental protection to be addressed by one set of regulations. It will also provide greater certainty for farmers regarding planning and investment decisions.

Initially organic N/ha will be limited to 210 kg ha commencing in 2003 and declining to 170 kg ha after four years. It will be possible for farmers to apply for derogation for organic N of 250 kg ha. This will be examined on a case-by-case basis. Nutrient management planning will be required on all farms exceeding organic N limits. The action programme will involve the expansion of the present river basin management projects into a more extensive catchment-based water quality monitoring and management system or 'River Basin Management System'. The new monitoring approach must be in place by 2006 at the latest. This will allow the effectiveness of the Action Programme to be assessed (Duggan, 2002).

6.6 Intensive dairy farming in Ireland

Intensive dairy production in Ireland during the 1990s

On a typical intensive dairy farm in Munster, involved in compact spring calving to grass, the whole of the farm is grazed during February and March. From early April between 45% and 55% of the farm is closed up for first-cut silage, and harvested in late-May or early June. On more intensive farms (~2.5 LSU/ha) a lower proportion is closed, i.e. 45%, whereas on less intensive farms (~2.0 LSU/ha) a greater area is closed. On more intensive dairy farms up to 30% is closed for second cut silage, harvested in July or early August. From August onwards the whole farm is available for grazing until housing at some stage during November and December depending on soil conditions. On less intensive dairy farms, little or no second cut is harvested. In both situations, grassland management to build up grass for extending the grazing season into the late autumn and winter is an important objective.

Generally speaking, grass-silage is harvested on paddocks furthest from the milking shed. Cattle slurry is recycled back to the silage area, either after grazing during March, depending on soil trafficability, or typically after harvest of the silage. Areas nearer the milking shed are used for grazing, to minimise the distances that have to be walked by the cows. On some farms, dirty wash water is disposed of using a sprinkler system on grazing ground nearest the farmyard (on around 10 to 15% of the farm area). On many farms dirty water is stored and applied with cattle slurry. In recent times a number of dairy farms have developed constructed wetlands as a means of managing dirty wash water. Detailed information on these issues is not available at present.

Teagasc, Moorepark, has been involved in collecting data from dairy farms for more than 20 years. A summary of data collected continuously on one group of 32 intensive dairy farms between 1993 and 2001 is presented (Table 4). Average milk output/ha in 2001 was 8.7 t, ranging between 4.4 t and 20.2 t. Between 1993 and 2001 there was a significant decline in stocking rates on farms that may, in part, be attributable to a tendency for increasing milk output per cow. Cow numbers, as a proportion of LSU on the farm, tended to remain constant at around 61% during this period, indicating that the number of other livestock, including replacement heifers, tended to decline in line with cow numbers. This stands to reason to a certain extent in that as milk output per cow increases in a fixed-quota situation, cow numbers will generally decline. Farmers will only retain as many replacement heifers as necessary to maintain cow numbers. However, average milk output per cow showed no significant increase from around 1997 onwards. Although, there is evidence of a progressive increase in milk output per cow on farms at the upper end of the range, there was stagnation at the lower end.

Table 4. Components of production and nitrogen and phosphorus balances for 32 intensively managed dairy farms in South-West Ireland between 1993 and 2001.

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	SEM	
					Stocking rate						
Overall Farm Stocking Rate (LSU/ha)	2.88	2.99	2.88	2.86	2.70	2.74	2.68	2.51	2.51	0.055	$P < 0.001$
Dairy cows/ha (1 cow = 1 LSU)	1.76	1.78	1.75	1.75	1.65	1.66	1.65	1.58	1.53	0.036	$P < 0.001$
Cow component of stocking rate (%)	61	60	62	61	61	61	62	62	60	1.2	NS
					Milk output and protein concentration and concentrates fed per cow						
Milk output (kg/cow)	5 399	5 351	5 494	5 589	5 738	5 599	5 605	5586	5680	67	$P < 0.001$
Min.	4 457	4 171	4 789	4 578	4 498	4 498	4 453	4221	4339		
Max.	6 363	6 951	7 003	7 054	6 713	6 591	6 755	7317	7342		
Milk Protein (g/kg)	32.4	32.4	32.1	32.5	32.7	33.0	33.3	33.6	33.7	0.07	$P < 0.001$
Concentrates (kg/cow)	702	816	835	723	600	660	705	543	598	37	$P < 0.001$
					Organic N loads on farms						
Mean Organic N load (kg ha)	240	249	240	238	225	228	223	209	209	4.5	$P < 0.001$
Min.	185	196	178	168	163	171	165	159	164		
Max.	321	336	292	305	301	320	318	281	264		
					Farm-gate N balance on farms						
Fertilizer N usage (kg N/ha)	304	320	321	315	289	316	315	299	287	9.3	$P < 0.05$
Total N Imports (kg N/ha)	324	343	345	336	306	335	335	314	305	9.4	$P < 0.01$
Total N Exports (kg N/ha)	66	67	66	67	65	65	64	61	61	1.2	$P < 0.001$
Surplus N (kg N/ha)	259	276	279	268	241	270	271	254	243	9.1	$P < 0.05$
Fertilizer N-use Efficiency (%)	21.2	20.2	19.9	20.6	21.9	19.8	20.0	19.9	20.9	0.65	NS
					Organic P loads and farm-gate P balance on farms						
Organic P load (kg ha)	35.2	36.4	35.2	34.9	33.0	33.4	32.8	30.7	30.6	0.64	$P < 0.001$
Fertilizer P usage (kg P/ha)	17.9	18.0	18.1	14.7	10.5	13.0	13.1	10.2	15.8	2.2	$P < 0.05$
Total P Imports (kg P/ha)	22.1	22.9	23.1	19.1	14.1	16.9	17.3	13.5	19.4	2.2	$P < 0.01$
Total P Exports (kg P/ha)	12.2	12.6	12.3	12.3	12.0	12.1	11.8	11.2	11.5	0.29	$P < 0.05$
Surplus P (kg P/ha)	9.9	10.3	10.8	6.8	2.1	4.9	5.5	2.2	7.9	2.2	$P < 0.05$

During the 1980s there was a considerable increase in the use of Holstein (North American, Dutch etc.) semen in Ireland, shifting the genetic make-up of the Irish dairy herd from the traditional British Friesian towards Holstein, and increasing national milk output per cow. However, during the early 1990s the suitability of these Holstein-Friesian cows for conditions in Ireland was increasingly being questioned by farmers. This was primarily because of a decline in reproductive performance and increasing culling rates on farms. It has been estimated that reproductive performance declined by around 0.9% per year on Irish dairy farms during the1990s (Mee *et al.*, 1999). Normally, around 9% of dairy cows were culled each year due to non-reproductive reasons (diseases such as mastitis, injury etc). This has not changed in recent years. However culling due to reproductive reasons (cows not in-calf at the end of the breeding season) has increased from around 7% a decade ago to around 16% at present. Overall culling rate on farms has increased from around 18% to 25% over the last decade and can be well in excess of 30% in some instances.

The cost competitiveness of Irish spring-calving herds is highly dependent on compact calving to grass. Buckley *et al.* (2000) pointed out that as milk output per cow increases, this places greater demands on each cow in terms of energy balance during early lactation. This increases the likelihood of cows failing to go back in calf within the period required to achieve a calving interval of around 365 days necessary to ensure compact calving to grass in spring. There has been a change on attitude with regard to breeding policy, with a general decline in the use of Holstein semen on many dairy farms in recent years. This may account in part for the lack of a significant increase in average milk output per cow from 1997 onwards on farms in Table 4. Evidence of clearly targeted breeding strategy can be seen in milk protein concentrations, which increased significantly during this period. Breeding for increased protein concentrations in milk is an objective on dairy farms as a means of improving milk price.

Another aspect of this is that, in a fixed quota situation, many Irish dairy farmers aim to minimise cost of milk production as a means of maximising farm profitability. This is often called the 'New Zealand Approach'. Targets include minimising winter-feed requirement (mostly grass silage), concentrate input and replacement rate. This approach involves milking cows of relatively low genetic merit for milk production (but good at maintaining body condition and fertility) over a relatively short lactation length of around 270 days. This maximises milk production from grass and minimises the need for concentrate supplementation. Furthermore, it involves a long inter-lactation period and hence minimises winter-feed requirement and tends to ensure that cows have relatively high body condition at calving. This contributes to improving pregnancy rates during the May to July breeding period (Buckley *et al.*, 2000). The data presented in Table 4 would tend to indicate that some farmers in the sample group have opted for this approach.

Impact of organic N limits on intensive dairy production

Virtually all of the dairy farms presented in Table 4 exceeded the 170 kg organic N/ha and half exceeded 210 kg organic N/ha in 2001. However, if all beef cattle were removed, only one-third of dairy farms in the sample would exceed 170 kg organic N/ha. McQuinn *et al.* (2003) have estimated that removing beef cattle would result in a reduction in farm income of around 6%. However, relative income may not be reduced to the same extent if there is full decoupling of direct payments following MTR of the CAP.

Other options dairy farmers would have to consider include rearing replacement LSU on rented land or on out-farms. (It has to be assumed that, in most cases, it will not be possible to purchase/lease land adjoining the home-farm). In this case only three of the 32 farms would exceed 170 kg organic N/ha. Another option would be to apply for derogation of 250 kg organic N/ha. This would be a possibility for all but one of these 32 farms. On this particular farm, the only remaining viable option is the transport of manures off the farm, which is allowable within the proposed rules of the action plan (Duggan, 2002). The de-stocking of dairy cows is not a viable option. Studies have shown that this would result in lowering of farm income by between 20 and 25% (Lally & Riordan, 2001; McQuinn *et al.*, 2003).

Fertilizer N and P use on intensive dairy farms

In a recent study of Irish dairy farms, based on data from the NFS-2000, stocked at rates exceeding 210 kg organic N/ha, McQuinn *et al.* (2003) found that average fertilizer N use was 268 kg ha. In the sample presented in Table 4, average fertilizer N use was a little over 300 kg N/ha/year with little change from year to year. This is reflected in the quantities of surplus N (farm-gate balance of imports minus exports) on these farms, averaging over 260 kg N/ha during this period. It is notable that N-use-efficiency on these farms did not change significantly from year to year (Table 4).

On the farms in Table 4, organic P loads/ha generally declined ($P < 0.001$) in line with stocking rates between 1993 and 2001. However, in contrast to N, there has been a significant drop in fertilizer P usage and P surpluses on these farms between 1993 and 2000. The P balance on farms during 2001 is an exception to the general trend in recent years. A similar general trend is seen in national fertilizer P usage in recent years. Annual fertilizer P use in Ireland was approximately 60 thousand t elemental P between 1991 and 1997 and then fell fairly sharply to around 50 thousand t between 1998 and 2000, before declining to its present level of just over 40 thousand t (Figure 2).

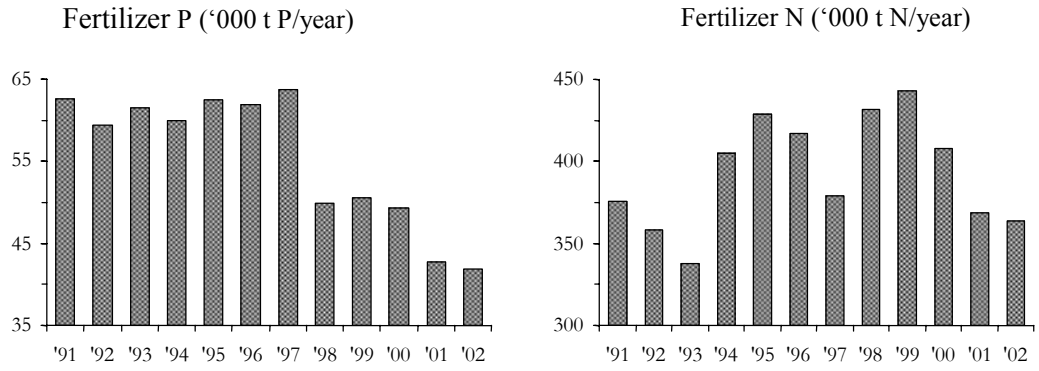

Figure 2. Phosphorus and nitrogen fertilizer use in Ireland between 1991 and 2002.

The decline in national fertilizer P usage since 1997 is partly due to a campaign by Teagasc, commenced in 1996, to increase awareness among farmers and bring fertilizer P inputs more in line with requirements. It is probably also partly due to the introduction of the P Regulations in 1998. It also coincided to a certain extent with a substantial number of farmers joining the REPS. On the other hand, there has been an upward trend in annual fertilizer N use in Ireland during the 1990s (Figure 2). Fertilizer N use in Ireland during this period has been higher than at any time previously. This coincides to a certain extent with the increases in livestock numbers during the 1990s outlined above. However, since peaking at over 440 thousand t/year during 1999, annual fertilizer N use has declined to present levels of a little over 360 thousand t/year, a level similar to that in 1990.

6.7 Actual and intended research

Nitrogen losses from intensive dairy production

A project to determine the risk of the various management components of intensive (~2.5 cows/ha) grassland-based dairy production contributing to nitrate leaching on a sandy shallow soil in Munster is ongoing since 2001 at the Moorepark – Curtins Farm. Results to date indicate that the application of dirty wash water (using a rotating sprinkler on an area representing 14% of the farm area in this study) entails the greatest risk of nitrate leaching. This was followed by where silage is harvested twice, and lowest risk is associated with the grazing area and where silage is harvested only once (Ryan, 2003). The elevated risk of leaching loss where silage is harvested twice is probably due to high application rates of fertilizer and manure N. This work has yet to be completed and project leaders stress that is too early to draw conclusions at this stage.

Experimental work on a three-year project examining the impact of reducing N inputs to grassland-based dairy production ended in the spring 2003. This work was conducted at the Moorepark – Solohead farm on a heavy clay soil with impeded drainage that has the capacity to supply around 120 kg N/ha/year from net mineralization of soil organic matter N (SOM-N). The results indicate that around 330 kg fertilizer N/ha/year was necessary to produce sufficient grass for grazing and grass-silage to meet the feed requirements of dairy cows stocked at 2.5 cows/ha. There were 18 cows/treatment. These cows produced over 6.0 t solids-corrected-milk/year while receiving concentrate input of around 600 kg/cow/year. This treatment was the control treatment. It is based on the 'Moorepark blueprint for intensive dairy farms' and conformed to the 'typical' intensive dairy farm outlined above.

This was compared to a system with the same stocking rate but where fertilizer N input was reduced to 250 kg N/ha/year. In this treatment management was more-or-less the same as in the control until the first-cut-silage was harvested. Only 15% of the farm area was harvested for second cut silage, making a greater amount of the farm available for grazing from June onwards. Fertiliser N input was 55% of the control treatment between June and winter housing. Soil mineral-N concentrations during the late autumn were substantially lower on this treatment than on the control (Humphreys *et al.*, 2002). To meet the feed requirements of the cows extra concentrate of approximately 300 kg/cow was required. These results are interpreted in terms of a farming system in Table 5. This system resulted in an overall reduction of farm-gate surplus N of around 63 kg ha (21%) compared to the standard system.

The economic viability of this lower fertilizer N system is questionable and depends on individual farm characteristics. It requires the purchase of extra concentrates and involves savings in fertilizer N costs and contractor charges for silage harvesting. (In Ireland, silage is mostly harvested by contractors). In recent years, contractor charges have increased steadily mainly due to rising labour costs. Fertilizer costs have also tended to increase whereas concentrate costs have not; at least, not to the same extent. Under present circumstances the lower fertilizer N-input system outlined above probably becomes competitive once silage contractor charges increase over present levels of around 225 Euro/ha combined with concentrate costs of around 150 Euro/t.

The minimisation or elimination of second-cut silage is something that is being considered on dairy farms stocked at between 2.0 and 2.5 LSU/ha. This may also entail potential environmental benefits. Making a greater area available for grazing and reducing fertilizer N input resulted in lower N uptake and crude protein in pasture. This is likely to have lowered N excretion per cow (Peyraud & Astigarraga, 1998). Deposition of this excreta over a wider area (available for grazing) is likely to have had the additive effect on lowering N deposition per ha. Hence, the lower mineral N concentrations in the soil during the late autumn and early winter. Such a situation would lead to a reduction in nitrate leaching on vulnerable soils, which is in agreement, to a certain extent, with the comparison of nitrate losses from the one-cut versus two-cut silage areas recorded on the Curtins farm.

Low N input dairy production systems

In the above experiment at Solohead farm, there was also a system based on grass & white clover, stocked at 1.75 cows/ha and receiving 80 kg fertilizer N/ha/year. Milk production by the cows on this clover treatment was not different from the control with the same level of concentrate input (600 kg/cow). However, large surpluses of silage (over 25% in excess of requirements) were harvested from this treatment, especially in the later two years of the experiment. This work is being continued in a further three-year experiment where the grass & white clover treatment receives 90 kg N/ha/year and is stocked at 2.0 cows/ha. It is being compared with two other treatments, both stocked at 2.0 cows/ha. One treatment receives 150 kg and the other receives 200 kg fertilizer N/ha/year. There are 22 cows/treatment. Previous work indicates that optimum fertilizer N for grassland-based (no clover) dairy farms stocked at 2.0 LSU/ha in Ireland is around 175 kg ha (e.g. Humphreys *et al.*, 2002). This quantity is very similar to that being used on dairy farms with this stocking rate (Coulter *et al.*, 2002). Results to date indicate that it is possible to achieve similar milk output per cow from the white clover treatment to that recorded in the previous experiment. This is interpreted in terms of a farm system in Table 5.

In the above experiment white clover was introduced into swards by broadcasting the seed with granulated fertilizer. This is necessary because white clover is not abundant in Irish grassland. Furthermore, farmers are not inclined to

cultivate and re-sow swards because of the high costs involved and the loss of production during the resowing process. There is also a lack of machinery such as strip- or slot-seeders in Ireland. Therefore, if white clover is to be of any use on Irish farms, simple and cheap methods of introducing it to swards have to be developed, using machinery that is widespread on farms. There is an on-going project examining ways of improving the effectiveness of introducing white clover into permanent grassland using this broadcasting approach.

Soil phosphorus availability for dairy production

There are a considerable number of projects examining pathways of P loss to water in overland runoff etc. At Johnstown Castle, a dairy systems project involving three herds of 21 cows and looking at the impact of soil P availability on dairy production is coming to an end. The results of the first phase of this project indicate that maintaining soil Morgans P concentrations at between 6 and 10 mg/l does not pose any limitation on grassland-based dairy production (Culleton *et al.*, 1999). These concentrations are useful guidelines and threshold values for avoiding excessive fertilizer P use on farms. Stocking rate on this experiment was 2.5 LSU/ha. Very low losses of P and nitrate to surrounding streams and groundwater were measured during this experiment (Culleton, 2003; Kurz *et al.*, 2003; Bartley *et al.*, 2002). There is also an ongoing project with the objective of improving fertilizer P recommendations in line with soil Morgans P status on different soil types.

Fertilizer N management

There is a project that involves studying the quantities of mineral N that become available for uptake as a consequence of net mineralization of SOM-N under permanent grassland on different soil types. There are two aspects to this. One aspect is the pattern in which this soil mineral N becomes available during the year, which can range from almost zero during the winter to over 1.0 kg ha/day during early summer. Average requirement for soil N by intensively managed grassland is around 2.0 kg ha/day during the growing season (e.g. 450 kg N/ha over 225 days). This source of soil N is especially important for extensively managed grassland. To make efficient use of fertilizer N it is necessary to apply the fertilizer N during the grazing season in a pattern that complements this release of soil N. The second aspect of this work is the extent to which this release of net mineralized SOM-N varies with soil type. Work to date indicates that this can be as low as less than 100 kg to as high as 330 kg N/ha/year under permanent grassland in Ireland. This is something that needs to be taken into account when making recommendations for fertilizer N use for permanent grassland.

Fertilizer and liquid organic manure & dirty wash water management on farms

Detailed information on issues such as slurry storage capacity, application dates and techniques, dirty water collection, storage and management on farms is not available. A survey to assess these and a range of other infrastructural/environmental factors on farms across the country has been initiated. The objective is to ascertain the extent to which farmyards are potential point sources of pollution and to identify the requirement for improvement.

Dirty wash water is potentially and probably an important conduit for nutrient losses to water from dairy farms in Ireland. There are a number of projects relating to this issue on-going at the moment. Two projects are examining aspects of the effectiveness of constructed wetlands (reed-beds) as means of dirty water amelioration. Another project is looking at the potential of a sand-filtering process to reduce the polluting-capacity of dirty wash water.

There is a project concerned with the effectiveness of clay-lined earthen-banked tanks to act as safe stores of liquid organic manures including dirty wash water. Substantial storage capacity is required if dirty water is to be safely and usefully recycled to grassland. Although there exists sizeable grant aid and tax relief for improvements in on-farm infrastructure to improve dirty water management etc., there is demand from farmers for research on clay-lined earthen-banked storage tanks. This is because many intensive dairy farmers, generally the ones involving the biggest risk, do not qualify for grant aid and want cheap alternatives to concrete structures. At the other end of the scale,

there are farmers, with smaller farms, that are ageing and whose offspring do not seek a future in farming. At present around 40% of farmers in Ireland exceed 55 years of age. Many of these farmers cannot afford or are not inclined to invest in concrete tanks that would probably outlast themselves, even when grant-aided to 40% of capital expenditure. For these, the clay-lined earthen-banked tank is seen as a transitional solution to immediate requirements for storage capacity.

Reproductive performance of dairy herds

The reproductive performance of dairy herds is an important issue on dairy farms and for dairy research in Ireland in recent years. Reproductive performance on dairy farms has been examined comprehensively from many perspectives including farm management, nutrition, reproductive physiology and disease. Detailed guidelines on management of dairy herds to improve reproductive performance are available (e.g. Ramsbottom & McCarthy, 2002).

The breed of cow has also come under scrutiny. Teagasc Moorepark in association with the Department of Animal Breeding and Genetics, ID-DLO, The Netherlands, and the Irish Cattle Breeders Federation (ICBF) has been involved with the development of a new index for categorising the value of dairy bulls for use under Irish conditions. New criteria, including valuation for reproductive performance and survivability (along with milk yield and composition, health traits etc.), are incorporated into the Economic Breeding Value (EBV) of dairy bulls. The objective is to simultaneously improve milk output per cow and fertility performance (reducing replacement requirement). This new index has been in use in Ireland over the last two breeding seasons.

This development has been conducted in parallel with the evaluation of the suitability for Irish conditions of various strains and breeds of dairy cow. Comparisons of strains has involved and involves examination of high merit Dutch Holstein-Friesian, typical Irish Holstein-Friesian and New Zealand black & whites (a mix of British Friesian, Holstein and some Jersey). The evaluation of the New Zealand strain is ongoing at the Curtins farm and a similar evaluation is being conducted in New Zealand by DEXCEL. The New Zealand strain is of particular interest because bulls have been selected for suitability to extreme grassland-based management: all-year-round grazing, high survivability under compact calving, very low concentrate input etc. There has been growth in the use of 'New Zealand genetics' on Irish dairy farms in recent years.

In a five-year experiment to compare high merit Dutch Holstein-Friesian, medium merit Irish Holstein-Friesian, French Montbelliardes and French Normandes, the Montbelliardes were found to be consistently the most profitable option for Irish spring-calving dairy herds under a range of different policy scenarios (Dillon *et al.*, 2001). The superior reproductive performance of the Montbelliarde over a 98-day breeding season was a key element determining its superiority over the two strains of Holstein-Friesian, in spite of the fact that the Montbelliardes had significantly lower milk output per cow than the high merit strain. This work is continuing at the Moorepark – Ballyhooley farm, where Holstein-Friesians, Montbelliardes, Normandes, Norwegian Reds and crosses of these latter three breeds x Holstein-Friesian are being compared and evaluated.

The overall objective of the above work is to simultaneously improve reproductive performance and milk output per cow, reduce replacement rate and hence improve profitability. Improving reproductive performance of dairy herds contains the additional benefit of improving capacity to meet organic N limits on farms. Under the Irish standards for organic N deposition for various categories of livestock outlined in Table 1, each 1.0% reduction in replacement rate results in an 0.8% reduction in organic N load on a dairy farm stocked with dairy cows and replacement LSU only. Hypothetically a reduction in replacement rate from 30% to 20% would reduce organic N load by 8%. In the five-year comparison of breeds outlined above, after a 98-day breeding period, 91% of the Montbelliardes were in-calf compared to 74% of the high-merit Holstein-Friesians. If a 9% non-reproductive related culling rate is factored in, annual replacement rate would be 18% versus 35%. This broadly indicates the scope for improvement on Irish farms. However, even more substantial improvements can be made, with regard to organic N loads on farms, if higher reproductive performance is combined with higher milk output per cow.

Synthesis of sustainable systems

The overall objective of the multi-pronged approach to improving reproductive efficiency on farms is to bring annual replacement rates on dairy farms to less than 20%. It is likely, looking forward, that this will involve using crossbred cows on farms. Ten years ago it would be unusual to see anything other than typical black & white Holstein-Friesian dairy cows on Irish dairy farms. Nowadays an increasing range of alternative breeds is being used for crossbreeding purposes; the objective being that resultant hybrid vigour will improve fertility and health of the cows. These breeds include the Montbelliarde, Norwegian and Swedish Reds, Jersey, Normande, Rothbunts, Brown Swiss etc. In Table 5, it is assumed that a replacement rate of 21% per year is achieved on farms.

In Table 5, summaries of four different approaches to milk production using different N inputs are presented. Two systems are targeted at organic N of 210 kg ha and the other two at organic N of 170 kg ha, based on standard book values outlined in Table 1. These systems are loosely based on past (Humphreys *et al.*, 2002) and present research at the Moorepark – Solohead farm. The Intensive system is based on the Moorepark blueprint as outlined above. The Moderate system is based on reducing annual fertilizer N input to 250 kg ha, harvesting only 15% of the farm for second cut silage and feeding extra concentrate, approximately 300 kg/LSU, to make up the deficit in silage production. The pros & cons of this system were outlined above.

In the two lower stocking rate systems, there is a requirement for around 175 kg N/ha/year in addition to the 120 kg N/ha made available by net mineralization of SOM-N. In the Extensive system, this is supplied solely by fertilizer N. In the REPS system, 90 kg N/ha is supplied by fertilizer N and another estimated 90 kg N/ha is supplied by white clover. This system is called the REPS system because it qualifies for the scheme, having total N load/ha of 260 kg, based on standard values of 85 kg organic N/cow: 170 kg organic N/ha; and 90 kg fertilizer N/ha/year. On the farms presented in Table 4, average milk output/ha was 8.7 t and ranged between 4.4 t and 20.2 t. Five of the 32 farms had milk output/ha exceeding 10.0 t/ha and only two had milk output higher than 12.0 t/ha. Both of these targets are possible on the REPS system outlined in Table 5, the first where replacements are reared on the farm, the second where replacements are reared elsewhere.

Since the initiation of REPS in 1994, it has been mostly drystock (beef and sheep) farmers that have joined the scheme; dairy farmers have tended not to join the scheme. There are compelling reasons why some dairy farmers would benefit from joining the scheme in the future, especially mixed dairy farmers with a relatively low ratio of milk quota to land area. Average organic N loading/ha on Irish dairy farms is a little under 170 kg ha, which is the maximum permissible under REPS. Following decoupling, it is likely that farmers will be able to receive direct payments without needing to retain beef cattle on the farm. This provides the opportunity of reducing or eliminating the beef element of the farm enterprise, reducing labour requirement, and de-intensifying the dairy element to reduce costs, for example, by basing production on a simple low-cost one-silage-harvest grass & clover system. The combination of reduced costs and REPS payments make this an economically attractive option. Furthermore, REPS standards are sufficient to meet the most stringent environmental requirements. Farm structures and management practices are coming under increasing scrutiny. This is likely to become increasingly widespread over the next few years. It would seem sensible for farmers to join REPS and to be remunerated to a certain extent for the costs associated with the above on-farm improvements.

There is no difference in milk output per cow between the systems in Table 5. Six tonne of milk is sold per cow. This is a reasonable target for cross-bred cows on Irish farms. This milk contains 35 g/kg protein, which is routinely achieved by better dairy herds at present (including the herd at Solohead farm). This along with sales of calves and cull cows amounts to an annual N output from the farm of 35 kg/cow. Surplus N on the REPS amounts to either 58 or 148 kg ha depending on whether the contribution of white clover is included. Only first cut silage is harvested on the REPS system. On ground for first cut silage, around 30 kg fertilizer N/ha is applied for early grazing in mid-March, although the cows are out grazing for more than a month at that stage. After closing for silage, another 86 kg fertilizer N/ha is applied. This with the contribution of the white clover is sufficient N to produce yields of grass for silage of 7.0 to 7.5 t DM/ha; yields comparable to swards receiving 115 kg N/ha with little or no clover. Silage is harvested in late May. On the grazing area of the REPS system, around 60 kg fertilizer N/ha is applied, split between around 30 kg ha in mid-March and 30 kg ha in mid-April. No further fertilizer N is applied.
Slurry is recycled to the silage ground. The whole farm is available for grazing from June to housing for the winter during November or December.

Table 5. Stocking rates, organic N loads/ha, and potential milk output per cow, farm-gate N balance, and N deposition per cow across four systems of grassland-based dairy production under Irish conditions.

System Name	Intensive	Moderate	Extensive	REPS
Farm stocking rate (LSU/ha)	2.48	2.48	2.01	2.01
Dairy cows/ha	2.05	2.05	1.66	1.66
Replacements (LSU/ha) replacement rate = 21%	0.43	0.43	0.35	0.35
'Book-Standard' organic N (kg ha) (see: Table 1)	210	210	170	170
Concentrate fed (kg/LSU)	600	900	600	600
(kg ha)	1488	2232	1206	1206
Milk sales/ha (t/ha) (6.0 t milk sold/cow)	12.3	12.3	10.0	10.0
		N imported onto the farm (kg ha/year)		
Fertilizer N	330	250	175	90 + 90•
Concentrate-N	35	53	29	29
Total N imports	365	303	204	119
		N exported from the farm (kg ha/year)		
Milk-N (6.0 t milk/cow with 35 g/kg protein)	67.4	67.4	54.6	54.6
N exported as calves and cull cows sold$^{\Psi}$	7.9	7.9	6.4	6.4
Total N exports	75.3	75.3	60.9	60.9
Surplus N (kg ha)	290	228	143	58
Imported N-use efficiency (%)	20.6	24.8	29.9	51.3
		Grass-Silage Production		
Area harvested for first-cut silage (%)	45	45	55	55
Fertilizer N (kg ha)	115	115	115	86
Yield of grass for silage (t DM/ha)	7.2	7.2	7.2	7.2
Area harvested for second-cut silage (%)	30	15	—	—
Fertilizer N (kg ha)	104	85	—	—
Yield of grass for silage (t DM/ha)	4.9	4.7	—	—
		Annual DM intake/cow		
Silage consumed (t DM/cow)	1.30	1.00	1.30	1.30
Crude protein concentration (g/kg DM)	145	140	140	140
Grazed pasture consumed (t DM/cow)	3.25	3.25	3.25	3.25
Crude protein concentration (g/kg DM)	215 – 245	190 – 230	180 – 215	170 – 200
Concentrate consumed (t DM/cow)	0.53	0.81	0.53	0.53
Crude protein concentration (g/kg DM)	175	175	175	175
		Annual N intake/cow (kg N/cow)		
Silage	30	22	29	29
Pasture	112 – 127	99 – 120	94 – 112	88 – 104
Concentrate	15	23	15	15
Total N consumed	157 – 172	144 – 165	138 – 156	132 – 148
Annual N output (kg N/cow)	35.0	35.0	35.0	35.0
Comprised of 210 kg milk protein, one 41 kg calf/cow and 35 kg weight gain/cow*				
Organic N excretion	122 – 137	109 – 130	103 – 121	97 – 113
Organic N deposition (10% gaseous losses)	110 – 124	98 – 117	92 – 109	88 – 102
Actual organic N load/ha	260 – 288	236 – 274	182 – 209	174 – 197
Replacement LSU = 81 kg organic N/LSU				

• *Contribution of white clover; not considered as an import onto the farm in this table.*

$^{\Psi}$ *79% of calves and 21% of cows exported from the farm/year (sold or disposed of in case of untimely death).*

* *Average annual N in weight gain of cow from first calving to sale.*

One issue that emerges in Table 5 is the large differences in N excretion and deposition per cow across the systems. In Ireland a dairy cow is classified as depositing 85 kg organic N/head/year. This is a reasonable estimate when it is considered that the 'average' Irish cow weighs around 525 kg and yields around 4 650 kg milk/year that contains around 33.5 g/kg protein. This cow is stocked at rates just less than 2.0 LSU/ha on farms (Connolly *et al.*, 2001) receiving 176 kg fertilizer N and 12 kg fertilizer P/ha/year (Coulter *et al.*, 2002). In Table 5, the crude protein concentration of pasture consumed by cows varies with that found in experiments under different conditions (soil type etc.) in Ireland. Grazed pasture is the main component of the diet (64%) and variation in the N concentration of the diet has a major bearing in organic N deposition per cow. This ranges from 88 kg at the low end of the REPS system to 124 kg at the high end of the Intensive system. Assigning a standard 'book value' is a very crude tool for regulating organic N loads on farms.

The future

It is likely that there will be a substantial reduction in the number of dairy farmers and of beef cattle in Ireland during the remainder of the present decade. Halving the number of dairy farmers implies the doubling of milk quota and probably means increasing intensification of production on remaining farms. This offers the prospect of a comparably good income from dairy farming for those who remain in the business. There is considerable scope to expand dairy cow numbers on farms without exceeding limits on organic N by reducing or eliminating beef cattle, replacing them with dairy livestock. The REPS system outlined above has potential under such circumstances.

However, it is not likely to be the solution for all Irish dairy farms. It is likely that the more intensive dairy farmers will tend to remain in dairy production. Increasing quota size on farms is not likely to be accompanied by an increase in size of the block of land adjacent to the milking parlour. Fragmentation poses a limitation. It is likely that rearing of replacements, winter fodder production (grass or maize silage etc.) and other drystock production will take place on out-farms located at a distance from the home-farm. However, it makes most economic sense for farmers, under such circumstances to push stocking rates on the home-farm as high as possible, for example, to 2.8 LSU/ha, to minimise the costs of transporting forage and other feeds to, and manure from, the home-farm. While stocking rates across the country as a whole are likely to decline, there is the possibility of increases in stocking rates on dairy farms as milk quota moves from the relatively less-favoured region in the North-West to the more favoured cost-competitive regions in the South and East. This may exacerbate nitrate concentrations in surface and ground waters in relatively vulnerable areas in the South and East, where sandy shallow soils coincide with lower volumes of runoff and drainage waters.

References

Bartley, P., Johnston, P. & Culleton, N. (2002)
Nutrient loss to groundwater from a conventional dairy farm & an organic dairy farm. End of Project Report (in press). Teagasc, 19 Sandymount Avenue, Ballsbridge, Dublin 4, Ireland. www.teagasc.ie

Behan, J. & McQuinn, K. (2002)
Projections of greenhouse gas emissions from Irish agriculture. Outlook 2002. Medium Term Analysis for the Agri-food Sector. Teagasc, 19 Sandymount Ave., Dublin 4, Ireland, pp. 77-86.

Binfield, J. Donnellan, T., Hanrahan, K., McQuinn, K. & Westhoff, P. (2002)
The baseline outlook for the agricultural sector in the EU and Ireland. Outlook 2002. Medium Term Analysis for the Agri-food Sector. Teagasc, 19 Sandymount Ave., Dublin 4, Ireland, pp. 13-47.

Binfield, J., T. Donnellan, Hanrahan, K., Hennessy, T. McQuinn, K & Westhoff, P. (2002)
'The Mid-Term Review: An analysis of the impact of changes to the extensification regime.' Outlook 2002: Medium Term Analysis for the Agri-Food Sector. Teagasc, 19 Sandymount Ave., Dublin 4, Ireland, pp. 59-76.

Buckley, F., Dillon, P. Mee, J., Evans, R. & Veerkamp, R. (2000)
Trends in genetic merit for milk production and reproductive preformance. In: Dairying 2000 – Opportunities for the New Millennium. Teagasc National Dairy Conference, Cork, November 2000. Teagasc Sandymount Avenue, Dublin 4, Ireland, pp. 43-59.

Collins, J. & Cummins, T. (Eds.) (1996)
Agroclimatic Atlas of Ireland. Published by the joint Working Group on Applied Agricultural Meteorology, Agriculture Building, University College Dublin, Belsfield, Dublin 4, Ireland, 152 pp.

Connolly, L., Burke, T. & Roche, M. (2001)
Teagasc National Farm Survey 2000. Teagasc, 19 Sandymount Avenue, Dublin 4, 13 pp. www.teagasc.ie

Coulter, B.S., Lee, J. & McDonald, E. (1996)
The status of soil survey information both conventional and GIS. In: LeBas C. & Jamagne M. (eds.) Soil databases to support sustainable development. Joint Research Centre European Commission, INRA, pp. 61-69.

Coulter, B.S., Murphy, W.E., Culleton, N., Finnerty, E. & Connolly, L. (2002)
A Survey of Fertilizer Use in 2000 for Grassland and Arable Crops. Teagasc, Johnstown Castle Research Centre Wexford.

CSO (2000)
Census of Agriculture, June 2000, Main Results. Central Statistics Office, Cork, Ireland. www.cso.ie

Culleton, N. (2003)
Is extensification good for Irish agriculture. Farm & Food. Spring 2003. 4-6.

Culleton, N., Murphy J. & Murphy, W.E. (1999)
The Evaluation of Environmental, Agronomic and Economic Implications of High and Low Input Dairy Systems. Investigations to determine the minimum phosphorous that is required to ensure optimum production. ARMIS 4020. Johnstown Castle Research Centre, Wexford, 12 pp. www.teagasc.ie

DAFF (1996)
The Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates (1996) Department of the Environment & Department of Agriculture, Food and Forestry, 57 pp. www.agriculture.gov.ie

DAFRD (2002)
Eco-Friendly Farming – A Report. The Department of Agriculture, food & Rural Development (DAFRD), 36 pp. Prepared by B. Brady, T. Arnold (until October 2001), J. Beecher, J. Flanagan, J. Fox, C. Gaynor, T. Moran, A. O'Driscoll (from January 2002), P. Moore, H. Murphy – Secretary. www.agriculture.gov.ie

DELG (2000)
National Climate Change Strategy Ireland. Department of Environment and Local Government (DELG), Dublin, Stationary Office. www.environment.gov.ie

Dillon, P., Buckley, F., Hegarty, D. & Sniders, S. (2001)
An evaluation of the role of dual-purpose dairy cattle under Irish grass-based spring milk production systems. End of Project Report No. 4350. Teagasc, 19 Sandymount Avenue, Dublin 4, Ireland, 32 pp. www.teagasc.ie

Dillon P. & Stakelum, G. (1999)
Spring Milk Production. In: 'A New Agenda for Dairying' J. Murphy (Ed.). Teagasc, 19 Sandymount Avenue, Ballsbridge, Dublin 4, pp. 3-7.

Duggan, P. (2002)
Information paper on good agricultural practice and protection of the environment. Department of the Environment and Local Government, Dublin, Ireland, 19 pp. www.environment.gov.ie

EDF (2002)
European and world-wise cost comparison analysis. European Dairy Farmers Database 2002. Central Publication: Annual International Farm Competition Network (IFCN) Dairy Report, Authors Hemme *et al.* see: www.ifcndairy.org. Pp 70-73.

EPA (2002)
Water Quality in Ireland 1998-2000. McGarrigle, M.L., Bowman, J.J., Clabby, K.J., Lucey, J., Cunningham, P., MacCárthaigh, M., Keegan, M., Cantrell, B., Lehane, M., Clenaghan, C. and Toner P.F. Environmental Protection Agency. PO Box 3000, Johnstown Castle Estate, County Wexford, Ireland. www.epa.ie

EPA (2001)
An assessment of the trophic status of estuaries and bays in Ireland. Environmental Protection Agency. P.O. Box 3000,Johnstown Castle Estate, County Wexford, Ireland. www.epa.ie

Hennessy, T. (2002)
The baseline outlook for farm incomes in Ireland. Outlook 2002. Medium Term Analysis for the Agri-food Sector. Teagasc, 19 Sandymount Ave., Dublin 4, Ireland, pp. 48-58.

Humphreys, J., Lawless, A., O'Connell, K. & Casey, I.A. (2002)
Reducing nitrogen inputs to grass-based dairy production systems. In: Profitable grass and forage: meeting the needs of the farmer and society. Proceedings of the British Grassland Society, 27 & 28 November 2002, Tillington Hall Hotel, Stafford, UK. in press.

Hyde B.P., Carton, O.T., O'Toole, P. & Misselbrook, T.H. (2003)
A new inventory of ammonia emissions from Irish agriculture. Atmospheric Environment 37: 55–62.

Kelly, P., Behan, J., Breen, J., Donnellan, T., Hanrahan, K. Hennessy, T. & McQuinn, K. (2003)
An Analysis of the Effects of Decoupling Direct Payments from Production in Beef, Sheep and Cereal Sectors. Rural Economy Research Centre, Teagasc, Dublin, Ireland.

Kurz, I., Tunney, H. & Coxon, C.E. (2003)
The impact of a dairy farm on stream water quality. Agricultural Research Forum, 3rd & 4th March, p. 32.

Lally, B. & Riordan, B. (2001)
Economic Impact on Irish Dairy Farms of Strategies to Reduce Nitrogen Application. Rural Economy Research Centre, Teagasc, Dublin, Ireland.

McQuinn, K., Riordan, B. & Lally Breda (2003)
Prospective impact of environmental regulations, and other policies on fertilizer use in Ireland. Rural Economy Research Centre. Teagasc. Dublin, Ireland.

Mee, J.F., Fahey, J. & Crilly, J. (1999)
Breeding the dairy cow of the future. Todays challenges. Is herd fertility declining in the UK ? Dairy in the new millennium. Teagasc National Dairy Conference, Adare, pp. 7-16.

Neill, M. (1989)
Nitrate concentrations in river waters in the south-east of Ireland and their relationship with agricultural practice. Water Research 23: 1339-1355.

Peyraud, J.L. & Astigarraga, L. (1989)
Review of the effect of nitrogen fertilization on the chemical composition, intake, digestion and nutritive value of fresh herbage: consequences on animal nutrition and N balance. Animal Feed Science & Technology. 72: 235-259.

Ramsbottom, G. & McCarthy, G. (2002)
Better Breeding – Spring Calving Cows. Teagasc, 19 Sandymount Avenue, Dublin 4, Ireland, 15 pp. www.teagasc.ie

Regan, S. (2001)
Update on Water Protection Regulations and Good Practice. REPS Conference 2001: Better Farming for a Better Environment. November 2001, Galway. Teagasc, 19 Sandymount Avenue, Ballsbridge, Dublin 4, pp. 15-23. www.teagasc.ie

Ryan, M. (2003)
Nitrate Leaching. Irish Farmers Journal, Vol. 55 No. 3: 18 January 2003, p. 30. www.farmersjournal.ie

Teagasc (2002)
Farm Management Data – Handbook 2002. Teagasc, 19 Sandymount Avenue, Dublin 4, Ireland, 245 pp. www.teagasc.ie

7. Flanders

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7.1 Introduction

An expanding fertilizer industry and the need for high production levels encouraged the use of mineral fertilisers after WW II. Also the possibilities to use more cost-effective concentrates promoted a further regression to higher yields per hectare.
Nitrogen is one of the most important inputs in dairy farming systems, but the conversion rate of input-nitrogen into nitrogen in products is rather low. Excess nitrogen leaks uncontrolled into the environment. These nitrogen losses increase pollution in the form of nitrate leaching into ground- and surface waters, ammonia emissions causing acidification and eutrophication of adjacent ecosystems and as emissions of nitrous oxides which contribute to global warming and depletion of the ozone layer.
The scientific evidence and the growing environmental concern resulted in several European laws to protect water quality. These EC laws were then translated in regional practical laws (e.g. Flemish manure decree).
These measures are, on one hand, political instruments and, on the other hand, suggestions for management options for a more efficient use of nitrogen. Despite these efforts, the situation of nitrogen use in agriculture is far from satisfying, but there is a positive evolution towards higher efficiencies. N surpluses evolve to a more sustainable level from an ecological point of view.

7.2 Dairy farming in Flanders

About 47% of the Flemish land area is used by agriculture. The agricultural share in land use decreased over time due to the conversion of agricultural to other land uses such as infrastructure, industry, housing and nature.

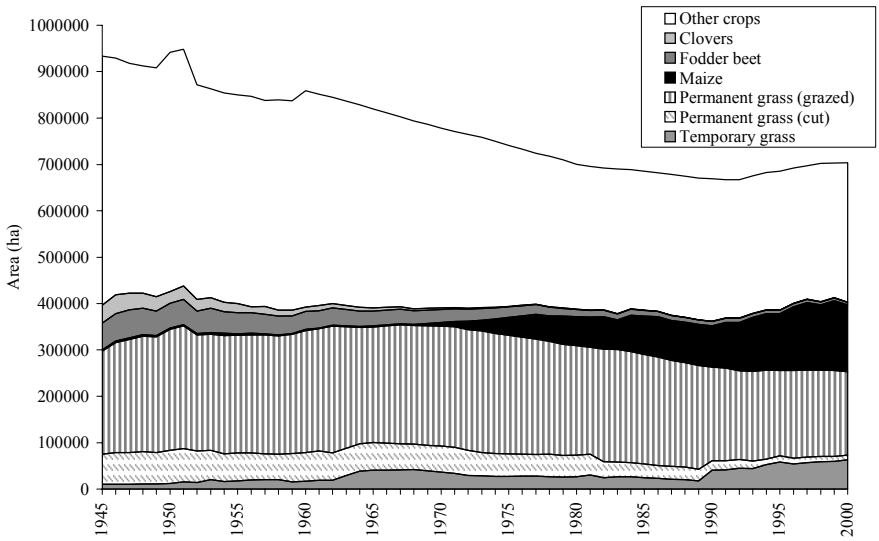

Figure 1. Evolution of soil use by different agricultural crops in Flanders (1945-2000).

After WW II clover and fodder beet cultivation declined to a negligible level; maize cultivation increased in a spectacular way. About 56% of the Flemish agricultural area is under grassland (2/3) and forage crops: maize (1/3) (Figure 1). Cattle farms take a large part of the agricultural area and thus have an important environmental impact. In the past 20 years the number of farms decreased by 2.3% per year. Remaining farms expanded their size and there was a further specialization with less mixed farms. The total number of farms in 2001 was 39 276 (Table 1). About 45% of these farms were specialized. The two dominant farm types are those with animals and animals + arable crops. 58% of the farms in Flanders have grazing animals (milk and meat production).

Table 1. Number and type of farms in 2001 (Lauwers and Overloop, 2002).

Farm type	Farm Number	Share of farm type in total (%)
Arable	1 102	3
Horticulture	4 185	11
Livestock	12 453	31
Arable + livestock	13 685	35
Arable + horticulture	999	3
Horticulture + livestock	2 031	5
Arable + horticulture + livestock	4 605	12
Total	39 276	100

In 2001, the number of farms with dairy cows in Flanders was 10 353. Nearly 50% were specialized dairy farms. There are 347 643 milking cows in Flanders, hence an average of 33.6 cows per farm. Twenty-seven percent (2 762 farms) of the dairy farms account for more than 50% of the milk production. There are only 200 farms with more than 100 cows and a lot of small farms: 21% of the farms have only 5% of the dairy cows (Van Hecke & Schrooten, 2003). The average farm on sandy soils is larger than that on loamy soils. A large proportion of the small dairy farms also has beef cattle.

The average milk quotum of a dairy farm in Flanders is 185 000 litres. Total milk production in Flanders was 2 million ton. To a certain extent, milk quota were transferable via a quota bank; free quota transfer is only possibly between family members. Recently a new, more freely quota system has been proposed. In this new system, transfer of milk quota between all farmers will be accepted again, but within restrictions: a farmer can only buy 60% of a given quotum, while 40% is transferred to the quota bank. Every farmer can buy each year a certain amount of the quota bank, except the farmers who bought from another farmer on the free market. The latter farmers are not allowed to buy from the quota bank during 3 years after their milk quota purchase on the free market. The new system will result in a better supply of milk quota to the quota bank.

The most intensive regions of cattle husbandry are in the north of the Provinces East- and West-Flanders and in the north of Antwerp and Limburg (sandy regions) (Figure 2). In some parts of Antwerp, there are farms with more than 5 animals per ha (young cattle included). The intensive cattle regions in Flanders are situated in zones vulnerable to nitrate leaching (darker colored in Figure 3). In these zones the fertilization rules are more severe and some intensive farms have to export organic manure.

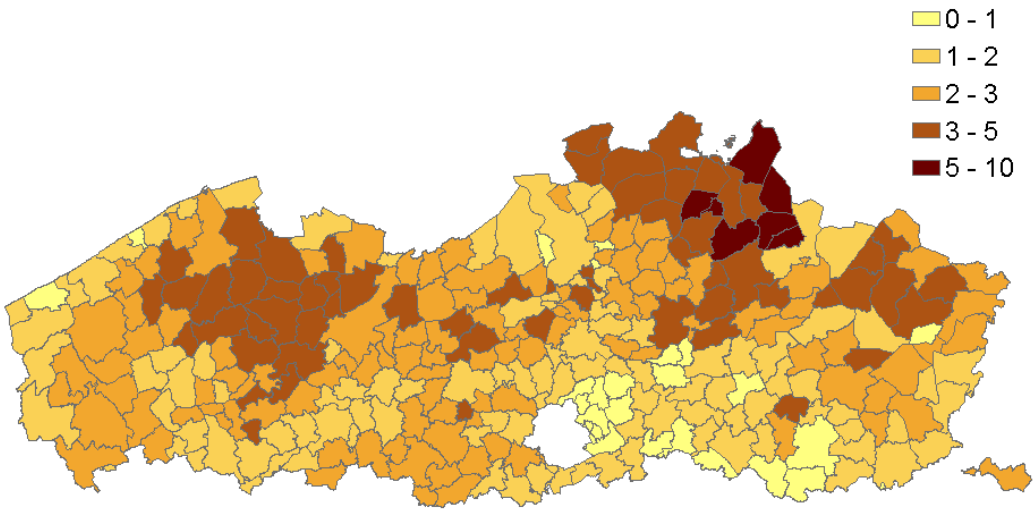

Figure 2. Distribution of cattle over Flanders (number of cattle per ha agricultural area) Source: OC-GIS, NIS.

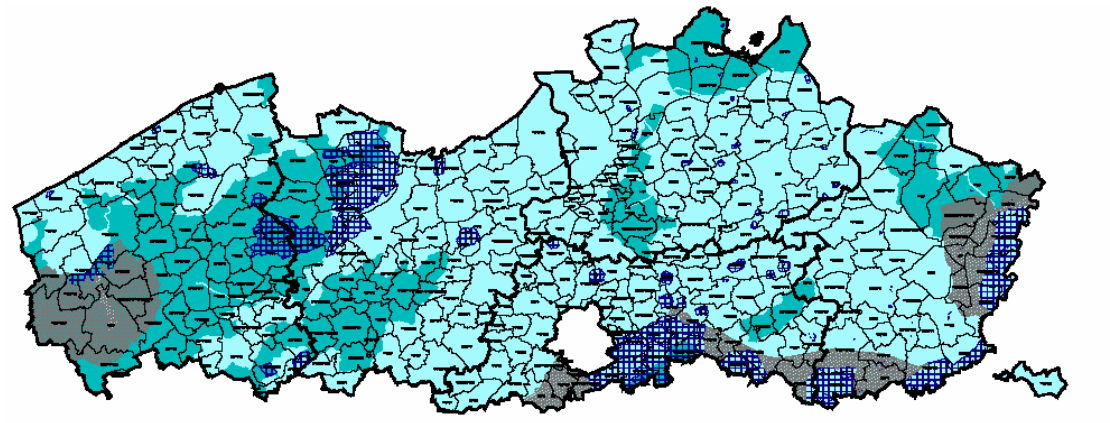

Figure 3. Vulnerable zones (darker colored) in Flanders in 2003.

7.3 Nutrient policy in Flanders

7.3.1 Background

An Environment and Nature Plan (MINA-plan 2000) was issued by the Flemish Minister of Environment in 1989. The 'MINA-plan' had two aims, i.e. to describe the environmental situation in Flanders and propose policy measures to improve the then existing situation within the period 1990-1995. One of the themes included in the MINA-plan was the overloading of ecological processes and cycles through an excess of nutrients in the environment called 'vermesting'. A substantial part of this problem was ascribed to manure surpluses resulting from agriculture (Kelchtermans, 1989). The manure decree of 1991 was the policy measure that tackled this problem (Anonymous, 1991b). The second MINA-plan functioned as a precept for the Flemish government in their environmental policy during the period 1997-2001. A long term goal of this plan is equilibrium in inputs and outputs of N, P and K (AMINAL, 1997). The most important Flemish legal sources that deal with control of nutrient pollution are Vlarem and the Manure Decree. Vlarem sets, *inter alia,* water quality, while the manure decree is the transposition of the Nitrate Directive (Anonymous, 1991a).

7.3.2 Standards

Water quality goals were laid down by the Flemish government relating to general and sector regulations concerning environmental hygiene (Vlarem II) from 1 June 1995. All surface waters must comply with the basic quality norms as set in Vlarem II. In 1998, several watercourses were put to specific uses such as drinking water production, swimming, fishing or shellfish production. Table 2 shows some of the characteristics and their associated norms for the basic quality goals and for the specific goals. There is no specific hierarchy between the different norms (Heyman & Smout, 1999).

Surface water is considered to meet the A-limit if more than 90% of the measurements within one calendar year meet this value. For the 10% of the samples that do not comply with the norms, the water may not deviate more than 50% from the limit value. For water intended for the production of drinking water, 95% of the samples must meet imperative norms and 90% must meet target values.

Table 2. Some criteria for the basic quality norms and norms for fishing water and drinking water production (Heyman & Smout, 1999).

Parameter		Allowed conc. Basic quality	Allowed conc. Fishing water		Allowed conc. Drinking water prod.
NH_4^+-N	A	< 5 mg l^{-1}	≤ 0.78 mg l^{-1}	I	≤ 3.1 mg l^{-1}
	M	< 1 mg l^{-1}			
Kjeldahl-N	A	< 6 mg l^{-1}		T	≤ 3 mg l^{-1}
NH_3-N	A	< 0.02 mg l^{-1}	< 0.021 mg l^{-1}		
NO_3^--N + NO_2^--N	A	≤ 10 mg l^{-1}			
NO_3^--N				I	≤ 11.3 mg l^{-1}
NO_2^--N			≤ 0.009 mg l^{-1}		
Total phosphates (P-tot)	A	< 1 mg l^{-1}	< 1 mg l^{-1}	T	≤0.03 mg l^{-1}
	M	< 0.3 mg l^{-1}			
Ortho-P: moving water	A	< 0.3 mg l^{-1}			
Ortho-P: still water	A	< 0.05 mg l^{-1}			

A ≤ absolute; M ≤ mean; I ≤ imperative; T ≤ target value.

Vlarem II also sets environmental quality norms for groundwater. The maximum admissible concentrations and target values for nitrogen and phosphorus are shown in Table 3. Not only water quality norms are laid down in Vlarem II, but also instructions on how to construct stables and manure storages.

Table 3. Criteria for the quality of groundwater.

Parameter	Target value	Maximum admissible concentrations
NO_3^--N (mg l^{-1})	5.6	11.3
NO_2^--N (mg l^{-1})		0.03
NH_4^+-N (mg l^{-1})	0.039	0.388
Total P (mg l^{-1})	0.175	2.183

7.3.3 Policy instruments: Manure Decree

In January 1991, the Flemish government accepted the decree concerning the protection of the environment against pollution caused by the production and the use of fertilizers. This decree has been amended several times during the past few years. The last amendment dates from March 2003. The Manure Action Plan of 1993 is the implementation order of the manure decree of 1991 (De Batselier, 1993). The objective of the decree and its implementation orders is to reach a sustainable nutrient balance in Flanders that meets the provisions set in the EU Nitrate Directive. Hence the problem of pollution through fertilizers must be tackled.

Fertilizers are defined in the decree as all substances that contain N or P and which can be applied to the soil to enhance the growth of crops. The main focus is, consequently, to tackle the N and P pollution to ground- and surface waters and to soils, as resulting from the use of fertilizers on agricultural farms. According to the decree, the total amount of nutrients applied to land (including excretion by animals during grazing) must be limited so that the pollution of ground- and surface water by nitrates does not exceed the limit value of 50 mg NO_3 l^{-1} or 11.3 mg NO_3-N l^{-1}. To attain this goal, the NO_3-N-residue on arable land up to a depth of 90 cm may not exceed the norm of 90 kg NO_3-N ha^{-1} during the period between 1 October and 15 November. This norm was valid till the end of 2002. New norms have been proposed (Table 4), but are not yet implemented.

Table 4. Newly proposed NO_3^--N-residue norms (kg NO_3^--N ha^{-1} [0-90 cm]) as a function of crop/combination of crops and texture (October 1st - November 15th) (Soil Service of Belgium et al., 2002).

Crop/Combination of crops	Texture	
	Sand	Other textures
Maize	60	90
Beets	50	70
Vegetables without removal of harvest residues	40	50
Grassland	70	100
Cereal crop + green manure	70	100
Other crops	50	80

The Manure Decree contains four major actions:
1. determining manure surpluses and fertilizer limits;
2. designation of vulnerable zones;
3. judicious application of nutrients to the soil and development of the code of good agricultural practice;
4. maintaining a status quo in N and P production in manures.

With respect to fertilizer norms, farmers can choose between two systems: the fixed system or the nutrient balance system. When they decide to use the fixed system, they must comply with the fertilizer norms as set in the decree. The norms of the fixed system are shown in Table 5. Some exceptions are allowed, for instance when two or more crops are grown on the same field in the same year.

Table 5. Fertiliser norms when using the fixed fertilizer norms system. The amount of nutrients that are allowed are expressed in P, total-N from animal manures and other fertilizers[a] and N from chemical fertilizers (kg [ha.year]$^{-1}$).

Crop group	P	Total N	N from animal manures and other fertilizers	N from chemical fertilizers
Grassland	57	450	250	350
Maize	44	275	250	150
Crops with a low N-need[b]	44	125	125	100
Other crops	44	275	200	200

[a] *All fertilizers except animal manures and chemical fertilizers.*
[b] *Chicory, fruits, shallots, onions, flax and leguminous crops.*

The other option for farmers in order to fulfil the aim of not exceeding the limit of 90 kg NO_3^--N ha^{-1} (or the newly proposed NO_3^--N-residue norms) within 90 cm during autumn is to choose the nutrient balance system. This system further comprises three kinds of balances: the farm balance, the manure excretion balance and the soil balance. Of these three balance types, only the application of the excretion balance is regulated by law (Anonymous, 2000a).

The Flemish government has designated four types of sensitive areas (2003: 46.7% of the agricultural area), *i.e.,* sensitive waters, ecologically valuable agricultural areas, nature conservation areas and phosphate-saturated areas. Different action programs for each of these zones have been launched, but with common feature that the amount of animal manure that can be applied to these soils on an annual basis is limited to 170 kg N ha^{-1}, except in phosphate-saturated areas. Within these zones, land users can enter into a management agreement with the government on a voluntary basis to take further measures to enhance the environmental quality. As an example, the management agreement 'water', contains following conditions (Anonymous, 2000b):

1. Maximum allowable N-fertilizer rates per hectare:
   - grassland: 280 kg N;
   - cereals: 175 kg N;
   - maize and other crops: 200 kg N;
   - crops with a low N-requirement: 100 kg N;
2. Since 2003, farmers can use 140 kg N from animal manure at maximum;
3. A fertilizer plan and fertilizer register must be made for each field every year;
4. The NO_3-N-content of each parcel must be measured each year between the curfew October 1st till November 15th up to a depth of 90 cm and should not exceed the NO_3-N-residue norm.

When all conditions are fulfilled, the farmer is granted a basic sum to compensate for possible yield losses. Furthermore, an encouragement supplement is granted when extra efforts were taken to further reduce the NO_3-N-content in the soil profile during the curfew.

The Flemish government also decided on a standstill of P and N production in manure in the Flemish region. The ceiling is based on the production quantities in 1992, i.e. 33 million kg P and 169 million kg N. This stand-still was first to be abolished 1 January 2005, but abolishment has been delayed to 1 January 2007. All municipalities in Flanders are categorised into one of four groups (white, light grey, dark grey and black municipalities), based on the permitted production pressure (expressed as kg P_2O_5 ha^{-1}) of 1992. Additionally, a P_2O_5-nutrient halt and a N-nutrient halt were allocated to each livestock holding. At least until 2007, no environmental permits will be granted for new livestock holdings, nor for conversion of existing livestock holdings when this would lead to an increase of the allowed manure production.

Penalties for not complying with the rules laid down in the manure decree are also regulated. Three basic levies and two super levies are included in the decree.

7.3.4 Code of Good Agricultural Practice

The Code of Good Agricultural Practice for Flanders is published by 'The Administration of Agriculture and Horticulture (ALT)'. ALT is part of the department of Economy, Employment, Home affairs and Agriculture of the Flemish government. The Code is split in three booklets:

1. Nutrients in arable crops;
2. Nutrients in grassland and fodder crops;
3. Nutrients in field grown vegetables and fruit crops.

Each booklet has the same structure. The first part contains general principles concerning fertilization, green cover and erosion. The second part gives instructions and techniques to set up an optimal and ecologically sound fertilizer plan for different crops. For each of the crops, the following aspects are dealt with:

1. crop rotation, preceding crop and cover crops;
2. basic fertilizer information norms;
3. nitrogen fertilizer practice (N need, N fertilizer advice, application time and manner).

In the last part the mandatory measures in the vulnerable zones according to the manure decree are explained (ALT, 2000a,b,c).

7.4 Environmental indicators: monitoring programs and trends

7.4.1 Nutrient surpluses at farm scale

Records of specialized Flemish dairy farms (minimum 95% of the labor income originating from dairy branch) are selected from the Farm Accountancy Data Network (Agricultural Economics Institute) for the years 1989-2001. The strict criterion used for the selection resulted in the small number of complying farms (Table 6), with the following characteristics:

Table 6. Number and characteristics of specialized Flemish dairy farms of the FADN.

		'89	'91	'93	'95	'97	'99	'01
Farm number		169	159	123	115	98	92	69
Farm area	ha	27.6	27.7	27.7	29.5	32.3	31.8	32.4
Share grassland	%	70	68	65	63	60	62	63
Concentrates	kg cow^{-1}	1 236	1 180	1 171	1 291	1 201	1 114	1 132
By-products	kg DM cow^{-1}	463	501	364	462	518	357	366
Fert. grassland	kg N ha^{-1}	309	277	266	246	273	241	186
Fert. arable land	kg N ha^{-1}	98	82	71	62	56	53	40
Milk production	l cow^{-1}	5 319	5 458	5 621	5 709	6 182	5 947	5 827
Milk production	l ha^{-1}	9 607	9 625	10 060	10 071	10 328	1 0014	9 643
Stocking density	LU[1] ha^{-1}	3.02	3.10	3.10	3.18	3.06	2.99	2.98

1 LU = 1 cow with a milk production of 4 000 l (per 1 000 l above: + 0.1 GVE).

The average farm area increased from 27.6 ha in 1989 to 32.4 ha in 2001. The share of grassland decreased from 70 to 63%. Mineral fertilizer use has strongly been reduced, both on grassland and maize land.

Nitrogen farm surpluses from specialized Flemish dairy farms were calculated for the period 1989-2001. Nitrogen deposition and nitrogen fixation were also taken into account. The nitrogen depositions are average values for Flanders (Van Gijseghem & Overloop, 2002). The evolution of the nitrogen budgets and their components is given in Table 7. There was a significant decrease of the surplus from 378 in 1989 to 238 kg N ha^{-1} in 2001 (Figure 4), attributable to a lower mineral fertiliser use and a decrease in concentrate use per ha. The share of mineral fertilizer in the total N-input diminished from 53 to 42%. The share of concentrates and by-products remained stable at 30%. There is only an absolute decline of the concentrate use. N-efficiency increased from 15 to 22%, but the better farms had efficiencies of more than 30%.

Figure 5 shows the relationship between total concentrate use per ha (sum of commercial concentrates and the dry matter of by-products) and milk production per ha. A higher concentrate use resulted logically in a higher milk production per ha.
When a farm uses 1000 kg total concentrates more per ha, it can produce about 1650 l milk extra per ha. These concentrates contain 34 kg N and the extra milk production contains about 9 kg N. There will be also some extra meat production, corresponding with an extra N production of ± 1.5 kg N. So, with an extra concentrate use of 1000 kg ha^{-1}, the farm N surplus will increase with 34 – 10.5 = ± 23.5 kg N ha^{-1}. Or when a farmer wants to produce 1000 l milk extra per ha (based on concentrates), his farm N surplus will increase with 23.5/1.65 = ± 14 kg ha^{-1}.

Contrary to the use of concentrate per ha, there was no strong relation between mineral fertilizer use per ha and milk production per ha (Figure 6). Hence, to reduce farm N surplus without sacrificing milk production per ha, reducing mineral fertilizer seems the more obvious track.

We divided the studied farms into 10 groups according to their farm N surplus. The results of the four groups with the lowest surplus are given in Table 8. The four groups are significantly different when their mineral fertilizer use on grassland, soil-efficiency and their mineral fertilizer use on arable land is concerned. To have low farm surpluses, it is important to focus on nutrient utilization on soil-crop level: better use of manures in order to save mineral fertilizer.

Table 7. Inputs and outputs (kg N ha^{-1}) of the nitrogen farm gate balances of the specialized dairy farms from 1989 to 2001.

	'89	'91	'93	'95	'97	'99	'01
Input							
Fertilizer	238	209	193	174	179	163	128
Concentrates	104	96	93	100	83	76	76
Manure-import	25	25	25	25	25	24	29
Straw	1	2	2	2	1	1	1
By-products	24	25	18	23	24	16	16
Maize import	2	4	1	3	2	1	1
Deposition	50	48	46	44	51	54	48
N-fixation	2	1	2	1	2	2	6
Output							
Milk	47	50	53	52	53	52	49
Animals	19	19	19	18	18	18	16
Arable crops	2	2	2	2	4	2	2
Total input	445	410	380	371	367	337	305
Total output	67	71	74	73	75	72	67
Surplus	**378**	**339**	**306**	**298**	**292**	**265**	**238**
St dev.	111	102	88	106	92	96	74
Efficiency (%)	***15.1***	***17.3***	***19.4***	***19.6***	***20.5***	***21.2***	***22.0***

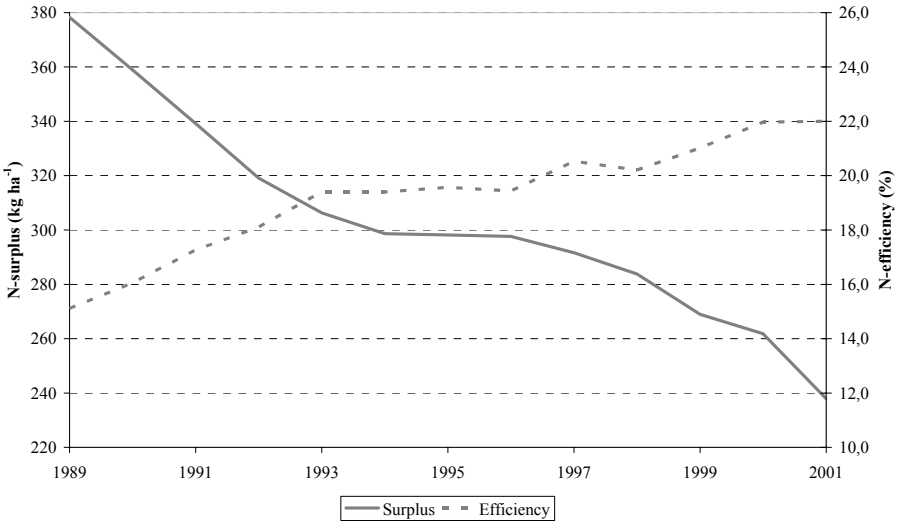

Figure 4. Nitrogen surplus (kg N ha^{-1}) and N-efficiency (%) from specialized dairy farms.

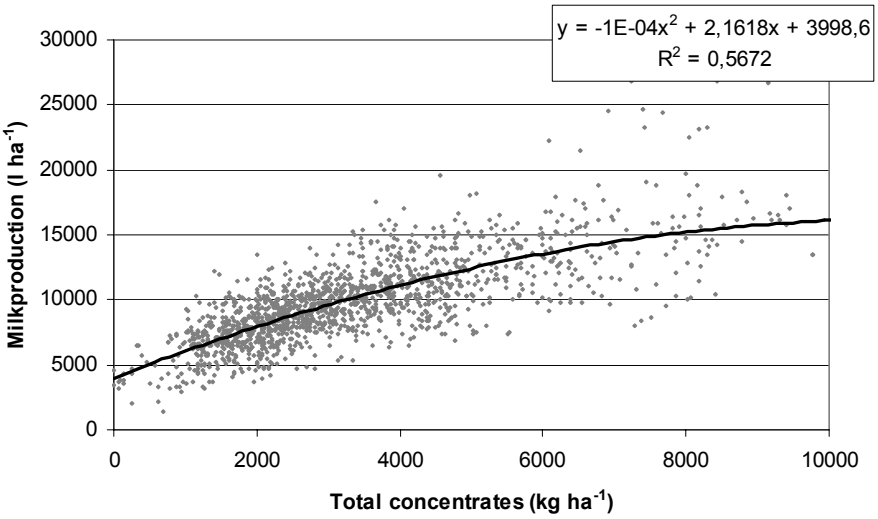

Figure 5. Relationship between total concentrate use per ha and milk production per ha.

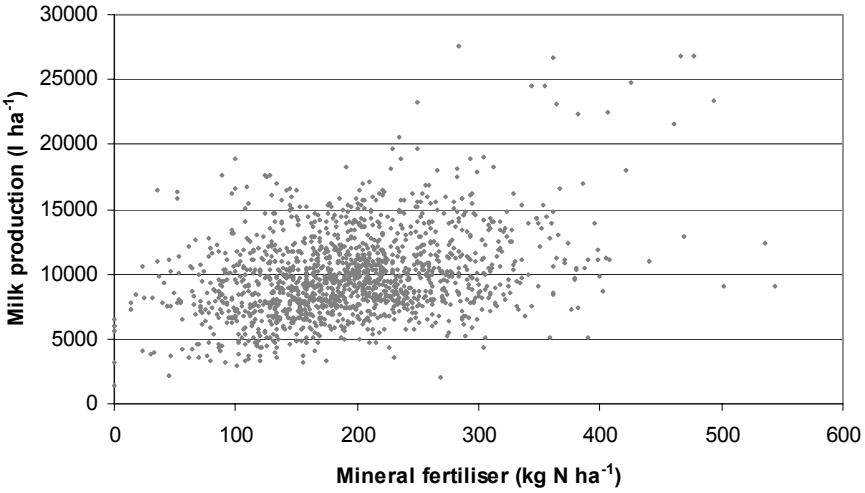

Figure 6. Milk production per ha in relation to mineral fertilizer use.

Table 8. Farm characteristics of farm groups categorized by farm-N-surplus.

		Group 1	Group 2	Group 3	Group 4
Farm surplus	kg N ha^{-1}	166	211	243	270
Farm efficiency	%	33	27	24	23
Fertil. grassland	kg mineral N ha^{-1}	119	169	207	239
Fertil. arable land	kg mineral N ha^{-1}	45	54	62	66
Farm area	ha	31.0	30.2	29.9	31.9
Share grassland	%	64	64	64	62
Milk production	l cow^{-1}	4 901	5 164	5 446	5 629
Milk production	l ha^{-1}	7 491	8 011	8 550	9 215
Stocking density	LU ha^{-1}	2.56	2.62	2.70	2.85
Soil surplus	kg N ha^{-1}	133	178	207	233
Soil efficiency	%	65	58	55	52
Concentrates	kg ha^{-1}	1 533	1 830	2 049	2 168
Concentrates	kg cow^{-1}	866	1 014	1 101	1 142
By-products	kg DM ha^{-1}	224	314	370	470
By-products	kg cow^{-1}	141	186	220	315

There is a significant difference in milk production per ha, except between group 1 and group 2. Also the concentrate use per cow and per ha is significantly different, except between group 3 and 4. Farm area and stocking density are not significantly different. Higher concentrate use resulted in a higher milk production per cow, but also per ha. The negative consequence is a higher surplus per ha, as shown above.

7.4.2 Soil nitrogen surplus

In the soil nitrogen balance, we assumed a manure N input of 93% of the manure N production. The other 7% is supposed to be lost by ammonia volatilization from the stables. Fodder crops export is a net export, i.e. export without trampling, refusing and harvesting (during silage making) losses.
The surplus on the soil balance decreased from 340 to 199 kg N ha^{-1} (Table 9). The lower nitrogen surplus is especially attributable to a lower mineral fertilizer input and a higher output with fodder crops, implying a better use of nutrients by the crops. Efficiency on soil level increased from 41% in 1999 to 57% in 2001.

Jarvis & Aarts (2000) state that a soil efficiency of 77% is technically possible. Figure 7 shows a strong relationship between soil N efficiency and soil N surplus. The figure also shows that an efficiency of 77% indeed is possible, corresponding with a N surplus of ca 80 kg N ha^{-1}. This corresponds with a surplus on the farm N balance of about 120 kg N ha^{-1}. Müller & Eiler (1995) showed in model calculations that N surpluses of 120 kg ha^{-1} could be realized without reducing stock.

To realize an efficiency of 77% with an output of 268 kg N ha^{-1}, the input has to decrease to a level of 348 kg N ha^{-1}. This is 119 kg N ha^{-1} less than in 2001 and nearly equals the mineral fertilizer input of 128 kg N ha^{-1}. If import of organic manure would be abandoned, a mineral fertilizer use of 38 kg N ha^{-1} would still be possible. When this mineral fertilizer would only be applied to grassland, 60 kg N ha^{-1} can be distributed over the growing season.

Table 9. Soil balances of specialized dairy farms from 1989 to 2001 (kg N ha^{-1}).

	'89	'91	'93	'95	'97	'99	'01
Input							
Fertilizer	238	209	194	173	179	164	128
Manure-import	25	25	25	25	25	24	29
Straw	2	2	2	2	1	1	2
Deposition	50	48	46	44	51	54	48
N fixation	2	1	2	1	2	2	6
Manure farm	258	268	264	274	261	251	254
Output							
Fodder crops	233	253	264	260	265	267	266
Arable crops	2	2	3	3	4	3	2
Total input	574	553	533	519	520	496	467
Total output	234	255	266	262	269	270	268
Surplus	**340**	**298**	**266**	**257**	**251**	**226**	**199**
St dev.	103	93	81	96	84	90	68
Efficiency (%)	***40.8***	***46.0***	***50.0***	***50.6***	***51.7***	***54.3***	***57.4***

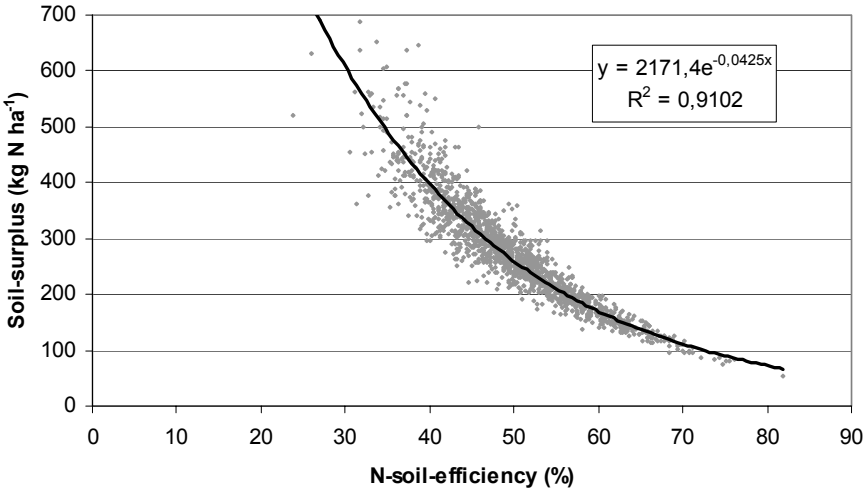

Figure 7. Relationship between soil N efficiency and soil N surplus.

7.4.3 Residual soil nitrate

As formulated in the Manure Action Plan, the amount of residual soil nitrate must not exceed 90 kg NO_3-N ha^{-1} in the layer 0-90 cm between 1 October and 15 November. In 2001 and 2002, about 25 000 parcels were sampled between 1 October and 15 November within the framework of the voluntary management agreements in the vulnerable zones 'water'. Besides fertilization, the differences in nitrate residue are highly influenced by soil (texture, carbon content) and crop characteristics. The influence of the crop on the nitrate residue in the soil profile is shown in Table 10. Depending on crop type, the percentage of nitrate residues below the limit value varied from 39% (flax) to 86% (Belgian endive) in 2001 and between 55% (peas and beans, potatoes) and 97% (Belgian endive) in 2002.

Table 10. Influence of the crop on the nitrate residue: percentage of the parcels with a nitrate residue below the limit of 90 kg NO_3-N ha^{-1} in 2001 and 2002 (Soil Service of Belgium).

Crop	Percentage of parcels with a nitrate residue ≤ 90 kg NO_3-N ha^{-1}	
	2001	2002
Belgian endive	85.7	97.4
Fallow	85.1	92.0
Orchards	77.7	86.0
Sugar beet	76.4	87.8
Grassland	67.8	79.7
Maize	63.2	67.3
Vegetables	62.8	75.3
Chicory	60.6	73.8
Potatoes	55.6	54.8
Cereals	54.8	69.1
Peas and beans	44.6	54.7
Flax	38.6	62.4

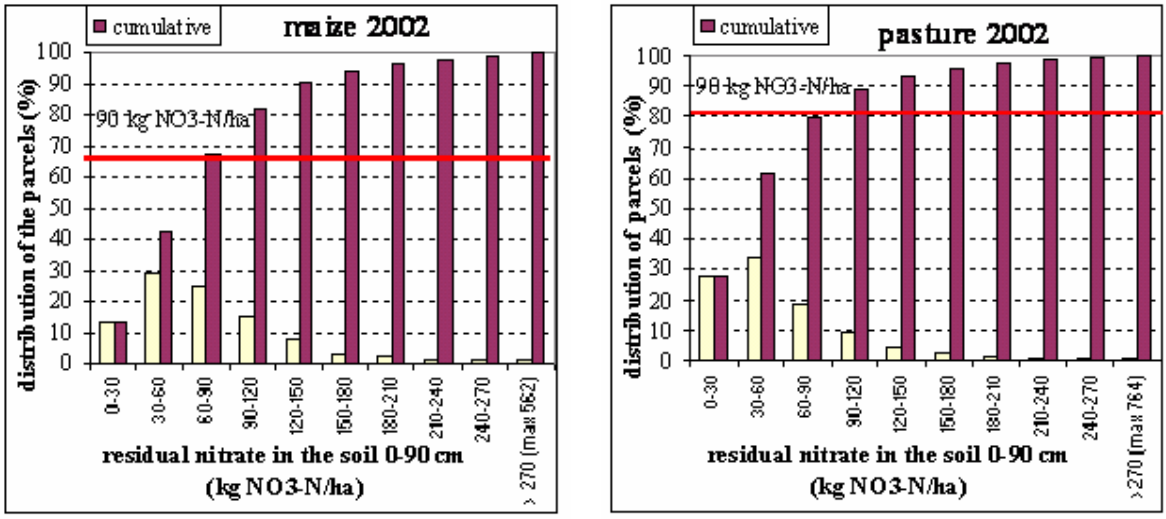

Figure 8. Distribution of the nitrate residue on the sampled soils for maize and grassland in 2002 (Soil Service of Belgium).

In dairy farming, grassland and maize are the major crops. Detailed information of these crops is given in Figure 8. The residual nitrate residue in the soil layer 0-90 cm is lower than 60 kg NO_3-N ha^{-1} (new proposal for sandy soils) in 43% of the analyses of maize land and in 61% of the analyses of pastures (70 kg NO_3-N ha^{-1} is the newly proposed threshold on sandy soils).

7.4.4 Milk urea of bulk tank milk

Urea content of bulk tank milk is a measure for protein utilization and nitrogen excretion in urine (Kauffman & St-Pierre, 2001). Especially in the grazing period there is a higher risk of high protein contents in dairy feed rations, resulting in higher urea contents in milk and higher N excretions. This implies also higher risks for nitrogen leaching losses. Considerable losses appear when urine burn spots occur. Risk on burn spots increases with urea levels above 300 mg l^{-1}.

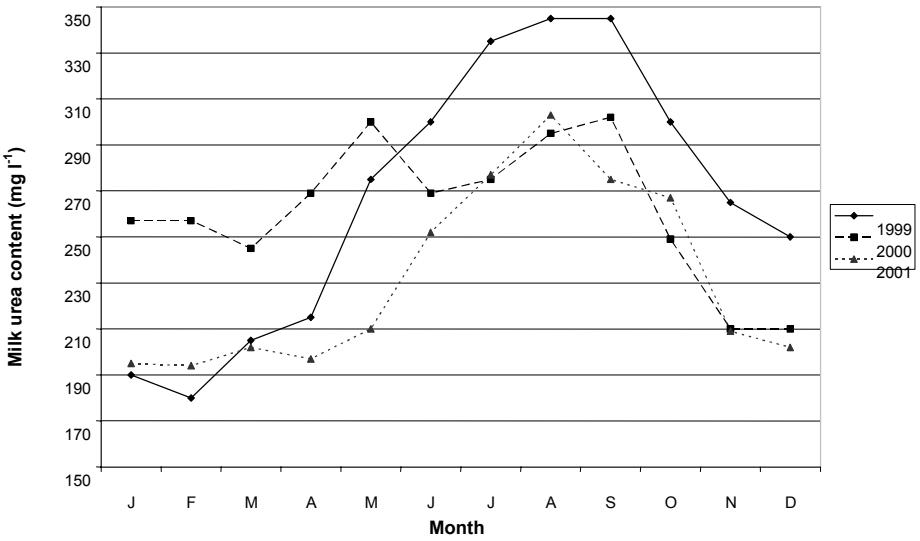

Figure 9. Urea content of bulk tank milk of an average Flemish dairy farm during the years 1999, 2000 and 2001.

The average milk urea content of bulk tank milk of about 5 000 farms (half the number of Flemish dairy farms) is given in Figure 9. The level of the urea content during the year 2001 is considerable lower than in 1999, especially during the grazing season.

7.4.5 N content of cattle slurry

The Soil Service of Belgium yearly analyses a large number of organic manure samples. The results are given in Figure 10 (nitrogen is corrected to a dry matter content of the slurry of 90 g per kg product). After a strong increase of the N content of cattle slurry (winter period) until 1995, a slight decline is observed. Less N in the manure could result in less ammonia losses from stables.

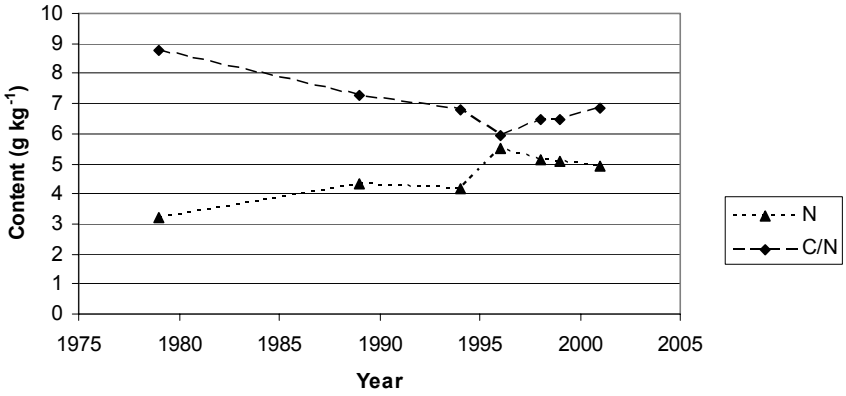

Figure 10. Nitrogen content and C/N ratio of cattle slurry (winter period) in the period 1978-2001.

7.4.6 Nitrate in surface water

The Flemish Environment Agency monitors nitrate concentrations in surface water. The agency made a selection of measuring points which are relevant for agricultural activity (i.e. excluding influences of industry and households as much as possible). Selection was done in co-operation with agricultural organizations.

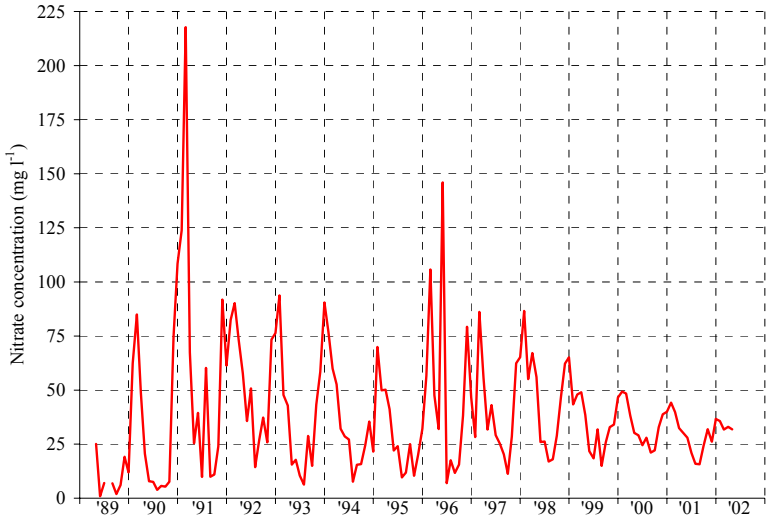

Figure 11. Monthly average nitrate concentration in all available monitoring points in the period 1989-2001.

Before 2002, only less than 100 points relevant for agricultural activity were monitored. In 2002 266 points were selected and in 2003 more than 800 points are monitored. Nitrate concentration is in principle measured monthly, but more frequently in rainy periods. Nitrate peaks are observed during winter periods (November, December and January).

Until 1998-1999, the values of the winter peaks were above 50 mg nitrate l^{-1}. From the winter 1998-1999 onwards, there is a tendency that the peaks of the nitrate values become lower than the limit of 50 mg nitrate l^{-1} (Figure 11). The proportion of measuring points in which the nitrate level is above the limit of 50 mg l^{-1} was 41.9, 37.3 and 24.7% respectively in January 2000, 2001 and 2002. This seems logic because of a decreasing nitrogen pressure (decreasing animal number and mineral fertilizer use) in agricultural areas. However, the extreme wet winters of the last years also influence these results: a strong dilution resulted in low surface water nitrate contents. Under normal winter conditions the proportion of measuring points below the nitrate limit of 50 mg l^{-1} will probably be lower (Stedula, 2003).

7.4.7 Arial ammonia concentration and N deposition

Ammonia concentrations in air and rainwater are only recently being monitored (from 2002 onwards) at 10 locations scattered over Flanders. Before 2002, rainwater concentrations were measured at just 3 locations. The data obtained from monitoring are used as inputs in computer models to calculate N depositions.

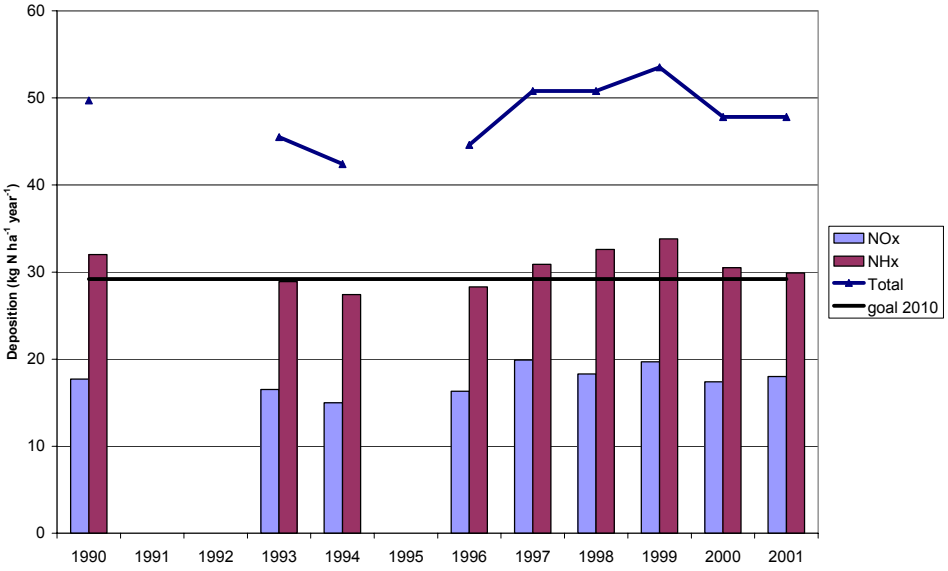

Figure 12. Evolution of the average nitrogen deposition in Flanders (Van Gijseghem and Overloop, 2002).

N deposition has not really declined since 1990 (Figure 12). This is despite the measures that were taken at farms (low emission techniques). Since 1990, N emission is reduced by 12% (Van Steertegem, 2002; estimated on the basis of statistics on animal numbers combined with emission factors per animal type, stable type and type of manure application in the field). This obviously did not result in a reduction of the N deposition. Emissions of neighbouring countries decreased less and this could be a reason for a smaller diminishing of the N deposition. Also climatic conditions could influence deposition (more deposition in wet years). From 2000 onwards, there is a decrease in N deposition, due to extra obligations regarding low-emission application.
In 2001, 17.5% of the total Flemish nitrogen deposition originates from agriculture (Van Gijseghem and Overloop, 2002).

7.5 Farm-economic consequences of nutrient policies for dairy farming and other farming sectors

As noted in Section 7.4.1, it is possible for farms to realize low N surpluses. Little is known about the consequences for labor income. We calculated the relationship between the N surplus per ha and labor income per ha (Figure 13).

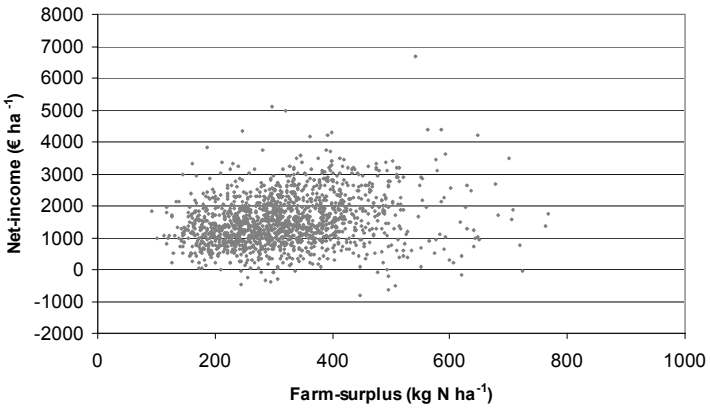

Figure 13. Net income of the farmer in relation to the farm N surplus.

We find no clear relation, hence decreasing the N surplus does not necessarily have a negative effect on labor income.

7.6 The search for 'sustainable' dairy farming systems

As we have seen before, concentrate use in Flanders today is at a low level. Further improvement for a better efficiency at cow level will be difficult to realize. Conversely, further improvement at soil-crop level is still possible. The soil efficiency of the specialized dairy farms was on average 57%. The best farms reached an efficiency of nearly 80%. There are still possibilities to increase the average efficiency:

- Reducing the length of the grazing period and silage cuts will affect residual soil nitrate levels. Reducing the length of the grazing season, i.e. housing the cows at an earlier date, is an effective way to reduce the accumulation of mineral nitrogen because excretions of urine in September and October have a major effect on the nitrate residue and losses.
- N uptake by maize after August is not significant and N released by mineralization after August will increase the nitrate residue. Ryegrass can function as a catch crop.
- It is better to apply fertilizer more frequently after the first cut at lower rates, thus realizing a more even distribution over the growing season. Figure 14 shows the influence of high fertilization rates on milk urea content of bulk tank milk. High fertilizer rates resulted in high protein contents of grass and the total diet. A more even distribution of mineral and organic fertilizer will diminish milk urea contents and subsequent nitrogen losses by high N urine excretions. A combination of white clover-grassland (smaller fluctuations in the grass protein content) with a good supplementary feeding strategy in late summer could also offer perspectives from this point of view (Verbruggen & Nevens, 2003).

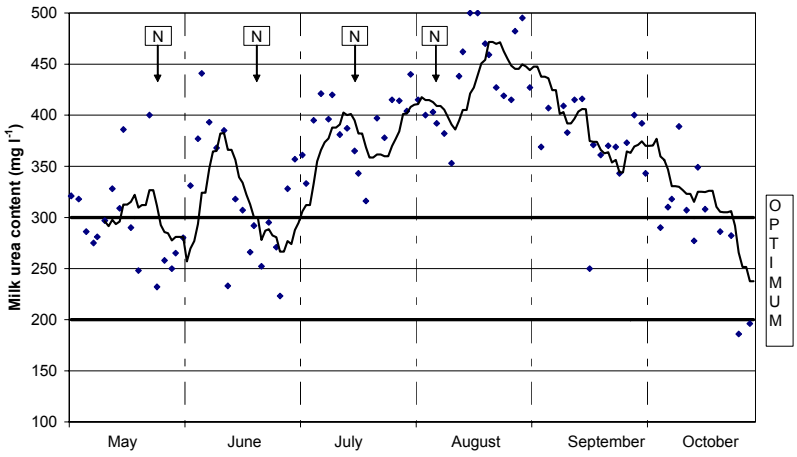

Figure 14. Relationship between mineral fertilization on grassland and milk urea content of bulk tank milk.

- Optimal use of organic manure to save mineral fertilizer can reduce further losses. A chemical analysis gives information about the composition of the manure and is the basis for the calculation of the fertilizing value of the manure on a parcel.
- Optimal yield and N uptake can only be achieved if soil fertility is optimal, also based on a topsoil analysis (texture, pH, carbon content, P, K, Ca, Mg and Na).

References

Alt, 2000a.
Code of Good Agricultural Practices-Nutrients in arable crops. Administration Agriculture and Horticulture, Ministry of the Flemish Community, Brussels, 76 pp.

Alt, 2000b.
Code of Good Agricultural Practices-Nutrients in field grown vegetables and fruit growing. Administration Agriculture and Horticulture, Ministry of the Flemish Community, Brussels, 93 pp.

Alt, 2000c.
Code of Good Agricultural Practices-Nutrients in grassland and fodder crops. Administration Agriculture and Horticulture, Ministry of the Flemish Community, Brussels, 76 pp.

Aminal, 1997.
MINA-plan 2: Flemish environmental policy plan 1997-2001 (in Dutch). Administration Environment, Nature, Land and Water Management, Brussels, Belgium, 256 pp.

Anonymous, 1991a.
Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal of the European Communities dd. 31/12/1991, L375, 1-8.

Anonymous, 1991b.
Decree concerning the protection of the environment against pollution by fertilisers (in Dutch and French). Belgian Law Gazette, 28.02.1991, N91-535, 3829-3838 (with amendments).

Anonymous, 2000a.
Decision of the Flemish government of 17 July 2000 concerning the excretion balance in order to execute article 3, §1, 4°, 5, §2, 1°, 6, §2 and 20bis, §2, §3 and §4 of the decree of 23 January 1991 concerning the protection of the environment against pollution by fertilisers (in Dutch and French). Belgian Law Gazette, 29.07.2000, N2000-1781, 26243-26256.

Anonymous, 2000b.
Decision of the Flemish government of 30 November 2000 to set a remuneration standard in order to execute article 15, 15bis, 15ter, 15sexies, §§1 and 3 and 15septies of the decree of 23 January 1991 concerning the protection of the environment against pollution by fertilisers and in order to change the decision of the Flemish government of 26 May 2000 concerning the execution of certain article of the same decree (in Dutch and French). Belgian Law Gazette, 22.11.2000, N2000-2957, 38813-38824.

De Batselier, N., 1993.
Manure Action Plan (in Dutch). Flemish Manure Bank, Brussels, 29 September 1993, 108 pp.

Heyman, J. & Smout, L., 1999.
Environmental law book-Vlarem II, 5th edition (in Dutch). Kluwer Jurisprudence, Antwerp, 960 pp.

Jarvis, S.C. and Aarts, H.F.M., 2000.
Nutrient management from a farming systems perspective. In: Søegaard, K., Ohlsson, C., Sehested, J., Hutchings, N.J. and Kristensen, T., Grassland farming: Balancing environmental and economic demands, Proceedings of the 18th General Meeting of the European Grassland Federation Aalborg, Denmark, 2000, pp. 363-373.

Kauffman A.J. & St-Pierre, N.R., 2001.
The relationship of milk urea nitrogen to urine nitrogen excretion in Holstein and Jersey cows. Journal of Dairy Science 84: 2284-2294.

Kelchtermans, T., 1989.
MINA plan 2000. Analysis and proposals for a renewed Flemish environmental and nature policy (in Dutch). Ministry of the Flemish Community, Brussels, 347 pp.

Lauwers, L. & Overloop, S., 2002.
Milieu- en Natuurrapport Vlaanderen, MIRA Achtergronddocument 2002, 1.4. Landbouw, Vlaamse Milieumaatschappij, www.milieurapport.be, 129 pp.

Müller, J. & Eiler, T., 1995.
Betriebsbedingte Nährstoffbilanzen am Beispiel des Futterbaubetriebes. In: Bundesarbeitskreis Düngung (EDS): Nährstoffbilanz im Blickfeld von Landwirtschaft und Umwelt. Frankfurt/M., pp. 44-51.

NIS.
15 May agricultural statistics from 1977-2001, National Institute of Statistics, Ministry of Economic Affairs, Brussels, http://www.statbel.fgov.be

Soil Service of Belgium, Catholic University of Leuven & Ghent University, 2002.
N-(eco)^2: determination of the amount of mineral nitrogen in the soil as a policy instrument. Final report, part 4 (in Dutch). Flemish Land Agency, Brussels, 270 pp.

Stedula (Steunpunt Duurzame Landbouw), 2003.
Annual report of the Flemish Policy Research Centre for Sustainable Agriculture. Stedula, Gontrode, Belgium, 272 pp. (in Dutch).

Van Avermaet, P. & Brouwers, J., 2002.
MIRA (2002) Milieu- en natuurrapport Vlaanderen, Achtergronddocument 2002, 2.13 Verzuring. Vlaamse Milieumaatschappij, www.milieurapport.be, 53 pp.

Van Gijseghem, D. & Overloop, S., 2002.
MIRA (2002) Milieu- en natuurrapport Vlaanderen, Achtergronddocument 2002, 2.12 Vermesting. Vlaamse Milieumaatschappij, www.milieurapport.be, 75 pp.

Van Hecke, E. & Schrooten, L., 2003.
Land- en tuinbouw in Vlaanderen. Feiten en cijfers editie 2003. VILT, Brussel, www.vilt.be, 51 pp.

Van Steertegem, M., 2002.
Milieu- en natuurrapport Vlaanderen MIRA-T 2002, Vlaamse milieumaatschappij en Garant, Antwerpen, 388 pp.

Verbruggen, I. & Nevens, F., 2003.
Relationship between nitrogen fertilisation on grassland and milk urea content of grazing dairy cows. In: Kirilov., A. Todorov., N. and Katerov., I., Optimal Forage Systems for Animal Production and the Environment, Proceedings of the 12th European Grassland Federation, Pleven, Bulgaria, 26-28 May 2003, pp. 533-536.

8. The Netherlands

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8.1 Introduction

In the European Union, objectives have been formulated regarding the state of the environment. EU Member States have rendered EU policies and objectives in national policies and national sets of objectives. The objectives are to be attained by the introduction of policy instruments in agriculture. Employed policy instruments differ between Member States. The following questions can be posed regarding relationships between EU policy objectives, Member States' policy objectives and employed policy instruments:

- which procedures have been followed by Member States in translating EU policy objectives into national policy objectives?
- which policy instruments have been implemented by Member States in agriculture to attain the EU and/or national policy objectives?
- what is the efficacy of policy instruments implemented by Member States?

This chapter addresses these questions for The Netherlands, focussing on the impact of nutrient policies on nitrogen (N) and phosphorus (P) emissions from dairy farming systems.
The Dutch dairy sector is characterised in Section 8.2. Section 8.3 describes the policy objectives and policy instruments. Section 8.4 reports on environmental monitoring activities and on trends emerging from these activities. Section 8.5 summarises farm-economic consequences of nutrient policies for dairy farms. A summary of research and extension projects, contributing to the design and dissemination of more sustainable dairy farming systems, is given in Section 8.6. Section 8.7 discusses options for improvement of the European and Dutch nutrient policy. Conclusions are formulated in the final Section 8.8.

8.2 Dairy farming in The Netherlands

8.2.1 General characterisation

About 70% of the Dutch land area is used by agriculture (2.0 million ha). This area gradually decreases over time due to the conversion of agricultural land to other land uses such as infrastructure, housing and nature reserves. Sand, clay and peat soils cover about 50, 40 and 10% of the land area, respectively. At present, about half of the total agricultural area is under grassland, 10% under maize land, 32% under arable land, and 6% is used for horticulture (CBS/LEI, 2002).
The contribution of agriculture to the total national income has declined from 3.9% in 1990 to 2.8% in 1997. Around 75% of agricultural production is exported, 80% of which to countries within the European Union.
The number of farms annually declines by 2-3%. Remaining farms expand their size and scale. The total number of farms in 2000 was 97 500 (Table 1). About 90% of farms comprises specialised farms. The dominant farm type is the grazing livestock farm, accounting for 48% of the total number of farms. Arable and horticultural farms each comprise 14% of the total number of farms.

Pig and poultry farms, often with few land holdings (on average 7.5 ha), are concentrated on sand soils in the southern and eastern provinces, and arable farms on clay soils in the North and West. Dairy farming is relatively evenly distributed over the country. The clustering of pig and poultry farming in the South and East and that of arable cropping in the North and West results in an uneven distribution of manure production over the country. Consequently, large quantities of manure are transported from the South and East to the North and West of the country, to be applied in the arable sector.

The number of farms with dairy cows in 1997 was about 34 600. The large majority of these farms are strongly specialised (62%) or specialised (25%) dairy farms[1] (Beldman & Prins, 1999), accounting for 93% of dairy cows held in The Netherlands. More than half of these dairy farms is located on sand soils, one third on clay soils and about 10% on peat soils (Figure 1). Dairy farms are evenly distributed over intensity classes – in terms of milk production per ha – at national scale, but not at regional scale (Figure 1). Dairy farms on sand soils, i.e. in the South and East of the country, are generally more intensive than farms on clay or peat soils in the North and West.

Main farm and farm management characteristics are given in Table 2. The size of an average Dutch dairy farm is about 31 ha, but the size of farms on clay and peat soils is slightly larger than that of farms on sand soils. The main inputs are concentrates and mineral fertiliser. Milk production per ha feed crops is approximately 12.3 tons in the clay and sand regions; production in the peat areas is about 2 tons lower. The dominant land use type on all dairy farms is grassland. Often, a part of the land is used for silage maize cultivation, particularly on sand soils. A summary of strong and weak points of the Dutch dairy sector is given in Table 3.

Table 1. Number and type of farms in 2000 (CBS/LEI, 2002).

Farm type	Number of farms	Share of farm type (%)
Grazing livestock	47 075	48
Arable	13 749	14
Horticulture	13 281	14
Pigs and poultry	8 382	9
Fruits/trees	5 146	5
Mixed crops-livestock	4 646	5
Mixed livestock	3 109	3
Mixed cropping	2 095	2
Total	97 483	100

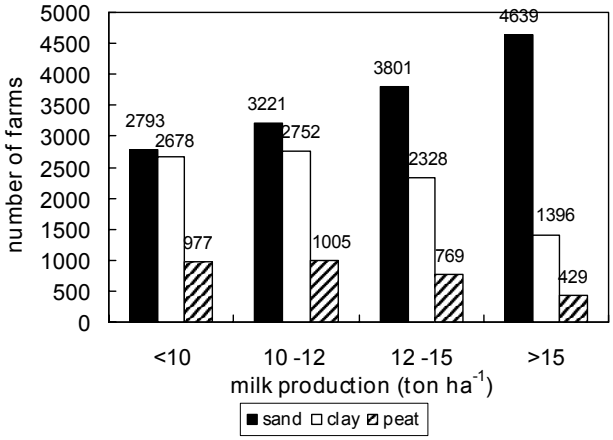

Figure 1. Distribution of (strongly) specialised dairy farms over soil type and milk production per ha in 1997. (Source: Reijneveld et al., 2000)

1 A dairy farm is classified as *strongly specialised* if more than 90% of the farm's activities refer to dairy farming, and as *specialised* if 66-90% refer to dairy farming.

Table 2. Main characteristics of (strongly) specialised dairy farms. (Source: Beldman & Prins, 1999).

	Clay	Peat	Sand	Total
Grassland (ha)	29.52	33.10	21.76	25.88
Maize (ha)	3.42	1.78	5.63	4.55
Total feed crops (ha)	32.94	34.88	27.39	30.43
Dairy cows (number)	55.04	53.52	48.01	50.91
FPCM[1] per cow (kg)	7728	7424	7636	7625
Milk production per ha feed crops (kg)	12158	10672	12778	12240
Young stock per 10 dairy cows	8.94	8.08	9.48	9.08
Concentrates per dairy cow (kg)	2186	2318	2234	2235
Mineral N fertiliser (kg ha^{-1} grassland)	300	262	285	285

[1] *FPCM = fat and protein corrected milk, about 6% above uncorrected milk production.*

Table 3. Strong and weak points of Dutch dairy farming systems.

	Strong	Weak
Socio-economic	- positive image - favourable infrastructural conditions - farmers have well-developed management skills - contract labour is amply available	- high level of skills and knowledge required - capital-intensive - partly dependent on EU price support - detailed book-keeping required - high land and quota prices
Agro-ecological	- high and efficient milk production per unit of land - favourable climatological and physical conditions	- high N emissions per unit of land - P accumulation in soils - decline of agricultural biodiversity - artificially lowered groundwater tables in peaty areas cause break-down of organic matter resulting in land subsidence - animal welfare increasingly at risk

8.2.2 Nutrient cycling in dairy farming systems

In dairy farming systems, nutrients are transferred in a cyclic way from the soil compartment via crops, animals and manure back to the soil again (Figure 2). In each step of the cycle, losses may occur of which some are inevitable. Losses and exports, in milk and sold cattle, are compensated for by inputs such as manufactured fertilisers, imported feedstuffs and biological N fixation.

The main terms in agronomic nutrient balances are fertilisers, feed imports and agricultural produce exports. The difference between inputs and outputs is the balance surplus, corresponding with the amount of nutrient that is either lost to the environment or temporarily stored in soil reserves. Nitrogen balances of average specialised dairy farms on sand, clay and peat soils in 1995 are indicated in Table 4. N surpluses are 375-405 kg ha^{-1}. Overall N utilisation (output/input) is 16%. P surpluses are about 30-40 kg ha^{-1}, and P utilisation is 27-33% (Aarts *et al.*, 1999; 1988).

The magnitudes of the main N flows of an average dairy farm on sand soil in 1995 are indicated in Figure 2. In practice, there is a large variation in nutrient flows and surpluses between dairy farms. The variation is attributable to differences in (1) intensity in terms of milk production per ha, (2) soil conditions, (3) types of crops, animals, housing, etc., (4) the extent to which a farm is self-sufficient in terms of feed production, and (5) management skills of the farmer.

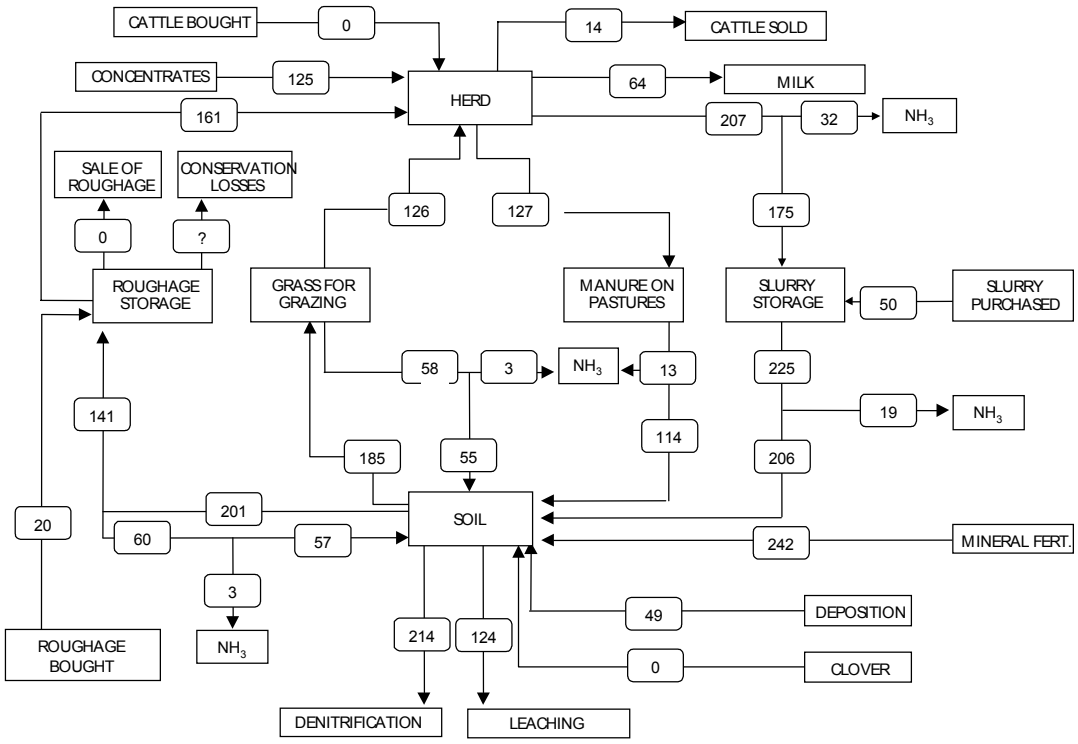

Figure 2. *Nitrogen cycle of an average dairy farm on sand soil in 1995. Data in kg N ha^{-1} yr^{-1}. (Source: Aarts et al., 1999).*

Table 4. *Agronomic nitrogen balances (kg ha^{-1} yr^{-1}) realised at average specialised dairy farms on sand, clay and peat soils in 1995 (Sources: Aarts, 2003; Aarts et al., 1999).*

	Sand	Clay	Peat
Inputs			
Feeds	145	139	171
Mineral fertilisers	242	274	248
Organic fertilisers	50	0	9
Deposition	48	39	42
Others	0	0	0
Total inputs	485	452	470
Outputs			
Milk	64	62	61
Cattle	14	12	11
Total outputs	78	74	72
Surplus (input – output)	407	378	398
Efficiency (output/input)	16%	16%	15%

8.3 Nutrient policies

8.3.1 Backgrounds

Pollution of Europe's waters led to increased efforts to address water pollution from the mid-1970s onwards. A 'first wave' of EU water legislation culminated in 1980 in setting binding quality targets for drinking water (1980 Drinking Water Directive). At that time, control of nutrient emissions was not the main goal; only quality standards for nitrates were set to ensure the use of selected surface waters for drinking water abstraction. A 'second wave' came in 1991, *inter alia,* with the adoption of the Urban Wastewater Directive and the Nitrates Directive. The objectives of the Nitrates Directive are to reduce water pollution caused or induced by nitrates from agriculture and to prevent further pollution. To meet these objectives, Member States have to identify surface waters and groundwaters affected by nitrate pollution, and waters which could be affected. Within such vulnerable zones, mandatory measures ('action programmes') have to be taken, encompassing restrictions to application of manure, minimum manure storage capacities and balanced N fertilisation of crops. Member States have the choice to either designate individual vulnerable zones or to apply the more stringent provisions of the Directive over all their territory. The latter option has been selected by The Netherlands.
The EU thoroughly restructured its water policy by adoption of the Water Framework Directive in 2000 (CEC, 2000). This directive aims at protection of all surface waters and groundwater by means of achieving 'good status' of these waters by the year 2015. A range of parameters defines 'good status', in which nutrients play an important role. Compared to earlier EU legislation, this concerns nitrogen *and* phosphorus. The Water Framework Directive will complement existing EU water legislation on nutrient reduction. Hence, the Nitrates Directive will remain one of the pillars of EU water policy, whilst at the same time being integrated into the wider-encompassing river basin management laid down in the Water Framework Directive (Blöch, 2001). The implications of the Water Framework Directive are yet unclear. A tentative conclusion for The Netherlands is that the current environmental quality goals (see below) need not to be tightened, but that the Directive stresses, more than in the past, the importance of ecological aspects of water management (Latour, 2001).

8.3.2 Policy objectives

In Dutch environmental policies, two types of policy objectives have been formulated, i.e., objectives specifying (1) the pursued environmental quality in terms of concentrations at which harmful effects disappear (environmental quality goals), and (2) maximum levels of environmental loads and/or emissions to realise the pursued environmental quality (emission-reduction goals).
Relevant environmental quality goals for groundwater and surface waters are summarised in Table 5. Two levels are distinguished. The so-called Maximum Permissible Risk (MPR) values indicate the minimum environmental quality and should not be exceeded in any case. Eventually, environmental quality should be further improved by attainment of so-called Target Values. All values in Table 5 are derived from national policy documents. Only the values for nitrate are also derived from European policy documents, notably the Nitrates Directive and the Drinking Water Directive.

Table 5. Nutrient-related general quality goals for groundwater and surface water (mg l[1]).

Parameter	Groundwater		Fresh surface water[2]	
	MPR value	Target Value	MPR value	Target Value
Total-N	-	-	2.2	1
Total-P	-	3 / 0.4[1]	0.15	0.05
NO_3	50	25[3]	-	-
NH_4-N	-	10 / 2[1]	-	-

[1] *The high value applies to clay and peat soils, the low value to sand soils.*
[2] *Average maximum values in summer in eutrophication-sensitive stagnant surface waters.*
[3] *Only applies to deeper groundwater in groundwater infiltrating zones and groundwater protection zones.*

Emission reduction goals for ammonia have been agreed by European member states in the so-called National Emission Ceilings (NEC) Directive. Within this framework, The Netherlands has committed itself to reduce NH_3 emission in 2010 to 128 kton per year, constituting a 22% reduction of the emission in 1999. In the Fourth National Environmental Policy Plan (VROM, 2001), 'national' NH_3 emission-reduction goals for the short and long term are formulated. In the short term (2010), total NH_3 emission from the agricultural sector in The Netherlands should be reduced by 50% to 86 kton at maximum (Table 6). In the longer term (2030), NH_3 emission should be further reduced to 30-55 kton. The 'national' emission-reduction goals for ammonia are hence stricter than the goal agreed in the NEC Directive, allowing for uncertainties in emissions and emission-reducing effects of measures.
The Fourth National Environmental Policy Plan also specifies N deposition goals. The goal for the year 2010 is to reduce the mean maximum N load entering soils to 1550 mol N ha^{-1} yr^{-1}, corresponding with 22 kg N ha^{-1} yr^{-1} (Table 6). This would result in a sufficient reduction of the atmospheric N-load in 30% of the Dutch nature reserve area. The goal for the longer term (2030) is to further reduce the atmospheric N load to 900-550 mol N ha^{-1} yr^{-1} (13-8 kg N ha^{-1} yr^{-1}).
To reduce nutrient emissions from agriculture to groundwater and surface waters, goals have been formulated in terms of maximum farm gate nutrient surpluses. These surpluses are calculated according to the Dutch MINeral Accounting System (MINAS; Section 8.3.3). The maximum N surplus is differentiated according to soil type (dry sand soils/other soils) and land use (grassland/arable land) (Table 6). The maximum P surplus is differentiated according to land use only. The maximum P surplus selected for the short term still allows the net accumulation of phosphorus in agricultural soils. To abate this, the Fourth National Environmental Policy Plan specifies that the P surplus should in the longer term be reduced to 0.5 kg ha^{-1} (=1 kg P_2O_5 ha^{-1}).
Emission-reduction goals for surface waters have been agreed within the framework of the OSPAR Convention by countries in the Rhine river basin and/or bordering the North Sea. The goal is to reduce N and P emission from agriculture to surface waters in 1995 by 50%, compared to 1985 (V&W, 1989).

Table 6. Emission reduction goals for agriculture.

Parameter	Goal
N deposition	< 22 kg ha^{-1} in 2010; < 13-8 kg ha^{-1} in 2030
NH_3 emission	< 86*10^6 kg in 2010; < 30-55*10^6 kg in 2030
N surplus[1] grassland	< 140 kg ha^{-1} on dry sand soils from 2004 onwards < 180 kg ha^{-1} on all other soils from 2003 onwards
N surplus[1] arable land	< 60 kg ha^{-1} on dry sand soils from 2004 onwards < 100 kg ha^{-1} on all other soils from 2003 onwards
P surplus[1] grassland	< 8.7 kg ha^{-1} from 2003 onwards
P surplus[1] arable land	< 10.9 kg ha^{-1} from 2003 onwards
P surplus grassland and arable land	< 0.5 kg ha^{-1} in 2030
N and P emission to surface waters	50% reduction in 1995 (reference year: 1985)

[1] *This surplus is not equal to the farm gate agronomic surplus, but has been calculated according to the Dutch MINeral Accounting System (see Section 8.3.3).*

8.3.3 Policy instruments

Policy instruments to reduce nutrient emissions from agriculture were first introduced in 1984. Initially, the policy instruments were input-oriented and means-oriented, e.g. specifying maximum amounts, periods and methods of manure application. Part of these 'early' policy instruments has by now been abolished, part is still in effect. The latter category includes a system to control the volume of national manure production (based on tradeable manure production rights, pig production rights and poultry production rights, allocated to individual farms) and requirements to manure storages and periods and methods of manure application.

As opposed to the 'early' policy instruments, the core policy instruments for the near future can be characterised as being balance-oriented and goal-oriented:

(1) The MINeral Accounting System (MINAS) is the core policy instrument to restrict nutrient emissions from farms and is based on a farm gate N and P balance. If the balance surplus exceeds a threshold value, the farmer has to pay a levy proportional to the excess.

(2) The manure contract system is a policy instrument that balances total national manure production with manure application opportunities. Such a balance is essential to avoid a strong increase of the costs of manure disposal, and hence to avoid a collapse of the MINAS system under fraud pressure. The core of the manure contract system is that it couples manure production at farm scale with application opportunities within that farm or at other farms. Provided the system proves to be effective in balancing manure production and manure application opportunities at national scale, the existing volume-control system of production rights will be abolished by the year 2005.

MINAS

MINAS obliges each agricultural holding to monitor N and P flows entering the farm in animals, feeds, mineral fertilisers and animal manures and leaving the farm in animals and/or their products, crops and animal manures. MINAS was first introduced in 1998 for livestock farms with more than 2.5 livestock units per hectare only, but applies to all farm holdings since 2002. Input and output terms accounted for in MINAS, relative to an agronomic balance, are indicated in Table 7. The difference between the agronomic N surplus and the farm gate surplus calculated according to the MINAS system depends on farm characteristics, but is on average 90 kg ha^{-1} yr^{-1} in dairy farming systems (RIVM 2002a; Hoogeveen *et al.*, 2000; 2002). This difference is mainly caused by the fact that MINAS excludes the input term deposition and includes an extra output term denoted 'unavoidable' gaseous N loss from stables and manure storage facilities. If the surpluses calculated according to the MINAS system exceed levy-free surpluses as set by the government, the farmer has to pay a levy proportional to the excess. Since the introduction of MINAS, these levy-free surpluses have gradually been tightened. The levy-free N surplus is differentiated according to soil type and land use. For dry sand soils from 2004 onwards, it amounts to 140 kg N ha^{-1} grassland and 60 kg N ha^{-1} arable land (Table 6). For grassland and arable land on all other soil types, the levy-free N surpluses are 180 and 100 kg N ha^{-1}, respectively, from 2003 onwards. The levy-free P surplus is set to 8.7 kg ha^{-1} grassland and 10.9 kg ha^{-1} arable land, irrespective of soil type (Table 6). The levies per unit surplus are € 21.00 for P and € 2.30 for N and are intended to be prohibitive.

With the introduction of MINAS in Dutch agriculture, the government intends to attain objectives of the EU Nitrates Directive at farm scale, notably the reduction of NO_3 concentrations in the upper groundwater under farms to values below 50 mg per liter. The efficacy of MINAS in achieving this objective is evaluated every two years (e.g. RIVM, 2002a). Future evaluations may prove further tightening of levy-free surpluses necessary.

Table 7. Input and output terms accounted for in MINAS, relative to an agronomic balance.

		Agronomic balance		MINAS balance	
		N	P	N	P
(1) Inputs	organic manure	X	X	X	X
	mineral fertilizer	X	X	X	X[4]
	seeds, plant material	X	X	X	X
	feeds	X	X	X	X
	animals	X	X	X	X
	biological fixation	X		X[1]	
	deposition	X	X		
	net mineralization	X	X		
(2) Outputs	organic manure	X	X	X	X
	animal products	X	X	X	X
	crop produce	X	X	X[2]	X[2]
(3) Losses	NH_3 stables and manure storage			X[3]	
Surplus		(1)–(2)	(1)–(2)	(1)–(2)–(3)	(1)–(2)

[1] *Excluding N fixation by clover in grass-clover mixtures. Default values are used for leguminous arable and horticultural crops.*

[2] *Default values are used for arable crops intended for human consumption (165 kg N and 28 kg P per ha). For fodder crops, default nutrient contents are used which, after multiplication with actual quantities sold, yield total nutrients leaving the farm.*

[3] *'Unavoidable' gaseous N loss from stables and manure storage facilities. The value of this term is a function of animal type and animal number.*

[4] *Currently not included. The incorporation of this input term into the MINAS system is certain, but when and how will be decided in 2004.*

Manure contract system

The Nitrates Directive specifies the maximum amount of animal manure that can be applied to farmland each year. This amount should not exceed 170 kg N per ha, including N excreted by grazing animals. A higher manure input can be allowed, on condition that realisation of the objectives of the Nitrates Directive is ensured. Based on a high N uptake of grass, the Dutch government has informed the European Commission that it allows a manure input of 250 kg per ha grassland, as motivated in Willems *et al.* (2000). The justification of the Dutch derogation for grassland is currently evaluated by the European Commission.

In 1998 the European Commission declared The Netherlands to be in default concerning the implementation of the Nitrates Directive. One of the Commission's criticisms was that the Dutch legislation allows a considerable greater input of manure than dictated by the Nitrates Directive. In response to the infringement procedure started by the European Commission against The Netherlands, the so-called manure contract system was introduced in January 2002. In this system, manure production at farms is coupled with application opportunities within the farm or at other farms. Manure production at farms is calculated in a standardised way by multiplication of default values for annual N excretion per animal type with the number of animals present at the farm, yielding the 'standardised manure production' (see below). Farms producing manure in excess of 170 kg N per ha arable land plus 250 kg per ha grassland are obliged to conclude contracts with 'consumers', e.g. arable farmers or processing industries. Actual transfer of the excess to 'consumers' is only obliged if either the MINAS N surplus or the MINAS P surplus exceeds the levy-free surplus. Livestock farms realising MINAS surpluses below levy-free surpluses are allowed to apply manure in excess of the stipulated rates. Hence, such livestock farms conclude 'manure contracts on paper' with

'consumers' but are not obliged to actually transfer the excess manure, thus saving manure disposal costs[1]. Note that the manure contract system thus regulates the *production* of manure, rather than its *application*.
To calculate standardised manure production at farms, default N excretion values per animal type are used. These are derived from anticipated 2003 excretion data (Sebek *et al.*, in prep; Tamminga *et al.*, 2000) minus gaseous N losses occurring in the stable and during manure storage (Oenema *et al.*, 2000) (Table 8). To avoid that all farms realising a below-average N excretion unnecessarily have to conclude manure contracts, the resulting values per animal category are reduced by 5%, in a last step.
The consequence of the Dutch translation of Nitrates Directive regulations is that standardised manure production *at national scale* does not exceed 170 kg N per ha arable land plus 250 kg per ha grassland, but this is not necessarily so at *farm scale*. Strictly speaking, the Dutch interpretation is not in accordance with the 170/250-regulation in the Nitrates Directive, which is formulated at (individual) farm scale. In The Netherlands, MINAS is the policy instrument that regulates the application of manure at farm scale, i.e. via the phosphorus loss standard. Based on the average annual P uptake of crops and the average N/P ratio in manure, it can be calculated that the average dairy farm will not apply more than approximately 250 kg N per ha in animal manure. However, individual farms with a high P uptake by crops and/or a high N/P ratio in manure may well exceed this limit.

Table 8. Calculation of default N excretion values in the manure contract system for dairy cattle categories.

	Anticipated N excretion in 2003 (kg yr^{-1}) (Tamminga *et al.*, 2000; Sebek *et al.*, in prep.)	Anticipated gaseous N loss (% of N-excretion) (Oenema *et al.*, 2000)	Reduction factor (% of N excretion)	N excretion to calculate standardised manure production at farms (kg yr^{-1})
Dairy cow	125	12.4	5	104.1
Yearling	82.9	6.3	5	73.8
Calf	40.5	6.2	5	36.1

8.4 Environmental quality indicators: monitoring programmes and trends

8.4.1 Nutrient surpluses at farm scale

8.4.1.1 Monitoring programmes

The Agricultural Economics Institute (LEI) keeps detailed records of economic, environmental and social data of about 1500 farms representing the main farm types in The Netherlands: the Farm Accountancy Data Network (FADN; Van Dijk *et al.*, 1999). Within the FADN, records of approximately 365 specialised dairy farms are monitored. Based on FADN-data, trends in nutrient surpluses can be calculated.

8.4.1.2 Trends

Soil-type-specific N surpluses at dairy farms in the period 1986-2001, retrospectively calculated according to the MINAS system, show a decreasing trend from about 400 kg ha^{-1} in the early 1980s to about 200 kg ha^{-1} in 2001 (Figure 3). The corresponding agronomic N surpluses have decreased from about 470 kg ha^{-1} in the early 1980s (Aarts *et al.*, 1988) to 340 kg ha^{-1} in 1999 (Hoogeveen *et al.*, 2002). In the same period, agronomic P surpluses have decreased from 31 kg ha^{-1} to 23 kg ha^{-1}. The reductions in nutrient surpluses until 1990 are attributable to the introduction of milk quota and more efficient use of manure-N, due to restrictions on timing of manure application.

1 Currently, the balance at national scale between production and 'consumption' of animal manures is such that in most regions livestock farmers have to pay to export their manure to arable farms.

The decrease from the mid-1990s onwards is related to a more efficient use of manure-N as a result of introduction of low-emission application techniques. The decrease from 1998 onwards is largely attributable to the introduction of the MINAS system.
Based on 1999/2000 nutrient balances, only 10% of specialised dairy farms realised N surpluses below the levy-free surpluses in 2003/04 (RIVM, 2002a). Consequently, almost all dairy farms will have to implement measures before then to avoid having to pay levies and/or costs for manure disposal. The gap to bridge between 2001 and 2003/04 is roughly indicated in Figure 3.

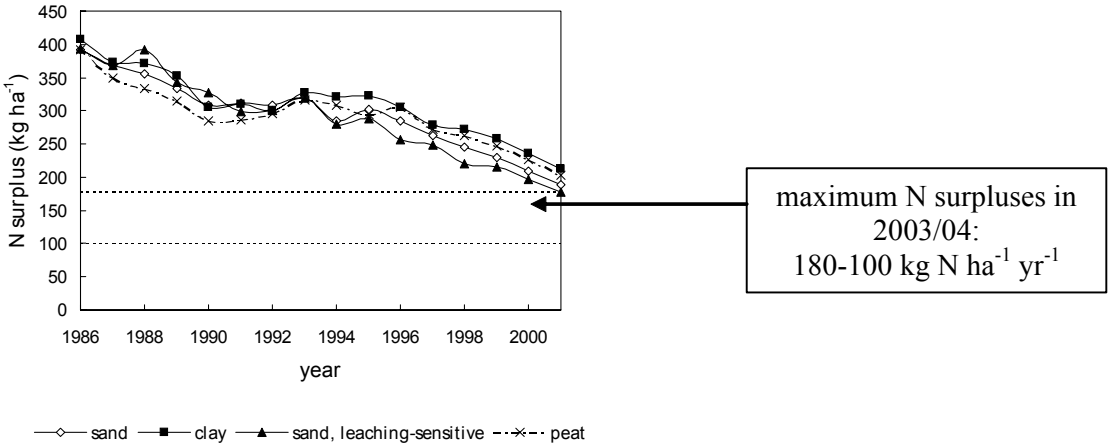

Figure 3. *Trends of N surplus at specialised dairy farms in the period 1986-2001 specified per soil type (Source: RIVM, 2003). N surpluses are calculated according to the MINAS system. The horizontal dotted lines indicate the range of levy-free N surpluses applicable in 2003/04.*

The exact levy-free N surplus per farm in 2003/04 depends on the ratio between grassland and maize and on soil type but ranges from 180 to 100 kg N ha^{-1} yr^{-1}.
Contrary to the dairy sector, agronomic N surpluses at arable farms have hardly changed since the mid-1980s. In some regions this surplus even increased, due to increased manure-N use which became an additional income source for arable farmers (RIVM, 2002a). In 1999/2000, i.e., before the introduction of MINAS in the arable sector, 50-60% of the arable farms realised N surpluses below the levy-free surplus. The 40-50% of arable farms with surpluses exceeding the levy-free level were farms that use considerable amounts of manure.
Resulting from positive P surpluses over a prolonged period of time, P statuses of soils have improved from an agricultural point of view. In 1999, P statuses of 25-50% of the total number of sampled plots were such that, in case farmers would follow the fertiliser recommendations, P inputs would be reduced to the level where they equal P removal with crop products (Willems *et al.*, 2002). In southern and eastern regions, P statuses of 34-65% of the sampled plots were even such that farmers could refrain from P fertilisation. Consequently, if farmers would follow the P fertiliser recommendations, the national manure surplus would substantially increase.
Based on model calculations, it is estimated that about 75% of agricultural soils is saturated with phosphorus (Willems *et al.*, 2002), which is associated with increased leaching risks.

8.4.2 Nutrient concentrations in groundwater and surface waters

8.4.2.1 Monitoring programmes

Two national groundwater monitoring networks are in operation in The Netherlands. The first network monitors groundwater quality at depths of 10 and 25 m. This network is not suitable to monitor the short-term effectiveness of nutrient policies, as groundwater at a depth of 10 m or more usually has a travel time of one or more decades.

The travel times of the *upper* groundwater (i.e. the upper metre of the groundwater occurring within five metres below the soil surface) are much shorter, and the effects of policy measures on nitrate concentrations in groundwater will be observed sooner. A second network has therefore been initiated, monitoring the quality of this upper groundwater in agricultural and natural areas. Besides upper groundwater quality, management characteristics of farms are monitored.
Water quality in state-managed surface water bodies (major rivers, lakes and canals) is monitored by taking monthly samples at 26 fixed locations. In regionally managed water bodies, water quality is monitored at several thousands locations.

8.4.2.2 Trends

Groundwater

Mean annual nitrate concentrations in the *upper* groundwater under dairy farms (Figure 4) vary strongly between soil types and years, but decrease in the order sand-clay-peat. Mean nitrate concentrations exceed the MPR value in all years in sand areas and in some years in the clay areas. Mean nitrate concentrations in upper groundwater under peat soils are very low, but those of other forms of N (ammonium N, organic N) are much higher than under mineral soils. Nitrate concentrations in the period 1992-1995 are on average higher than in the period 1997-2000. To illustrate, in the period 1992-1995, 15% of the groundwater samples collected at dairy farms showed nitrate concentrations below the MPR value (Willems *et al.*, 2002). In the period 1997-2000 this percentage increased to 25%, largely attributable to reductions in N surpluses at dairy farms (Willems *et al.*, 2002).
The mean annual nitrate concentration in groundwater at a depth of 10 m under sand soils shows a small increase since the early 1990s (Figure 5). The proportion of sampling locations where measured concentrations exceeded the MPR level varied between years from 20 to 25%. Nitrate concentrations in groundwater at a depth of 10 m under peat and clay soils are much lower than under sand soils (<10 mg l^{-1} in all years).
The nitrate concentration in groundwater infiltrating under agricultural soils is determined by soil-N loads. Until 1950, these were relatively low and hence also nitrate concentrations in infiltrating groundwater. Since then, N loads strongly increased, reaching a maximum in 1986 and stabilising at this maximum level until the second half of the 1990s, and only recently started decreasing. This pattern is also apparent in the nitrate concentration of infiltrating groundwater (Willems *et al.*, 2002). Accordingly, nitrate concentration of groundwater at a given depth is strongly linked to the composition in terms of the year of infiltration (average 'age' of the groundwater). Because groundwater at a depth of 10 m largely infiltrated after 1980, i.e. in a period with high soil-N loads, it is expected that nitrate concentrations at this depth have already reached relatively high values and will not substantially increase in the future (Willems *et al.*, 2002).

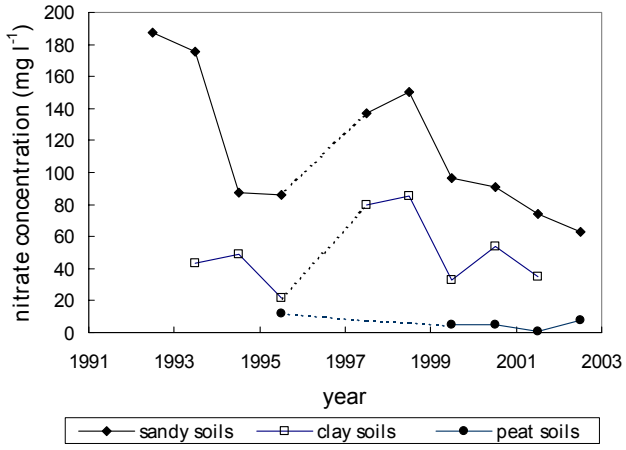

Figure 4. *Trend of mean annual nitrate concentration in the upper groundwater under dairy farms on sand, clay and peat soils in the period 1992-2002. Dotted lines bridge years without measurements. (Source: Willems et al., 2002, supplemented with recent data.)*

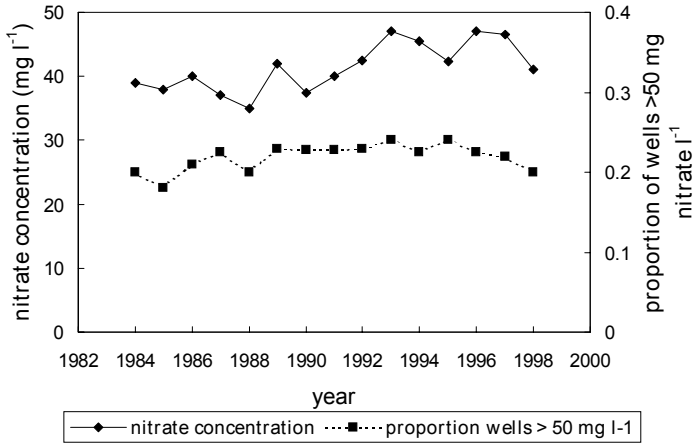

Figure 5. Trend of mean annual nitrate concentration in groundwater under sand soils at a depth of 10 m in the period 1984-1998 (left y-axis) and the annual proportion of wells where nitrate concentration exceeds the MPR-value (right y-axis). (Source: Fraters et al., 2000).

Surface water

At a national scale, agriculture accounts for 68 and 49% of the total N and P emission to surface waters in 2000, respectively (RIVM, 2002a). N emission from agriculture to surface waters in 2000 is approximately the same as in 1985. Agriculturally induced emission of phosphorus has been reduced by 12%.
An analysis of a large dataset, as resulting from monitoring activities in 300 regional surface waters covering the years 1985-2000, shows a significant improvement of surface water quality, attributable to a 50% reduction of the P concentration. N concentrations, however, have hardly changed. Currently, P concentrations in surface waters (0.18-0.20 mg l^{-1}) are only slightly larger than the MPR value (Table 5: 0.15 mg l^{-1}), but N concentrations are about twice the MPR value (Table 5: 2.2 mg l^{-1}) (RIVM, 2002a). The reduced P concentration is largely attributable to reductions in non-agricultural emissions.

8.4.3 Arial ammonia concentration and N deposition

8.4.3.1 Monitoring programmes

A national air quality network has been operational since 1973. The network monitors concentrations of gaseous and acidifying components, particulate matters and heavy metals and the chemical composition of precipitation (Van Elzakker, 2001). Monitoring intensity varies between components. Ammonia concentration is monitored at eight locations scattered over the country.

8.4.3.2 Trends

N deposition has been reduced by about 15% since 1980 (Figure 6). Mean annual N deposition in the year 2000 was about 2500 mol ha^{-1}. N deposition varies strongly between regions. In regions where pig and poultry production is concentrated, N deposition may reach 4500 mol ha^{-1} yr^{-1}, attributable to high NH_3 emissions in these regions. The Dutch agricultural sector accounts for 53% of the total N deposition (RIVM, 2002b).
Although a downward trend is noticeable since 1998, measures to reduce ammonia emission, introduced on a large scale in agriculture, such as low-emission manure storage and application systems, have not yet resulted in a substantial reduction in the contribution of ammonia to N deposition. Related to this is the existence of a discrepancy between *measured* ammonia concentrations in the air and the *estimated* NH_3 emission from agriculture, quantified on the basis of statistics on animal numbers combined with emission factors per animal type, stable type and type of

manure application in the field. Measured ammonia concentrations between 1990 and 1997 have not changed, whereas the estimated NH_3 emission has shown a 35% reduction. According to Van Jaarsveld *et al.* (2000), the discrepancy is partly explained by an overestimation of emission-reducing effects of measures, notably of low-emission manure-application. Consequently, the NH_3 emission estimates were too low and the emission-reduction is not 35%, but estimated at 16-25% (Van Jaarsveld *et al.*, 2000).

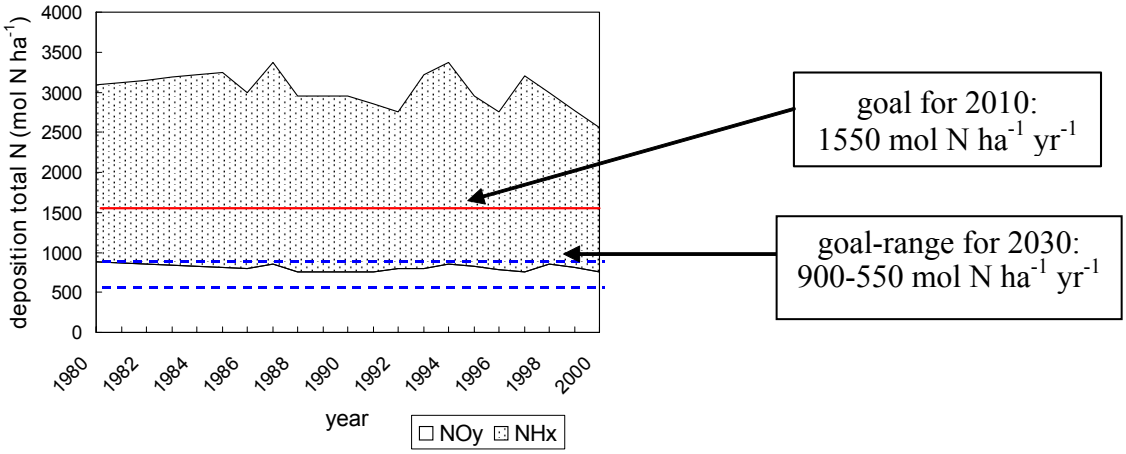

Figure 6. Trend of mean annual N deposition (mol N ha^{-1}), 1980-2000 (RIVM, 2002b).

8.5 Farm-economic consequences of nutrient policies for dairy farming and other farming sectors

As noted in Section 8.4.1.2, the large majority of dairy farms will have to implement measures to realise nutrient surpluses below the levy-free surpluses applicable in 2003/04. A recent study (Van der Kamp, 2002) assessed the associated income loss for 'typical' dairy farm types, varying in soil type and milk production per ha, compared to a reference situation in which higher levy-free surpluses (i.e. those of the year 1998) apply. Results show that most dairy farms can comply with the levy-free surpluses without being confronted with high income losses, which are restricted to € 1000 per farm at maximum. At intensive dairy farms and/or dairy farms on dry sand soils – in the latter case with lower loss standards applying (Table 6) – income loss is higher, amounting to about € 2000-4000 per farm, depending on intensity.

The contribution of the dairy sector to total ammonia emission in 1999 (164 kton) was about 50%. Assuming that the relative contribution of the dairy sector to total ammonia emission remains 50% in the future, the dairy sector can emit 65 kton at maximum to attain the objective of the EU NEC Directive, and 43 and 15-28 kton to attain the short-term and long-term objective of the Fourth National Environmental Policy Plan. Rougoor & van der Schans (2001) estimated total ammonia emission from the dairy sector under various future scenarios, assuming unchanged national milk quota (10.9 million ton). Their results indicate that a reduction in ammonia emission to 50 kton is technically feasible, but requiring that 'all possible measures' are taken to reduce the emission, including low fertiliser N rates in grassland, low-emission manure storage systems and low-emission manure application. Implementation of the measures at farms would result in an ammonia emission per ton milk which is comparable to that currently realised at the experimental dairy farm De Marke, and would have drastic farm-economic consequences. Clearly, attainment of the long-term objective requires even more drastic measures and probably reductions in animal numbers.

8.6 The search for 'sustainable' dairy farming systems

8.6.1 'Sustainable' dairy farming: objectives, methods and results

To enhance sustainability of agriculture, the Dutch government (1) has defined practical indicators for sustainability, such as maximum nutrient surpluses as indicators for ecological sustainability, and (2) stimulates efficient management by improving farmers' skills. The number of means-oriented regulations, such as restrictions in fertilisation periods or fertilisation levels, is kept as low as possible, thus providing farmers maximum freedom to choose their own means to reach the policy objectives.

The efficiency (i.e. output/input) with which nutrients are converted from one compartment to another in each stage of the farm nutrient cycle (Figure 7) varies strongly between farms and depends on farm and soil characteristics and management capabilities of farmers. For instance, conversion efficiency from manure to the soil varies between farms due to differences in ammonia volatilisation, and from harvestable crop to the herd due to differences in grazing system and soil type.

To explore to what extent conversions have to be improved to meet strict, long-term environmental standards, the experimental farming system De Marke was started on a light sand soil in 1992. In this research project, nutrient flows are studied in detail, effects of measures on crop and cattle performance are quantified and environmental quality is monitored. A permanent discussion to understand the processes underlying the system is part of the research method. Results show that nutrient inputs with fertilisers and feed can be reduced by 60% (N) and 70% (P), compared to an average commercial system in 1995 (Aarts *et al.*, 1999), without the need to reduce milk production.

A limitation of De Marke is that it is a research farm, the design of which might not correspond with personal goals of individual farmers. Therefore, in 1999, knowledge gained at De Marke was used to optimise 17 commercial farms (project 'Cows & Opportunities'). These farms represent the main dairy farm types in The Netherlands with respect to soil type and milk production per ha. However, farm size is above average and participating farmers are above average motivated to improve environmental performance. The environmental goals set for these farms in 1999 were about 5 years ahead of actual regulations. Results show that farmers can reduce nutrient surpluses swiftly to a level below maximum levels imposed by MINAS from 2003/04 onwards, without financial losses. Initially, farmers needed assistance to increase their nutrient management skills and to reduce their fear for a drop in cattle and crop performance. Farmers lack experience with low input farming, and with only De Marke available as an example, confidence is low. To disperse knowledge gained in the 'Cows & Opportunities' project, the participating farmers were trained to teach neighbour farmers, and teaching rooms were installed at their farms. Annually about 4 000 farmers visit one of the 17 project farms. As a result and within a short period of time, most of the Dutch 'progressive' farmers will have personally met one of the experienced farmers. Besides, all Dutch farmers received a € 250 cheque, to 'buy' knowledge to improve nutrient management. Available products (including software and personal advice), quality-controlled by people involved in system research projects, can be bought in a virtual 'Nutrient Knowledge Shop' (www.steunpuntmineralen.nl).

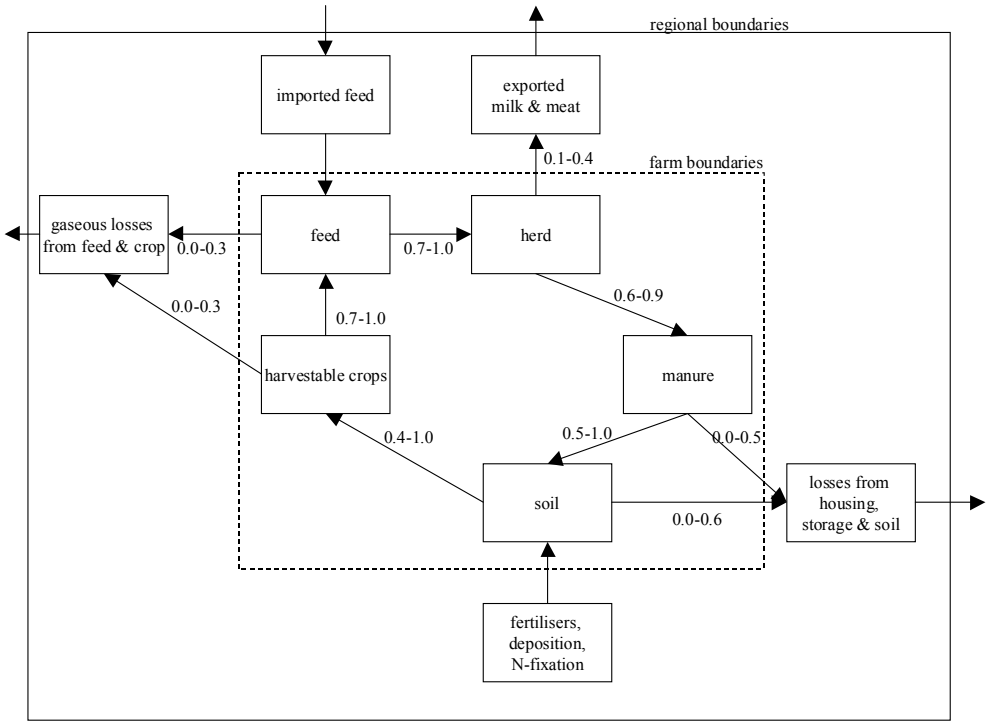

Figure 7. Flow diagram for a dairy farming system with indicative values for the conversion coefficients (Schröder et al., 2003).

8.6.2 Measures and their expected results

Improved utilisation of nutrients in manure, by reducing grazing (more manure available for fertilisation, reducing the input of mineral fertilisers) and by improving manure application (period and methods), is the most effective measure. Reducing fertilisation levels is to some extent also very effective, because it improves uptake efficiency. Too strong reductions in fertilisation levels, however, will lead to an unacceptable increase of nutrient inputs via purchased feed. Fertiliser inputs can be reduced by the substitution of grass by maize, as maize has a lower N content and hence a lower N requirement. However, growing more maize reduces protein production which can necessitate additional protein purchases. The optimal ratio between maize and grass area depends mainly on soil type and intensity (milk per ha) and varies between 45/55 and 0/100. Another important measure is reducing feed requirements by a reduction in young stock and, to a certain extent, by increasing milk production per cow. Nitrogen intake can be reduced by balancing the diet of cattle such that the protein content of dry matter does not exceed 14-16%.
A more drastic measure is rearing young stock off-farm, shifting the associated nutrient losses to other farms. It will reduce feed requirements and improve conversion of nutrients from feed, because conversion from feeds to milk is more efficient than conversion to body weight. A similar measure is export of slurry. This is a very expensive measure, but needed if the farm is very intensive, farm conditions difficult, or the farmer not very 'professional'.
Each of the 17 farmers participating in the project 'Cows and Opportunities' has implemented a coherent package of measures, tuned to the specific situation on the farm. As a result, in the period 1999-2001 the average agronomic N surplus decreased by 60 kg ha^{-1}, i.e. from 255 to 195 kg (Oenema *et al.*, 2002; Oenema & Aarts, 2003). The lower N surplus is largely explained by reductions in mineral fertiliser N input. Reductions in N surpluses have also resulted in reduced nitrate concentrations in the upper groundwater. Based on three-year data from the participating farms, Oenema & Aarts (2003) suggest that agronomic N surpluses of dairy farms on sand soils should not exceed 150 kg ha^{-1}, in order not to exceed the MPR value in the upper groundwater. This agronomic N surplus corresponds with an N surplus according to the MINAS system of 65 kg ha^{-1}. The latter value is about 70 kg ha^{-1} lower than the average levy-free N surplus currently allowed by the government on the 17 farms[1] (Oenema & Aarts, 2003).

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1 The average levy-free N surplus currently allowed on the 17 farms was calculated from the maximum permitted N surpluses per ha grassland and arable land as given in Table 6 and grassland and maize areas on the 17 farms (data not shown).

8.7 Policy options

8.7.1 Main problems

As explained in Section 8.3.3, the consequence of the Dutch interpretation of Nitrates Directive regulations is that the average manure application does not exceed 170 kg N per ha arable land plus 250 kg per ha grassland, but this is not necessarily so at each individual farm. The Dutch interpretation is not fully in accordance with the 170/250-regulation in the Nitrates Directive, which is formulated at individual farm scale. The Dutch interpretation is therefore coined here a 'flexible interpretation of Nitrates Directive regulations', as opposed to the EU's 'strict regime of compliance to Nitrates Directive regulations', i.e. at farm scale. The 'flexible interpretation' reflects the way of thinking of Dutch policy makers, who consider MINAS as the regulating instrument to comply with Nitrates Directive objectives at farm scale, and the manure contract system as a helpful, but sometimes redundant tool. The ultimate goal in the view of Dutch policy makers is the realisation of low nutrient surpluses at each farm, irrespective of manure application at the farm.
The Dutch manure policy is beset with three major uncertainties. These refer to (1) the acceptance by the EU of the MINAS system as the regulating instrument to comply with the objectives of the Nitrates Directive, (2) the acceptance by the EU of the Dutch 'flexible interpretation' of one of the Nitrates Directive regulations, and (3) the decision on the Dutch derogation request as submitted to the European Commission. In its nutrient policy, the Dutch government finds itself in an unenviable position. On the one hand, there is the European Commission that is to be convinced of the efficacy of the MINAS system in sufficiently improving groundwater and surface water quality, with legal infringement procedures as unattractive outlook in case of non-compliance. On the other hand, there are farmers and farmers' organisations in The Netherlands that 'do not like MINAS' and oppose against a further tightening of the manure policy regulations.

8.7.2 Improvements to European nutrient policy

Regulations on nutrient management need an indicator, just as speed as an indicator of traffic safety. The appreciation of indicators can be based on four criteria (Schröder *et al.*, 2004):

1. an indicator should be effective in that it is related to the intended goal;
2. it may be convenient that the indicator has an integral nature, i.e. it may be desirable that other goals run along with it, so that the total number of indicators can be limited;
3. to enable the use of the 'polluter pays' principle, an indicator should preferably be responsive and attributable to (recent) actions of individuals, subject to the control based on that indicator;
4. the costs of a sufficiently accurate measurement of the value of the indicator should be limited.

The indicator selected by the Dutch government is the nutrient surplus as resulting from the MINAS system. Whilst (1) the nutrient surplus is not *per se* a perfect indicator of N and P losses, and (2) the methodology applied within the MINAS system to calculate nutrient surpluses can be improved (see below), this indicator is generally considered a better predictor of nutrient loss than e.g. nutrient input per ha. Nutrient input per ha performs worse because similar inputs may yield different surpluses across farm types and crop rotations (Schröder *et al.*, 2003). Even within farm types and crop types, similar inputs may result in different outputs due to variation in husbandry techniques, crop and soil characteristics and climate. The indicator 'field-applied manure' – with animal density closely linked to it – is even less indicative of nutrient losses, because this indicator neglects nutrient inputs with mineral fertilisers, deposition and biological N fixation. Nevertheless, this is the primary indicator selected by the European Commission. This may seem surprising, but indeed, a glance at data bases of livestock density, nutrient surpluses and emissions across Europe reveals a negative correlation between the presence of animals and environmental quality. The robustness of the underlying relationships can, however, be questioned. Moreover, another disadvantage of the EU indicator is that it is uncertain whether it will result in sufficiently low nutrient losses, without additional yardsticks and thresholds. For example, in many types of manure, the amount of P associated with 170 kg manure-N ha^{-1} yr^{-1}, exceeds the annual P uptake of most crops, which eventually may lead to considerable P losses. It is uncertain whether this potential shortcoming of the present N-oriented EU threshold, can be fully met by the currently gently formulated 'codes of good agricultural practice'. Some European countries, therefore, established an

additional ceiling to the annual P input through manure. Another problem linked to the indicator 'field-applied manure' is that manure production is difficult to measure and control. The necessary default values are only a rough estimate of the actual manure production, especially so at dairy farms, where manure production per animal varies greatly between farms.

We suggest here that no single indicator performs best in terms of all four criteria simultaneously. For instance, using the indicator 'groundwater quality at farm scale' is relatively closely related to the intended goal 'regional groundwater quality', but this indicator does not cover N emissions to the atmosphere and ongoing P accumulation, while costs of accurate measurement are high. Alternatively, the value of the indicator 'livestock density' can be accurately assessed on each farm at low costs. Unlike the first indicator, livestock density implicitly encompasses various goals, including emissions of nitrate, nitrous oxides, ammonia and phosphorus. At the same time, as argued, the indicator 'livestock density' has a relatively uncertain effect on the achievement of the various goals and should be seen in terms of probability rather than of guarantee.

Obviously, the 'flexible interpretation' of the Nitrates Directive by the Dutch government allows a higher animal density than would have been the case under a regime of strict compliance, as it reduces the supply of manure on the manure market and hence reduces the costs of manure disposal for livestock farms, leaving more livestock farms engaged in production[1]. A regime of strict compliance with Nitrates Directive regulations, in which manure in excess of 170 kg N per ha arable land plus 250 kg N per ha grassland is either not produced or transferred to 'consumers' of manure, will have a strong impact on Dutch agriculture. In the short term, it will result in a substantial increase in manure supply on the manure market and is probably associated with a further increase in manure disposal costs, particularly affecting landless livestock farms or farms with limited land holdings. In the longer term, an equilibrium between manure production and manure application opportunities will develop, in which national manure production – and animal density – is expectedly lower than under a regime of 'flexible interpretation' of Nitrates Directive regulations. To what extent this also results in lower N losses to air and water depends on other additional restrictions, yardsticks and thresholds employed in the nutrient policy under both regimes.

8.7.3 Improvements to national nutrient policy

Due to missing terms and estimates in the MINAS system (Table 7), there is scope for improvement of the MINAS surplus as indicator of potential N losses. For a more accurate estimate, the MINAS surplus needs correction for inputs that currently are not included, notably biological fixation by clover in grassland and P in mineral fertiliser, and possibly net mineralisation. The MINAS surplus also needs a more precise estimate of outputs in crop products and gaseous losses, for which at present high default values are used.

As indicated in Section 8.6.2 for dairy farming systems, levy-free surpluses will have to be further reduced to meet the environmental quality goals for groundwater and surface water and the emission reduction goals for ammonia. This applies especially to levy-free N surpluses for arable land, levy-free N surpluses for dry sand soils and levy-free P surpluses. Further reducing levy-free surpluses will also result in reductions of nitrous oxide emissions.

8.8 Conclusions

- Nitrogen and phosphorus surpluses on dairy farms in The Netherlands have decreased in the periods 1986-1991 (milk quota system, voluntary measures) and 1997-2001 (MINAS system) and are expected to have further decreased since then. In the same period, nitrogen surpluses at arable farms have hardly changed.
- P statuses of agricultural soils have increased to levels at which crop yields are no longer responding to P inputs, implying that annual inputs could equal outputs. In practice, however, P surpluses at all farm types are still positive and – unless the manure policy is tightened – are expected to remain positive in the future, so that net-loading of agricultural soils continues, resulting in an increase in the area of P-saturated soils and increased P-leaching risks.

[1] For example, when the levy-free surpluses for the year 2003 apply and based on animal numbers in 2000, it is estimated that 70% of the dairy farm population will need to conclude manure contracts, because these farms produce manure in excess of 170 kg N per ha arable land plus 250 kg N per ha grassland. However, 75% of the total amount of manure-N for which manure contracts are needed can in fact be applied within the associated dairy farms, because their MINAS surpluses are lower than levy-free surpluses. The manure contracts of these farms will thus fully or partly be 'manure contracts on paper' (Bruins, 2002).

- Mean annual nitrate concentrations in the second half of the 1990s in the *upper groundwater* under dairy farms on clay and peat soils are well below the MPR value for nitrate. These concentrations under dairy farms on sand soils exceed the MPR value by a factor 2 to 3. Nitrate concentrations in the upper groundwater show a decreasing trend. It is unlikely that the achieved reduction in nitrogen surpluses at dairy farms on dry sand soils by the year 2003 will suffice to attain concentrations in the upper groundwater less than the MPR value.

- Mean annual nitrate concentrations in the second half of the 1990s in *groundwater at a depth of 10 m* under sand soils are just below the MPR value for nitrate (40-48 mg NO_3 per liter) and are expected to remain below that value in the future. Nitrate concentrations in groundwater at a depth of 10 m under clay and peat soils are well below the MPR value.

- P concentration in surface waters in 2000 shows a 50% reduction since 1985, attributable to reductions in non-agricultural emissions. N concentration has not changed. Correspondingly, N emission from agriculture to surface waters is approximately the same as in 1985.

- In the period 1980-2000, mean annual N deposition has been reduced from 3 000 to 2 500 mol per ha per year. N deposition is still well above the goal for 2010: 1 550 mol. Attaining this goal requires a further, substantial reduction of ammonia emission.

- In its nutrient policy, the Dutch government finds itself in an unenviable position, with, on the one hand, the European Commission that is to be convinced of the efficacy of the MINAS system in sufficiently reducing nutrient losses and, on the other hand, farmers and farmers' organisations that 'do not like MINAS' and oppose a further tightening of the manure policy regulations.

- The approach adopted by the Dutch government in its nutrient policy, with the indicator 'nutrient surplus' predicting 'nutrient loss', has clear advantages compared to the indicator 'manure application' or 'animal density' adopted by the European Commission: better relation to environmental goals, freedom for farmers to choose their own means, and better controllability for government agencies.

- There is scope for improvement of the MINAS surplus as indicator of potential nutrient losses, requiring fair adjustments of the methodology to calculate the surpluses. Two arguments call for these adjustments: (1) the Dutch nutrient policy approach enables higher animal densities than the approach followed by the European Commission, and is only justifiable if potential negative environmental trade-offs are avoided, and (2) an inaccurate methodology undermines the validity of the foregoing conclusion.

- Given the weak position of the indicators 'animal density' and 'manure application' it is questionable whether the figure of 170 kg N per ha from animal manure should keep its central position in the Nitrates Directive.

References

Aarts, H.F.M., 2003.
Changes in nutrient surpluses of Dutch dairy farms (in prep).

Aarts, H.F.M., B. Habekotté, G.J. Hilhorst, G.J. Koskamp, F.C. van der Schans & C.K. de Vries, 1999.
Efficient resource management in dairy farming on sandy soils. Netherlands Journal of Agricultural Science 47: 153-167.

Aarts, H.F.M., E.E. Biewinga, G. Bruin, B. Edel & H. Korevaar, 1988.
Dairy farming and the environment; an approach to reduce nutrient losses (in Dutch). Report 111. Research station for Cattle, Sheep and Horse Husbandry (PR), Lelystad, 136 pp.

Beldman, A.C.G. & H. Prins, 1999.
An analysis of differences in nutrient surpluses between specialised dairy farms (96/97) (in Dutch). Report 2.99.01, Agricultural Economics Research Institute (LEI), Den Haag, 42 pp.

Blöch, H., 2001.
EU policy on nutrients emissions: legislation and implementation. Water Science and Technology 44: 1-16.

Bruins, W.J., 2002.
Manure contracts in the dairy sector: explorative study of problems with 'manure contracts on paper' (in Dutch). Expertise centre LNV (EC-LNV), report 2002/098, Ede, 41 pp.

CBS/LEI, 2002.
Agricultural Data 2001. Central Bureau of Statistics (CBS)/ Agricultural Economics Research Institute (LEI), 's-Gravenhage, Voorburg, 280 pp.

CEC, 2000.
Council Directive 2000/60/EC of the European parliament and of the council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities L 327, 72 pp.

Elzakker, B.G. van, 2001.
Monitoring activities in the Dutch National Air Quality Network in 2000 and 2001. Bilthoven, RIVM rapport 723101055, 73 pp.

Fraters, B., M.M. van Eerdt, D.W. de Hoop, P. Latour, C.S.M. Olsthoorn, O.C. Swertz, F. Verstraten, W.J. Willems, 2000.
Agricultural practices and water quality in The Netherlands; background information period 1992-1997 for the country report EU Nitrates Directive (in Dutch). EC-LNV, LEI, Ministerie van VenW, CBS, RIVM, RIVM-rapport 718201003, Bilthoven, 128 pp.

Hoogeveen, M.W., C.H.G. Daatselaar, H.C. Visee, H.C.J. Vrolijk & J.H. Wisman, 2000.
The manure and ammonia policy: monitoring with the Farm Accountancy Data Network (in Dutch). Report 2.00.04, LEI, Den Haag, 46 pp.

Hoogeveen, M.W., C.H.G. Daatselaar, H.H. Luesink, D.A. Oudendag & J.H. Wisman, 2002.
The manure and ammonia policy: monitoring 2000 (in Dutch). Paper 02.04, LEI, Den Haag, 32 pp.

Jaarsveld, J.A. van, A. Bleeker & N.J.P. Hoogervorst, 2000.
Evaluation of ammonia emission reductions using measurements and model calculations simulations (in Dutch). Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Rapport 722108025, Bilthoven, 62 pp.

Kamp, A. van der (Ed.), 2002.
Technical, economic and societal consequences of levy-free surpluses (in Dutch). Praktijkonderzoek Veehouderij, Lelystad, 96 pp.

Latour, P., 2001.
The search for 'good status' - a closer look at the objectives of the Water Framework Directive (in Dutch). In: H.J.M. Havekes (Ed.), Article series European Water Framework Directive. Unie van Waterschappen, Den Haag, p. 23-45.

Oenema, J. & H.F.M. Aarts, 2003.
Does MINAS bring us the water we wish? (In Dutch.) Cows & Opportunities Newsletter 12, p. 3.

Oenema, O., G.L. Velthof, N. Verdoes, P.W.G. Groot Koerkamp, G.J. Monteny, A. Bannink, H.G. van der Meer & K.W. van der Hoek, 2000.
Defaults for gaseous nitrogen losses from stables and manure storage systems (in Dutch). Report 107. Research Instituut voor de Groene Ruimte (Alterra), Wageningen, 185 pp.

Oenema, J., H.F.M. ten Berge, C.J. de Jong & B. Fraters, 2002.
Nitrogen surpluses in 'Cows & Opportunities' and relationships with nitrate concentrations in groundwater and surface water; analysis of nitrogen surpluses in 1997-2000 and nitrate concentrations in 1999-2001 (in Dutch). Report 49, Plant Research International, Wageningen, 83 pp.

Reijneveld, J.A., B. Habekotté, H.F.M. Aarts & J. Oenema, 2000.
'Typical Dutch'; an outlook on diversity within Dutch dairy farming (in Dutch). Report 8. Plant Research International, Wageningen, 87 pp.

RIVM, 2002a.
MINAS and the environment; balance and exploration (in Dutch). Rijksinstituut voor Volksgezondheid en Milieu (RIVM), 205 pp.

RIVM, 2002b.
Annual report air quality 2000. Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Rapport 725 301 008, Bilthoven, 123 pp.
RIVM, 2003.
Milieubalans 2003. The Dutch environment explained (in Dutch). Rijksinstituut voor Volksgezondheid en Milieu (RIVM), 162 pp.
Rougoor, C.W. & F.C. van der Schans, 2001.
Ammonia in dairy farming; feasibility of the objectives. Centrum voor Landbouw & Milieu (CLM), Utrecht, 28 pp.
Schröder, J.J., H.F.M. Aarts, H.F.M. ten Berge, H. van Keulen & J.J. Neeteson, 2003.
An evaluation of whole-farm nitrogen balances and related indices for efficient nitrogen use. European Journal of Agronomy 20: 33-44.
Schröder, J.J., D. Scholefield, F. Cabral & G. Hofman, 2004.
The effects of nutrient losses from agriculture on ground and surface water quality: the position of science in developing indicators for regulation. Environmental Science & Policy 7: 15-23.
Sebek, L.B.J, A. Bannink & G. J. Gotink, in prep.
Milk urea as an estimator of nitrogen excretion and nitrogen intake of dairy cows (in Dutch). Praktijkonderzoek Veehouderij (PV), Lelystad.
Tamminga, S., A.W. Jongbloed, M.M. van Eerdt, H.F.M. Aarts, F. Mandersloot, N.J.P. Hoogervorst & H. Westhoek, 2000.
Defaults for nitrogen excretion of farm animals (in Dutch). Report ID-Lelystad nr. 00-2040R, 71 pp.
Van Dijk, J.P.M., J.J.P. Groot, K. Lodder, L.C. van Staalduinen & H.C.J. Vrolijk, 1999.
De steekproef voor het Bedrijven-Informatienet van het LEI; Bedrijfskeuze 1998 en het selectieplan 1999. Rapport 6.99.94, LEI, Den Haag.
VROM, 2001.
The Fourth National Environmental Policy Plan. Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Den Haag, 220 pp.
V&W, 1989.
The Third Water Management Plan: water for today and tomorrow (in Dutch). Ministerie van Verkeer en Waterstaat, Den Haag, 61 pp.
Willems, W.J., Th. V. Vellinga, O. Oenema, J.J. Schröder, H.G. van der Meer, B. Fraters & H.F.M. Aarts, 2000.
A justification of the Dutch derogation request within the framework of the European Nitrates Directive (in Dutch). Report 718201002. Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Bilthoven, 102 pp.
Willems, W.J., B. Fraters, C.R. Meinardi, H.F.R. Reijnders & C.G.E.M. van Beek, 2002.
Nutrients in soil and groundwater: environmental quality objectives and quality 1984-2000 (in Dutch). Rapport 718201004, Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Bilthoven, 92 pp.

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9.1 Introduction

Currently, agriculture is responsible for 67% of the nitrogen (N) charge of surface waters in Germany, mainly due to diffuse immissions. Of the total N charge in surface waters, 48% is immitted via the groundwater pathway (BMU, 2000). Protection of groundwater is thus of major importance, not least because 70% of the drinking water in Germany is taken from groundwater. Consequently, there is an increasing pressure on the agricultural sector and in particular on livestock farming to reduce nutrient surpluses and nutrient emissions to other ecosystems. As the conversion efficiency of nutrients is especially low in dairy farming, there are still great opportunities to improve the nutrient cycle in dairying systems. Furthermore, dairy farming is undergoing substantial changes due to economic pressure brought about by CAP reforms and upheavals of the markets. The necessary environmental and economic adaptation of dairy farming systems represents a major challenge to be coped with in the near future. The current status of dairy farming in Germany, trends, figures on nutrient cycling and options for improvement are presented in the following.

9.2 Dairy farming systems in Germany

9.2.1 General information

The total agricultural area in Germany is currently 17.1 million ha, of which permanent grassland accounts for 5.0 million ha (29.4%). Permanent grassland areas are located mainly in Northwest Germany, in the alpine region, and in some low mountain ranges in central Germany (Figure 1). 11.8 million ha is arable land (69.3%), the remaining 1.3% of the total agricultural area is used for horticulture and permanent cultures (BMVEL, 2003). Maize is cultivated on 1.5 million ha, which is 14% of the total arable land. Of the total maize area in Germany, 1.1 million ha account for silage maize, whereas corn-cob mix (CCM) and grain maize are grown on approximately 400 000 ha, mainly in southern Germany but also in the regions close to The Netherlands where intensive pig production and concentrate factories are located (DMK, 2003). Time trends reveal a decrease in the permanent grassland area of approx. 1.5% since 1992, mainly attributable to conversion of grassland into arable land (BMVEL, 2003). Maize production is characterized by a slight decline in the silage maize area, whereas the area of CCM and especially grain maize has increased during the last years (DMK, 2003).

Milk production in 2002 was 27.8 million t, which is 5.9% of the world milk production. There are currently 135 000 specialized[1] dairy farms in Germany, which account for the major proportion of milk production since the majority of mixed farms keeps pigs rather than dairy cows. As in other countries, both the number of dairy farms and the number of cows is consistently declining. For instance, in Schleswig-Holstein the number of dairy farms is declining by 3-4% per year, while the number of dairy cows has been reduced by 35% since the introduction of milk quota due to increased milk yields per cow. Since milk quota trading has been liberalized in the early 1990s there is a continuous concentration of quota and cows in bigger, intensive enterprises. This development is accompanied by an increasing specialization of farms, i.e. from mixed farming systems towards specialized farming enterprises. This polarization has implications for the intensity of production and associated nutrient losses and other environmental impacts.
The contribution of the agricultural sector to the national GDP is 0.9% (BMVEL, 2003).

1 Specialized dairy farms obtain >67% of their marginal return from milk production.

With regard to regional characteristics, at least two categories of dairy farming systems can be distinguished. As shown in Figure 2, main dairy farming areas are located in the coastal regions of Northwest Germany and at the foothills of the Alps in South Germany. Differences in soil, climatic and topographic conditions consequently do not allow a 'general' characterization of dairy farming in Germany. Dairy farming systems in South Germany are comparable to those in alpine regions as present in Austria or Switzerland, while dairy farming in Northwest Germany shows some similarities with Dutch or Danish dairy farming systems.
Structural differences between regional dairy farming systems are also indicated in Figure 3, showing that dairy herds are much larger in former East Germany. The collectivized large farming enterprises have been set up as commercial farms in the early 1990s by private investors. Dairy farming is, however, of minor importance in eastern Germany. Within western Germany, dairy herds are largest in Schleswig-Holstein and smallest in the southern provinces.

N surpluses in Germany show a declining trend (Table 1). As N application rates were already reduced in the late 1980s as a result of intensive discussions on good agricultural practice and reduced nutrient surpluses, the total N input remained almost constant during 1990-1999. Consequently, the main reasons for decreasing N surpluses in the 1990s were increased N outputs per hectare. This can be explained by a decrease in livestock density due to increased efficiency in animal production, which is also indicated by reduced N application from organic fertilizers (Table 1), while crop yields were increased. Furthermore, the total set-aside area in Germany has declined by approximately 800 000 ha since the mid 1990s. Fertilizer sales figures indicate a slightly declining trend since the late 1990s for the main elements N, P and K (BMVEL, 2003). Average P surpluses have consistently declined since the early 1980s from 30 kg P_2O_5 ha^{-1} to currently 5 kg P_2O_5 ha^{-1}, mainly due to reduced P fertilization (BMU, 2002).

In 1995 national N and P balances were 2.3×10^9 kg N and 1.55×10^8 kg P, respectively (Fleischer, 1998). The contribution of dairy farming to national N and P surpluses is somewhere between 49% and 66%. An accurate quantification is not possible due to many local nutrient fluxes between milk production and arable farming enterprises, both between specialized farms as well as within mixed farms.

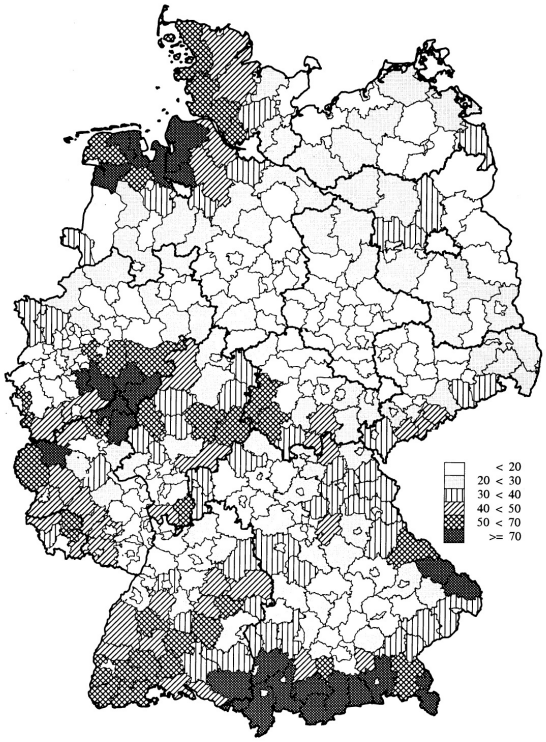

Figure 1. Proportion of permanent grassland of the total agricultural area in Germany in 1996 (DOLL, 1999).

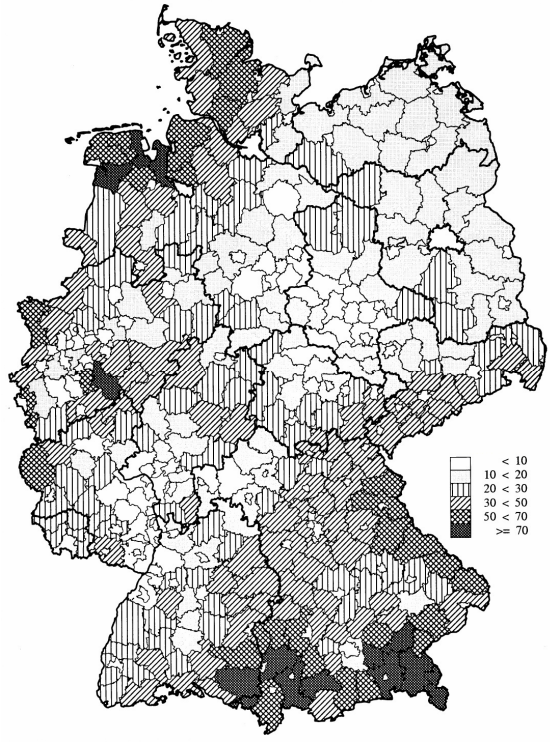

Figure 2. Number of dairy cows per 100 ha in Germany in 1996 (DOLL, 1999).

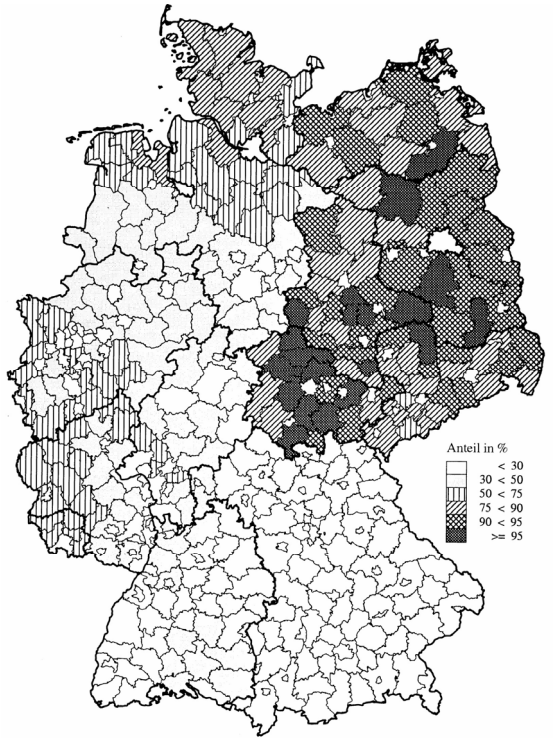

Figure 3. Proportion of dairy cows in 'large' herds (>40 cows in western Germany, >100 cows in eastern Germany) in 1996 (DOLL, 1999).

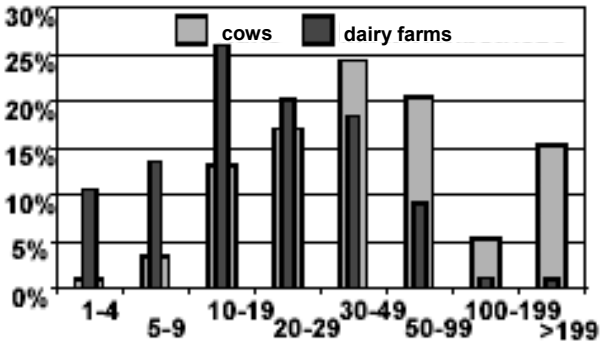

Figure 4. Distribution of cows and dairy farms in farm size classes (IFCN, 2001).

Table 1. Nitrogen budgets in German agriculture (national average) in 1990 and 1999 (data sources: BMU, 2000; BMVEL, 2003).

	1990	1999
Livestock density [LSU ha^{-1}]	1.12	0.87
Mineral N applied [kg N ha^{-1}]	98.0	113.1
N from organic fertilizers applied [kg N ha^{-1}]	63.5	54.0
Total N input [kg N ha^{-1}]	203.5	205.5
Total N output [kg N ha^{-1}]	115.3	122.0
N surplus [kg N ha^{-1}]	88.2	83.5

N surpluses vary pronouncedly amongst provinces. In Lower Saxony and Northrhine-Westfalia, where intensive pig production is an important enterprise, average N surpluses still exceed 100 kg N ha^{-1}. In contrast, N surpluses are currently below 60 kg N ha^{-1} in some provinces of former East Germany, where agriculture is characterized by large-scale all-arable farming.

Strong and weak points of dairy farming in Germany are (Christoffers, 2003):

Strong points: farmers have high level of management skills, high and efficient milk production, low interest level, availability of capital, favourable climatologic conditions (in the main dairy regions)

Weak points: farm structure (many small-sized farms, especially in South Germany), capital-intensive, relatively high quota prices, measures to reduce costs are often not adopted in practice, many restrictions and requirements by authorities, still relatively high N emissions

9.2.2 Characteristics of German dairy farming systems and trends

This section focuses on dairy farming in the extreme North (Schleswig-Holstein) and in the extreme South (Baden-Württemberg, Bavaria) of Germany only. These regions represent the range of dairy farming systems in Germany. Another important dairy region is the Northwest of Lower Saxony, close to The Netherlands. Dairy farming in this region, however, is not very different to Schleswig-Holstein apart from a higher importance of beef cattle and pig production as secondary enterprises on many milk-producing farms.

9.2.2.1 Northern Germany (Schleswig-Holstein)

Forage production is carried out on 56% of the total agricultural area in Schleswig-Holstein. 470 000 ha is permanent grassland, of which roughly 40 000 ha is located on low moor sites. These sites can be characterized as 'obligatory' grassland since they are not suitable for arable crop production. Most of the remainder can be addressed as 'facultative' grassland, which is also suitable for arable crops. Currently, 68 000 ha are cultivated for silage maize production, while leys account for only 40 000 ha. These figures suggest that permanent grassland is the dominating forage crop in Schleswig-Holstein. Especially on low moor sites, however, forage production from permanent grassland is often not economically viable. Consequently, a considerable proportion of the permanent grassland area is set aside, managed extensively, or is being made subject to agri-environment programs.

The most comprehensive data collection from commercial dairy farms in Germany is published annually by the Agricultural Chamber of Schleswig-Holstein (Anonymous, 2000). This 'Dairy Report' includes management data of more than 1 500 dairy farming enterprises. It should be noted that these farms participate in the specialized dairy advisory service, which is owned by the farmers. The farms included in this Dairy Report thus represent the upper end of the range. The average milk yield in Schleswig-Holstein is in the range of 6 300 - 6 500 kg FCM per cow, which is 1 000 kg less than on farms that take advantage of the dairy advisory service (see Table 2).

As elsewhere, there is a continuing concentration of quota on larger farms in Schleswig-Holstein. As milk yields per cow increase at a lower rate (200-400 kg per year) than the enlargement of quota and farm area on individual farms, herd sizes have consistently increased during the 1990s. Most farms are specialized mixed dairy farms, with cash crop production and fattening bulls as second enterprises. The average stocking rate is 1.7 LSU ha^{-1}, of which fattening bulls account for 26% on average. Cash crops account for 15-20% of the farm area. The dominating breeds are Black Holstein × Holstein Frisian (57% of all dairy farms in Schleswig-Holstein), Red Holstein (35%) and Angler (8%), which is a traditional regional breed with high milk fat production. Cubicle houses with slatted floors are the dominant housing system on more than 90% of all dairy farms. Farmyard manure is of marginal importance. Most farmers try to increase both milk yields per cow and milk quota per farm, but a small number of farmers so far did not give priority to this. However, the farm-economic analysis showed that both factors are a prerequisite for an economically viable milk production (Anonymous, 2000).

As indicated in Table 2, 72% of all dairy farms rely on both grass silage and maize silage, with roughly similar proportions of the two silage types in the basic ration. In the marshes close to the North Sea, less maize is used due to climatic conditions. This is often compensated for by cereal whole-crop silage. Few farms rely on grass silage as the only roughage component. Permanent grassland is used mainly as pasture (40% of the total permanent grassland area) or as mixed system with 2-3 silage cuts (40%). Only 10% of the permanent grassland area is used exclusively for cutting (Wachendorf & Taube, 2001). Grassland swards are dominated by *Lolium perenne* L., with other forage grasses being of minor importance. The proportion of *Trifolium repens* L. is only in the range of 2% (on a DM basis) on conventionally managed grassland (Wachendorf & Taube, 2001).

Table 2. Management data of dairy farms in Schleswig-Holstein (average of >1,500 specialized dairy farms). Source: ANONYMOUS (2000).

General data		**Grazing management** †	
Farm size [ha]	89.5	Rotational grazing [%]	57
Herd size [dairy cows per farm]	67	Continuous grazing [%]	13
Replacement rate [%]	41.8	Half-day grazing [%]	23
Principle forage area [ha cow^{-1}]	0.55	Strip grazing [%]	1
Pasture [ha cow^{-1}]	0.19	Year-round confinement [%]	5
Winter feeding area [ha cow^{-1}]	0.36		
Concentrates [t cow^{-1} yr^{-1}]	2.04	**Forage production**	
Milk yield [kg FCM cow^{-1} yr^{-1}]	7,408		
Black Holstein herds	7,802	***Grazed pasture***	
Red Holstein herds	6,769	mineral N [kg N ha^{-1}]	140
Milk yield from basic ration [kg FCM cow^{-1} yr^{-1}]	3,357	mineral P [kg P_2O_5 ha^{-1}]	8
		mineral K [kg K_2O ha^{-1}]	15
Marginal return [€ cow^{-1}]	1,425	Slurry [m^3 ha^{-1}]	7
Marginal return [€ ha^{-1}]	2,669	Grazing yield [GJ NEL ha^{-1}]	25.8
Basic feeding ration *		***Grass silage from permanent grassland***	
		mineral N [kg N ha^{-1}]	202
Grass silage only [% of farms]	4	mineral P [kg P_2O_5 ha^{-1}]	12
Grass silage + WCS [% of farms]	8	mineral K [kg K_2O ha^{-1}]	39
Grass silage + maize silage [% of farms]	72	Slurry [m^3 ha^{-1}]	21
		Silage yield [GJ NEL ha^{-1}]	51.6
Total DM from basic ration [kg cow^{-1} d^{-1}]	12.8		
		Maize silage	
DM from maize silage [kg cow^{-1} d^{-1}]**	5.9	mineral N [kg N ha^{-1}]	53
Concentrates [g kg^{-1} FCM]	275	mineral P [kg P_2O_5 ha^{-1}]	46
		mineral K [kg K_2O ha^{-1}]	6
		Slurry [m^3 ha^{-1}]	31
		Silage yield [GJ NEL ha^{-1}]	69.6

* *on farms having Black Holstein herds*
** *average of farms that grow silage maize*
† *% of all dairy farms*

Grazing is allowed to lactating cows on more than 90% of all dairy farms. Rotational grazing is still dominating, but half-day grazing ('siesta grazing') and also zero-grazing becomes more important, especially on farms that have above-average milk yields. With increasing herd sizes and increasing milk yields, grazing becomes less important because grazing management is more difficult with a large herd, and nutrient supply is not sufficiently constant on pasture to obtain maximum milk yields. On those farms at the upper end of the range, high-quality grass silage is made from the first cut in spring. The grazing period thus begins later, and supplementation is more important during the grazing period in order to obtain maximum milk yields in the early lactation.
Assuming that the current trends will continue in the future, many farms will have to rear their young stock outside their own farm and/or reduce the number of beef cattle in order to avoid the construction of new livestock buildings. Especially in densely populated areas the construction or enlargement of livestock buildings is often denied by authorities.

On commercial farms it becomes increasingly evident that costs for insemination and veterinary measures are consistently increasing, and that the amount of non-marketable milk is much higher in high-yielding herds (*ca.* 1% of the milk in high-yielding herds (> 9 000 kg milk yield per cow) is not marketable due to mastitis, while the proportion is only 0.5% in average herds). The replacement rate is also very high (currently 41.8%, Table 2), but there is no difference in replacement rate between low-yielding and high-yielding herds. However, the proportion of cows that is culled due to mastitis has consistently increased during the last 10 years, whereas low milk yield has become much less important as a reason for replacement (Anonymous, 2003).

9.2.2.2 Northwest Germany (Lower Saxony)

Important dairy regions in Lower Saxony are the region between the rivers Weser & Elbe (see Figure 2), but also some regions bordering The Netherlands. In the Weser/Elbe region, dairy farming takes place on both marshes and sandy soils. In the marshes, permanent grassland is the only possible crop as soils do not allow tillage. Where soils are sandy, silage maize is also grown. Apart from the marshes, agricultural land use is quite heterogenic in Lower Saxony. Pig and beef cattle production are major enterprises, but dairy farming can also be found in most parts of the province. Close to The Netherlands, dairy farming is comparable to that in the Southeast of The Netherlands, with a higher proportion of leys and silage maize compared to the marshes (see Dutch country report). Management and nitrogen intensity are comparable to dairy farming in Schleswig-Holstein and will thus not be discussed in detail.

9.2.2.3 South Germany

Generally, dairy farms in South Germany are much smaller compared to the rest of the country (see also Figure 3), with a considerable proportion (in some regions more than 40%) of the farms being managed as part-time farms. There are, however, also differences between dairy farming systems in South Germany. The average herd size in the province Baden-Württemberg is 53 cows (Over, 2001), whereas an average of 20 cows per farm is a typical range in the 'Allgäu' region at the foothills of the Alps (STMLF, 2003). Brown cattle, Fleckvieh and Simmental are important breeds in southern Germany, but Holsteins are also found on many farms. The average milk yield in Baden-Württemberg is 6,725 kg FCM per cow and year (Over, 2001).

Soils are mainly sandy-loamy, with lime formations in the mountainous areas. Management intensity is almost similar to that in North and Northwest Germany. For instance, concentrate input in Baden-Württemberg is on average 2.07 t per cow and year (Over, 2001), which is similar to this input in Schleswig-Holstein (see Table 2). In mountainous regions, however, dairy farming is far less intensive. Mountain slopes and high amounts of rainfall (1,000-2,400 mm per year) do not allow arable cropping and hamper cutting of grassland. Thus, more than two thirds of the agricultural area in the 'Allgäu' region is used as pasture. From a survey on commercial dairy farms in the 'Allgäu' region, Wetterich & Haas (1999) reported mineral N application rates to permanent grassland of 50-100 kg N ha^{-1}. Grassland swards are generally more species-rich than in Northwest Germany. Wetterich & Haas (1999) found between 20 and 30 species in swards of commercial farms. DM yields were reported 8.7-10.2 t ha^{-1} on a net basis (excluding grazing losses and losses in the forage chain). Conservation of landscape elements is of major importance in the mountainous regions, not at least because of tourism, which provides a considerable part of the farm income. Much of the milk is sold to cheese factories. In order to meet the requirements for cheese making, these farmers are not allowed to feed silage. Thus, hay is an important component in the diet of dairy cows (STMLF, 2003).

9.2.3 Nutrient surpluses and losses in intensive dairy farming

9.2.3.1 N and P surpluses

Table 3 shows N and P_2O_5 balances for average dairy farms in Schleswig-Holstein, calculated for the entire farm with cash crop and beef cattle production as second enterprises, and also for the milk production enterprise only. It should be noted that in Germany phosphorus is expressed as P_2O_5 ($P = 0.43 \times P_2O_5$).

Time trends reveal an increase in the N surplus per hectare from 179 kg N ha^{-1} in 1990 to currently 193 kg N ha^{-1} in 100% specialized dairy enterprises. Milk yields increased by 19% during 1990-2000, whilst N application rates to fodder crops did not change significantly. Concentrate feeding, however, increased by 25% during the same period of time, which is the main reason for increased N surpluses. In contrast, P_2O_5 surpluses decreased from 31 to 26 kg P_2O_5 ha^{-1} during 1990-2000, despite an increased cultivation of silage maize. Mineral P fertilizer application to maize, however, has been reduced by roughly 50%. Per kg milk, both N and P_2O_5 surpluses decreased since 1990 (1990: 26.9 g N kg^{-1} milk, 4.7 g P_2O_5 kg^{-1} milk). The efficiency of N and P_2O_5 at the farm scale increased by 0.5% and 7.3%, respectively.

For typical dairy farming systems in Lower Saxony in Northwest Germany, Müller & Eiler (1995) determined a nitrogen surplus of 144 kg N ha^{-1}. Beef cattle and pig farms, however, which are of even greater importance in this region, had N surpluses of 161-276 kg N ha^{-1}. Based on an on-farm survey on 46 specialized dairy farms in Lower Saxony, Scheringer (2002) found an average N surplus of 146 kg N ha^{-1} on conventional dairy farms. The 10 'best' farms realized an average N surplus of 77 kg N ha^{-1}, which was not significantly different from the average of organic dairy farms analyzed (56 kg N ha^{-1}). Main reasons for low N surpluses on conventional dairy farms were a high milk yield from roughage, a higher proportion of silage maize, less grazing days per cow and year, a more balanced feeding ratio and reduced imports of concentrates and mineral N fertilizer. Reduced N application rates did not result in consistently lower yields of grassland and maize.

In a mountainous area in southern Germany, average N surpluses on conventional dairy farms of 80 kg N ha^{-1} were reported (Wetterich & Haas, 1999), which reflects the lower management intensity in these regions. Both mineral fertilizer and concentrate input are roughly halved when compared to northern German conditions, while milk yields per cow are only 10% lower.

9.2.3.2 Nitrate leaching losses

On sandy soils in Schleswig-Holstein, nitrate leaching in intensive dairy farming was comprehensively investigated in the 'Nitrogen Project Karkendamm', using ceramic cups (see Section 5.2.4.3). The experiments showed that nitrate leaching on permanent grassland increases with increasing grazing intensity and with increasing N input into the sward (Figure 8). If grazing takes place (mixed cutting/grazing systems or grazing-only), the EU limit of 50 mg NO_3-N l^{-1} was exceeded in drainage water even without additional N application through mineral fertilizer or slurry (Büchter *et al.*, 2002). Comparable results at the same experimental site were obtained by Benke *et al.* (1992). Silage maize was proven very N-efficient, with a low risk of nitrate leaching losses, even up to N application rates that were much higher than practiced on commercial farms (Büchter, 2003).

On a sandy site in Lower Saxony, Kayser *et al.* (2003) observed increasing N loads with increasing age of the sward. In the first three years after establishment, N loads in a cutting-only regime were 5-25 kg NO_3-N ha^{-1} with mineral N application rates of 0 and 320 kg N ha^{-1}. From the fourth year onwards, leaching losses were between 20-60 kg NO_3-N ha^{-1}. The effect of grazing cattle was, however, not investigated.

The very few publications available for South Germany indicate that nitrate leaching is of lower relevance compared to northern Germany, due to more continental climatic conditions.

Table 3. N and P_2O_5 balances of specialized dairy farms in Schleswig-Holstein (data source: Anonymous, 2000).

	N	P_2O_5
Inputs [kg]		
Mineral fertilizer	11376	2134
N_2 fixation	0	0
Atmospheric deposition	2685	0
Livestock	14	8
Concentrates	6240	2203
Total	**20315**	**4345**
Outputs [kg]		
Milk	2432	1055
Cows	423	222
Calves	24	12
Heifers	63	33
Beef cattle	339	178
Cash crops	2467	1178
Total	**5747**	**2679**
Surplus [kg]	14568	1666
Farm size [ha] *	89.5	89.5
Surplus [kg ha^{-1}]	**162.8**	**18.6**
Surplus [g kg^{-1} milk] †	**31.8**	**3.6**
Efficiency [%]	**28.3**	**61.7**
Dairy enterprise only ‡		
Input total [kg]	14557	2888
Output total [kg]	2977	1342
Surplus [kg]	11580	1546
Farm size [ha]	59.9	59.9
Surplus [kg ha^{-1}]	**193.3**	**25.8**
Surplus [g kg^{-1} milk]	**25.2**	**3.4**
Efficiency [%]	**20.5**	**46.5**

* *including set-aside area*

† *referring to the amount of milk sold off the farm (6,827 kg cow^{-1} yr^{-1})*

‡ *without cash crop and beef cattle production*

9.2.3.3 Ammonia losses

Table 4. *NH_3 emission factors [kg NH_3 per cow place and year] (UBA, 2001a).*

	Schleswig-Holstein		Baden-Württemberg and Allgäu	
	min	max	min	max
During grazing	0.8	1.4	0.1	1.4
During the housing period	12.0	14.1	4.3	10.0
During manure storage	1.8	3.0	1.8	7.5
During manure application	24.1	27.5	17.1	31.2
Total	**37.1**	**46.0**	**28.1**	**46.0**

UBA (2001*a*) determined regional NH_3 emission factors for dairy farming, as depending on the prevailing conditions in the region (soils, climate, milk yield, feeding management, grazing management, crop and manure management). Table 4 indicates NH_3 emission factors [kg NH_3 per cow place and year] for dairy farms on sandy soils in Schleswig-Holstein under management conditions as described in Section 9.2.2.1, and for dairy farms in South Germany as described in Section 9.2.2.3.

9.2.4 Possibilities for improvement

This section presents and discusses possibilities for improving nutrient utilization in dairy farming systems, especially under German conditions and partly resulting from scientific research projects and from on-farm surveys carried out by extension services and Agricultural Chambers. Following the systematization of Aarts *et al.* (1992), management options are presented for the cattle component, the manure component, the plant-soil component and the forage component. This approach is useful to identify weak points and possibilities for improvement in each component of the system.

9.2.4.1 The cattle component

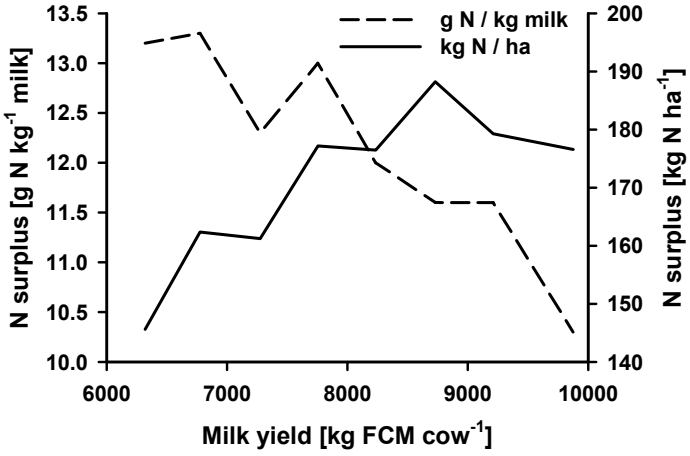

Figure 5. *N surplus per hectare and per kg milk as affected by milk yield per cow in a fixed quota situation of 500 000 kg per farm (FCM: fat corrected milk, approx. 8% above uncorrected milk production). Data source: Anonymous (2000), n = 872 dairy farms, Black Holstein herds.*

It might be expected that a higher milk yield per lactation leads to a better utilization of dietary N, due to lower feed requirements per kg milk (Aarts *et al.*, 1992). Data from Schleswig-Holstein (Anonymous, 2000) indeed confirm lower N surpluses per kg milk with increasing milk yield per cow (Figure 5). The N surplus per hectare, however, increases with increasing milk yields up to a certain level in a fixed quota situation on an average dairy farm in Schleswig-Holstein (Figure 5). A further increase in milk yield above 8 000 kg does not cause a consistent further increase in the N surplus per hectare. This figure is based on the following calculations:

- The number of cows required for the fixed quota of 500 000 kg can be reduced from 83 to 52 cows when milk yield is increased from 6 500 kg to 9 500 kg
- As a consequence, the principal forage area can be reduced from 47 ha to 31 ha
- The amount of concentrates needs to be increased from 130 t to 145 t
- Energy from roughage declines from 70% to 60% of the total energy in the diet
- Milk from roughage declines from 50.0% to 42.5% of the total milk production

The total N surplus of a given farm with a quota of 500 000 kg decreases by *ca.* 1 000 kg N when milk yield per cow is increased by 3 000 kg. As the required forage area decreases to a proportionally greater extent, however, the N surplus per hectare forage area increases.

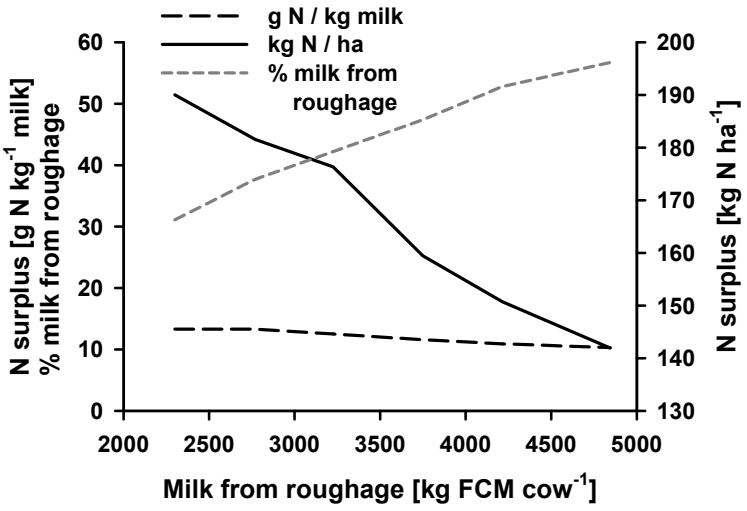

Figure 6. N surplus per hectare and per kg milk as affected by milk yield from roughage. Data source: Anonymous (2000), n = 872 dairy farms, Black Holstein herds.

A higher N efficiency of the cattle component and, as a consequence, lower N surpluses at the farm scale can be achieved by an increase in the milk yield from roughage (Figure 6). Maximum milk yields from roughage are not only desirable with regard to reducing N surpluses, but also from an economic point of view. Farms that obtain >60% of the milk production from roughage have the lowest N surpluses (Figure 6) and also the best economic result as roughage is still the cheapest feedstuff (Anonymous, 2000), and because these farms obtain also higher total milk yields from roughage + concentrates (Figure 7). High milk yields from roughage are obtained through

- optimum forage quality
- high DM intake from roughage (optimum diet composition)
- accurate and adjusted concentrate supplementation

Especially the latter aspect deserves attention. In herds with low milk yields from roughage, 2.5 t concentrates are fed per cow and year. Farms with high milk yields from roughage (> 4 000 kg) need only 1.8 t concentrates per cow and year. The amount of concentrates per kg milk is reduced from 330 to 210 g per kg milk. This, in combination with the positive relationship between milk yields from roughage and total milk yields as observed on northern German dairy farms (Figure 7), might be explained by a non-adjusted concentrate supplementation especially to lower-yielding

cows. Dividing the herd into two or three groups (which is practiced in most high-yielding herds) can be helpful in lower-yielding herds. Compared to current practices, concentrate supplementation can also be reduced by 2-3 kg per cow and day during the grazing season (Anonymous, 2000). A more sophisticated diet composition, as mainly found on farms with high milk yields, is another key factor for high milk yields from roughage. Summarized, there is a significant potential for reducing N inputs via concentrates, while both milk yields and economic outcome can be improved.

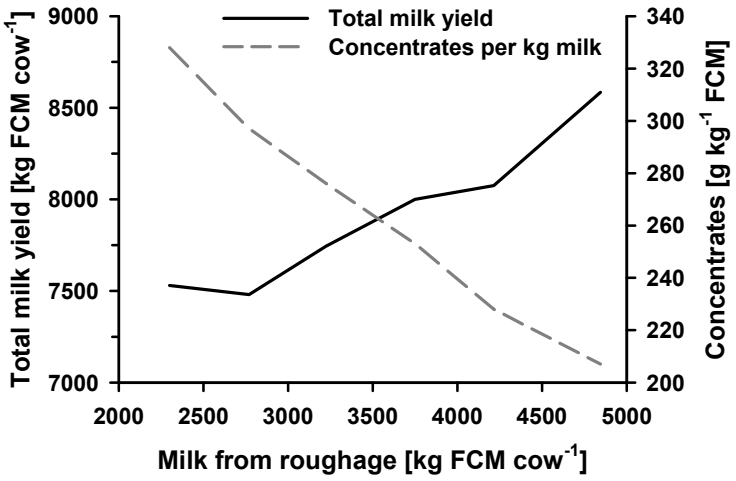

Figure 7. Total milk yield per cow and concentrate input per kg total milk produced in relationship to the milk yield from roughage. Data source: Anonymous (2000), n = 872 dairy farms, Black Holstein herds.

9.2.4.2 The manure component

Options to reduce ammonia losses from manure storage and application that are proposed or implemented in Germany are described in Section 9.3.2.2.

Concerning the utilization of manure, field experiments at Karkendamm on a sandy soil confirmed that silage maize uses moderate amounts of slurry (up to 20 m³ per hectare, corresponding to 70 kg N) quite efficiently (Jovanovic *et al.*, 2000; Volkers *et al.*, 2002), whereas no consistent yield effect of a moderate slurry application (70 kg plant-available N ha^{-1}) could be observed on permanent grassland over a five-year period (Trott, 2003).

9.2.4.3 The plant-soil component

As permanent grassland and silage maize grown in monoculture are the dominating forage crops under northern German conditions, research has focused on these production systems. As most dairy farms in northern Germany are located on sandy soils with a considerable risk of nitrate leaching, an interdisciplinary research project has been carried out at Kiel University's experimental farm Karkendamm in order to examine and quantify the various inter-relationships that affect nitrogen utilization and nitrogen losses in intensive dairy farming on sandy soils (Taube & Wachendorf, 2000; Wachendorf *et al.*, 2002).

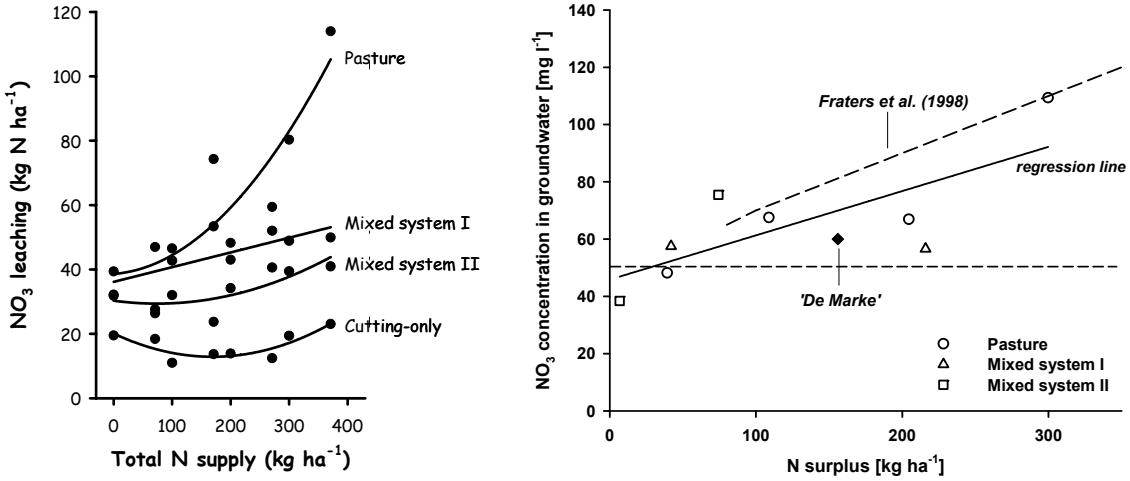

Figure 8. Results from the grassland experiment at Karkendamm (means of 1997-2001).

Left: NO_3 leaching (NO_3-N load per hectare) as affected by total N supply (N from mineral fertilizer and slurry) to permanent grassland swards (Büchter, 2003).
Right: Relationship between N surplus per hectare on permanent grassland and nitrate concentration in groundwater (Bobe, 2003).
Mixed systems I and II refer to 1 or 2 silage cuts, respectively, and subsequent rotational grazing.

The grassland experiment at Karkendamm (Trott *et al.*, 2002) revealed increasing N surpluses on permanent grassland (white clover/grass swards) with increasing N input into the sward. Defoliation regime had a major impact on N surpluses on grassland, with highest N surpluses in grazed and lowest N surpluses in cut swards, whilst mixed cutting/grazing systems had intermediate N surpluses. Nitrate concentrations in the drainage water and calculated nitrate-N loads revealed a similar figure, showing an increased risk of nitrate leaching with increasing grazing intensity and increasing N input. In grazed pasture, nitrate concentrations in the drainage water always exceeded the EU limit of 50 mg NO_3-N l^{-1}, even if no N (mineral N fertilizer or slurry) was applied (Figure 8, left) (Büchter *et al.*, 2002). A strong relationship between N surpluses and nitrate leaching losses from the root zone could be determined. NO_3 concentrations in the drainage water could, however, not be used to predict NO_3 concentrations in the groundwater due to considerable denitrification rates between the root zone and the groundwater table. Denitrification rates in deeper soil layers increased linearly with increasing N surplus (Bobe, 2003), similar to observations made by Fraters *et al.* (1998) in The Netherlands on sandy soils (Figure 8, right).

Concerning silage maize grown in monoculture, mineral N application between 0 and 150 kg N ha^{-1}, combined with varying slurry application rates, had only a minor effect on N yields, which were in the range of 120-140 kg N ha^{-1}. Only if no slurry was applied, N yields were significantly reduced. If grown with undersown ryegrass, N yields were always lower than without understorey (Jovanovic *et al.*, 2000). N surpluses at typical rates of N supply on commercial farms were about 50 kg N ha^{-1}, with a further reducing effect of undersown ryegrass (Volkers *et al.*, 2002). Nitrate concentrations in the drainage water were below 50 mg l^{-1} up to N application rates of 160-210 kg N ha^{-1} via slurry and mineral N. Thus, silage maize was characterized by a much lower risk of nitrate leaching compared to grassland under the prevailing soil and climatic conditions. With undersown ryegrass, nitrate leaching was further reduced. To obtain a similar yield, however, more N has to be applied because considerable amounts of N were accumulated in the ryegrass biomass (Büchter *et al.*, 2001; Büchter, 2003).

The forage crop rotation experiment at Karkendamm (Volkers *et al.*, 2001, 2003) revealed that crop rotation systems can contribute to improved N use efficiency in intensive dairy farming as 'surplus' N from the ley course is transferred to the succeeding crop. Compared to a permanent grassland – maize monoculture system, the N surplus at the field scale could be reduced by 60-80 kg N ha^{-1} through a forage crop rotation (grass/clover ley –

silage maize – triticale) depending on the nitrogen intensity of the entire system. This experiment, however, did not account for effects at the farm scale (i.e., the interactions between herd and plant production).

9.2.4.4 The forage component

With regard to efficient nutrient utilization, grazing is the 'weak point' in German dairy farming systems, as elsewhere. As the main losses of forage occur on grazed pasture, an optimum grazing management is a prerequisite for high milk yields from grazed grass, which in turn helps to reduce concentrate input. As mentioned previously, grazing becomes increasingly restrictive, especially in high-yielding herds.

Concerning the possibility to reduce N fertilization to pasture by introducing white clover into ryegrass swards, Konyali (2001) compared intensive (grass-only swards, 200 kg mineral N ha^{-1}) and extensive (unfertilized grass/clover swards) grazing treatments at Karkendamm. In the extensive treatment, dry matter and net energy uptake from pasture were higher, while concentrate uptake was lower. Milk yields were also higher on the extensive sward. An explanation might be that digestibility of organic matter can be maintained at a higher level if white clover is included in the sward (Südekum *et al.*, 1994). Several reports in the literature confirm the improved animal performance on legume/grass swards compared to grass-only pasture (for instance, Penning *et al.*, 1991).

Sward composition is generally regarded as essential for obtaining an optimum performance of the cattle. Wachendorf & Taube (2001) showed in a survey on conventional and organic dairy farms in northern Germany that a high proportion of desired forage grasses such as *Lolium perenne*, *Festuca pratensis*, *Phleum pratense*, *Poa pratensis*, and of white clover (*Trifolium repens*) is a prerequisite for high forage quality. However, not only the performance of the cattle can be improved by maintaining highly digestible swards, but also nitrate leaching losses are affected by the botanical composition of the sward. High-yielding grass species such as *Lolium perenne*, *Dactylis glomerata* or *Festuca pratensis* have a higher N uptake capacity during the growing season, which has been demonstrated effective for reducing residual soil mineral N in autumn and, as a consequence, nitrate leaching during winter on a Central German site (Theiss, 1989). However, only well-established dense swards are capable of high N uptake from the soil, and at the same time help to avoid selective grazing which often leads to unbalanced nutrient ingestion by the cattle. Both understocking and excessive stocking can lead to sward damage, with the consequential increase in weeds or undesired grasses such as *Elymus repens*. Maintenance works and oversowing are important factors, but on commercial farms in northern Germany only one third of the grassland fields has been oversown during the last ten years (Wachendorf & Taube, 2001). High forage quality and a high proportion of desired grassland species requires an intensive defoliation regime, as demonstrated in a number of studies under German conditions. With a lower defoliation frequency, both herbage digestibility and crude protein content are reduced, leading to lower amounts of N removed with the herbage (Kühbauch *et al.*, 1991; Anger *et al.*, 1994). This holds especially if high-yielding bottom grasses are displaced by top grasses under extensive defoliation regimes. At the same level of N fertilization, Benke *et al.* (1992) found higher nitrate leaching losses with three cuts per year compared to a six-cut regime on a sandy soil in northern Germany. Generally, the level of N supply and defoliation frequency have to be adjusted to each other in order to obtain optimum sward productivity, low amounts of residual N and high forage quality. Theiss (1989) found that the field N balance (N fertilizer – N removed) was between –50 and +50 kg N ha^{-1} in highly productive swards up to N fertilizer rates of 400 kg N ha^{-1} in an intensive cutting regime. With increasing sward age and sward deterioration, however, considerable N surpluses occurred. Under grazing conditions in a Central German low mountain range, Hüging (1997) found lower leaching losses in an extensive system. Herbage digestibility, dry matter yields and stocking rate, however, were also much lower in extensively grazed swards.

In order to optimize the harvest date on cut grassland, a model-based system for prognostication of grassland yield and herbage quality has been introduced in Schleswig-Holstein more than ten years ago (Kornher *et al.*, 1991). This service has led to a considerable improvement of forage quality during the last years, and is currently being introduced in other provinces as well.

Another important aspect is the improvement of herbage digestibility through means of plant breeding. Especially an increase in water-soluble carbohydrates is necessary when improving the animals' performance with a grass-based diet (Lantinga & Groot, 1996).

9.2.4.5 Systems approach

All management options mentioned in this section are surely efficient in reducing nutrient losses under northern German conditions, as well as technical measures that can be applied everywhere (e.g., slurry injection). It is, however, important to test the overall effect of these measures in combination with each other, which is quite difficult to realize in practice. Nevertheless some measures can be formulated in general terms for northern German conditions:

- Inclusion of one or, ideally, two silage cuts in grassland in order to maximize yields while significantly reducing nitrate leaching, compared to grazed-only pasture.
- Changing from highly fertilized pure grass swards to white clover/grass swards. Adjusting N fertilization to maintain an adequate clover content.
- Increasing the proportion of maize silage.
- Preferring forage crop rotations to permanent grassland and silage maize monoculture.
- Optimized feeding management for a well-balanced diet and high milk yields from roughage.

These measures have been shown to maintain a high level of production or to reduce costs at the same level of production, which is a prerequisite for the economic viability of dairy farming. Uncertainties may arise from the well-known low yield stability of white clover, which can motivate farmers to increase their forage area to a greater extent than necessary.

Using the data of the Karkendamm project, a systems modelling approach with the *DAFOSYM* whole-farm model (Rotz *et al.*, 2002) revealed a decrease in N surpluses and total N losses with a lower proportion of grazing and higher amounts of silage maize. Higher amounts of grazing decreased ammonia volatilization, but increased nitrate leaching to a proportionally greater extent. Ammonia losses could be reduced significantly in the silage maize-based system, as slurry can be injected into the soil before sowing. The number of cows that was supported by home-grown forages could be increased by reducing grazing and increasing maize silage production.

9.3 Nutrient policy in Germany

Generally, measures to reduce nutrient emissions from agriculture and/or nutrient immissions to other ecosystems can be classified into four categories:

I. Law and order
II. Market forces
III. Cooperation and voluntary agreements
IV. Extension and education

Due to the federal system, legislation on nutrient management in Germany comprises national, regional (provinces) and local regulations. An overview on national regulations is given in Table 5.

Table 5. National laws and directives affecting nutrient management in German agriculture (September 2003).

	Ratification/ Amendment	Content / Implications / Comments
Fertilization Directive	1996 / *	*see below*
Soil Protection Act	1998 / –	Good Agricultural Practice with regard to soil management
Nature Protection Act	1976 / 2002	Good Agricultural Practice from an ecological point of view; provinces have to implement measures on landscape conservation and protection of biotic resources
Drinking Water Directive	1990 / 2001	maximum NO_3 concentration in drinking water: 50 mg l^{-1}
Sewage Sludge Directive	1992 / 2002	defines max. concentration of toxic elements in sewage sludge and max. application rates on agricultural land; application to grassland is generally forbidden
Fertilizer Directive	1991 / *	defines criteria for fertilizers and their admission
Water Household Act	1996 / 2002	see Section 9.3.1.2
Act on Environmental Risk Assessment	1990 / 2001	define tolerable levels of NH_3 emissions and technical measures to reduce emissions; every farm building that offers place to more than 250 cows is subject to an environmental risk assessment (according to the European Directive EEC 96/61)
Immission Protection Act	1993 / 2001	
Technical Manual on Air Quality	1986 / 2002	

* *Amendment expected.*

Nutrient policy in Germany is embedded in multilateral agreements on both air and water pollution and goals for improvement. In accordance with the working plan of the EU Nitrates Directive, the following steps of implementation have been realized so far in Germany: (i) setting up of water monitoring networks (see Section 5.3.4), (ii) designation of nitrate vulnerable zones (NVZ) (the whole national territory is designated), (iii) implementation of codes of good practice, and (iv) implementation of action programs. General goals formulated by the Federal Government are to reduce the N surplus to 80 kg N per ha agricultural land on a national average until 2010, and a 70% reduction of air pollution through NH_3, SO_2, NOx and volatile organic compounds (VOC) compared to 1990 (measured by an index of the four pollutant groups). NH_3 emissions from agriculture are to be reduced by 28% until 2010 (from 765 kt to 550 kt). Concerning NO_3 in flowing watercourses, the general goal was formulated 10 mg l^{-1}.

The designation of the whole country as a NVZ reflects the dependence of the German water sector on clean groundwater (70% of the drinking water is taken from groundwater). Furthermore, a number of problems would arise if a large number of small NVZs were designated. Farms would often be divided into NVZ and non-NVZ area, making effective control extremely difficult.

The relevant legislation act on nutrient management at the farm scale is the 'Fertilization Directive'. It is mandatory for all farms in Germany. It contains both mandatory and recommending parts.

Mandatory measures are:
- Maximum amount of N from organic fertilizers: 210 kg N ha^{-1} on grassland, 170 kg N ha^{-1} on arable land (maximum 80 kg N ha^{-1} subsequent to the harvest of the main crop before winter).
- Application of organic fertilizers forbidden from November 15th to January 15th.
- On arable land, slurry has to be incorporated immediately into the soil.
- Fertilization has to be conducted in accordance with the actual nutrient demand of crops. Estimation of the N demand: through soil analyses (soil mineral N), plant analyses, technical instruments (e.g., chlorophyll sensors), or calculations according to official tables. From the N content in organic fertilizers, 'unavoidable N losses' can be subtracted. These accountable losses are restricted to 20% through application, and 10% (slurry) or 25% (farmyard manure) through storage and handling, respectively. Thus, total 'unavoidable' losses of N can amount to a maximum of 30% (slurry) or 45% (manure). Estimation of the basic nutrient demand (P and K): soil analyses mandatory every 6 years (arable crops) or 9 years (permanent grassland).
- Calculating nutrient balances at the farm level: annually for N, every 3 years for P and K. 'Unavoidable' losses of N in organic fertilizers during storage and application (see above) are not accounted for in N balances.

Recommended measures are:
- Compliance with good practice, especially with regard to manure/slurry application (emission-reducing techniques) and adjustment of nutrient supply to demand of crops.
- Direct immissions of nutrients into surface waters have to be avoided, either through obeying an appropriate distance to surface waters when applying fertilizer, or through measures that avoid soil erosion.

The implementation of the Nitrates Directive in Germany (with the German Fertilization Directive as the main instrument) has been the subject of a legal action of the European Court of Justice in 2002. As a consequence, an amendment of the German Fertilization Directive is being prepared and will be implemented soon.
The following measures are expected:
- More accurate calculation tables for estimating ammonia losses from organic fertilizers. Thus, an accurate calculation by farmers will replace general values for 'unavoidable N losses' during storage and application of organic fertilizers. As a consequence, the maximum amount of organic fertilizers to be applied per hectare will thus be reduced.
- The maximum permitted amount of N from organic fertilizers to grassland will be reduced.
- The period in winter when application of organic fertilizers is forbidden will be prolonged.
- Requirements for slurry application techniques will be concretized. Emission-reducing slurry application techniques will be *mandatory* on arable land. Incorporation of farmyard manure into the soil will also become *mandatory* in arable farming.
- P fertilization will be restricted on fields with a high plant-available P content.
- Minimum distances to surface waters will be defined.
- Application of both solid and volatile (liquid) urea fertilizers will be regulated.

These amendments of the German Fertilization Directive surely represent a considerable improvement with regard to the reduction of nutrient surpluses and nutrient emissions. However, some aspects are still missing: (i) N and P surpluses at the farm scale will still not be limited, (ii) *mineral* N application will not be restricted either, (iii) nutrient balances for individual fields will not be required, (iv) mandatory regulations on slurry storage capacity and construction of reservoirs are still not defined, and (v) the essential item of winter cover crops remains unaddressed. Generally, farmers must be encouraged to realize these objectives. This can be achieved by compensations rather than by restrictive regulations and bans (Flaig *et al.*, 2002).

9.3.1 Water protection

9.3.1.1 Monitoring

Most provinces began the establishment of groundwater monitoring networks in the mid-1980s. These monitoring networks comprise (i) a 'basic monitoring network' which observes natural (geogenic) characteristics of groundwater

tables, and (ii) a 'trend monitoring network', focusing on anthropogenic influences on groundwater quality. The total number of monitoring points in Germany is currently about 2 500. Methods of sampling and analyzing are, however, not harmonized at a national scale. Furthermore, no national database on groundwater quality is currently available. The only available national compilation on nitrates in groundwater originates from 1995 (LAWA, 1995), showing that 11% of all monitoring points had NO_3 concentrations above 50 mg l^{-1}. This report revealed a general increase in nitrate concentrations from northern to southern Germany, which can be associated with geological characteristics (often solid rock formations in southern Germany, where water percolation is not disturbed). A representative national nitrate monitoring network is currently being prepared and will be published in the forthcoming German report to the European Environment Agency in Copenhagen in 2004. Significant time trends, however, are not expected (W. Wolters, *pers. comm.*).

The report of the European Commission on the implementation of the Nitrates Directive during the first action programs (1996-1999) (CEC, 2002) indicated that there was no consistent trend in nitrate concentrations in groundwater in Germany when comparing the 1992-1994 data with the 1996-1998 monitoring exercises.
In Schleswig-Holstein, where intensive dairy farming takes place, 15 out of 42 groundwater monitoring points had nitrate concentrations above 50 mg l^{-1} during the sampling period 1995-2000. Time trends showed almost constant nitrate concentrations during this period of time (LANU, 2000). Furthermore, the monitoring results did not indicate consistent effects of soil type and agricultural specialization. Where land use is dominated by arable farming on loamy soils, average nitrate concentrations and the frequency of excess concentrations over 50 mg l^{-1} are in the same range as in the 'Geest' region, which is characterized by intensive dairy farming on sandy soils.

Concerning surface water, nutrient charges (both N and P) show a declining trend. Nitrogen discharges to the North Sea and to the Baltic Sea were reduced by 35% between 1985 and 1999. This is, however, less than the 50% reduction as agreed in multilateral conferences. Contrary to the effect on groundwater, reduced N surpluses in agriculture have had a positive effect on both nitrate and NH_4 concentrations in most rivers. Concerning phosphates, the reduction of P loads in surface waters can largely be attributed to reductions in non-agricultural sectors and improved wastewater management (BMU, 2000, 2002).

9.3.1.2 Measures

I. Legislation ('law and order' measures)

At the national scale, the 'Fertilization Directive', which can be regarded as the German action program to comply with the EU Nitrates Directive, contains a number of measures which are relevant for water protection. As the German territory as a whole is designated as NVZ, it is not possible to designate individual catchments as 'vulnerable'. However, the Federal Water Household Act allows for the implementation of water protection areas if (i) water for actual or future human consumption needs special protection, or (ii) if areas are needed for groundwater enrichment or for protection of other watersheds from immissions. The framework for water protection areas is defined by Water Household Acts of the provinces. The setting-up of water protection areas and the definition of required measures is carried out by local authorities. Generally, water protection areas are divided into an inner, a middle and an outer protection zone (zones I, II and III). In the inner zone around the well, all agricultural activities are forbidden. In zones II and III, mineral N fertilizer application is forbidden from September to January. Application of slurry and sewage sludge is generally forbidden in zone II, and from September to January in zone III. Fertilization in autumn is restricted to 40 kg N ha^{-1}. If the field is left bare during winter, tillage operations are not allowed except for the establishment of cover crops. N fertilization to grassland is restricted. In zone II, neither grazing nor grassland renovation are allowed. On organic soils, permanent grassland is the only possible crop. Regulations and measures affecting agriculture are, however, matter of local authorities and can differ pronouncedly with regard to local conditions.

II. Market forces

The use of market forces to reduce nutrient emissions is often connected with 'law and order' measures. Measures comprise (i) the implementation of a quota (for instance, a nitrogen quota as in Denmark), (ii) levies on nutrient surpluses exceeding a defined quantity, or levies on nutrient inputs such as fertilizer or concentrates, (iii) subsidies or credits for investments, and (iv) payments for environmentally-sound ways of production (e. g., organic farming, modulation, extensification, agri-environment programs). The latter comprises the measures of the second pillar of the CAP and holds for Germany as for all other EU member states. Nutrient quota or levies on nutrient inputs or surpluses are not implemented in Germany, and are not discussed either. Subsidies for investments address ammonia emissions rather than nutrient emissions to waters.

III. Cooperation and voluntary agreements

Similar to France, co-operations between agriculture and the water management sector are important measures at the local scale. In contrast to the French 'FertiMieux' program, however, the water management sector (waterworks, local administration bodies) is often the driving force for such co-operations. Such voluntary co-operations are usually characterized by restrictions in fertilization and plant protection practices, on-farm advice, and compensation payments to the farmers ('water protection contracts'). More than 1 000 co-operations currently exist in Germany. Some provinces (Northrhine-Westfalia, Lower Saxony) give absolute priority to such co-operations, as significant reductions in N surpluses, residual soil mineral N and nitrates in groundwater have frequently been obtained. Furthermore, local co-operations provide scope for site-specific considerations and are widely accepted by farmers. The expansion of co-operation models from a local to a regional scale has so far been adopted by three provinces (Baden-Württemberg, Saxony, Lower Saxony). In contrast to the province-wide legal act in Baden-Württemberg ('SchALVO', for detailed information see Happe *et al.*, 2001), which does not account for site-specific and farm-specific conditions and did – since 1990 until now – not lead to significantly reduced nitrate concentrations in groundwater, the legislation frameworks in Saxony and Lower Saxony allow for more local flexibility.

IV. Extension and education

All provinces have set up action programs in order to implement codes of good agricultural practice. Priority is given to preventive measures such as advice, extension and education. For instance, results of representative soil analyses are published regularly, which act as a guideline for estimating the actual nutrient status of the soil and the nutrient demand of crops. Due to declining public budgets, however, provinces are reducing their efforts in agricultural extension.

Outlook: the European Water Framework Directive

The European Water Framework Directive (in the following: WFD) (EEC 2000/60) created a common framework for the protection of all surface waters and groundwater. More than in the past, ecological (and also economical) aspects of water management will become increasingly important (BMU, 2002). An essential aspect of the WFD is a coordinated water management within river basins. Water quality will be evaluated in terms of ecological quality (i.e., the state of aquatic flora and fauna) rather than in terms of pollutant concentrations. This framework means that water protection in Germany will change towards an area-wide water management, which is a quite different approach than in the past because water protection has, so far, focused mainly on catchment areas where groundwater is taken for human consumption. The objectives and systematization of water management as formulated in the European WFD have been adopted by the recently amended 'Federal Water Household Act'. As water management and water protection is a matter of the provinces, regional and local authorities now have to coordinate their management plans. Beneath compliance with the Nitrates Directive, the WFD obliges member states to reverse significant pollution trends and to achieve the quality goal of 25 mg l^{-1} nitrate in groundwater. It is consequently not the threshold value that is an ambitious goal (as it already exists for many years), but the time scale for its area-wide adherence as it may take a long time until nitrates reach the groundwater table.

9.3.2 Ammonia emissions

9.3.2.1 Monitoring

A national ammonia monitoring program with a high regional resolution has been carried out by UBA (2001*a*), showing that emissions of > 25 kg NH_3 ha^{-1} (on the basis of the total land area) occur mainly in Northwest Germany, with a main focus on regions with intensive pig production along the border with The Netherlands. Resulting from both a decreasing number of livestock in Germany and the measures implemented so far, NH_3 emissions have declined from 613 kt (1990) to 466 kt (1999). Until 2010, a further reduction to 419-435 kt NH_3 is expected from model scenario calculations (UBA, 2001*a*). Dairy farming is responsible for 40.7% of the total national ammonia emission. Pig production accounts for 21.9%. Of the total emission from dairy farming, 50% occurs during the application of organic fertilizers, 25% is lost during the housing period, 19% during manure storage and the remaining 6% during the grazing period. On an area base, ammonia emissions from dairy farming rarely exceed 15 kg NH_3 ha^{-1} (UBA, 2001*a*).

9.3.2.2 Measures

The national German program for implementation of the NEC Directive (UBA, 2001*b*) suggests the following measures, which – if all measures are implemented – are expected to reduce national ammonia emissions by 40-60 kt:

- A reduction in the number of livestock through CAP reforms (reduction and decoupling of the beef cattle premium, introduction of a premium for permanent grassland) (first pillar) and increased importance of agri-environment programs (second pillar).
- Increasing the proportion of organic farming (no use of mineral N fertilizer, lower stocking rates).
- Coupling of public capital-spending programs (no capital aid for investments in livestock buildings if the stocking rate exceeds 2 LSU ha^{-1}) or, more restrictive.
- Denying the permission for building or enlargement of livestock buildings if the stocking rate exceeds a certain value or if a farm is located in a region with a high livestock density.
- Public capital-spending for investments in emission-reducing slurry application techniques and covered slurry reservoirs.
- Adjusting the regulations of the German Fertilization Directive (already in progress).
- Adjusting the feeding management.
- Tightening the construction requirements for livestock buildings.

So far, all provinces have set up capital spending programs for the construction of slurry reservoirs in order to assure a storage capacity of at least 6-9 months. Some provinces promote the construction of covered slurry reservoirs. Investments in emission-reducing slurry application techniques are also promoted by some provinces. It is expected that the adoption of such techniques will increase due to modulation payments.

Focusing more than in the past on a reduction of stocking rates implies that 'critical loads' (on a regional basis) and the extent to which emission-reducing measures are set off have to be defined as a prerequisite. In regions where arable farming is dominating, a restriction of the stocking rate on individual livestock farms does not seem adequate. The acceptance of areas for slurry application outside the farm (e.g. on all-arable farms) can contribute to a greater flexibility.

9.3.3 Strong and weak points of the policy instruments

There are some weak points in the German nutrient policy, as stated in the action program assessment of the European Commission (CEC, 2002*b*). The restricted period for fertilizer application, as defined in the German Fertilization Directive, holds only for organic but not for mineral fertilizers. Another general point of attention is the lack of well-defined measures and minimum distances for fertilizer application near water courses and ditches, and for application in steeply sloping areas. The essential item of winter cover crops is also not mandatory in Germany. Furthermore, Germany has implemented the option provided in the EU Nitrates Directive to allow 210 kg N ha^{-1} to

grassland instead of the proposed amount of 170 kg N ha^{-1} from organic fertilizers. Definitions on minimum capacity and construction of slurry storage facilities are not included in the Fertilization Directive. It is, however, expected that these weak points will be improved substantially with the implementation of the amended Fertilization Directive. Flaig *et al.* (2002) stated that current deficiencies concerning the reduction of nitrates in groundwater in Germany are due to (i) deficiencies in required skills of the relevant actors, (ii) often inefficient co-operation between authorities, farmers and waterworks, and (iii) an unbalanced relation between mandatory and voluntary measures.

However, there is also a number of positive actions that has been carried out at the local scale. These successful co-operations between agriculture and the water management sector provide experience with measures that are efficient, accepted by farmers, and at the same time of adequate financial impact for water consumers, farmers and administration bodies.

One example, which is not only a co-operation but a 'Research & Development' project under practical conditions, was the development of a new local directive on the water protection areas on the island of Föhr (Föhr is a small island in the mudflat of the North Sea). The new directive results from a co-operation process between the local community (local administration, citizens, farmers), the Ministry of Environment, Nature and Forestry of Schleswig-Holstein, the Institute for Crop Science and Plant Breeding / Grass and Forage Science at the University of Kiel, and the Agricultural Chamber of Schleswig-Holstein. The old directive allowed only permanent grassland farming in the catchment area of the island. In order to allow also the possibility for arable crop production, crop rotations of silage maize, cereals and leys have been tested by commercial dairy farms in the respective area under the specifications of fertilization and management plans. The field trials on dairy farms were accompanied by soil and plant analyses. As average values of potential leaching losses did not differ pronouncedly between crop rotations and permanent grassland, the new directive allows arable crop production under specified conditions. These include, amongst others, the cultivation of crops in crop rotations only (not in monocultures), growing cover crops, adjusting the nutrient supply to the actual demand of crops, and restricting nutrient application to defined levels.

9.4 Economic consequences of nutrient policies

Economic consequences of nutrient policies are principally the same in Germany as in other countries. A general limitation of the stocking rate is not planned in Germany; it is, however, increasingly difficult to obtain a permission for building or enlarging livestock buildings, especially in densely populated regions. Consequently, it will become more difficult for many dairy farms to grow through quota acquisition, which is an important prerequisite for economic viability under the current and expected market and premium situation.

Direct costs of cover crops or buffer strips vary between 100 and 200 € per hectare and year. These costs roughly balance the compensations paid by the modulation. Direct costs for advanced slurry storage facilities can be significant (approx. 30-50 € per m^3). However, capital-spending programs that cover a part of the investments are available to farmers in all German provinces. In some provinces, farmers can also apply for capital in order to buy emission-reducing slurry spreaders. The restriction of organic fertilizer application can lead to increased costs for transportation of slurry/manure. On dairy farms, which typically have more land available than intensive pig farms, these additional transportation costs are relatively low (approx. 20-50 € per ha and year). Costs of soil analyses, which are mandatory in Germany for P and K and recommended for soil mineral N, can be significant. As the objective of this regulation is a reduction in fertilization levels, these costs will, in most cases, be compensated for by reduced costs for mineral fertilizers (except for organic farms).

A reduction of fertilization levels to the foreseeable nutrient demand of crops, as required in the German Fertilization Directive, is unlikely to lead to a significant yield loss. This holds especially for forage crops such as grass/clover and maize. For instance, grassland and silage maize yields on organic dairy farms in Lower Saxony were 83% and 75%, respectively, of the yields on conventional farms (Scheringer, 2002).

9.5 Future challenges

Concerning research and development of sustainable dairy farming systems, a number of management options for reduced nutrient emissions were presented in Section 9.2.4. However, other indicators such as biodiversity, biotic resources, fossil energy use, greenhouse gas emissions, etc. have to be included as well. Side-effects were often disregarded. For instance, reduced ammonia emissions are likely to result in increased nitrate leaching losses or N_2O release *at a constant level of N input into the farm*. An extended grazing period reduces ammonia volatilization at the farm scale, but increases nitrate leaching in grassland. Such undesirable effects have to be avoided by a coherent conception of measures. Indicator-based methods can help to identify systems that provide a high level of environmental, economic and social sustainability.

Legislation should contribute to responsible nutrient management in agriculture without counteracting this by increased economic pressure on farms. On the other hand, increasing economic pressure can lead to a reduction in 'luxury' external farm inputs such as fertilizer and concentrates, i.e. inputs which are not necessarily related to the level of production. The modulation and other programs of the EU 'green box' represent an essential tool with regard to efficient reduction of nutrient surpluses. National regulations in Germany have to be concretized, which is currently in progress.

Another challenge is the improvement of co-operation and communication between the various relevant persons and sectors (farmers, scientists, the water sector, administration).

References

Aarts, H.F.M., Biewinga, E.E. & Van Keulen, H., 1992.
Dairy farming based on efficient nutrient management. Netherlands Journal of Agricultural Science, 40: 285-299

Anger, M., Schellberg, J., Gan, Y. & Kühbauch, W., 1994.
Extensivierung auf eutrophen Standorten (8-jährige Versuche auf dem Standort Rengen/Eifel). 8. Wissenschaftliche Fachtagung des Lehr- und Forschungsschwerpunktes 'Umweltverträgliche und standortgerechte Landwirtschaft' 1994: Integrative Extensivierungs- und Naturschutzstrategien, Forschungsberichte Heft 15, Faculty of Agricultural Sciences, University of Bonn (Germany), pp. 43-54

Anonymus, 2000.
Rinderreport 2000 – Ergebnisse der Rinderspezialberatung Schleswig-Holstein. Landwirtschaftskammer Schleswig-Holstein (ed.), Betriebswirtschaftliche Mitteilungen der Landwirtschaftskammer Schleswig-Holstein Nr. 544/545

Anonymous, 2003.
Rinderreport 2002. Mitteilungen der Landwirtschaftskammer Schleswig-Holstein Nr. 568/2003

Benke, M., Kornher, A. & Taube, F., 1992.
Nitrate leaching from cut and grazed pastures as influenced by nitrogen fertilization. Proc. 14th Gen. Meeting Europ. Grassl. Fed., Lahti (Finland), pp. 184-188

BMU (German Ministry of Environment), 2000.
Mitteilung der Regierung der Bundesrepublik Deutschland vom November 2000: 2. Bericht gemäss Artikel 10 der Richtlinie 91/676/EWG des Rates vom 12. Dezember 1991 zum Schutz der Gewässer vor Verunreinigungen durch Nitrat aus landwirtschaftlichen Quellen. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)

BMU (German Ministry of Environment), 2002.
Umweltbericht 2002. Bericht über die Umweltpolitik in der 14. Legislaturperiode. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)

BMVEL (German Ministry of Consumer Protection, Nutrition and Agriculture), 2003.
Ernährungs- und agrarpolitischer Bericht der Bundesregierung (Agrarreport) 2003. Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft (BMVEL)

Bobe, J., 2003.
Vergleich der Nitratkonzentrationen im Grund- und Sickerwasser bei variierter Grünlandbewirtschaftung auf sandigen Böden Norddeutschlands – Erste Ergebnisse. Mitteilungen der AG Grünland und Futterbau, 5: 263-266

Büchter, M., Wachendorf, M. & Taube, F., 2001.
Nitratauswaschung unter Silomais in Abhängigkeit von der Bewirtschaftungsform und der N-Düngungsintensität – Ergebnisse aus dem N-Projekt Karkendamm. AG Grünland und Futterbau – Tagungsband 45: 75-77

Büchter, M., Wachendorf, M. & Taube, F., 2002.
Nitrate leaching from permanent grassland on sandy soils – Results from an integrated research project. In: Durand J.-L., Emile J.-C., Huyghe C. and Lemaire G. (eds.) Multi-function grasslands. Proc. 19th Gen. Meeting Europ. Grassl. Fed., La Rochelle (France), pp. 668-669

Büchter, M., 2003.
Nitratauswaschungen unter Grünland und Silomais in Monokultur auf sandigen Böden Norddeutschlands. PhD thesis, Faculty of Agricultural Sciences, Kiel University (Germany)

CEC (Commission of the European Communities), 2002b.
Implementation of Council Directive 91/676 EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Synthesis from year 2000 member states reports. COM(2002)407, Brussels, 2002

Christoffers, K., 2003.
Rentabilität der Milcherzeugung in Deutschland im internationalen Vergleich. International Farm Comparison Network (IFCN), Institute of Farm Economics and Rural Studies, Federal Agricultural Research Center (FAL), Braunschweig (Germany)

DMK (German Maize Commitee), 2003.
Bedeutung des Maisanbaues in Deutschland. Deutsches Maiskomitee (DMK) www.maiskomitee.de/fb_fakten/

Doll, H., 1999.
Betriebliche Konzentration und räumliche Schwerpunktbildung in der Milchkuhhaltung. Wissenschaftliche Mitteilungen der Bundesforschungsanstalt für Landwirtschaft (FAL). Landbauforschung Völkenrode, 49: 200-223

Flaig, H., Lehn, H., Pfennig, U., Akkan, Z., Elsner, D. & Waclawski, N., 2002).
Umsetzungsdefizite bei der Reduzierung der Nitratbelastung des Grundwassers. Materialienband der Akademie für Technikfolgenabschätzung Baden-Württemberg, Stuttgart

Fleischer, E., 1998.
Nutztierhaltung und Nährstoffbilanzen in der Landwirtschaft. Angewandte Umweltforschung, Band 10. Analytica Verlagsgesellschaft, Berlin

Frater, B., Boumans, L. J.M., Van Drecht, G., De Haan, T. & De Hoop, D.W., 1998.
Nitrate monitoring in groundwater in the sandy regions of The Netherlands. Environmental Pollution, 102: 479-485

Haakh, F., 2003.
Agrar-Reform und Grundwasserschutz. Wasser Abwasser 144: 13-22

Happe, K., Kilian, B. & Kazenwadel, G., 2001.
Environmental pressures and national environmental legislation with respect to nutrient management – Germany. In: P. De Clercq, A. C. Gertsis, G. Hofman, S. C. Jarvis, J. J. Neeteson and F. Sinabell (eds.) Nutrient management legislation in European countries. Wageningen Pers, pp. 170-187

Hüging, H., 1997.
Auswirkungen unterschiedlicher Weideverfahren im Bergischen Land auf den Nitrataustrag, die Futterproduktion und die Weideleistung. PhD thesis, Faculty of Agricultural Sciences, University of Bonn (Germany)

IFCN, 2001.
Dairy Report 2001 – Status and prospects of typical dairy farms worldwide. International Farm Comparison Network (IFCN), Institute of Farm Economics and Rural Studies, Federal Agricultural Research Center (FAL), Braunschweig (Germany)

Jovanovic, N.J., Wachendorf, M. & Taube, F., 2000.
Impact of a grass understorey on the performance of silage maize. In: Søegaard K., Ohlsson C., Sehested J., Hutchings N. J., Kristensen T. (eds.) Grassland farming. Balancing environmental and economic demands. Proc. 18th Gen. Meeting Europ. Grassl. Fed., Aalborg (Denmark), 2000, pp. 446-448

Kayser, M., Müller, J. & Benke, M., 2003.
Vergleich von Weissklee-basierten Grünlandflächen mit mineralisch N-versorgten Grasbeständen im Hinblick auf Parameter des Nährstoffaustrags. Mitteilungen der AG Grünland und Futterbau 5: 283-286

Konyali, A., 2001.
Effects of synchronous and asynchronous concentrates on performance and efficiency of nitrogen utilization of lactating dairy cows. PhD thesis, Faculty of Agricultural Sciences, Kiel University (Germany)

Kornher, A., Nyman, P. & Taube, F., 1991.
Ein Computermodell zur Berechnung der Qualität und Qualitätsveränderung von gräserdominierten Grünlandaufwüchsen aus Witterungsdaten. Das wirtschaftseigene Futter 37: 232-248

Kühbauch, W., Dahmen, P. & Thome, U., 1991.
Veränderung der Grundfutterproduktion als Folge einer Umstellung von konventioneller Mähweidenutzung auf extensive Schnittnutzung auf dem Standort Rengen. Das wirtschaftseigene Futter 37: 100-112

Lantinga, E.A. & Groot, J.C.J., 1996.
Optimization of grassland production and herbage feed quality in an ecological context. In: Groen A. F. and van Bruchem J. (Eds.) Utilization of local feed resources by dairy cattle. EAAP Publication No. 84, Wageningen Pers, pp. 58-66

LANU (Office for Nature and Environment), 2000.
Trendmessnetz 1995-2000. Landesamt für Natur und Umwelt des Landes Schleswig-Holstein (LANU)

LAWA (Working Group on Water of the German Provinces), 1995.
Bericht zur Grundwasserbeschaffenheit: Nitrat. Länderarbeitsgemeinschaft Wasser (LAWA)

LAWA (Working Group on Water of the German Provinces), 2000.
Gewässerschützende Landbewirtschaftung in Wassergewinnungsgebieten. Länderarbeitsgemeinschaft Wasser (LAWA)

Müller, J. & Eiler, T., 1995.
Betriebsbedingte Nährstoffbilanzen am Beispiel des Futterbaubetriebes. In: Bundesarbeitskreis Düngung (BAD) (Ed.) Nährstoffbilanz im Blickfeld von Landwirtschaft und Umwelt. Tagung des Verbandes der Landwirtschaftskammern e. V. und des Bundesarbeitskreises Düngung (BAD) am 29. und 30. März 1995 in Würzburg, pp. 44-51

Over, R., 2001.
Rinderreport Baden-Württemberg. Ergebnisse der Rinderspezialberatung in Baden-Württemberg im Wirtschaftsjahr 2000/01. LEL Schwäbisch-Gmünd

Penning, P.D., Rook, A.J. & Orr, R.J., 1991.
Patterns of ingestive behaviour of sheep continuously stocked on monoculture of ryegrass or white clover. Applied Animal Behavior Science, 31: 237-250

Rotz, C.A., Wachendorf, M., Herrmann, A., Kornher, A. & Taube, F., 2002.
A modelling approach to management impacts on nitrogen fluxes in specialized dairy farms. In: Durand J.-L., Emile J.-C., Huyghe C. and Lemaire G. (eds.) Multi-function grasslands. Proc. 19th Gen. Meeting Europ. Grassl. Fed., La Rochelle (France), pp. 728-729

Scheringer, J., 2002.
Nitrogen on dairy farms: balances and efficiency. PhD thesis, Faculty of Agricultural Sciences, University of Göttingen (Germany)

STMLF (Bavarian Ministry of Agriculture and Forestry), 2003.
Die Landwirtschaft in Oberbayern – Situation und Entwicklungstendenzen. Bayerisches Staatsministerium für Landwirtschaft und Forsten (STMLF)

Südekum, K.H., Taube, F., Wörner, M. & Pabst, K., 1994.
Slot-seeding of white clover into a permanent pasture: impact on nutritive value estimated in vivo and in vitro. Das wirtschaftseigene Futter 40: 129-141

Taube, F. & Wachendorf, M., 2000.
The Karkendamm Project: A systems approach to optimize nitrogen use efficiency on the dairy farm. In: Søegaard K., Ohlsson C., Sehested J., Hutchings N. J., Kristensen T. (eds.) Grassland farming. Balancing environmental and economic demands. Proc. 18th Gen. Meeting Europ. Grassl. Fed., Aalborg (Denmark), pp. 449-451

Theiss, H., 1989.
Zur Dynamik der Nitrat- und Wasservorräte verschiedener Bodenschichten in Abhängigkeit von Hauptbestandsbildner, Narbendichte und N-Düngung. PhD thesis, Faculty of Agricultural Sciences, Justus-von-Liebig University, Giessen (Germany)

Trott, H., Ingwersen, B., Wachendorf, M. & Taube, F., 2002.
Management of permanent grassland for reduced nitrogen surplus – Results from an integrated research project. In: Durand J.-L., Emile J.-C., Huyghe C. and Lemaire G. (eds.) Multi-function grasslands. Proc. 19th Gen. Meeting Europ. Grassl. Fed., La Rochelle (France), pp. 744-745

Trott, H., 2003.
Mittelfristige Auswirkungen einer variierten Bewirtschaftungsform und N-Intensität auf Leistungsparameter und die Stickstoffbilanz von Dauergrünland. PhD thesis, Faculty of Agricultural Sciences, Kiel University (Germany)

UBA (Federal Environment Agency), 2001a.
Abschlussbericht zum Projekt 'Anpassung der deutschen Methodik zur rechnerischen Emissionsermittlung an internationale Richtlinien sowie Erfassung und Prognose der Ammoniak-Emissionen der deutschen Landwirtschaft und Szenarien zu deren Minderung bis zum Jahre 2010'

UBA (Federal Environment Agency), 2001b.
Nationales Programm der Bundesrepublik Deutschland nach Art. 6 der Richtlinie 2001/81/EG vom 23. Oktober 2001 über nationale Emissionshöchstmengen für bestimmte Luftschadstoffe

Volkers, K., Wachendorf, M. & Taube, F., 2001.
Steigerung der N-Effizienz im spezialisierten Milchvieh-/Futterbaubetrieb durch Futterbau in Fruchtfolgen – Erste Ergebnisse. AG Grünland und Futterbau – Tagungsband 45: 79-81

Volkers, K., Jovanovic, N.J., Wachendorf, M. & Taube, F., 2002.
Management of forage maize for reduced nirogen surpluses – results from an integrated research project. In: Durand J.-L., Emile J.-C., Huyghe C. and Lemaire G. (eds.) Multi-function grasslands. Proc. 19th Gen. Meeting Europ. Grassl. Fed., La Rochelle (France), pp. 744-745

Volkers, K., Wachendorf, M. & Taube, F., 2003.
Leistungsfähigkeit und N-Effizienz einer Futterbau-Fruchtfolge im Vergleich zum Bewirtschaftungssystem Dauergrünland/Maismonokultur. Mitteilungen der AG Grünland und Futterbau 5: 149-152

Wachendorf, M. & Taube, F., 2001.
Artenvielfalt, Leistungsmerkmale und bodenchemische Kennwerte des Dauergrünlands im konventionellen und ökologischen Landbau in Nordwestdeutschland (Plant species diversity, features of productivity and soil characteristics in grassland from conventional and organic agriculture in northwest Germany). Pflanzenbauwissenschaften 5: 75-86

Wachendorf, M., Büchter, M., Ingwersen, B. & Taube, F., 2002.
Management impacts on nitrogen fluxes and nitrogen losses in grassland systems: results from an integrated project. In: Durand J.-L., Emile J.-C., Huyghe C. and Lemaire G. (eds.) Multi-function grasslands. Proc. 19th Gen. Meeting Europ. Grassl. Fed., La Rochelle (France), pp. 746-747

Wetterich, F. & Haas, G., 1999.
Ökobilanz Allgäuer Grünlandbetriebe. Schriftenreihe Institut für Organischen Landbau, University of Bonn (Germany). Verlag Dr. Köster, Berlin

Wolters, W.
(Landesamt für Natur und Umwelt des Landes Schleswig-Holstein (LANU)) Personal communication, May 22, 2003

Part III. Synthesis and discussion

1. Synthesis and discussion

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1.1 Introduction

The last morning of the workshop was devoted to a plenary discussion about environmental problems related to intensive dairy farming systems, possibilities to solve these problems, research methodologies and ideas about scientific collaboration in the future. To start the discussion, André Pflimlin first presented an overview (1.2 below) of the situation in different countries, based on information from country reports and previous discussions, addressing:

- main characteristics of dairy farming systems in each country;
- state of affairs regarding the implementation of the Nitrates Directive in each country;
- demonstration of the situation in each country in metaphoric terms.

The plenary discussion (1.3) was split into a number of more or less clear-cut topics, i.e. 'maize or grass?', 'grazing or cutting?', 'milk production per cow and per ha', 'leys', 'nitrogen source and fertilization level', 'manure management', 'research methodologies and dissemination of knowledge', 'monitoring of farm performance', 'policy recommendations' and a 'follow-up' session.

1.2 Synthesis: diversity of European dairy farming systems, features of environmental problems and possible solutions

Dairy farming systems in North-West Europe are often very productive per cow and per hectare, but may not be very efficient in their use of minerals, in particular of nitrogen and phosphorous. The Nitrates Directive, aimed at reducing risks of water pollution, provides for the designation of nitrate vulnerable zones (NVZs) where a number of compulsory measures apply. These NVZs cover most of the regions with intensive dairy farming extensively, others still being under discussion with the Commission. Among the most restrictive measures for livestock farmers is, without doubt, the limitation of stocking rate by using the threshold of 170 kg of nitrogen of animal origin (Nanim) per hectare, which gives rise to much debate about two aspects in particular:

- it is the nitrogen surplus that pollutes, hence not only nitrogen that comes from animals,
- one single threshold of 170 Nanim for the whole of Europe has little scientific, agronomic or environmental justification.

Special derogations to exceed this threshold are explicitly provided for in the Nitrates Directive, but ways to access these are not very clear. Only Denmark has obtained special dispensation, of a fairly limited range and duration. Consequently, the 170 kg Nanim threshold usually appears as a fixed limit that must not be broken but which every country interprets it in its own way, with its own references for animals and land areas or allowing higher thresholds without having the support or dispensation of the Commission. The focus on this threshold, and therefore on only one of the means, and not necessarily the most relevant one, should be reconsidered during implementation of the

Water Framework Directive. This Directive obliges Member States to comply with a wide range of quality indicators for all aquatic environments in 2015, but leaves more initiative to regional structures around catchment basins.

The objective of this contribution is to give a progress report on the state of knowledge required at the farm scale to improve practices and reduce emissions to a satisfactory level as regards drinking water and risks of eutrophication, by better integrating the diversity of environments and livestock problems. We will elaborate on two aspects:

- the diversity of typical dairy farming systems and regions, as well as the diversity, but also complementarity, of their environmental problems, using the metaphor of the mountain and the rock.
- the spatial representation of some environmental indicators at European level.

1.2.1 Diversity of dairy systems and environmental typology

The most intensive dairy farming systems in Europe are in three major types of environments (Pflimlin & Todorov, 2003).

1) Areas of fodder crops on light soils that are easy to plough in the North-West of continental Europe. It is on these sandy soils, often originally very poor before the arrival of mineral fertilisers and intensification of livestock farming, that the most intensive livestock systems have developed. This group includes Flanders, the South and East of The Netherlands, North Germany, Jutland and Brittany. Intensive dairy farming systems and systems for finishing young cattle are both present, with forage systems based on temporary grassland and maize silage. Other farming sectors commonly present in these regions include more or less landless pig and poultry farming and horticulture, including arboriculture and vegetable cropping. Because of the high added value of products from these sectors, their presence considerably increases the price of land. The most overloaded situations are unquestionably found in the South and East of The Netherlands, but also in Flanders, with an organic nitrogen load of 300 kg Nanim per ha AA! Within specialised dairy farming systems, however, the organic nitrogen load generally remains between 150 and 250 kg Nanim per ha AA.

2) Grassland regions in the plains, characterised by intensive grassland management, where dairy farming has developed on soils that are more difficult to plough. This comprises the West of England, Ireland, Wallonia and Friesland, with stocking rates of 2 to 2.5 LU per ha, thanks to mineral nitrogen fertiliser applications of 200 to 300 kg N per ha. In these regions, the competition for land has been linked to dairy production profitability. Here permanent grassland and pasture still predominate.

3) The dairy regions of the Mediterranean region, more limited in extent but also highly intensive, based on irrigated maize and rye-grass as a catch crop, with stocking rates of 3 to 4 cows per hectare. Here, too, land is scarce and expensive, and the purchase of forage, in particular maize silage, is frequent and quantities of purchased concentrates often exceed 3 tons per cow per year. Regions belonging to this group are the Plain of the Po in Italy and northern Spain and Portugal. During this seminar, these regions were represented only by North Italy, but a project is currently in progress with the Basque Country and Galicia in Spain and the North of Portugal. In these regions, dairy intensification is relatively recent and not yet much restricted by the Nitrates Directive because there is not yet a problem of water quality, at least for drinking water. However, these partially landless dairy systems with no manure spreading contracts do not seem very sustainable given the evolution of European regulations. In this context, the Parmesan system of Emilia Romagna shows that the quality route, with milk from lucerne hay and concentrate, may be an alternative solution, reconciling economy and ecology and preserving the gastronomic and cultural heritage in a region with very intensive crops where land is expensive. However, this example cannot be generalised because it benefits from the geographical protection of PDO (Protected Designation of Origin).

We have taken information from typical dairy farming systems in each region (Table 1) and grouped it together according to three criteria that together make up the metaphor used at this workshop (see Box in Introduction chapter): the mountain, the rock and practices to stabilise the rock.

- The mountain represents the soil, climate and hydrological environment that have to be dealt with. This also includes the proportion of permanent grassland, duration of crop cover and regularity of plant growth, bearing capacity of the pasture and ease of ploughing for the grass-maize-cereals balance.

When a system on a sandy soil, based on forage crops and with the soil left bare in winter, is combined with heavy inputs of slurry, there is a high risk of nitrate leaching. In terms of the metaphor, the mountain is steep. Conversely, in grassland regions with more clayey soils, drainage and leaching of nitrogen surpluses will be limited, even with heavy rainfall. Here 'the mountain flattens out' and the leaching risk is low, at least for the water tables.

- The rock represents the intensity of livestock farming as expressed in, for example, stocking rate, load of animal nitrogen or quantity of milk per hectare of AA. The larger the value of these indicators, the greater the potential risk, as the capacity for recycling nitrogen by the soil is limited and manure treatment costly and not very well developed. Reducing the size of the rock is often constrained by the lack of land and/or its high price (€15 to 30 000 per hectare in many regions of Europe, against €3 to 6 000 in France including Brittany). On the other hand, a given amount of milk can be produced in many different ways (for example with 'many' low-productive cows or 'few' high-productive cows and/or with much or few grazing), as shown in Table 1. Ireland with a grazed-grass dairy system, Flanders with a mixed maize-grass system and North Italy with a forage system based on lucerne, all produce about the same quantity of milk per hectare, but with very different types of cows and feeding systems.

- Stabilising of the rock requires management practices of the livestock farmer to reduce environmental risks. Some examples of 'insurance' against pollution include balanced fertilisation, good use of farm-produced fertiliser ('applying the right amount at the right time'), soil cover in winter and a balanced crop choice. These are all short term actions, often not very expensive (apart from the increase in slurry storage capacity) but requiring observation and anticipation, i.e. good management skills.

When these three types of information come together for one type of risk, for example nitrate leaching towards aquifers, a relative hierarchy can be established for each region and it can be seen what are the most crucial points in each region. The exercise of translating the agri-environmental situations in countries/regions in metaphoric terms proved to be very enlightening during the seminar, even if there was not always unanimity in qualifying the most risky situations. But like any simplification, the exercise has its limits. In the present case, it is relatively simple to use, as we considered only one risk indicator: nitrate leaching. It would be necessary to combine different risks associated with leaching on the one hand, with those associated with run-off on the other, both of them relative to a type of environment, then treat risks that contribute to air pollution in another approach. The needs to do this are of course much wider than nitrogen based issues and relate also to methane, carbon balance, biodiversity etc.

Table 1. Main characteristics of typical intensive European dairy farming systems and translation in terms of the rock/mountain metaphor: the rock on top of the mountain.

	Belgium Flanders	Denmark	The Netherlands		France Brittany W	Germany Schl - Holst	England South West	Ireland South West	Italy	
			South East	North West					Piemonte	'Parmensan'
Sensitivity to leaching										
Type of soil	Sandy loam	Sandy	Sandy	Clay loam	Sandy loam	Sandy loam	Clay loam	Clay loam	Clay loam	Clay loam
Climate										
- Summer	Mild dry	Mild dry	Mild dry	Mild wet	Mild wet	Mild dry	Mild wet	Mild wet	Hot dry	Hot dry
- Winter	Mild wet	Cold wet	Cold wet	Cold wet	Mild wet	Cold wet	Mild wet	Mild wet	Cold wet	Cold wet
% permanent grassland	40	15	65	75	50	60	80	100	-	75
Water resources	Groundwater	Groundwater	Groundwater	Surface water	Surface water	Groundwater	Groundwater	Surface water	Groundw. + surface water	Groundwater
Mountain / slope	*steep*	*steep*	*steep*	*shallow*	*steep*	*moderate*	*moderate*	*moderate*	*variable*	*variable*
Livestock intensity										
Milk production (kg cow^{-1} $year^{-1}$)	6 000	7 500	7 500	7 500	6 00	7 500	6 000	5 000	6 700	6 100
Milk production (kg ha^{-1} AA)	10 000	7 000	13 500	12 000	6 500	6 000	7 400	9 600	16 000	11 000
Concentrate use (kg cow^{-1} $year^{-1}$)	1 100	2 000	2 000	2 000	1 000	2 000	1 500	600	+ 3 000	+3 000
Animal N excretion (kg ha^{-1} AA)	250	150	230 (+50)	230	125	120	160	250	300	200
Size of the rock	*big*	*moderate*	*big*	*big*	*moderate*	*moderate*	*moderate*	*moderate*	*big*	*big*
Management practices										
% grazed grass in annual diet	30	15	30	40	35	35	45	70	-	-
% annual crops (maize, cereals)	60	70	35	25	50	40	20	-	-	25
% bare soils	30	35	(10)	10	20	10	-	-	-	10
Mineral N (kg ha^{-1})	180	100	285	300	100	130	250	250	120	40
N surplus (kg ha^{-1})	200	170	400	380	140	160	280	300	340	300
Importance of good management	*high*	*high*	*high*	*high*	*high*	*moderate*	*moderate*	*moderate*	*high*	*low*
Nitrate in groundwater (mg l^{-1})	50	25-40	+50	30-40	30-50	25-50	20-40	20-30	20-50	20-50

1.2.2 Careful use of map statistics to estimate the risk factors for water pollution by nitrates

Dairy farming systems often exist alongside other livestock and crop systems which can attenuate or aggravate the risks of water pollution. A more global approach may shed a different light on the situation. The need to do this is well demonstrated by the requirements of the Water Framework Directive. The chosen risk factors are the following:

1. Pressure of nitrogen of animal origin and by fertilisers per hectare of AA.
   Animal numbers per category and the AA are supplied by the European census of 2000. However, the value of nitrogen excretion per type of animal is not harmonised within the EU, causing variations of up to a factor 2 for a given animal type. So as a first simplified representation, we have chosen standard French excretion values, which we have applied to all countries so as to have a homogeneous reading of animal nitrogen pressure (Map 1). Map 1 shows that the dairy regions in North-West Europe have the highest animal densities, a certain number of them exceeding the threshold of 170 kg Nanim per hectare AA at a departmental or even regional level.
   Depending on the purpose, the accuracy of Map 1 could be improved by the following modifications:
   - If the purpose is to get a better picture of the regulatory pressure upon farmers, the standard French excretion values would have to be replaced by the standard excretion values used in each country.
   - If the purpose is to get a better picture from a scientific point of view, the standard French excretion values would have to be replaced by excretion values corrected for volatilisation losses according to the latest scientific information in each country. Also the land areas used for agriculture could be determined in a more precise way.

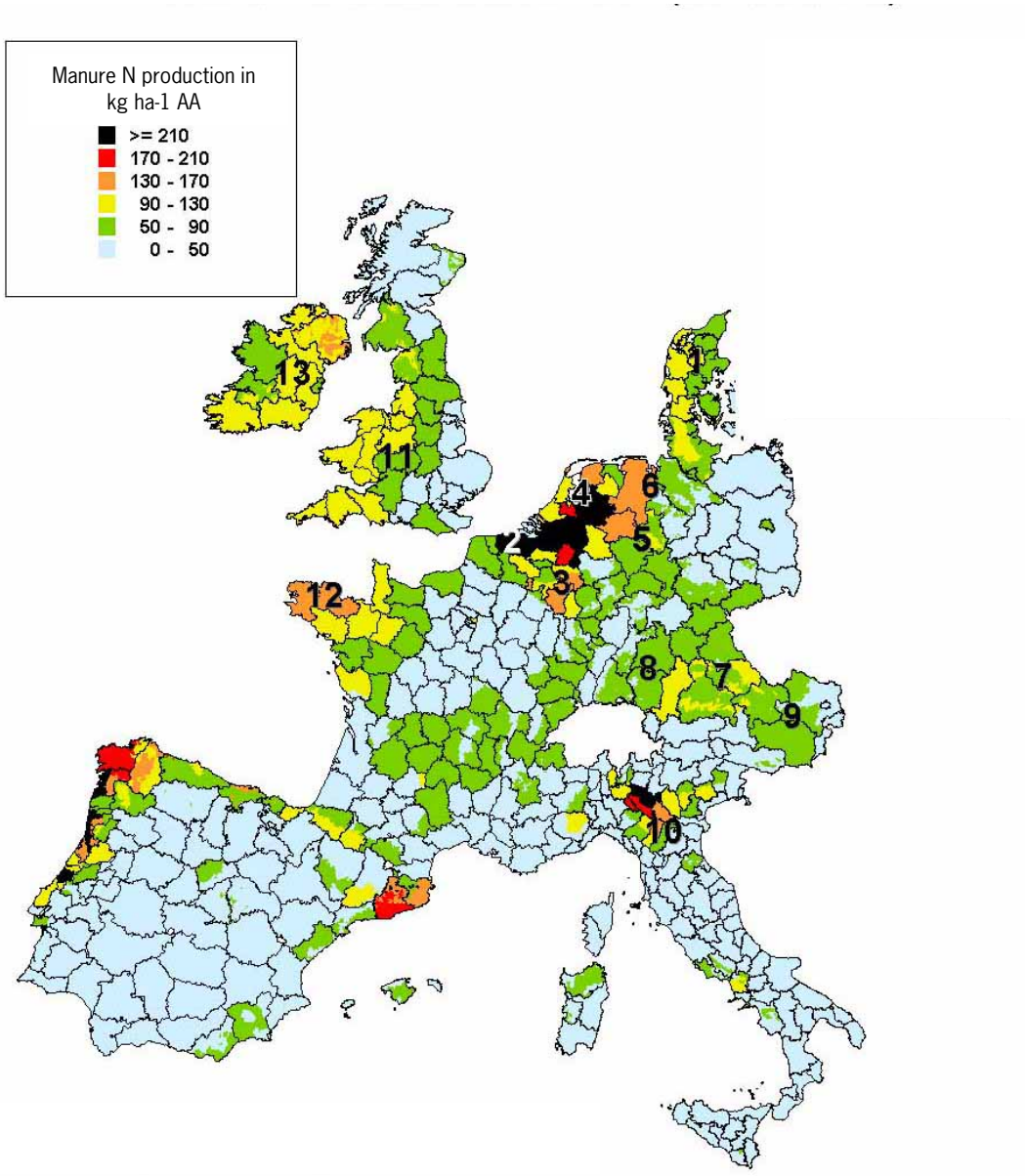
2. Nitrogen surplus per ha AA.
   For the estimation of nitrogen surpluses, a soil-surface balance is used, with, as inputs mineral and organic N, and with exports with crops and forages at the scale of the canton, region or country as outputs. Maps have been published by Eurostat (1997) where intensive livestock farming areas generally prove to be among the ones with the highest surpluses (Map 2). But some surprising results can also be observed:
   - North Italy appears to have a lower surplus than the South,
   - Despite having a higher animal density, Northern Ireland appears to have a lower surplus than the Republic of Ireland.

   This is an incentive to look more closely at the reference data and calculation rules used, and carry out research into this subject with a group of experts from the different countries. Among the possible improvements is a better quantification of the quantities of mineral fertilisers used. This quantity is quite well known at national and regional scales, but becomes imprecise at a more local level, if balances at the level of catchment basins or cantons are to be made.

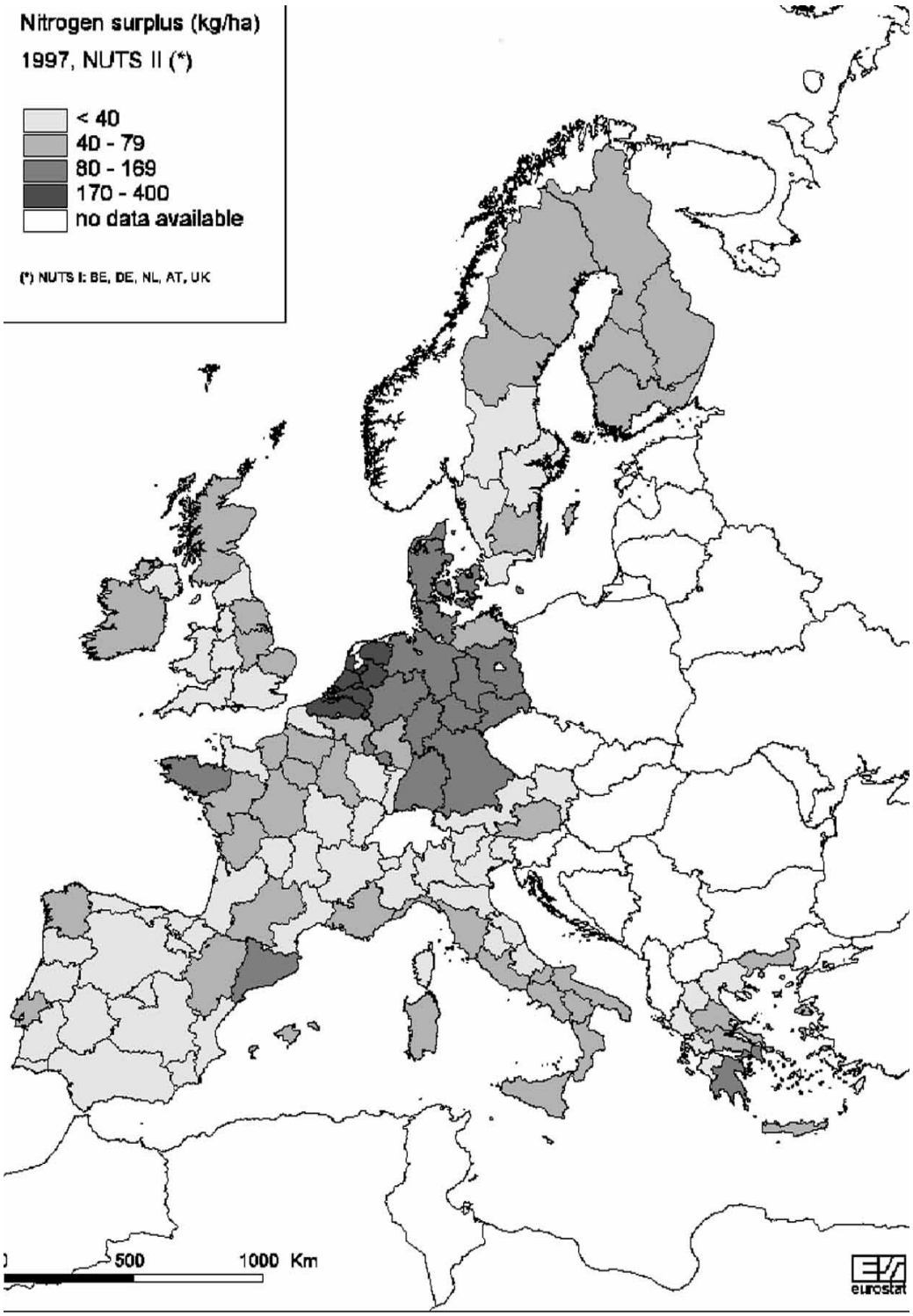
3. Sensitivity to leaching.
   The two factors that determine leaching risks are drainage water volume and soil type as assessed by soil water retention capacity. The BURNS model (1976) enables us to assess the nitrogen fraction which is likely to be leached, taking into account these two factors. A priori, the sandy soils of The Netherlands and Jutland are soils at risk. Conversely, a large part of the Plain of the Po, with a layer of clay loam several metres thick (30 to 50% clay), is an area at low or moderate risk. However, this model is only suitable in fairly flat areas and when there is vertical drainage only. It is not suitable for either mountains and foothills or for hydromorphic areas. In the latter case, not only drainage will be reduced, there may also be more 'leaching' in surface run-off and denitrification becomes more important. Consequently, Map 3, illustrating sensitivity to leaching, has to be used with considerable caution. Having said that, it does show that:
   - the most intensive livestock farming regions in the EU, with strong pressure in organic nitrogen and total nitrogen, are also regions with high leaching risk: West Brittany, Flanders, the South and East of The Netherlands, Schleswig-Holstein and Jutland.

- the grassland dairy areas of the British Isles can also be sensitive to leaching, i.e. when there are sandy soils or granitic sands. Conversely, where there is grassland on soils of hydromorphic clay loam, drainage is very much reduced (but there is still significant leaching in surface and subsurface transfer of water) and denitrification can be high, resulting in two types of opposing situations in the same climatic region. However, all these regions are characterized by heavy rainfall, thus benefiting from a significant dilution effect, reducing nitrate concentrations per volume unit of water.

Map 1. Production of manure N in NUTS-regions of Europe per ha AA in 2000.

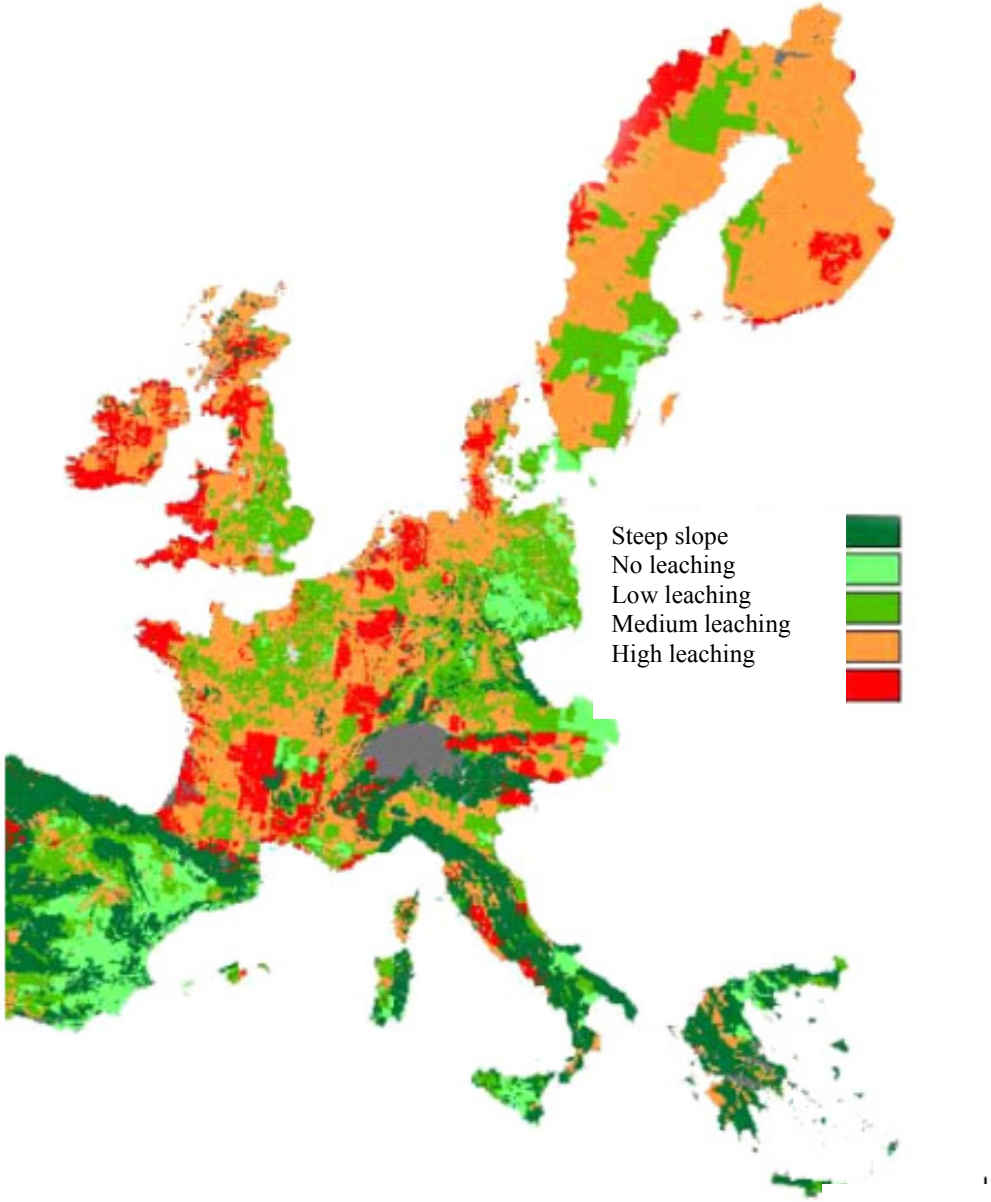


Map 2. Nitrogen surplus calculated according to a soil-surface balance[1] (Eurostat 1997).



1 Inputs: mineral N + manure N. Outputs: exports with forages and crop produce.

Map 3. Sensitivity to nitrate leaching (Delaunay 2002)[1].



These three indicators, organic N loads, N surpluses per ha and sensitivity to leaching, should make it possible to predict in an indicative way the quantities of leachable nitrogen, according to the type of environment, and compare them with the values observed. However, the links are too weak to show up at this scale. Other characteristics also intervene, e.g. types of crops, the proportion of AA relative to the total land area, size of forested areas, etc.

The observed values of nitrate concentrations in ground or surface waters are very heterogeneous, as are sampling point densities and sampling frequencies within countries and, even more so, between countries. But the quality of the maps incorporated by the Commission (Com., 2002) ought to make progress for the new combined report planned for 2005.

1 Sensitivity to leaching is estimated with the Buns model (1975) in which drained water plays a major role. This model can only be used in soils where drainage can occur and with little slopes.

1.2.3 Conclusions

The two approaches followed here, characterising typical dairy farming systems and the cartography of risk indicators, potentially enable more transparent and constructive exchanges between R&D partners in the different dairy regions of the EU. However, each approach raises more new questions than it solves, caused by the complexity of interactions between environmental phenomena and livestock systems. One major complicating factor is the unfolding of environmental phenomena at very different scales of space and time.

The single threshold of 170 kg Nanim is not the most suitable indicator, neither from an agronomic point of view, nor from a water quality point of view, because it is the surplus of total mineral and organic nitrogen that has potential to pollute. The first and fastest step, and the least expensive for the farmer and the community, consists first of all of reducing, if not ceasing purchases of N and P mineral fertilisers and making better use of farm manure fertilisers.

Reducing the nitrogen surplus will often have little effect on nitrate concentration in waters in the medium term, because of the dual inertia of organic matter accumulated in the soil and the size and the long term nature of changes occurring in the aquifers, even in the case of surface waters. On the other hand, knowledge of the mechanisms of eutrophication phenomena is still insufficient to decree standards in the matter. Finally, following the mode of thought adopted in the Water Framework Directive, it would be wise to design integrated farming systems, i.e. farming systems that address all water pollution risk factors simultaneously at different scales. This is shown in the thematic debates and discussions that follow.

1.3 Plenary discussion

Maize or grass?

In many regions of Europe, maize plays an important role in dairy farming systems, with its area still increasing in some regions. The popularity of maize is attributable to some advantages of maize over grass: dry matter yields can be higher, especially in the warmer regions, and needs for water and fertilizers are relatively low. However, protein production capacity and therefore capacity to take up mineral nitrogen are low too although this has advantages in terms of nitrogen intake by cows, see below). Consequently, high or inappropriate slurry applications will cause environmental problems. Because the growing season of maize is relatively short and harvest usually followed by a period of bare soil, nitrate leaching risks from mineralization beyond the growing season are high. Other problems associated with maize are that it is often cultivated on erosion-vulnerable soils, that more herbicides are needed and that it has negative effects on farmland biodiversity. Note, however, that these problems also occur in other non-grass feed crops. Note also that discussions about maize are often prejudiced by the previous bad reputation of maize gained through the practice of 'dumping manure' on maize land.

When discussing the pros and cons of maize, we should not only consider the crop component of the farm system, but the system as a whole. From that perspective, maize can reduce the protein level of the cattle diet and, as a result, reduce nitrogen excretion and related ammonia volatilization and other losses when the manure is spread on land. Deciding between maize and grass thus may influence the balance of losses between NO_3 leaching and NH_3 volatilisation for example.

In the majority of regions, well managed maize can reduce N losses of dairy farming systems, but only if a catch crop like Italian ryegrass (*Lolium multiflorum*) can be grown successfully after harvest of maize. The challenge for system research is finding a good balance between the grassland area and the maize area (or another fodder crop with comparable benefits), and its dependency on farm and regional climatic conditions. Introduction of maize in a permanent grassland system can lead to high nitrate losses, as a result of high mineralization levels in the first years after ploughing the grassland. Therefore the challenge is not only to find the best ratio between maize and grass, but also finding acceptable ways to realise the optimal ratio.

Two other important issues related to the choice of fodder crops were not explicitly dealt with during the workshop: effects on biodiversity and nutritional value, in particular the relationship between fodder quality and biochemical composition and milk composition (with potential interest for human health).

Grazing or cutting?

Currently, economics are the major driving force in deciding between grazing or cutting, with costs of land, investments (stable) and labour being the decisive factors. In some countries (e.g. England and parts of France) farmers are reducing costs by increasing grazing (less investments, less grass to cut and slurry to apply, less labour), whilst farmers in The Netherlands reduce costs by reducing grazing (fewer cows needed because of higher milk yield per cow, lower costs for mineral fertilizer, higher crop yields and therefore less land needed). The opposite strategies selected in the two countries to reach the same goal illustrate the importance of taking into account differences in the physical and socio-economic environment in which dairy farming systems across Europe are embedded. For example, high dry matter production per ha, favoured by cutting, is economically more attractive as land prices are higher, such as in The Netherlands. The decision to restrict grazing is further made easier in northern regions, where high quality stables are a necessity anyway, given the cold winters. In regions with milder winters, such as in Brittany, it is in principle possible to keep the cows outdoors year-round.

Grassland management and N input level interact: in grazed grassland the optimum fertiliser rate is lower than in cut grassland. Despite the lower optimal N input level, grazing generally increases nitrate leaching but reduces ammonia volatilisation. Possibly, increased nitrate leaching by grazing can largely be avoided if grazing during some critical periods is restricted or if stocking rates are reduced. Reduction of ammonia volatilization from stables and slurry storage is possible too, not only by adaptations of the buildings, but also by reducing the protein content of the diet, which is easier to realise in indoor feeding systems. If the size of the farm increases, grazing can become problematic for logistic reasons (not enough grassland near the stable where the cows have to be milked).

Milk production per cow and per ha

There exists a strong and positive relationship between milk production per ha and N surplus per ha. At high milk production levels, additional high quality feed (concentrates) is needed, which often cannot be produced on the farm and so has to be bought. Hence, at high rates of milk production per ha (such as in The Netherlands and Belgium), increased production per cow is more opportune, because feed has to be bought anyway and feed requirements in terms of energy per kg milk are lower with high-productive cattle (fewer animals needed). Moreover, fewer animals on a farm reduces total nutrient excretion, making it easier to comply with the Nitrates Directive, and methane emission is thought to be lower if the proportion of concentrates in the diet is high: reducing cow numbers also will reduce overall methane emission if production per animal is higher and fewer animals are kept. In more extensive systems, high inputs of concentrates reduce net grass yields, because intake of grass is reduced by the higher intake of concentrates. Reduced net yields can cause increased nutrient surpluses, if fertilization level is not adapted to the lower grass production level. High milk production levels per cow are less easy to combine with grazing, because high quality demands of the diet can not be met during some periods (autumn) or weather conditions. In countries where climatic conditions make high quality stables imperative anyway, it can under the milk quota system be economically attractive to have high yielding cows, as a means to reduce fixed costs per cow. High quality feed is easier to produce, if fodder crops (maize, cereals) can be grown. Production of fodder crops is possible in many countries, but for example in Ireland farmers almost completely have to rely on grass, rendering the increase of milk production per cow to a high level less attractive.
Participants generally view high milk productions per ha as risky, requiring excellent management and high investments to avoid environmental problems and high feeding and veterinary costs. Some participants are of the opinion that protein requirements needed to produce one kg of milk increase with an increasing milk production level per cow.

Leys

In general leys produce better yields than permanent grassland, especially during the first years after sowing. Short leys should be regarded by the farmer as an arable crop in an arable rotation. Leys stimulate yields of the other crops in the rotation, partly by improving soil quality and partly by providing nutrients (enhanced mineralization). A combination of leys and maize also provides a wider playing field for manure management than a situation with continuously cropped maize and permanent grassland. Leys do, however, require higher management skills than permanent grassland and investments are high. In the UK, leaching losses increased with the age of the sward.

More research is needed about the role of leys versus permanent grassland in relation to (temporary) storage of carbon in soils and optimal organic matter content of soils, both from an agronomic and environmental point of view. In many countries this is an issue (also reported by the EGF working group 'Grassland resowing and grass-arable rotations', as a result of meetings in 2002 and 2003). There is no agreement among participants about the effects of the length of the ley period on crop productivity and leaching sensitivity in the arable period following the ley period. Leaching is more likely in regions with relatively high temperatures and high rainfall in autumn and winter (e.g. Brittany). In that case, growth of a succeeding (catch) crop after harvest of maize might be limited by reduced light intensity, while the release of nutrients in the soil is very high. Fodder beets can be regarded as an excellent crop to succeed leys but with some additional work and costs.

Nitrogen source and fertilisation level

The type of N fertilizer affects potential losses of ammonia, nitrous oxide and nitrate. For instance, urea is associated with relatively high losses of ammonia. Intensively grazed grassland should be fertilized in general with about 200 kg plant available N at maximum, leading to about 85% of the maximum yield in many situations. Of course, this level varies somewhat, depending on climatic conditions and grazing system. Fertilisation above the recommended agricultural maximum should be avoided, because this has no financial benefit and will substantially increase N losses. In the recommendations some sub-optimal utilisation of nutrients is presupposed. Hence, farmers can reduce the recommended agricultural maximum by 10% without yield losses, provided they optimize the utilisation of fertilizers (better timing, better spreading of manure). There is scope for improving the efficiency of N fertilizer use with greater precision in determining amounts and timing.

White clover can replace mineral N. In farming systems depending on manure and white clover as fertilizers, intensity should be 1.5 to 2.0 livestock units per ha. The benefits of clover in grassland depend on management, but for most countries much is still unclear regarding optimal management in dairy farming systems. An exception is Brittany, which has long and successful experience with clover. Legumes are of course a key component of organically managed systems.

Manure management

Manure plays an important role in the nutrient cycle of livestock systems. Quantity and quality can be managed and management should be strongly connected with farm goals and circumstances but many farmers are still not aware of its quality and optimised management. It might be attractive to produce more than one manure type, for instance one for grassland fertilisation and one for fertilisation of arable crops. It could be attractive to separate solid and liquid fractions. The solid part, with a high C/N ratio, can be used in winter to fix mineral N. However, there are costs associated with these options.

Application of 170 kg manure N can be associated with excessive P inputs, depending on the N/P ratio of the manure. If manure is used properly, most of the intensive dairy farming systems do not need mineral P. The proportion of nitrogen in manure thought to be available for the plant in the first year after application, greatly differs among countries. These differences can only partly be explained by differences in circumstances. This raises the question: what is the basis underlying the fertiliser values in each country? Recent research results indicate that in the near future the fertilising value and biodegradability can be better characterized on the basis of biochemical composition, which can help farmers to appreciate differences in quality and optimise animal manure use.

Methodology of research and dissemination of knowledge

There is much that we know, but also a lot we don't know about the functioning of farming systems and their interactions with the environment. As agronomists we are faced with two main challenges: (1) to unravel hidden structures (a scientific challenge), and (2) to use what we already know to synthesise proper systems or to manage systems in a way that performance is improved (an engineering challenge).

Desk studies may be the most attractive way to integrate the many processes that have to be studied in complex systems, as agricultural systems in general are. Models are important tools for high level systems (for instance a watershed), because the number of involved processes is high and studying all relevant processes in such a system in an experimental way is impossible. A problem of models is that they are based on assumptions, derived from experiments, and that it is often difficult to validate models.
Experimental systems research is very costly and weather conditions have a big influence on outcomes. If a system is large, only parts (sub-systems or selected processes) can be studied extensively. A major advantage of experiments is that important processes can not easily be overlooked, because results of experiments will always reflect reality. Experimental results are sometimes difficult to explain on the basis of existing theories, and therefore unexpected results can force to adapt theories about involved processes.

Research can be done at several hierarchical levels, such as the plot, field or farm scale. For experimental research, the most suitable scales are probably the plot and field scale, because at these scales it is possible to study the effects of single influencing factors isolated from other factors, e.g. effects of changes in fertilisation or grazing intensity. Models at field scale can be used in close association with experimental research to explore ways of further improving management and to uncover gaps in understanding. Models can thus help in directing future experiments. Another key role of models is to help analyse experimental results and extrapolate these to other circumstances.

Compared with the field or crop scale, at the farm scale it is more difficult to restrict research to experiments only. Each farm is unique (therefore replications are hardly possible), a lot of processes are relevant, especially if livestock is involved, and there are important interactions between farm components. The farmer, with his personal interests and skills, is an important part of the system and therefore also has a major influence on farm performance. The difficulty of replicating and the complexity of a farming system increases the need for modelling in research. However, the acceptance of research results by farmers relies to a high extent on the possibility to demonstrate the functioning of the system in real practice, so requiring experimental research and demonstration farms. Hence, a combination of modelling and experimentation has to be used if 'sustainable' livestock farming systems should be developed and introduced in practice. For farmers, the field and animal houses are the preferred venues for exchange of information between researchers and farmers.

Simple, transparent models could be used to estimate effects for a wide range of situations with respect to the individual farm components (livestock, manure, soils and crops) and their management. Outcomes can then be used for the design of farming systems that, in theory, meet the objectives of the farmer and/or governmental policies. Such a model design can subsequently be implemented on an experimental farm and its performance in practice monitored. With the results, models can be improved and used to extrapolate, by assuming other conditions. Pilot commercial farms can play an important role in demonstrating the reliability of the models to practical farmers and they provide more insight into the role of the farmer (skills, goals) and farming conditions (soil type, milk quota) on farm performance. Therefore, pilot farms should also be monitored and analysed, but less intensively than the experimental farm.

Monitoring farm performance

The farm gate nutrient balance is an acceptable indicator for environmental impact. Farm gate nutrient balance data is probably the highest level of detail which is feasible in practice, with acceptable reliability, if large scale monitoring is the aim. Environmental performances of different farms can be mutually compared by comparing farm gate surpluses or surpluses of underlying soil and crop components. The ratio output/input can be regarded as an

indicator for efficiency of utilisation of nutrients in the system. Acceptable levels of surpluses depend on regional conditions (soil type, hydrology, location). Heterogeneity within a farm can be high. P inputs in grassland close to the housing may be high as a result of intensive grazing, while fields at a longer distance may have a much lower P input. How to monitor heterogeneity within farms and what agricultural and environmental damage is caused?

Policy makers (partly) base their decisions on results of monitoring programmes running in EU countries. Ideally, monitoring programmes should use identical protocols in all EU Member States, but in reality this is not the case and there is therefore a need for more uniformity in farm measurements. We should also relate farm performance data to reference data and targets, and we should stress the relevance of accurate monitoring for policy makers.

Policy recommendations

If we, scientists, provide 'bad' data, it is not surprising that policy makers make 'bad' policies. Nevertheless, choosing 170 kg N per ha as maximum application of manure for the whole of Europe does not take into account the large variation between countries and farming systems. From a control point of view, regulations should be much more fine-tuned and scientists should produce region-specific grounds/arguments for that fine-tuning.

As scientists, being better informed on nutrient flows than farmers (and policy makers and politicians??) we should anticipate foreseen policies, much more than in the past. For example, what will be the consequences of implementation of the Water Framework Directive? We know that both P and N in surface waters will get more attention, but it is yet too early to assess what the exact consequences will be. Nevertheless, it would be profitable to foresee how intensive farming systems could cope with the Water Framework Directive.

Follow-up activities

All the participants would like to participate in a follow-up to this workshop, for instance by starting a Working Group Dairy Farming Systems and Environment within the European Grassland Federation (EGF). The scope of the working group could be: 'improving environmental quality by improving nutrient cycling in dairy farming systems, taking into account the consequences for other sustainability issues, notably farm-economics, animal welfare and nature and landscape'. The working group explicitly wishes to address (1) the large diversity in the physical and socio-economic environments in which dairy farming systems across Europe are embedded, which is a pre-condition to design effective, efficient and attractive farm-strategies to improve nutrient cycling and (2) strategies to disseminate knowledge among farmers.

Most of the participants are attending the general EGF meetings. Hence it is attractive to combine workgroup meetings with the EGF meetings. Non-workshop participants are welcome to join our meetings and join the working group. It is the intention to prepare and discuss two 'discussion papers' during each working group meeting and decide upon two new discussion papers for the next meeting. After each meeting, discussion papers can be worked into scientific papers, which can be presented in a plenary session during the following EGF meeting. Thus, our input to each EGF meeting is two 'internal' discussion papers as well as two scientific papers for plenary presentation. Discussion papers for the first meeting are (1) what factors influence the optimal maize/grass ratio and what is the optimal ratio in different regions? and (2) grazing or cutting?

One of the findings of this workshop was that there was no uniformity in calculations of farm gate nutrient balances. Uniformity was particularly lacking with regard to input and output terms included in the balances, severely complicating comparisons of nutrient balances across countries. Therefore, a sub-group 'Nutrient Balances' was initiated (Françoise Vertès, Ib Sillebak Kristensen, David Chadwick and Jaap Schröder) that will work on uniformity of nutrient balance calculations. The sub-group will also address questions related to interpretation of nutrient balance calculations.

A crucial regulation in the Nitrates Directive is that the amount of animal manure that can be applied to farmland each year should not exceed 170 kg N ha^{-1}. Different Member States have adopted different methods to relate 'animal manure applied to farmland' to a corresponding number of animals. During the workshop, a second sub-group ('Livestock Unit Definitions'; André Pflimlin, Ignace Verbruggen, Martin Gierus and Nick Hutchings) was formed which will provide an overview of the different methods applied in the different Member States. This sub-group will probably face some difficulties, namely:

- The method for estimating total N excretion in relation to N intake is quite clear. The proposal made by a Dutch research team (EC, 1999) can be a common base, but estimating volatilisation losses from stables and manure storage and during grazing is much more difficult and varies strongly with the type of building, litter use (nature, quantity), storage cover, climate, etc. This inevitably leads to very different estimates of volatilisation losses between countries. The Dutch study, ordered by the European Commission (DG Environment), does not treat this aspect.
- Official N excretion references per animal category are often a result of national discussion with some socio-economic arguments, which are not easy to put in an equation.

Therefore, in the absence of a more sympathetic attitude of the Commission in showing an interest in quantifying volatilisation losses, any initiative of harmonization by groups of experts will inevitably suffer from a lack of legitimacy and means.

References

COM, 2002.
Implementation of Council Directives 91/676/EEC concerning the protection of waters against pollution caused by Nitrates from agriculture sources. Synthesis from year 2000 Members States reports COM (2002) 407 final

European Commission, 1999.
Establishment of criteria for the assessment of the nitrogen content of animal manures. Final report, 42 pp.

Delaunay V., 2002.
Approches cartographiques de la pollution azotée dans les élevages européens. Rapport de stage – ENSA Rennes, Institut de l'Elevage – ALTERRA - WUR

Eurostat, 1997.
Nitrogen Surplus in Environmental signals 2001 EEA Environmental assessment report N°8-53

Pflimlin, A., & Todorov, N.A., 2003.
Trends in European forage systems for milk and meat production: facts and new concerns in Grassland Science in Europe 8 1-10 EGF Pleven Bulgaria, May 2003

Pflimlin, A., 2004.
Implementation of the Nitrates Directive in 2002-2003 in eight EU Member States and twelve dairy regions. Institut de l'Elevage – MAAPAR June 2004

Appendix I.
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Appendix II.
Case study farms

Country teams were asked by the organising committee to prepare an oral presentation of a case study farm, typical for the country. Explicit consideration of case study farms served to provide participants an overview of the very different farm situations in Europe, and different ideas to improve performance. During the morning of the second day, small groups were formed and each group discussed two case-study dairy farms from two different and rather 'contrasting' countries, focusing on environmental problems and potential measures to improve farm performance. Group results as reported below were presented in a plenary session.

1. Belgium and Italy

Secretary: Martin Gierus

Farm characteristics

The main characteristics of the Flemish and Italian farm are shown in Table 1. The Flanders/Belgium farm represents the average specialized farm in this region, i.e. representative of farms where at least 95% of the farm income stems from dairy activities. The majority of these farms is located on sandy soils and average N surplus in 2001 was 199 kg ha^{-1} yr^{-1}.
The Italian farm was typical of the Parmigiano-Reggiano production area (plain zone) in the mid 1990s, relying more on alfalfa cultivation. In this area strict regulations apply regarding the use of forage crops and animal feeds. It is forbidden to feed silage or industrial by-products to the cows.

Table 1. Main characteristics of the Belgian and Italian case study farm.

	Belgium	Italy
Growing season (days $year^{-1}$)	200	275
Precipitation (mm)	700	800
Stocking rate (milking cows ha^{-1})	3.0	1.8
Milk production per cow (kg yr^{-1})	5827	6130
Concentrates fed (kg milking cow^{-1} yr^{-1})	1132	2350
Milk production per ha (kg ha^{-1})	9643	10900
Forage:Maize:Other area	39:26:35	86:0:14
Manure import/export	Very few	Import of pig slurry, export of dairy manure
Irrigation	No	Yes
Grazing	Yes	No
Farm N surplus (deposition excluded) (kg ha^{-1} yr^{-1})	199	324

Environmental issues

The main environmental problems in the Belgian case are related to the dairy activity itself. Several factors contribute, such as soil type (sandy soils), stocking rates and climate. Due to legislation, there is scope for more environmentally friendly dairy farming in the future. Results of water quality monitoring programmes show a decreasing nitrogen load to surface waters since 1989. Farm N surplus also decreased, i.e. from 340 in 1989 to 199 kg ha^{-1} yr^{-1} in 2001.

The main environmental problems in Italy are eutrophication of surface waters, rising nitrate concentrations in groundwaters and high inputs of phosphorus and heavy metals in soils repeatedly treated with manure or sewage sludge. Losses of N to the air from these dairy systems are generally high, due to climatic conditions and manure management practices. Also, there has been a growing problem of a shortage of water for irrigation purposes. Furthermore, the region is characterised by intensive pig production, in which animals are partly fed with the whey coming from cheese production.

Potential solutions

The solutions envisaged in the Belgian/Flemish case are:

- Improvement of the utilisation of nutrients in manure, i.e. better timing of manure spreading and lower doses.
- Provide more information from case studies to define ceiling values for mineral N in the soil, N leaching and N in surface and groundwater, and to support policy recommendations.
- Stricter legislation for phosphate, which currently allows a maximum of 30-40% saturation in the soil.

Remaining problems are related to uncertainty about the organic N composition of slurry and farm yard manure and feasible management options for the post-harvest period, such as the use of (undersown) catch crops, especially for maize. One solution would be to advise the farmer to perform a regular analysis of slurry and/or farm yard manure composition.

The solutions envisaged in the Italian case are:

- Change towards a more effective use of nutrients in manure, i.e. by modifying application times and improving spreading techniques (i.e. band spreading or incorporation as soon as possible, at least within 6 hours for slurry and 24 hours for solid manure).
- Spreading of manure on alfalfa fields to reduce both N fixation by the alfalfa crop and manure application rates on permanent meadows, at the same time saving mineral P and K fertilisers.
- Optimise the use of animal feed, to reduce the need for imported feeds.
- Completely stop the input of mineral P.

These objectives can be achieved mainly by improving farmers' skills. Currently, an organised flow-system of information on optimal nutrient management from experimental situations to commercial farms does not exist in Italy. Such a system could be established by working with a small number of farmers to achieve better nutrient management and subsequently use these as examples/demonstration farms for the wider farming community. Environmental legislation in Italy imposes only a few restrictions on dairy farmers, with the main focus on nitrogen. Phosphorus and heavy metal inputs and losses are not yet a focus of attention. Policy strategies include the reinforcement of incentives for better manure storage, transport and spreading.
There are only a few reliable data on ammonia emissions from these types of farms and applicable under Italian conditions. Within the framework of the MIDAIR European Project, CRPA is collecting data on nitrous oxide emissions from different crop rotations within dairy farms.

2. England and Germany

Secretary: Carlo Grignani

Farm characteristics

The main characteristics of the English and German farm are shown in Table 2. The British farm is a typical commercial dairy farm in Devon (South West of England). The data presented here were collected through a specific interview and the compilation of check sheet in conversation with the farmer. The British farm is not located in a nitrate vulnerable zone.

For Germany, the case-study farm refers to the average commercial farm in the Schleswig-Holstein region, as based on a large data set from more than 1500 farms in the region. The German farm is located in a nitrate vulnerable zone, as the whole country was designated a 'vulnerable zone' according to the Nitrates Directive. Irrespective of this, the dairy regions in Northern Germany are located on sandy soils, rainfall is high (> 800 mm), and the groundwater table is shallow, so the risk of nitrate leaching is quite high.

Table 2. Main characteristics of the English and German case study farm.

	England	Germany
Growing season (months)	6-8	9-10
Precipitation (mm)	1370	824
Soil type	clay loam	sandy soil
Farm area (ha)	87	89
Stocking density (LSU ha^{-1})	1,9	1,6
Milking cow density (cows ha^{-1})	1,4	0,8
Landscape	slope	no/little slope
Milk production per cow (kg cow^{-1} $year^{-1}$)	5 883	7 755
Milk production per ha (kg ha^{-1})	8128	5821
Concentrates fed (kg DM cow^{-1} $year^{-1}$)	info not available	1 728
Concentrates used (g DM kg^{-1} milk)	-	222
Area to Forage:Maize:Cash crops	100:0:0	50:30:20
Percent of cut grass/ total grassland	50	25
Manure import/export	none	none
Fertiliser input (kg N ha^{-1})	324	126
Feed and bedding input (kg N ha^{-1})	68	69
Milk output (kg N ha^{-1})	43	28
Livestock output (kg N ha^{-1})	6	10
Cash crop output (kg N ha^{-1})	0	31
Farm N surplus (deposition included)	367	157
N efficiency (at the farm gate balance) %	12	30

Environmental issues

The main environmental problems in the English case are the following:

- the farmer uses a high amount of mineral fertilizer; he feels that mineral N is much easier to manage and results in a higher level of production than clover;
- tactical use of manure is perceived as a complicated technique and manure/slurry is normally spread twice per year in spring or autumn; the farmer does not show confidence in the fertiliser value of manure;
- any strategy to promote a better efficiency in grass use or manure management must carefully consider soil physical conditions; this is one of the most limiting factors, as the soil carrying capacity will dictate many of the rules for pasture management;
- the farm produces three different types of fertilizer (farm yard manure, liquid manure and dirty water): this increases the difficulty in managing them efficiently;
- estimated losses from the farm are high: 67 kg N ha^{-1} as ammonia, 63 through denitrification and 48 as leached nitrate; moreover the sloping landscape, together with a high rainfall, creates runoff risks with the possible negative effects on the quality of surface waters;
- the farmer has not been influenced to a great extent by all of the information available in the UK resulting from scientific research on nitrogen use and losses in grassland; codes of good agricultural practices are available but not followed in any great detail by many farmers.

The main environmental problems in the German case are the following:

- leaching of nitrate is probably high; in fact, average nitrate concentration in groundwater in the region is 44 mg l^{-1};
- ammonia volatilisation is also a major problem: total ammonia losses per cow place per year are in the range 37-46 kg; it was shown that the standard manure/slurry application techniques contribute much more to ammonia losses than grazing, therefore a longer confinement of animals in stables could increase volatilisation;
- lateral transport of nutrients to surface waters does not seem to be important;
- the rather high proportion of land devoted to cash crop production helps a lot in reducing the farm gate N surplus: without cash crop production, N efficiency would decrease from 30% to 20%
- mineral fertilisation is still high and legumes are not used; the combination of grazing and high N application rates in grassland contribute to the increase of the nitrate problem;
- the replacement rate is quite high.

Potential solutions

Some of the solutions envisaged are the following:

- Some easy-to-apply indicators on N efficiency should be applied in both cases in order to prevent N excess, but this seems more important in the English case (larger N surplus); the urea content of milk may be among the suitable indicators.
- It is important to strengthen the confidence of farmers in fertilizer values of manure: mineral nitrogen might have a more visible effect early in the growing season, but at the end no major differences between mineral nitrogen and organic nitrogen are normally measured.
- It seems important to stress that a reduction in mineral N inputs can result in significant money savings.
- In both cases the use of maize could be regarded as an important tool to better manage nitrogen. Maize could be introduced on part of the area of the British farm, whilst on the German farm this area could be enlarged, but land management might be difficult. Some experimental data from the German Karkendamm experimental farm show the environmental benefit of raising the proportion of maize silage.
- N fixation is a very small flux in both farms: a better use of white clover should be considered to help reducing nitrogen fertilization.
- Reduction or exclusion of any nitrogen fertilisation in pastures and inclusion of one (ideally two) silage cuts on all pastures in order to reduce nitrate leaching could be useful, although many of the pastures in the UK farm were already used for both cutting and grazing.
- If grazing is reduced, a higher proportion of the total manure production is collected in the stable and this exposes dairy farms to a higher ammonia volatilisation risk: emission-reducing slurry storage and application techniques (trailing hose boom tankers, slurry injectors, etc.) should then be adopted.
- Increasing total milk yield per cow should improve dairy farm sustainability, particularly when this is achievable via roughage feeding and accompanied by a reduction in animal numbers.
- Replacement rates should be reduced.
- A recommendation for policy makers is to harmonise the increasing number of directives and regulations affecting dairy farms (nitrate leaching, gaseous losses, P runoff, etc.).
- Availability of free or low cost technical advise is necessary; information on environmental effects of agricultural practices should be linked to other information sources that flow back and forth the farm (for example nitrogen and phosphorous balance sheets could be linked to economic balance sheets or produced through the normal financial accounting of the farm).

3. France and The Netherlands

Secretary: Nick Hutchings

Farm characteristics

The main characteristics of the French and Dutch farm are shown in Table 3. The French farm was typical of Brittany whilst the Dutch farm was typical of the intensive dairy areas in the Netherlands in the mid 1990s.

Table 3. Main characteristics of the French and Dutch case study farm.

	France	Netherlands
Growing season	365 days yr^{-1}	About 200 days yr^{-1}
Precipitation	About 1000mm	About 700mm
LSU/ha	2.2	3.5
Milk production per cow	6400 kg yr^{-1}	7500 kg yr^{-1}
Concentrates fed	840 kg $head^{-1}$ yr^{-1}	2000 kg $head^{-1}$ yr^{-1}
Milk production per ha	5000 kg	12500 kg
Forage:Maize:Other area	40:25:35	75:25:0
Manure import/export	Imported pig slurry	No
Farm N surplus (deposition excluded)	127 kg ha^{-1} yr^{-1}	350 kg ha^{-1} yr^{-1}

Environmental issues

The main environmental problems experienced in the French case were rising nitrate concentrations in groundwater, algal blooms in adjacent inshore waters and excessive phosphate input at the farm scale. The problem for farmers was how to comply with the Nitrates Directive without causing an excessive reduction in income. The main environmental problems in the Netherlands were the high levels of nitrate leaching and ammonia emission, whilst the problem for farmers was the need to intensify production to maintain an acceptable income, the legislative restrictions placed on farming activities and the high price of land.

Potential solutions

The solutions envisaged in the French case were:

- reduce the import of pig slurry;
- change from pure grass to grass/clover swards and reduce fertiliser input;
- introduce a rotation system so that the maize crop followed the grassland and better utilise the carry-over effect of the nutrients accumulated under the grass.

These measures were assessed to reduce the N surplus to 87 kg ha^{-1} yr^{-1} and to be sufficient to ensure that the farm complied with the Nitrates Directive. The problems remaining were the continued accumulation of phosphate (12 kg ha^{-1} yr^{-1}) and uncertainty whether the measures adopted would be sufficient to reduce the eutrophication (algal blooms) in inshore waters. The reduction in the import of pig slurry would cause the pig farmer problems, since the animal density in the area is high and so there is little scope for utilisation of this manure elsewhere.

The solutions envisaged in the Dutch case were:

- optimise the use of animal feed, to reduce the need for imported feedstuffs;
- optimise the use of manure nutrients, to reduce the reliance on imported fertilisers;
- correct imbalances in both feed and fertiliser composition by selective imports of supplementary feed/fertiliser.

The first objective would be achieved by reducing cattle numbers (through achieving a higher milk yield), reducing the number of followers, improving grazing methods and reducing losses during forage conservation. The second objective would be achieved by planting more maize and relying less on grazing, using less fertiliser (with a shorter period during which fertiliser is applied), planting catch crops and using slurry injection. There was also a need to increase the flow of information on optimal nutrient management from experimental situations to commercial farms. This is being achieved by working with a small number of farmers to achieve better nutrient management and then using these as show-cases for the wider farming community.
The problems remaining for the farmer are the continued shortage of land for utilisation of manure and whether the increase in production could be achieved economically. It also seems likely that in the longer term, the permissible farm N surpluses will have to be reduced to about 150 kg ha^{-1} yr^{-1} if the objectives of the Nitrates Directive are to be achieved.

Policymakers in France will have to address a number of issues:

- Should the restriction on applications of N in organic manures be calculated on the basis of the agricultural area or the area to which spreading is allowed? Legislation forbids application to some parts of some fields (e.g. near watercourses or houses). (It was suggested that the whole agricultural area could be used).
- Does the restriction on applications of N in organic manures apply at the farm scale or the watershed scale? (It was suggested that it must be at the farm scale).
- Current legislation in Brittany prevents changes in animal numbers on the farm. Although this was introduced to restrict the growth of the pig population, it also affects cattle farms, limiting options for rationalisation.

In the Netherlands, there is still the problem of convincing the EU Commission that the system of regulation used in the Netherlands is adequate to ensure compliance with the Nitrates Directive. The Dutch also need to improve the MINAS nutrient accounting system, so that it is closer to an agronomic nutrient balance (e.g. addition of N fixation in clover and P additions in fertiliser).

4. Denmark and Ireland

Secretary: Hélène Chambaut

Farm characteristics

The main characteristics of the Danish and Irish farm are shown in Table 4.
The Danish case is a representative average dairy farm (see also Danish country report, part II, Table 2). Main products are milk (61 cows, 2.5 LU per ha of feed crops) and cash crops, which are cultivated on 40% of the farm area. Manure production on the farm is under 170 kg N ha^{-1}.
The Irish farm is situated in North Cork and the farm is more specialised in animal production (livestock density is 30% higher). Main products are milk from dairy cows and meat from beef fattening on grass. Milk production per cow is 5200 kg. The high stocking rate (2.6 LU ha^{-1}) causes manure production to exceed 170 kg N ha^{-1}.

Table 4. Main characteristics of the Irish and Danish case study farm.

	Ireland	Denmark
Precipitation (mm yr^{-1})	1050	900
Soil type	sandy loam over sand	sandy soil
Farm area, LU's, cows	52 ha; 136 LU's; 96 cows	68 ha; 100 LU's; 61 cows
% beef cattle/herd	13%	0
LU's ha^{-1}	2.6	1.46
Kg milk cow^{-1}	5200	7373
Concentrate fed (kg cow^{-1})	500	728
Kg milk ha^{-1}	9600	6614
Roughage area/total area	100	59%
Grassland/roughage area	100	49%
Import/export manure	no	no
Import/export roughage	no	no
Manure production (kg N ha^{-1})*	225	146
Manure storage capacity (months)	2	9
N efficiency on farm (output/input)	17%	24%
Farm N surplus (kg N ha^{-1}; deposition included)	304	172
Leaching (kg N ha^{-1})	50	115
Nitrate concentration (mg l^{-1})	39	88**

* *Denmark: 1 LSU = 100 kg N; 1 cow = 118 kg N year^{-1}; 1 LSU = 0.85 cow. Ireland: 1 cow = 85 kg N year^{-1}.*

** *Measured at 1m depth. Up to 50% is denitrified during transport to deeper groundwater.*

Environmental issues and potential solutions

Both farms have to cope with high organic loads on the forage area (2.5 LSU ha^{-1}) which causes phosphorus accumulation in soils and high nitrate leaching (over 50 kg N ha^{-1} yr^{-1}). The Danish solution would be to exchange land with neighbours, to spread manure on a larger area and increase grazing. Fertilising maize with animal manure reduces mineral phosphate inputs. Nitrogen fertiliser inputs can be reduced by catch crop cultivation and introduction of grass/clover mixtures.

The Irish farm is divided in two areas: 65% of the farm area is close to the stable (where all the slurry is spread) and 35% is more distant and used for cutting and grazing by heifers. That situation results in accumulation of nutrients in the home farm. The 2 month storage capacity leads to slurry applications in November and mid January, which explains the very low nitrogen efficiency on the farm and phosphorus run-off in wintertime. Proposed solution would be to decrease the stocking rate by more than 20%, i.e. by stopping beef production (which is uneconomic today) and by increasing milk production per cow (+20% milk per cow; number of cows -16%). The use of mineral N fertiliser could then also be reduced (to 175 kg N ha^{-1} or to 90 kg N ha^{-1} when combined with grass/clover, in the latter case also qualifying for REPS subsidies). If the farmer would adopt one of these strategies, he would comply with the regulations: manure production would be less than 170 kg N ha^{-1} and phosphorus accumulation in the home farm's soils would decrease (Irish regulation). Following the new strategies would reduce leaching by 60%.

Unsolved problems

Since leaching in the Danish case is so high, it is unsure whether the 50 mg NO3 objective can be attained, even if farmers would follow regulations. In the Irish case, there is no need to take measures to reach environmental goals formulated in the Nitrates Directive. However, there remain some problems with regulations in the Nitrates Directive, i.e. the limited manure storage capacity and the spreading of wastewater from the milking parlour in winter. Solutions would be to construct artificial wetlands or increase storage capacity, but farmers perceive the associated costs as high.

In Denmark, detailed regulations do not bring closer the attainment of goals. Group members believe that economic instruments could be more effective in achieving farmers to change practices. Setting a penalty on high farm gate surpluses could not only be more effective, but would also let farmers free to choose which measures to adopt on their farms. Decoupling and modulation could also be very efficient.